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SUMMARY OF
SIGNIFICANT
RESULTS IN—

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

LISTS OF—

Investigations in
progress
Cooperating agencies
Geological Survey offices

GEOLOGICAL SURVEY RESEARCH 1973

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

GEOLOGICAL SURVEY PROFESSIONAL PAPER 850

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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 : 1973

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

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FOREWORD

This volume, "Geological Survey Research 1973," is the 14th annual review highlighting and summarizing the U.S. Geological Survey's programs and their results. In past years, it has been the first or A Chapter of a four-chapter series, the other three of which were composed of short scientific and technical papers. These short articles are now being made available in a bimonthly subscription periodical, "Journal of Research of the U.S. Geological Survey," whose first issue was published in January 1973.

The Geological Survey continues to direct its research activities toward the solution of the multitude of problems that relate to the earth's natural processes, history, and physical resources, including land, fuels, minerals, and water. These studies are diversifying to help develop new technologies, such as remote sensing from satellites and aircraft applicable to the assessment of earth resources and land use analysis; to explore new domains, such as underground space, the moon and other celestial bodies, and subsea resources; to reduce the hazards from floods, earthquakes, and volcanic eruptions by developing a predictive capability; and to understand the natural processes and natural baselines necessary to preserve a satisfying environment. In the aggregate, these studies are providing a basis for intelligent planning and decisionmaking in the use of the land and its resources and in meeting the needs of the future.

The present volume provides a synoptic review of many of these undertakings.

V. E. McKelvey

V. E. McKelvey,
Director.

CONTENTS

ILLUSTRATIONS

ABBREVIATIONS

A ---------------------- angstrom
ABS --------alkylbenzene sulfonates
acre-ft --------------------acre-foot
A.D. -----------------Anno Domini
ADP ------automatic data processing
AEC ---Atomic Energy Commission
AID -------Agency for International Development, U.S. Department of State
AIDJEX ------Arctic Ice Dynamics Joint Experiment
alt ------------------------altitude
APDC -------ammonium pyrrolidine dithiocarbamate
BOD ----biochemical oxygen demand
B.P. ----------------before present
b.y. --------------------billion year
cal ---------------------------calorie
Ci ----------------------------curies
CIPW ------Cross, Iddings, Pirsson, and Washington
cm ----------------------centimeter
cm^2 ---------------square centimeter
COD -------chemical oxygen demand
cps ---------------counts per second
CRIB ------Computerized Resources Information Bank
CVUAP --Connecticut Valley Urban Affairs Project
d --------------------------------day
d-c ------------------direct-current
DCP ------Data Collection Platform
DCS --------Data Collection System
DDD -----dichloro-diphenyl-dichloroethane
DDE -----dichloro-diphenyl-dichloroethylene
DDT ----dichloro-diphenyl-trichloroethane
DO ---------------dissolved oxygen
DSDP ----Deep Sea Drilling Project
EDTA --ethylenediamine tetraacetic acid
Eh -----oxidation-reduction potential
emu -----------electromagnetic unit
EPA -----Environmental Protection Agency
EROS --Earth Resources Observation Systems
ERTS --Earth Resources Technology Satellite
ESIAC ---Electronic Satellite Image Analysis Console
ft ------------------------------foot
ft^2 ---------------------square foot
ft^3 ----------------------cubic foot
ft^3/s ----------cubic foot per second
g ----------------------------gram
g ------------acceleration of gravity
gal --------------------------gallon
Ggal ----------------billion gallons
h ------------------------------hour
HUD ----------Housing and Urban Development
IDOE ------International Decade of Ocean Exploration
IFYGL ----International Field Year for the Great Lakes
IGC --------International Geological Congress
IHD -----International Hydrological Decade
in. ----------------------------inch
$in.^2$ -------------------square inch
$in.^3$ --------------------cubic inch
IUGS -------International Union of Geological Sciences
JOIDES -------Joint Oceanographic Institutions' Deep-Earth Sampling program
K ---------------------------kelvin
keV ---------------kiloelectron volts
kg -----------------------kilogram
km ----------------------kilometer
km^2 ---------------square kilometer
KREEP ---potassium, rare-earth elements, phosphorus
l ------------------------------liter
LAS ---linear alkylate sulfonate-type
lat -------------------------latitude
lb ---------------------------pound
log ------------logarithm (common)
long --------------------longitude
m ---------------------------meter
mg ---------------------milligram
Mgal ---------------million gallons
mGal ---------------------milligal
MHz -------------------megahertz
mi ----------------------------mile
mi^2 -------------------square mile
MIBK -------methyl isobutyl ketone
min -------------------------minute
ml ----------------------milliliter
mm ---------------------millimeter
mo ------------------------month
MSS ----------multispectral scanner
MW ---------------------megawatt
MWh --------------megawatt-hour
m.y. -----------------million years
μ -------------------------micron
μcal -----------------microcalorie
μg --------------------microgram
μm ------------------micrometer
μmho -------------------micromho
NASA -----National Aeronautics and Space Administration
NAWDEX -----National Water Data Exchange
NEIC ---National Earthquake Information Center
nm ----------------------nanometer
NMAS ------National Map Accuracy Standards
NOAA -National Oceanic and Atmospheric Administration
NPS ---------National Park Service
NTIS --National Technical Information Service
ohm-m -----------------ohm-meter
p/b ---------------part per billion
PCB ------polychlorinated biphenyls
pCi ----------------------picocurie
pH --------measure of hydrogen ion activity
p/m ---------------part per million
p/t --------------part per thousand
RALI -----------Resource and Land Information
RBV ---------return beam vidicon
rms -------------root mean square
s ---------------------------second
SCARP --Salinity-Control and Reclamation Projects
SCS ------Soil Conservation Service
SH --------------------shear waves
SP -------------------self potential
t --------------------metric tonne
$tons/mi^2$ ------------tons per sq mi
TRIGA ---Training, Research, Investigations, Gulf Atomic
UNESCO ---United Nations Educational, Scientific, and Cultural Organization
U.N. ---------------United Nations
USAF -------------U.S. Air Force
USBM ------U.S. Bureau of Mines
USGS ------U.S. Geological Survey
USPHS --U.S. Public Health Service
UTM --------Universal Transverse Mercator
VES -----vertical electrical sounding
WHOI --Woods Hole Oceanographic Institution
yd ---------------------------yard
yd^2 -------------------square yard
yd^3 --------------------cubic yard
yr -------------------------year

GEOLOGICAL SURVEY RESEARCH 1973

MINERAL-RESOURCE AND MINERAL-FUELS INVESTIGATIONS

BASE, FERROUS, AND PRECIOUS METALS

DISTRIBUTION OF MINERALIZATION RELATIVE TO CRUSTAL PLATES

Mineral deposits and lithospheric plates

P. W. Guild has analyzed the distribution of metallogenic provinces and concluded that various sorts of deposits are formed at positions that can be defined in plate-tectonic terms as follows: (1) At or near plate margins: (a) accreting, (b) transforming, or (c) consuming, or (2) within plates: (a) in oceanic parts, (b) at trailing continental margins, or (c) in continental parts. Some fairly clear-cut examples of type 1c are the Andean (continent/ocean) and Western Pacific (ocean/ocean or island-arc) provinces. Unequivocal examples of 1a endogenic deposits are rather rare, and of 1b, quite uncertain. Known endogenic deposits of class 2 are naturally restricted to continental areas in type 2c; it is unlikely that any exist in 2a or 2b.

This categorization is too simplified to account for all situations. For example, much of the Cordilleran area of the western United States combines features of 1c and 2c, and the rift-associated mafic and alkalic-mafic deposits of 2c can also be considered as having formed at abortive accreting margins (1a) in continental settings.

The correlation of mineral-deposit distribution with new data and theory being developed in various earth science disciplines is indispensable to an understanding of how ores form and where to explore for new supply sources.

Puerto Rican porphyry copper deposits and trench deactivation

D. P. Cox presents the geologic relations of the porphyry copper deposits of Puerto Rico as a model related to plate tectonics. Porphyry copper deposits in Puerto Rico were formed in Eocene time during the final stage of igneous activity in the Greater Antilles. At this time, according to tectonic reconstructions by Malfait and Dinkelman (1972) and others, the Puerto Rico Trench was deactivated as a consuming plate boundary and took on its present strike-slip configuration. Isostatic rebound of the whole arc-trench system and resulting tensional structures presumably contributed to a favorable environment for ore deposition. According to this theory, Eocene volcanic and plutonic rocks throughout the Greater Antilles are favorable for prospecting. Copper deposits in Panama and the Solomon Islands may be other examples of the coincidence of porphyry-type mineralization and trench deactivation.

Massive sulfide deposits may indicate former plate boundaries

On the basis of his studies of metallogenic provinces, P. W. Guild (1973) points out that strata-bound massive sulfide deposits commonly form more or less contemporaneously with the marine volcanic and (or) sedimentary rocks that enclose them and may subsequently be deeply buried, infolded, and protected from erosion. Most post-Paleozoic massive sulfides apparently formed in island arcs (products of consuming plate margins in oceanic environments); the positions of older deposits may mark former plate boundaries and indicate their nature. Paleozoic (Caledonian and Hercynian) belts of deposits are clearly apparent and suggest pre-Mesozoic movements; fragmentary evidence exists for younger Precambrian belts. Although numerous, the older Precambrian deposits lack extended linear patterns and by their distribution seem to confirm the conclusion that the early Precambrian tectonic-volcanic-sedimentary style was fundamentally different from that obtaining in younger terranes.

COPPER, MOLYBDENUM, TUNGSTEN, AND POLYMETALLIC ORES

Relation between mineral deposits and tectonic features, central Sierra Nevada, California

F. C. W. Dodge reports that the distribution of some metals in ore deposits in the central Sierra Nevada is closely related to tectonic features rather than simply being regionally zoned around the Sierra Nevada batholith. Copper and gold deposits on the west side of the batholith generally occur in prebatholithic rocks in or near two large fault zones or extensions of zones. Gold tends to be concentrated in the fault zone nearest to the batholith (the Melones fault zone), and copper, near the most distant zone (the Bear Mountain fault zone). On the east side of the batholith the pattern of distribution of deposits of these metals is seemingly random.

Chromium is associated with large masses of ultramafic rocks in the western fault zones or in their southerly extensions. Tungsten deposits occur in tactite bodies adjacent to granitic rocks generally belonging to a specific one of eight intrusive sequences (the scheelite sequence) provisionally established in the central Sierra Nevada batholith.

The geographic distribution of the ore deposits has been studied by plotting and contouring occurrences and production values of the metal deposits. Highest values of copper and gold along linear belts of concentration are paired, suggesting derivation of the two metals from a common, but unidentified, source.

Edna Mountain area, Humboldt County, Nevada

Detailed geologic and geochemical mapping by R. L. Erickson and S. P. Marsh in the Coldrun Creek 7½-minute quadrangle, Humboldt County, Nev., has revealed areas that contain anomalous amounts of a variety of metals. Copper, molybdenum, gold, and silver anomalies occur in and along the contacts of a small granodiorite mass and associated dikes cutting altered greenstone of the Pumpernickel Formation in the upper plate of the Golconda thrust on the southeastern flank of Edna Mountain. The altered greenstone contains abundant euhedral pyroxene metacrysts and small amounts of disseminated pyrrhotite. Basinward extension of the altered rock is concealed by fan gravel. The rock types and geochemical suite suggest concealed copper-molybdenum mineralization.

Mercury, arsenic, antimony, tungsten, gold, lead, and silver anomalies occur along and west of a north-northeast-trending fault marked by hot spring activity in the southwestern part of the quadrangle. The volatile suite of metals probably was emplaced by hot-spring activity; lead-silver mineralization may be older.

Scheelite as a guide to stratabound polymetallic deposits in the Carolina slate belt

The geologic environment of some bedded polymetallic sulfide deposits in Europe and Korea was described by Albert Maucher of the University of Munich at the 1972 International Geological Congress. This environment so resembles bedded tuffaceous parts of the Carolina slate belt that R. G. Schmidt decided that similar deposits should be sought in North and South Carolina and Georgia. As a test of the use of the easily detected mineral scheelite as a guide to the polymetallic suite, cores of metavolcanic rock from the Ellis prospect, a copper-molybdenum prospect in Halifax County, N.C., were examined with an ultraviolet light, and thin scheelite-bearing layers were identified. Subsequent analyses of these drill cores showed that they contain anomalous but subeconomic amounts of W, Cu, Pb, and Zn. Intrusion of an alaskite pluton at this prospect may have introduced or remobilized some of these metals, but little W, Cu, Pb, or Zn were detected in the alaskite itself. While far from proving that the anomalous metals in the tuffaceous sediments are truly stratabound, the discovery suggests that scheelite, a fairly common constituent of heavy mineral suites from alluvium in this region, may be useful as a guide in prospecting.

Sedalia copper-zinc deposit, Chaffee County, Colorado

The areal geology in the vicinity of the Sedalia copper-zinc deposit near Salida, Colo., was mapped by R. E. Van Alstine. The deposit was the State's largest copper mine and also yielded significant quantities of zinc ore and a little silver and gold, but the workings are now largely caved. The deposit, of Precambrian age, is localized in and near a metagabbro sill intruded into gneiss, schist, and phyllite. Layering and foliation strike northeast and dip to the southeast. The ore body was a flat lens about 800 ft long and at most 150 ft thick, striking east and dipping to the south. The deposit is cut by a pegmatite dike about 50 ft thick. A great variety of minerals resulting from metamorphism, sulfide mineralization, and oxidation is found in the vicinity of the mine. A fault system at the mine extends northwest and in the Browns Canyon district is strongly mineralized with fluorite.

Postore sinistral movement along Basin and Range-type faults in Dripping Spring Mountains, Arizona

Petrologic studies and detailed mapping by N. G. Banks revealed that the Chilito mine (a small porphyry copper deposit) in the Dripping Spring Mountains and two other copper deposits, the New Year prospect and the Christmas mine, occur along the same distinctive dikes within an east-west dike swarm. The dike swarm and perhaps the Chilito deposit are cut on the east side of Dripping Spring Mountains by the Keystone fault which has local stratigraphic offsets of as much as 3,000 ft. Dikes of the distinctive type on the north edge of the swarm have associated Pb-Zn mineralization where they cut limestone. Similar dikes that also have Pb-Zn mineralization where they cut limestone occur on the west side of the fault at the 79 mine about a mile south of their projected position if the fault had only dip-slip movement. This suggests that the hanging-wall part of the Chilito deposit may have been offset sinistrally 1 mi south along the east side of the Keystone fault and is now covered by Tertiary basin-fill material. The area seems suitable for study by geophysical methods.

Copper mineralization in south-central Brooks Range, Alaska

On the basis of studies made while he assisted members of the Alaska Division of Mines and Geology in mapping north of Bornite in the Ambler River quadrangle, I. L. Tailleur reports that little copper mineralization is evident on the surface. He notes, however, that the mineralization found below the surface of quartz schist and other metamorphosed sedimentary and igneous rocks in the area apparently is more promising, as indicated by extensive exploration, drilling, and the recording of numerous claims within the general area.

New interpretation indicates less taconite potential in western part of Marquette County, Michigan

An iron-formation of interest for taconite development occurs in a north-trending belt about 11 mi long near the western boundary of Marquette County, south of the Marquette Iron Range in northern Michigan.

The results of mapping combined with gravity and magnetic surveys are interpreted by W. F. Cannon as indicating that the structure is a west-facing monocline which is probably faulted against older gneiss to the west and hence contains only one belt of Negaunee Iron-formation. Exploration drilling has proved that this limb contains steeply dipping magnetic taconite at least several hundred feet thick, but the overall potential of the area is only about half of what would be inferred from older interpretations that the structure is a syncline.

Iron and rare earth resources, Mineville, New York

Recent studies by Harry Klemic in the Mineville district, Essex County, N.Y., lead to the conclusion that significant resources of magnetite and associated rare-earth-bearing apatite exist in a deep extension of the Old Bed ore body. This conclusion is based upon extensive examination of the ore body in the subsurface and upon studies of drill core, logs of exploration drill holes, and other geologic data made available by the Republic Steel Corp., and from aeromagnetic data previously compiled by the U.S. Geological Survey.

Millions of tons of tailings accumulated at Mineville during the past two decades in the beneficiation of magnetite ore from the Old Bed ore body are a large low-grade potential resource of rare-earth-bearing apatite and other minerals.

Distribution of silver in sulfides, Park City district, Utah

Petrographic study and microprobe analyses by J. T. Nash indicate that matildite ($AgBiS_2$), argentite, tetrahedrite, and galena carry the majority of the silver in the Mayflower mine, Park City district. Sphalerite, chalcopyrite, and enargite contain virtually no silver, but rare bornite carries about 0.7 weight-percent Ag. Matildite and argentite, exsolved from galena, contain 28 and 84 percent Ag, respectively. Compositions are variable in the tetrahedrite-tennantite series, and Ag substitution ranges from 4.1 to 0.5 percent. Silver contents are highest in antimonian members of the series. Galena commonly contains 0.1 to 0.2 percent Ag in atomic substitution, but values range as high as 2.9 percent Ag.

Chemical distribution of gold and mercury in Carlin, Nevada, gold ores

Studies of the gold ores of the Carlin deposit, Lander County, Nev., by A. S. Radtke (USGS), C. M. Taylor (Stanford Univ.), and C. L. Christ (USGS) (1972) have shown that in unoxidized ores gold and mercury occur in association with carbonaceous materials and on the surfaces of pyrite. Gold also occurs as rare metallic particles, and mercury occurs as fine-grained cinnabar.

Oxidized ores contain cinnabar and secondary mercury minerals and fine-grained gold and mercury free of other metals.

Trace elements in sphalerite and galena from the northern Arkansas zinc district

A. V. Heyl, Jr., reports that semiquantitative spectrographic analyses of pure-picked sphalerite and galena collected in the northern Arkansas zinc district show that the sphalerites contain copper, cadmium, germanium, and gallium in some abundance as is typical of most sphalerites of the Mississippi Valley type. Silver, indium, zirconium, titanium, barium, manganese, and nickel, which are commonly present in sphalerites of the tristate and southeast Missouri districts, are lean or absent in the northern Arkansas district's sphalerite. One specimen of sphalerite and one of galena contain bismuth, the first reported bismuth in sulfides in the Mississippi Valley type of deposits. The galenas analyzed were lean in silver and antimony.

Interpretation of microprobe analyses for copper and sulfur in biotite and chlorite associated with some Arizona copper deposits

N. G. Banks reports that igneous and hydrothermal biotites in and around the Ray and Esperanza-Sierrita porphyry copper deposits in Arizona generally do not contain copper in amounts detectable by microprobe analysis. Copper is present in chlorite derived from biotite and in transitional material at the boundary between chlorite and biotite.

Because of the difficulty in removing transitional material from biotite separates, the copper contents reported for biotite analyzed in bulk probably do not reflect the actual amounts of copper in biotite. The distribution of copper in chlorite is extremely inhomogeneous, and most of the copper in chlorite is believed to be in attached sites rather than in proper lattice sites. The copper content of chlorite is likely to be a poor indicator of ore because of the questionable values derived from the analyses of bulk separates and because of the expense in time in obtaining meaningful microprobe analyses.

Sulfur is present in igneous biotite in rocks around the Ray and Esperanza-Sierrita copper deposits, but it is either present in lesser amounts or undetectable in alteration products of the biotite. Examination and electron probe scanning of the biotite, alteration products, and nearby igneous silicates indicate that the sulfur released from biotite was not immediately redeposited. Some of the sulfur in the porphyry ore deposits could have been supplied by preore igneous biotite that was altered during development of the subject deposits at Ray and Esperanza-Sierrita.

GEOCHEMICAL EXPLORATION

Gold anomaly in soils, Yellow Pine district, Idaho

B. F. Leonard reports that a gold anomaly partly delimited by soil sampling in the West End Creek area near the Yellow Pine mine, Stibnite, Valley County, Idaho, presents an attractive new exploration target. Gold prospects in the area were cursorily explored by a mining company during the 1940's. Soil sampling in July 1972 shows that gold mineralization is more extensive than was demonstrated by the company's drilling. The gold anomaly north of the drill sites measures 100 by 450 ft within the 1 p/m Au contour. Within this area, the peak value is 8 p/m Au. A substantial silver anomaly and conspicuous but minor mercury, antimony, arsenic, and tungsten anomalies are coextensive with the gold anomaly.

Geochemical exploration for zinc in the southern Appalachian Valley

Analysis of geochemical data from stream-sediment sampling programs in the southern Appalachian Valley by R. H. Carpenter (Georgia Univ., Athens) and Helmuth Wedow, Jr. (USGS) (1972) shows that such exploration is an effective tool in the search for zinc deposits concealed by deep residuum on the Knox Group in this region. Large anomalies, as much as 9 mi in length, are locally associated with the Kingsport Formation and lower part of the Mascot Dolomite and are interpreted to reflect the same type of zinc mineralization currently being mined in the Mascot-Jefferson City district, Tennessee. Small intense anomalies appear to be related to presently uneconomic mineralization in the upper part of the Mascot Dolomite. In some areas, the ratio (Zn+Pb)/(Fe+Mn) may be more useful in targeting favorable mineralized areas than actual metal concentrations values in the stream sediments.

Geochemical sampling in the Hurricane quadrangle, Wisconsin

A stream sediment sampling program in the Hurricane quadrangle by W. S. West has defined areas of lead and zinc mineralization and possibly the location of an ore body. Samples containing 100 to 1,000 p/m Zn indicate a belt of mineralization about a mile wide extending in a southwesterly direction along Pigeon Creek across the entire quadrangle.

Lead mineralization indicated by samples containing 70 to 5,000 p/m Pb overlaps and follows the belt of zinc mineralization across the quadrangle. The lead zone forks in the middle of the quadrangle, and a branch extends in a northwesterly direction along Hackett Branch and State Highway 53 to the west edge of the quadrangle. Lead mineralization is more widespread than zinc mineralization although there are isolated localities of zinc mineralization in several parts of the quadrangle.

The sparse analytical data available suggest that a zinc-lead ore body may occur generally north of the Blackjack mine, possibly in secs. 28, 29, 32, and 33, T. 4 N., R. 4 W.

Metals in "meta-iron formation," southern Black Hills, South Dakota

Preliminary results of geochemical analyses of 300 bedrock samples of "meta-iron formation" collected by W. H. Raymond in the southern Black Hills, S. Dak., indicate at least five areas of anomalous concentration of copper, silver, and molybdenum.

FLUID INCLUSION STUDIES AT BAGDAD, ARIZONA

J. T. Nash and C. G. Cunningham, Jr., report that quartz-chalcopyrite and quartz-molybdenite veins from the porphyry copper deposit at Bagdad contain halite-bearing fluid inclusions with salinities of 30 to 35 weight-percent and homogenization temperatures in the range from 233° to 310°C. Somewhat later primary and pseudosecondary inclusions with 5.8 to 9.2 weight-percent salinity homogenized at temperatures in the range from 302° to 373°C. Boiling occurred, but was rare, indicating that the depth of cover had to be somewhat greater than about 6,200 ft. The disparity in homogenization temperatures of the high- and moderate-salinity inclusions is the reverse of that commonly observed and may indicate that the former were trapped under higher pressures.

ISOTOPE STUDIES

Hypothetical process for formation of O^{18}- and deuterium-rich ore-forming waters at Crede, Colorado

The oxygen and hydrogen isotopic compositions for sericite, chlorite, quartz, carbonates, and fluid inclusions, as determined by R. O. Rye, show that the water of the ore-forming system differs dramatically from both normal magmatic water and modern ground water. Paul Barton, P. M. Bethke, and R. O. Rye interpret the data as suggesting either a drastically different climatic regime in the San Juan area in the late Oligocene, or a hypothetical process (such as the evaporation of a lake) that could enrich the meteoric water in both O^{18} and deuterium, or prolonged reaction of magmatic water with volcanic rocks at low temperature to produce an oxygen shift of heretofore unrecognized magnitude.

RARE MINERAL OCCURRENCE

Osarizawaite found at Silver Cliff, Custer County, Colorado

W. N. Sharp has determined that a bright green, finely crystalline mineral found occurring as felty masses at Silver Cliff rhyolite volcano is osarizawaite, a recently defined mineral of the alunite group. The composition of osarizawaite is close to the stoichiometric formula $Pb(Cu\,Al)_3SO_4{\cdot}OH_6$. At Silver Cliff the osarizawaite occurs in fracture fillings of galena and sphalerite that were altered by venting during late rhyolite doming. This is the first reported occurrence of the mineral in the United States; localities previously described are in Japan and Australia.

LIGHT METALS AND INDUSTRIAL MINERALS

Trace element halos in tuff at Spor Mountain, Utah

Geochemical studies by D. A. Lindsay show that the beryllium-fluorspar mineralization at Spor Mountain has left a distinct trace-element signature in water-laid rhyolitic tuff adjacent to the known perimeter of mineralization. F, Cs, Li, Be, Ga, Nb, and Y are among the elements found in anomalous quantities in the beryllium deposits at Spor Mountain (Lindsey and others, 1973) ; these elements also tend to form halos extending as much as 2 mi into otherwise unmineralized tuff. This association of trace elements should be useful in detecting the presence of similar mineralization beneath or adjacent to tuffaceous rocks elsewhere in the Basin and Range province. Accurate delineation of the halos near Spor Mountain shows that they enlarge a potential target two to three times and fix the location and extent of a mineralized district.

Multivariate analysis (*R*-mode factor) was used to examine the extent to which each element participated in the mineralization process rather than other petrologic processes such as diagenesis. The analysis indicated that the distribution of some elements, notably Cs, Be, and Ga, was determined mainly by the beryllium-fluorspar mineralization. These appear to be ideal pathfinder elements for use in searching for beryllium-fluorspar deposits. Other mineralization-related elements, notably fluorine, participate in other petrologic processes; their geographic distribution is the result of complex overprinting by one or more processes. This tendency of some elements to participate in more than one petrologic process emphasizes the importance of studying trace-element associations carefully before using a particular element as a pathfinder to mineralization.

Fluorite deposits formed after associated carbonatites

Edwin Roedder (USGS), in cooperation with Dr. Thomas Deans of the British Institute of Geological Sciences, studied fluid inclusions in fluorites and associated carbonatites from two important fluorite deposits, each in the range of 10 million tons—one at Amba Dongar, Gujarat, India, and the other at Okorusu, South-West Africa. The problem of the conditions of formation of carbonatites is still unsolved, but the inclusions indicate that toward the end of the carbonatite formation, two immiscible fluids were present—one consisting essentially of CO_2 and the other of water with large amounts of salts in solution at fairly high pressures and temperatures. The fluorite deposits formed still later, as a postcarbonatite event (in keeping with the reported field evidence), from water solutions at much lower temperatures and salinities and at only a relatively few atmospheres of CO_2 pressure.

Lightweight aggregate in the Eastern United States

Preliminary investigations by J. W. Hosterman indicate that the raw materials used in 23 lightweight-aggregate plants in the eastern part of the United States bloat easily when heated to about 1,204°C (2,200°F) in a rotary kiln. The raw materials used are shales, slates, and argillites that range in geologic age from late Precambrian to late Triassic. In all these shales, slates, and argillites sampled, chlorite and illite are the only clay minerals that were identified by X-ray diffraction methods; kaolinite is absent in every sample tested. Quartz and feldspar are the predominant nonclay minerals.

Resources of lightweight aggregate materials

Estimates of lightweight aggregate resources by A. L. Bush (1973) indicate that the United States has adequate reserves of all types and far more than adequate reserves of some types to meet anticipated cumulative demand through the year 2000. Cumulative production of expandable clays, shales, and slates to that year will be about one-millionth of the tonnage of argillaceous rocks in the 48 contiguous States to a depth of 20 ft from the surface. Cumulative demand for scoria and cinder (about 200 million tons) is less than recoverable reserves in deposits being mined in 1970 and may be less than half those reserves. Identified resources of pumicite west of the Great Plains are more than half the cumulative national demand, and those in the Great Plains represent two to three times that demand. Identified resources of vermiculite and perlite appear to at least equal the cumulative demand, and total resources are at least several and 10 times as large respectively.

Peat in Maine

C. C. Cameron recently mapped 20 peat deposits containing an estimated total of 4,000,000 tons of air-dried peat moss in Washington County, Maine, a State where peat production in 1971 almost doubled that of 1970. An open-file report (Cameron, 1972) that contains quantitative data on quality and environmental settings of peat deposits in eastern Maine is currently used by several out-of-State companies.

In addition to mapping and exploration for commercial quality peat, a systematic sampling was started for trace elements in different types of peat and underlying materials along compass and pace traverses of each deposit. Computerized spectrographic analyses of 159 samples of peat ash from 32 deposits in southeastern Aroostook County show the presence of copper in amounts exceeding maximum limits of detection (1,000 p/m) in seven deposits located in the vicinity of known plutons.

Harney Peak Granite and pegmatites, South Dakota

A new map of the Harney Peak Granite of the Black Hills, S. Dak., the first map to show this pluton's size and shape with exactitude, has been completed by J. J. Norton and J. A. Redden. This Precambrian granite has been regarded as the source of the fluids that formed the many pegmatites of the surrounding region, which have produced potash feldspar, mica, lithium minerals, beryl, and other minerals.

The main body of the granite occupies an area of 34 mi^2; several satellitic intrusions add another 3 mi^2. The main body is approximately oval, but the contact is exceedingly irregular in detail and several offshoots extend into the adjacent schists as much as 3 mi. Mount Rushmore is on one of the offshoots.

Though superficially the granite appears homogenous, detailed examination of 29 bulk samples by Norton and R. J. McLaughlin has brought out many systematic variations. The granite is generally most feldspathic in its center and silicic at the periphery; it is most potassic from its center to the southeast border and most sodic to the north and west; muscovite is most abundant in the north and southwest, where it commonly exceeds 10 percent of the mode; biotite is common in the center and the southeast, but very sparse elsewhere.

These compositional studies were made to determine whether, and how, the granite can be the source of a pegmatite magma containing the several thousand parts per million lithium as observed in many spodumene deposits in adjacent schist. Granite samples were divided into heavy mineral, muscovite, biotite, and quartz-feldspar fractions, and each fraction was analyzed for lithium, rubidium, and cesium. The north part of the granite, which is nearest to spodumene-rich pegmatites, has the most lithium, both in the whole rock and each fraction, and it is also enriched in rubidium and cesium. The maximum lithium content of the rock is 125 p/m. One part of the granite with about 100 p/m lithium is a large offshoot connected to the rest of the batholith only by thin sills; perhaps in such an isolated locality a residual fluid capable of forming spodumene pegmatite could have been formed and ejected. Yet no part of any such fluid was trapped within the granite, for none of the many pegmatitic pods and fracture-fillings in the granite contains spodumene. Furthermore, it is improbable that conventional differentiation processes within granite of such low lithium content could have caused the enrichment necessary for spodumene pegmatite. Also, the relationship is not obvious between the patterns of distribution of lithium and of major constituents of the granite. A plausible view is that lithium-rich magma formed directly by partial melting of lithium-bearing quartz-mica schist and that nearby granite originating at the same time is enriched in lithium only because it received a contribution from this schist.

MINOR ELEMENTS

Tellurium in geochemical prospecting

Tellurium may be a useful pathfinder element for deeply buried ore deposits according to G. B. Gott and J. M. Botbol (1972) from a study of metal zoning in the Coeur d'Alene district in Idaho. In this district tellurium forms halos far out from the centers of mineralization and seems to have been driven beyond the ore metals at the time the ore deposits were emplaced.

Tellurium and thallium in manganese nodules

Manganese nodules from the ocean floor are a major resource of tellurium according to D. F. Davidson and H. W. Lakin (1973). The demand for the element is now adequately met with byproduct tellurium from the copper and lead industries, but a shortage could develop with adoption of in-situ leaching of copper ores.

The ocean floor manganese nodules are the largest source of thallium. Estimates made by Keith Robinson (1973) show that as much as 9,900,000 tons of thallium are contained in identified ocean deposits, which is over 10 times the estimated tonnage available from all other sources.

Thallium and indium analyses

The thallium and indium content of geologic materials is seldom reported as these elements are commonly present in amounts below the limit of detection by semiquantitative spectrographic methods. An atomic-absorption method developed by A. E. Hubert and H. W. Lakin (1972) now provides a sensitivity of 0.2 p/m for thallium and indium and will facilitate the investigation of the geochemical behavior of these rare elements.

NUCLEAR FUELS

URANIUM

Uranium resources

Resources of uranium in the United States are interpreted by W. I. Finch, A. P. Butler, Jr., F. C. Armstrong, and A. E. Weissenborn (1973) as those that are recoverable under current economic conditions, those that might be available at a moderate increase in the price of uranium, and those that might be obtained only with a large increase in cost. Those recoverable at current prices include 273,000 tons of U_3O_8 in identified reserves in known deposits as of January 1, 1972 (U.S. Atomic Energy Commission, 1972), and about 500,000 tons of U_3O_8 in hypothetical resources in undiscovered deposits. Most of these hypothetical resources are probably in the same formations and general areas as the identified resources, but some are in similar deposits in new areas. Resources that might be available at a moderate price increase total about 600,000 tons of U_3O_8 (Theobald and others, 1972, fig. 19). Most of these resources are in low-grade (submarginal) concentrations that border the known and undiscovered deposits mentioned above. Additional resources available at a moderate price include the uranium in phosphorites that would be available only as a byproduct of making treblesuperphosphate fertilizer. Resources that might be obtained at a large price increase total several million tons of U_3O_8 and are in very low-grade accumulations in known deposits of marine phosphorite and black shale and certain bodies of igneous rock. Not only would the unit cost of uranium from these sources be very high, but the mining of huge tonnages of rock to obtain a significant amount of uranium might be environmentally intolerable.

Genesis of roll-type uranium deposits, Wyoming and Texas

E. N. Harshman reports that his studies of roll-type uranium deposits in Tertiary rocks in Wyoming and Texas show that the genetic processes responsible for their formation may have differed in significant ways. For example, the absence of magnetite in sandstone altered by ore-bearing solutions in the Gas Hills, Wyo., and in parts of south Texas suggests that ore-bearing solutions differed from those in the Shirley Basin, Wyo., where magnetite remains unaltered. The lack of alteration of feldspar in the ore sandstone in the Shirley Basin contrasts with considerable alteration of feldspar in the Gas Hills—again suggesting that the ore-bearing solutions differed significantly. Differences in the reductant responsible for the deposits are suggested by the presence of molybdenum, as a sulfide, associated with the deposits in the Gas Hills and in Texas and the total absence of molybdenum in the Shirley Basin deposits. Strong reductants were probably responsible for uranium deposits in the Gas Hills and in Texas and weaker ones, for the Shirley Basin deposits.

Sulfite-uraninite reaction in formation of roll-type uranium deposits

In roll-type uranium deposits, the maximum concentrations of redistributed pyrite are typically found in unoxidized rock just beyond the roll front and decrease down gradient into the unoxidized zone. In contrast, the maximum uranium contents either coincide with the maximum pyrite content or are a few centimeters to several meters or even tens of meters down gradient from the maximum pyrite concentrations. This suggests to H. C. Granger and C. G. Warren that dissolved oxygen in the altering and ore-forming fluids oxidized the pyrite but did not directly contact the uranium zone. Sulfite ions seem to be one of the first products of pyrite oxidation under limited oxygen supply (Granger and Warren, 1969), and because the Eh-pH stability field of sulfite (and bisulfite) ions does not overlap the stability field of uraninite, it seemed likely that sulfite-bearing solutions could oxidize and dissolve uraninite while simultaneously producing a more reduced sulfur species. Preliminary experiments—conducted both in the presence of and exclusive of calcite—indicate that either natural or synthetic uraninite will dissolve in sulfite-bisulfite-bearing solutions at a pH of approximately 7 until the solution contains at least 40 to 60 p/m uranium. If this is, indeed, the reaction that oxidized earlier formed uraninite and allowed the uranium to move down gradient in the ore-forming process to its final position, it is quantitatively adequate to explain these particular steps in roll-type ore genesis.

Control of uranium deposition by hydrodynamic entrapment of oil and gas

Investigations by C. G. Bowles on the movement of uranium-bearing solutions (ground water) show that hydrodynamic principles set forth by Hubbert (1953) for the entrapment of oil and gas (including H_2S, CH_4, and CO_2) probably controlled the localization of oil and gas and that reductants contributed to the deposition of uranium in some districts. The hydrodynamic traps are formed by unclosed tectonic and stratigraphic structures as well as by locally less permeable rock. An example of a hydrodynamic trap is in the Edgemont district, South Dakota, where structural terraces probably trapped H_2S and caused uranium deposition.

Depositional environments as basis for subdividing Morrison Formation—northwest New Mexico

A continuing study of the uranium-bearing Morrison Formation in the Grants-Gallup area of northwest New Mexico by M. W. Green has resulted in division of the formation into two separate depositional sequences based on evaluation of comparative depositional and environmental characteristics and on the presence of a well-defined depositional break separating the sequences. Based on lithologic definition, the Morrison in the Grants-Gallup area has been subdivided, in ascending order, into three members: the Recapture (predominantly siltstone), the Westwater Canyon (predominantly sandstone), and the Brushy Basin (predominantly siltstone). The recently defined depositional break occupies a stratigraphic position ranging from 0 to 160 ft (50 m) below the contact between the Recapture and Westwater Canyon Members.

The depositional unit below the break is characterized by low- to medium-energy eolian, lacustrine, and eolian-lacustrine facies represented in the outcrop by fine-grained, well-sorted sandstones and siltstones intermixed with minor thin beds of limestone. Laterally adjacent, predominantly in the eastern part of the area near Grants, a medium- to low-energy fluviatile facies is present in the lower depositional sequence and is represented by fine- to medium-grained, moderately well to poorly sorted sandstone and siltstone.

The sequence above the depositional break is characterized by high- to medium-energy fluviatile facies represented by coarse- to medium-grained, poorly sorted sandstones that grade upward into siltstones and minor claystones.

Although the full implication of dividing the Morrison on the basis of depositional rather than lithologic character is not yet known, it is suspected that the twofold division, as outlined here, may have regional continuity and represent deposition into two different, superimposed basins of deposition that had different source areas.

Zeolites in Morrison Formation, San Juan Basin, New Mexico

Although the zeolite analcite was reported by Keller (1962) from a single locality in the Brushy Basin Member of the uranium-bearing Morrison Formation in western Colorado, E. S. Santos discovered not only analcite but also the zeolite clinoptilolite in the Brushy Basin Member in the San Ysidro area, Sandoval County, N. Mex. He found that many thin, well-indurated siltstone beds contain as much as 75 percent zeolite minerals. Red siltstone contains mainly clinoptilolite that replaces shards of volcanic glass, and green siltstone contains mainly analcite that replaces some shards but most is in fracture-filling veinlets. Samples collected in other parts of the San Juan Basin by L. C. Craig also contain these zeolite minerals in the Brushy Basin Member, and it is postulated that they are probably widespread in this member in other parts of the Colorado Plateau.

Structural and host-rock controls at Schwartzwalder mine, Colorado

Geologic mapping of the Schwartzwalder uranium veins by E. J. Young shows that all the veins are in fractures and that they are predominantly in fine-grained metasedimentary rocks such as quartz-biotite schist, garnet-biotite gneiss, lime-silicate hornblende gneiss, and quartzite and subordinately in pegmatitic rock. Although pitchblende (uraninite) in nearby veins has been reported to be about 70 m.y. old (Sheridan and others, 1967), no igneous rocks of the general age have been found in the mine or on the nearby surface. The productive veins dip either steeply to the west or moderately to the east; the latter veins branch off the steeply dipping ones.

Uranium-rich Silver Plume Granite cut by Roberts Tunnel, Colorado

Samples of Silver Plume Granite from widely spaced intrusions cut by the Roberts Tunnel were collected by E. E. Wahlstrom (Colorado Univ.) without regard to their radioactivity and were analyzed by L. B. Jenkins and coworkers (USGS) and found to contain an average of 42.2 p/m thorium, 49.8 p/m lead, and 43.3 p/m uranium. The uranium content is high relative to the thorium and lead contents, and the range in uranium contents is large. In a zone about 1.6 mi (2.6 km) west of the east portal, uranium ranged from 140 to 364 p/m. The depth of cover of the zone is about 3,000 ft (900 m). Study of the uranium-rich samples by G. W. Phair (USGS) found cubes of calcite-veined uraninite that are largely replaced pseudomorphically by gummite. These samples contain only about one-tenth as much uranium as similar uraninite-bearing pegmatitic Silver Plume Granite in the Central City district to the northeast. Phair suggests that granite richer in uranium than indicated by these random samples may be present in the tunnel area.

THORIUM

Thorium resources

Although the current demand for thorium is small, future needs may be large if thorium is utilized as a fuel for nuclear generators. M. H. Staatz and J. C. Olson (1973) estimate that the identified thorium resources in deposits containing more than 0.1 percent ThO_2, recoverable primarily for thorium, total about 100,000 tons ThO_2; nearly all are in vein deposits in the Western States. The only minable reserves at present are some of the Atlantic Coast beach placers which could produce about 16,000 tons of ThO_2 from monazite as a rather minor byproduct of titanium mining.

Thorium veins related to alkalic intrusives

A study of resource-important thorium veins in the United States by M. H. Staatz shows that in 8 out of 13 areas studied, thorium veins are associated with alkalic igneous rocks, carbonatites, or both. There is a general zonal relation between the veins and these rock types; carbonatites are found either with or near the alkalic intrusive rocks, but the thorium veins are mostly several miles from the alkalic rocks. The thorium veins are believed to have formed from a volatile late-stage phase of the magma that formed the alkalic rocks. The vein fluids were of low viscosity and traveled long distances along major fractures in brittle country rocks. The thorium veins were formed at low temperatures over a considerable period of time.

COAL

Composition of coal in the southwestern United States

Chemical analyses (V. E. Swanson, 1972) were made for 71 samples from Upper Cretaceous and Paleocene coal beds in New Mexico, Arizona, Utah, Colorado, and Wyoming as a part of the Department of the Interior's Southwest Energy Study. Sixteen samples of fly ash and bottom ash from five major electricity generating plants were also analyzed. A total of 4,814 chemical determinations show that the organic-element composition of the high-volatile B and C bituminous coal beds of the region are strikingly similar. Excluding a few samples of weathered coal from Utah, the average moisture- and ash-free composition is, in percent: carbon, 76.5 ($\pm$2.9); oxygen, 15.8 ($\pm$2.6); hydrogen, 5.6 ($\pm$0.4); and nitrogen, 1.5 ($\pm$0.4). Coal that is burned in the five operating plants and coal to be burned in five proposed plants contain 0.4 to 1.0 percent sulfur and 5 to 21 percent ash. The ranges of selected trace elements in the coal are, in parts per million: arsenic, $<$1 to 2; copper, 3.4 to 13; fluorine, 50 to 190; mercury, 0.04 to 0.09; lithium, 1.5 to 19; antimony, 0.13 to 1.3; selenium, 0.7 to 2.3; tellurium, $<$0.01 to 0.02; uranium, 0.27 to 2.6; and zinc, 1.6 to 12. Cadmium values were uniformly $<$0.1 p/m, lead values $<$10 p/m, and thallium $<$0.2 p/m. Analyses for 9 major inorganic components and for 21 additional trace elements showed comparable normal or low values. Although variable fractions of some trace elements are volatilized and emitted as powerplant stack effluent, most are incorporated and concentrated in the captured fly ash.

Low-sulfur coal in the Powder River Basin, Wyoming and Montana

A study by N. M. Denson of sonic-density, gamma-ray, and electric logs of numerous oil and gas tests drilled during the past few years in the Powder River Basin disclosed as many as 12 low-sulfur coal beds in the upper part of the Fort Union Formation of Paleocene age and the lower part of the Wasatch Formation of early Eocene age. These coal beds average 30 ft or more in thickness; they are extensive around the margin of the basin and in places extend into the central part.

Sulfur distribution trends in the Pittsburgh coal bed

The sulfur content of the Pittsburgh coal bed in southwestern Pennsylvania, northern West Virginia, and eastern Ohio may be related to the depositional environment of overlying strata according to J. B. Roen. Lithofacies and sulfur distribution maps show that the coal contains 2 percent or more sulfur where the overlying rocks consist largely of brackish to freshwater limestone. Coal with less than 2 percent sulfur is overlain by sandstone and shale that appears to have been deposited in a fluvioterrestrial environment. Westward across the panhandle of West Virginia and eastern Ohio, an increase in the sulfur content of the Pittsburgh coal bed is accompanied by an increase in the brackish or marine character of the overburden. A similar relationship has been demonstrated with the Lower Kittanning coal bed in western Pennsylvania (E. G. Williams and M. L. Keith, 1963). An anomaly may be present near the western edge of Belmont County, Ohio, where limestone is replaced by fluvial channel-fill sandstone and the sulfur content of the underlying coal remains constant. Assuming that the sulfur content of the coal is related to the overlying strata, this anomaly may be explained by the erosion of brackish to marine strata and subsequent deposition of fluvial, channel-fill sandstone.

OIL AND GAS

Origin of overthrust faults and oil and gas possibilities in the Southern Appalachians

Analysis of recent work by R. L. Miller and others has led to an interpretation of the mechanics of formation of the Cumberland overthrust block and of other extensive areas in the southern Appalachians that constitute the Valley and Ridge province. According to this interpretation, uplift during the late Paleozoic produced a very gentle northwest slope, down which extensive crustal areas slid along a deep sole fault or decollement which was slightly above, but not at, basement. Later rupturing of the moving block because of internal strains resulted in the large overthrust and thrust faults now visible at the surface. These join the sole fault at depth above an undeformed basement.

Because of the nearly total absence of compression during movement, the oil and gas content of the rocks above the sole fault should have been little affected, and there may be areas of prospective accumulation, in spite of the many faults in the province.

Recurrent growth of structures, Great Divide basin, Wyoming

Detailed subsurface studies of Upper Cretaceous and Tertiary rocks in the northern part of the Great Divide basin by M. W. Reynolds show that the Flattop Buttes fault zone approximately coincides with the axis of an anticline that was actively rising during Late Cretaceous and Cenozoic time. Rocks of the Mesaverde Group were thinned markedly on the north flank of this fold and were truncated beneath an unconformity at the base of the Lewis Shale on the structurally high block just north of the present fault zone. Subsequent movement along normal faults at Lost Creek during post-early Eocene to pre-middle Pliocene time produced nearly 3,000 ft of displacement, down on the south (basin) side. Holocene movement has been as much as 100 ft down on the south. Shows of gas were encountered in a test well drilled on the south side of the fault zone in the thinned edge of the Mesaverde Group.

Tectonics at beginning of Mississippian Period

Regional studies summarized by L. C. Craig have documented the timing of large-scale tectonic events in the United States at the beginning of the Mississippian Period. The Late Devonian Antler and Acadian orogenies, in the Cordilleran and Appalachian geosynclines, respectively, coincided approximately with the uplift of the Transcontinental arch, Texas arch, and Ozark uplift on the craton. A period of widespread Late Devonian erosion was followed by epeiric subsidence and flooding by the sea of all but the axial parts of the uplifted cratonic positive elements. A thin layer of marine sediment was deposited in shallow water over most of the craton during latest Devonian and earliest Mississippian time. Except on the relic Devonian positive elements, the Devonian-Mississippian boundary appears to be paraconformable.

World resources of natural gas

On the basis of earlier work (T. A. Hendricks, 1965), S. P. Schweinfurth has estimated that ultimately recoverable world resources of natural gas on land and continental shelves may approximate $16{,}000 \times 10^{12}$ ft^3. Of this, as of the end of 1970, about $2{,}450 \times 10^{12}$ ft^3 had been found, including about 645×10^{12} ft^3 already produced, and leaving about $13{,}550 \times 10^{12}$ ft^3 to be discovered. The United States had accounted for about 680×10^{12} ft^3, or some 27 percent of the gas found in the world to the end of 1970. The bulk of world proved reserves of gas, about $1,000 \times 10^{12}$ ft^3, are in the Middle East and the U.S.S.R. Of the total ultimately recoverable world gas resource of $16,000 \times 10^{12}$ ft^3, it is estimated that approximately 80 percent will be found onshore and 20 percent on the continental shelves. Furthermore, it is estimated that about 80 percent of the onshore gas resource will be found in sedimentary rocks less than 15,000 ft thick and that about 70 percent of the resources of the continental shelves will be found under water less than 300 ft deep.

Possible targets for oil and gas exploration in the southern Basin and Range region

Stratigraphic investigations by P. T. Hayes of Cambrian and Ordovician rocks in southern Arizona and New Mexico have led to the conclusion that, although the potential is not high, the Abrigo Formation (Cambrian) could contain petroleum reservoirs in part of southernmost Arizona and rocks of both the El Paso Limestone and Montoya Group of Ordovician age could contain reservoirs in southern New Mexico. The most favorable exploration target may be porous weathered rock at the top of the El Paso Limestone where it is unconformably overlain by shale-bearing Devonian beds in the vicinity of the Arizona-New Mexico border.

CHEMICAL RESOURCES

Correlation of tuff beds in the Green River Formation by electron microprobe analysis of biotites

Biotites from well-known tuff beds in the Parachute Creek Member of the Green River Formation in the Piceance Creek basin of Colorado and in the Uinta Basin of Utah were studied by G. A. Desborough, J. K. Pitman, and J. R. Donnell (1973). The Parachute Creek Member contains beds of rich oil shale. Microprobe analyses of the biotites indicate that the biotite composition among tuff beds is sufficiently different to permit some tuffs to be distinguished from others. The arithmetic means for the weight percentages of FeO, MgO, and TiO_2 for a bed may be distinctly different from those of other beds in a sequence. Biotites from an individual tuff bed from various localities, however, have the same mean within 1½ standard deviations. Thus, microprobe analysis may provide a quantitative method of identifying individual beds within a sequence of biotite-bearing tuff beds in the absence of other stratigraphic controls, and the analysis is also useful in extending correlations over relatively long distances without detailed measurements between localities.

Contact between the Parachute Creek and Evacuation Creek Members of the Green River Formation

In the Piceance Creek basin of Colorado the upper part of the Green River Formation (Eocene) consists of two units, the Parachute Creek Member and the overlying Evacuation Creek Member. The Parachute Creek Member contains potentially important oil-shale resources. Mapping by R. B. O'Sullivan in the east-central Piceance Creek basin shows that marlstone units within the Evacuation Creek Member merge to the south and southeast with the main body of the Parachute Creek Member. As a result, there is a marked stratigraphic rise of about 275 m in the upper contact of the Parachute Creek Member within a distance of about 8 km. Recognition of this stratigraphic relationship will aid interpretations of the character and thickness of overburden above the oil-shale zones of the Parachute Creek Member.

Biogeochemistry of bedded barite deposits

Studies of the organic and inorganic geochemistry of black bedded barite deposits from Arkansas and Nevada indicate that these deposits are of a syngenetic, low-temperature origin. The presence of fatty acids similar to those found in sulfate-reducing bacteria, together with field relations, petrography, and trace-element content of the barite, supports a primary sedimentary origin. A model for the origin of bedded high-grade barite deposits has been proposed by R. E. Miller, D. A. Brobst, and P. C. Beck (1972). Exploration for such deposits should especially include the examination of siliceous sedimentary sequences in basins of middle Paleozoic age. In these basins, the presence of the fatty acids in close association with $BaSO_4$ suggests that the initial step in the formation of primary barite was a complex organic-inorganic reaction.

Boron-bearing potassium feldspar in closed-basin deposits

Studies by R. A. Sheppard and A. J. Gude 3d (1973a) of several saline, alkaline lacustrine deposits in the Western United States have shown that silicic vitric tuffs are commonly altered to a variety of zeolites and potassium feldspar. The tuffs generally show a lateral gradation in a basinward direction of fresh glass to zeolites and then to potassium feldspar. Zeolites formed early in diagenesis by reaction of the glass with the interstitial water. The feldspar, however, formed later by reaction of the zeolites with interstitial water, and its formation can be correlated with water of relatively high salinity and alkalinity. Semiquantitative spectrographic analyses for boron in the zeolites and potassium feldspar show that most of the boron resides in the relatively late feldspar. The boron content of the zeolites is commonly less than 100 p/m, whereas the boron content of potassium feldspar is commonly greater than 1,000 p/m. Boron apparently substitutes for aluminum in the feldspar structure and causes distortion of the monoclinic unit cell, thereby shortening the *b* and *c* dimensions. These boron-bearing potassium feldspars having anomalous cell parameters seem unique to saline, alkaline lacustrine deposits and could serve as a prospecting aid for locating buried saline minerals.

Evaluation of evaporite mineral and brine resources

Commodities derived from evaporite and brine deposits include potassium and magnesium compounds, salt, gypsum and anhydrite, calcium chloride, sodium carbonate and sulfate, nitrates, boron, strontium, bromine, and iodine. A survey by G. L. Smith, C. L. Jones, W. C. Culbertson, G. E. Ericksen, and J. R. Dyni (1973) has shown that world and national resources of most evaporite minerals are very large. Some are adequate for a few centuries at present rates of consumption; others are adequate for thousands of years; still others are virtually unlimited. It seems quite likely that within the next several hundred years, no evaporite resources will be exhausted or increase greatly in cost.

Evaporite mineral resources of the United States are large. Unlimited supplies of nitrates, bromine, and magnesium are available from air and sea water. Resources of salt and sodium carbonate seem adequate for thousands of years at present consumption rates. Known supplies of gypsum and anhydrite, sodium sulfate, borates, strontium, iodine, and calcium chloride should be adequate for hundreds of years. At present production levels, potash resources available in crystalline deposits and brines within the United States are sufficiently large to last at least 100 yr, and Canadian resources are sufficient to fulfill requirements in North America for thousands of years.

Inorganic chert in a Pliocene lacustrine deposit near Rome, Malheur County, Oregon

Nodules and thin beds of chert occur in the upper part of an unnamed lacustrine deposit, 8 to 11 km southwest of Rome, Oreg. R. A. Sheppard and A. J. Gude 3d (1973b) found that the chert is in green to greenish-gray mudstone, about 8 m beneath a conspicuous zeolitic tuff. The bedded chert contains molds of saline minerals and grades southward and marginward into nodular chert. The nodular chert is of two varieties: (1) relatively large lobate nodules that have dark-brown interiors and abundant saline crystal molds, and (2) relatively small lobate nodules that have gray interiors and a surface reticulation. The latter variety is called snakeskin agate and is prized by lapidaries.

The cherts are similar, if not identical, to Magadi-type cherts reported from Quaternary lacustrine deposits in eastern Africa by H. P. Eugster (1967) and R. L. Hay (1968). Magadi-type chert is thought to have formed from a hydrous sodium silicate precursor such as magadiite. The magadiite is generally a primary precipitate from a highly alkaline lake which is capable of attaining a high concentration of silica. Evidence of a saline, alkaline depositional environment for the chert-bearing lacustrine rocks near Rome includes authigenic zeolites, potassium feldspar, and fluorite and abundant molds of gaylussite and pirssonite. Thus, the chert probably formed during diagenesis from a hydrous sodium silicate precursor by removal of sodium and water.

Element partition ratios determined among sedimentary rock constituents

Simulated data were employed by Yves Tardy (Centre de Sédimentologie et Géochimie de la Surface, Strasbourg, France) while a guest of J. D. Vine (USGS) to establish guides for interpreting partition ratios of minor elements distributed among the detrital, sulfide, organic, phosphate, carbonate, and sulfate fractions of sedimentary rocks. Principal component analysis of correlation data, using two-dimensional vector diagrams and multiple regression analysis of the chemical components, were used to determine the coefficient of concentration of each fraction of the rock according to the general formula: $X=\alpha A+\beta B+\gamma C+ \ . \ . \ .$ where X is any given minor element; A, B, C, . . . are the major rock constituents; and α, β, and γ are coefficients of concentration of element X in each major rock constituent.

The technique was applied to 20 sets of data, representing nearly 1,000 analyses of individual rocks ranging from dominantly detrital to dominantly phosphate or carbonate rocks, including some black shales and associated rocks. Results for 18 minor elements indicate that some, such as Mo may be as much as 150 times more concentrated in the organic fraction than the detrital fraction. Other elements concentrated in the organic fraction are Y, La, V, Cr, Co, Ni, Cu, Zn, and Ag; whereas Co, Ni, Mo, Cu, and Zn are also concentrated in the sulfide fraction; V, Sr, Y, La, Cr, and Zn are in the phosphate fraction; Sr, in the carbonate fraction; Sr and Ba, in the sulfate fraction; and B, locally in the authigenic silicate fraction. Other elements, including Be, Ga, Sc, and Zr, are mostly confined to the detrital fraction of these rocks and show little tendency to be enriched.

This technique has application not only for classical studies of geochemical abundance and distribution of minor elements but also for studies of the origin and distribution of elements in commercial mineral deposits.

GEOTHERMAL RESOURCES

Geothermal resource appraisal

L. J. P. Muffler (1973) has prepared an analysis of the reasons why published estimates of geothermal resources of the United States differ by up to six orders of magnitude. This analysis utilizes the concept of the geothermal resource base, defined as all the heat above 15°C in the earth's crust. Although this geothermal resource base is indeed immense, only a small part can properly be considered a resource. The magnitude of the geothermal resource depends on the evaluation of many physical, technological, economic, environmental, and governmental factors. The physical factors that control the distribution of heat at depth can be evaluated, at least rudely. More tenuous are the assumptions of technology, economics, and governmental policy. These assumptions are critical to geothermal resource estimation, and differences among them are in great part responsible for the vast range in magnitude among different geothermal resource estimates.

Utilization of a greater proportion of the geothermal resource base depends on achieving one or more of the following items:

1. Technological advances that would allow electrical generation from low-temperature reservoirs.
2. Breakthroughs in drilling technology that would permit low-cost drilling of holes to depths significantly greater than 3 km, the present limit for geothermal drilling dictated by economics.
3. Development of techniques of artificial stimulation to increase the productivity of geothermal reservoirs.
4. Expansion of the use of low-grade geothermal resources for space heating, product processing, agriculture, desalination, and so forth.

D. E. White (1973) has analyzed the magnitude of geothermal resources and the problems of their utilization by classifying geothermal resources into four major categories or thermal regimes: (1) areas dominated by near-normal conductive gradients, (2) restricted areas characterized by abnormally high conductive gradients, (3) hot-water convection systems, and (4) vapor-dominated convection systems. Utilization of geothermal resources in the near future is restricted to the last two regimes, the hydrothermal convection systems.

Published estimates of future geothermal power production differ by as much as a million times, largely because of differences in assumed state of technology; the optimistic estimates assume breakthroughs that have not yet occurred. Other differing assumptions include rate and cost of discovery, productivity and spacing of wells, and abundance of vapor-dominated systems. White concludes that the economically favorable vapor-dominated systems are very rare. In his opinion, world geothermal electrical capacity is unlikely to exceed 30,000 MW until major technological breakthroughs have occurred and cost is demonstrated to be low, particularly for the abundant hot-water hydrothermal systems. Geothermal power production at more than a few percent of national needs will require technological developments that would permit recovery of the huge quantities of heat stored in deep sedimentary basins and in hot dry rocks.

Extraction of geothermal energy from hot dry rocks by fracturing

The past several years have seen increasing interest in the artificial stimulation of hot impermeable rock by fracturing which permits circulation of water and the recovery of the heat contained in the rock (M. C. Smith, 1971; F. H. Harlow and W. E. Pracht, 1972). Most of the proposals involve circulation of hot water through the fractured rock under pressure sufficient to maintain the water in a liquid state everywhere throughout the system, with the energy being transferred via a heat exchanger to a cold-vapor turbine and generator. This suggested procedure is similar to the production scheme proposed for many natural hot-water geothermal areas.

D. E. White has suggested that, if artificial stimulation by fracturing proves feasible, utilization modeled after the natural vapor-dominated geothermal systems should be considered. Such systems have many advantages (low cost, few environmental hazards, and no major unsolved problems) over the natural hot-water geothermal systems. Direct steam generation rather than circulation of hot water may well prove to be a more efficient way of extracting the heat of hot dry rock.

Volcanic rocks as guides to geothermal exploration

Most, if not all, of the geothermal areas of the world that are producing power, or are currently under development for power, are areas of late Tertiary or Quaternary silicic volcanism. From this relationship, from the abundant evidence of a preferred relationship between ancient hot spring systems and silicic intrusives, and from observations bearing on the longevity of hot spring systems associated with silicic volcanic centers of large volume, it seems logical to conclude that the younger the chamber, the larger it is, and the higher it resides in the crust, the greater its potential for the support of convective hydrothermal systems.

Accepting these premises as a starting point, R. L. Smith and H. R. Shaw have classified volcanic systems into several categories of silicic and basic types and have devised a scheme for evaluation of the silicic systems based on ages of latest volcanism, volumes of silicic ejecta, and probable volumes of the magma chambers. Volumes and ages are plotted against a family of curves showing solidification times for a spectrum of shapes and volumes of chambers. Both convective and conductive heat flow models are considered as are depths and cooling environments. Clearly no simple model fits all chambers, largely because of the shape and depth variables, and every area must have its own specifications when considered in detail.

Approximately 50 silicic volcanic areas in the western United States have been screened for data useful in formulating this approach to geothermal exploration. Most of these areas are not well known and provide only fragments of information. The major conculsions are based on more complete data from about 25 volcanic areas both within and outside the United States.

Geothermal resources of northern Nevada

Assessment of the geothermal resources of northern Nevada by R. K. Hose includes field examinations of the thermal spring systems plus an analysis of a diverse variety of geological, geophysical, and chemical data and comparison of these features with those in areas in other parts of North America where geothermal resources are known.

Virtually all known or potential geothermal resource areas of North America are associated in some fashion with silicic Quaternary volcanic rocks. The thermal energy of these geothermal systems is probably derived via fluid convection from a perched igneous heat source in the form of a magma chamber at some intermediate level in the crust. In northern Nevada, however, Quaternary silicic volcanic rocks are all but lacking, and with minor exceptions, the youngest silicic volcanic rocks are >10 m.y. old. It would seem reasonable then that any intermediate level magma chambers associated with the older volcanics would have cooled long ago.

Despite the absence of the requisite Quaternary silicic volcanic rocks, thermal springs are distributed widely in northern Nevada. It is known that in the Great Basin, heat flow in general is higher than elsewhere in the continents, and in northern Nevada it is greater than 1.5 units. J. H. Sass and others (1971) identified a large area around Battle Mountain where heat flow ranges from 2.8 to 3.5 units and thermal gradients range from 27° to 64°C/km. The high heat flow over the province has been attributed to a combination of thin crust ($\approx$30 km) and a lower crust-upper mantle of high temperature.

Field examination discloses that most hot springs in northern Nevada occur along Basin and Range (late Miocene to Holocene) faults. Hose suggests that heat energy of the spring systems is derived from deep circulation of meteoric waters along faults in areas of high heat flow and high geothermal gradient rather than from a perched heat source at intermediate depths in the crust. Such a suggestion is compatible with preliminary maximum temperature determinations based on chemistry of hot-spring waters.

A hydrologic reconnaissance of geothermal areas in northern Nevada by F. H. Olmsted, P. A. Glancy, and J. R. Harrill is defining areas of large heat flow associated with rising thermal ground water on the basis of temperatures and geothermal gradients measured at depths from about 50 to 150 ft below the land surface. The method has been tested with shallow test drilling in the Black Rock Desert and Carson Desert areas where it appears to be promising as a relatively inexpensive exploration tool. In both areas, faults probably provide the conduits through which deep thermal ground water rises to or near the land surface.

Geothermal resources of Idaho

The geochemistry and the geologic setting of 124 thermal springs and wells in Idaho were used to select areas where additional data should be collected to better define the geothermal resource potential of the State. Nineteen areas were selected by H. W. Young (USGS) and J. C. Mitchell (Idaho Dept. Water Adm.) on the basis of estimated aquifer temperatures of 140°C or higher as indicated by either the silica or sodium-potassium-calcium geochemical thermometer or their proximity to silicic volcanic rocks of Pleistocene age. Dissolved solid concentrations in the samples collected ranged from 14 mg/l to 13,700 mg/l.

Geothermal resources of Alaska

T. P. Miller and Ivan Barnes have made a reconnaissance study of selected hot springs in central and eastern Alaska, the Seward Peninsula, Copper River valley, and southeastern Alaska. The geologic setting of hot springs in southeastern and interior Alaska indicates that most hot springs occur near the margins of granitic plutons probably because of the availability of fractures, joints, and faults near the plutons. The distribution of hot springs, however, is independent of the age, composition, or regional geologic setting of the plutons and country rock.

Geothermal studies in Long Valley, California

Detailed geologic mapping of the Casa Diablo geothermal area in Long Valley caldera, Mono County, Calif. (see section on volcanic rocks and processes) by R. A. Bailey shows that the present thermal activity (mainly hot springs and fumaroles) is associated with recently reactivated faults on the south and east flanks of the Long Valley resurgent dome. More ancient fossil fumarolic structures pervasively distributed in deltaic sediments over 30 km^2 in the same area suggest that the surface thermal activity was more extensive and probably more intensive in the past. Whether this change in surface activity is a result of an actual decrease in heat flow with time or is due to lowering of the groundwater table that accompanied the draining of the Pleistocene Long Valley Lake is not yet known.

R. E. Lewis is studying the Long Valley geothermal area to define the relations between the hydrologic system and the geothermal heat source. Recent work includes an inventory and sampling of springs, initiation of a 1-m temperature survey with a shallow (less than 30 m) test-hole drilling program, and measurement of geothermal gradients in wells and test holes. Preliminary interpretation of completed thermal-gradient measurements indicates three anomalous areas in the eastern half of the caldera. Two negative anomalies are probably caused by a downward component of movement of shallow ground water and may indicate areas of recharge to the geothermal system. A pronounced high geothermal-gradient anomaly is probably indicative of high conductive and (or) convective heat flow. Isotherms drawn for temperatures at a depth of 1 m correlate with the positive anomaly and one of the negative anomalies.

W. D. Stanley, D. B. Jackson, and A. A. R. Zohdy have completed a geoelectrical survey in the Long Valley geothermal area. A shallow conductive body encompasses much of the hot spring activity in the eastern half of the caldera. This near surface body is as much as 500 m thick and has a resistivity of 2 to 6 ohm-m. Hydrothermally altered silicic volcanic rocks are thought to be the cause of the low resistivities. The Casa Diablo hot springs, which is the site of several geothermal steam wells, are situated on the north edge of an elongate east-west resistivity low in the southeast part of the caldera. This resistivity low is also believed to be caused by hydrothermally altered silicic volcanics. A third resistivity low was mapped about 3 km northwest of Casa Diablo; this low is caused by a conductive layer at a depth of about 300 m and of several hundred meters thickness. In addition, a conductive layer at a depth greater than 300 m was detected on an electrical sounding just northwest of Lake Crowley. The reasons for the low resistivity layers northwest of Casa Diablo and northwest of Lake Crowley are not known at this time, although one cause might be the presence of rhyolitic ash flows which contain hot waters or are highly altered.

L. A. Anderson has measured natural potentials by surface methods in an area north and west of Casa Diablo hot springs in Long Valley, Calif. The contoured data produce an anomaly of positive polarity centered approximately 2 km northwest of the hot spring area. The anomaly is interrupted to the east by a known fault, and a similar effect is observed on the southwest flank of the anomaly. Although the cause of the anomaly is uncertain at present, it may be related to streaming potential produced by upward moving thermal water.

Resistivity investigations near Clear Lake, California

W. D. Stanley and D. B. Jackson carried out a geoelectrical survey near Clear Lake, Calif. The study area is 10 km northwest of The Geysers dry stream field and in the vicinity of the Clear Lake Quaternary volcanic field. Apparent resistivity maps (Stanley and others, 1973) compiled from the dipole mapping surveys outline a large conductive body coincident with a 25 mGal Bouguer gravity low; both features are in the Mount Hannah-Seigler Mountain region south of Clear Lake. The two geophysical anomalies are probably caused in part by marine Great Valley sedimentary rocks, but comparison of the geoelectrical data with electrical well logs indidates that there probably is abnormally high heat flow in the area of the anomalies. The thickness of the conductive zone in the center of the anomaly is at least 4,500 m although its lower surface was not detected.

Geoelectrical survey at Marysville, Montana

Total field resistivity mapping from one source dipole has been completed by D. B. Jackson in an area around the Marysville stock northwest of Helena, Mont. The area, characterized by a 12-mGal Bouguer gravity anomaly, has an anomalously high heat flow of 3 to 20 μcal cm^{-2} s^{-1} (Blackwell, 1970) although no thermal features are associated with it. Six total field resistivity lows ranging from 30 to 135 ohm-m in a background that is 3 to 10 times as resistive are scattered throughout the area. Vertical electrical soundings made over several of the areas of low resistivity reveal no shallow conductive layers that would explain the total field anomalies. On the basis of the sounding data, the tops of the zones that produce the total field anomalies must lie at depths exceeding 700 m.

Geochemical prospecting for geothermal resources

The waters discharged by some warm springs with large rates of flow are mixtures of cold, low salinity, shallow circulating meteoric water and hotter, generally more saline water that has ascended from depth. R. O. Fournier and A. H. Truesdell have developed a method of estimating the temperature and proportion of the hot water component of such springs using the temperature and silica content of the spring water and the temperature and silica content of the nonthermal groundwater in the region. The method should be of use to those using compositions of hot spring waters as a reconnaissance tool in the search for geothermal energy.

EXPLORATION RESEARCH

REMOTE DETECTION OF GEOCHEMICAL SOIL ANOMALIES

In an attempt to better define the relationship between geochemically induced plant stress and spectral reflectance, R. D. Watson and T. D. Hessin are growing black valentine bean and sweet potato plants under greenhouse conditions in nutrient solutions containing various concentrations of copper, lead, zinc, and molybdenum. Very preliminary data indicate a pronounced but complicated relationship between spectral effects and geochemical stress. Physiological changes are also noted with increasing concentrations of each element. Fluorescence has also been demonstrated in these studies as a very sensitive indication of plant stress. Results suggest that ultimately it will be possible to detect geochemical soil anomalies by appropriate sensors mounted on aircraft or space platforms.

ORE-FLUID CONDUITS AS EXPLORATION AIDS

Montezuma district, central Colorado

Evaluation of the ore-fluid plumbing as a prospecting tool is the object of an exhaustive geochemical and mineralogical study of the Montezuma district in the Colorado mineral belt (G. J. Neuerburg and Theodore Botinelly, 1972). Despite repeated telescoping of ore deposits and of associated hydrothermally altered rocks, mineral and element distribution patterns are adequate data by which to identify and define the plumbing for the Pb-Zn-Ag deposits of the district.

Major conduits are mostly in fault and shear zones and preserved as pipes and tabular bodies of porous quartz-sericite-pyrite rock. These sericitic conduits are altered very largely from felsic porphyries. They show no significant addition of ore metals and very rarely host ore deposits. The distributary plumbing consists of propylitized rock, bulking much larger than and grading abruptly from sericitized rock. The propylitized rock frays outward along planar structures into unaltered rock; no particular rock type is dominant in the propylitic plumbing. Ore metals were added to the propylitized rock, and the ore deposits are concentrated on the fringes of propylitized rock and immediately beyond.

The sericitic conduits appear to have been solute-concentrating columns for the ore fluid. Analogous to evaporation, water was removed: on the order of 40 l/m^3 of sericitized rock. Although potassium and sulfur were precipitated, solute concentration was further increased by dissolution of sodium, calcium, magnesium, and iron from the rock. In the distributaries, propylitic alteration of biotite to chlorite appears to have localized, if not catalyzed, the precipitation of ore and gangue minerals. Precipitation of ore increased exponentially with the increasing restriction of the ore fluid to planar structures.

Coeur d'Alene district, Idaho

Altered rocks along the footwall of the Osburn fault and along the hanging wall of the Dobson Pass fault are reported by G. B. Gott, J. M. Botbol, and J. B. Cathrall to exhibit a 5- to 10-fold enrichment of potassium over sodium. Restriction of potassium enrichment to the footwall of the Osburn fault probably resulted from the relative impermeability of the Wallace Formation in the hanging wall. The potassic alteration along these two faults seemingly identifies them as principal conduits for large volumes of potassium-bearing solutions, whose relation to the sulfide deposits of the district is yet to be determined.

TRACE-ELEMENT DISTRIBUTIONS IN MINERAL EXPLORATION

Trace elements in mineralized structures

Geochemical studies by G. B. Gott, J. H. McCarthy, Jr., G. H. VanSickle, and J. B. McHugh (1969) in the Cripple Creek district related gold, silver, and tellurium to deep fissure zones in volcanic breccia. Recent work by J. H. McCarthy, Jr., and W. H. Ficklin show that iodine and fluorine are also systematically related to these zones. The fissure zone is the depositional locus for gold, silver, tellurium, and iodine, and these anomalous concentrations are surrounded by a halo of fluorine. From this distribution it can be surmised that the mineralizing solutions ascended into the volcanic basin through the fissure zones, depositing gold, silver, tellurium, and iodine along this conduit. Fluorine was apparently transported through the conduit as well as laterally beyond the fissure zone, whereas the iodine probably was precipitated in the conduit as silver iodide. The inverse relation of fluorine to gold, silver, tellurium, and iodine may define those fissure zones that are the most favorable areas for the occurrence of economic concentrations of gold.

Trace elements in gold

Analyses by J. C. Antweiler and E. L. Mosier of gold from the Central City district, Colorado, correlate with zoning patterns outlined by P. K. Sims and P. B. Barton, Jr. (1962). The silver content increases from a low of 5 to 10 percent in the central high-temperature zone to as much as 35 percent at the edge of the nonproductive low-temperature zone. The copper content of the same gold samples decreases from a high of 500 to 1,000 p/m to less than 100 p/m. Thus, silver and copper contents of gold may identify the zonal position of a deposit and help to predict its potential productivity.

Trace elements in fluvial manganese oxide

G. A. Nowlan reports that fluvial manganese-iron oxide deposits in Maine commonly have trace-element contents approximating those of marine manganese oxide concentrations and are therefore unusual among fluvial and lacustrine manganese-iron oxides in general. The higher trace-element contents among the manganese-iron oxides of Maine streams are generally from drainage basins with known mineralization. Also, the high contents of a given suite of elements reflect the sulfide minerals found in the drainage basin.

Trace elements in mull

G. C. Curtin and H. D. King report that areas of high antimony, gold, zinc, and molybdenum in mull and of mercury in soil near Stibnite, Idaho, define an anomaly for more than a mile along the trace of a major shear zone which has yielded appreciable antimony, gold, and silver from two mines, 1 and 3 mi north of the anomaly. Metals in the mull and mercury in the soil have migrated through an extensive cover of Quaternary colluvium and glacial drift tens of feet to more than 100 ft thick. Except for mercury, metal contents of soil samples yielded a much less well defined anomaly than did the matching mull samples.

NEW ANALYTICAL TECHNIQUES

Heavy metals in manganese oxides

An atomic absorption spectrophotometric method has been developed by T. T. Chao and R. F. Sanzolone for the determination of seven metal ions in the hydroxylamine extract of soils and sediments. Manganese, iron, and zinc are directly determined in the aqueous extract upon dilution. Copper, nickel, cobalt, and lead in a separate aliquot of the extract are chelated with APDC and extracted into MIBK before determination. Microgram levels of cobalt, nickel, copper, and lead are quantitatively recovered by APDC-MIBK chelation-extraction from synthetic solutions containing up to 2,000 μg/ml manganese or 50 μg/ml iron. Recovery of known amounts of the metal ions from sample solutions is equally satisfactory. This method will facilitate work to establish the interelement relations of heavy-metal ions associated with manganese oxides of soils and sediments.

RESOURCES COMPILATIONS

Geologic summary of U.S. mineral resources

A comprehensive account of the United States mineral resource position is provided in Professional Paper 820, "United States Mineral Resources" (D. A. Brobst and W. P. Pratt, eds., 1973), the first such general, geologically oriented review since the report of the President's Materials Policy Commission (1952). The volume contains 67 chapters by 95 authors. Briefly discussed are the uses, production, history, geochemistry, and geology of deposits; the reserves, resources, and outlook for finding additional deposits; methods of prospecting; problems for research; and a bibliography for 65 commodities from abrasives to zirconium. The volume is written for a general readership of planners, technicians, scientists, and the public-at-large; it considers three basic questions about each mineral commodity: (1) how important is it to our present industrial civilization and standard of living, (2) how much of it do we have and to what extent is it economically and technologically available, and (3) how and where can we find more?

Initial implementation of the Computerized Resources Information Bank—CRIB

The Computerized Resources Information Bank (CRIB) of the U.S. Geological Survey, developed by J. A. Calkins, Olaf Kays, and E. K. Keefer (1973), has been implemented and is playing an increasingly important role in facilitating study of the Nation's mineral resources. The file is still small (about 10,000 records in November 1972) but has already proved useful as a rapid means for organizing, summarizing, and cataloging mineral resource information and for displaying the results in summary reports, tables, and maps. CRIB consists of records that contain, in alphabetic or numeric characters, information on mineral commodities, mineral deposits, and groups of related deposits. The file is flexible; the attributes of a record entered into CRIB can be decided largely by the user within the size limit of 32,000 characters. Most entries are in free text, but certain key characteristics are formatted, coded, or both. The retrieval part of the program allows highly selective searches based on words, parts of words, phrases, numeric data, word or numeric ranges, and the logical interrelationship of variables.

Summary of selected mineral resource statistics for 120 countries

A summary of statistics related to onshore and offshore oil and gas resources and selected mineral resources for 120 countries was compiled by J. P. Albers, M. D. Carter, A. L. Clark, A. B. Coury, and S. P. Schweinfurth (1973). The report is an initial assessment of the world's supplies of critical mineral and fuel commodities that either are being extracted or are likely to be extracted from offshore accumulations. The report contains comparative statistics on production, imports, exports, proved reserves, and estimated potential resources of oil and gas, copper, nickel, cobalt, and manganese. A brief profile is given for each country, including a statement about the physical nature of its offshore regions; the country profiles are followed by summary tables of coastal and offshore resources for the six continents—Africa, Asia, Oceania, Europe, North America, and South America. General conclusions are: (1) Although North America and Asia are the dominant petroleum-producing regions of the world today and have the largest reserves for the world of tomorrow, Asia alone contains more than 70 percent of all the reserves tabulated, (2) a major shift in production is occurring from North America to Africa and Asia, with Africa now doubling its production every 2 yr compared with a doubling time of 20 yr for North America, and (3) a major future shift in gas production may take place from North America to that part of the USSR east of the Urals where large gas resources are located.

Alaska bibliography of metallic mineral resources

A bibliography prepared by E. H. Cobb lists all Federal and State reports through 1972, as well as selected articles in journals, that describe metallic mineral occurrences in Alaska. The bibliography provides supporting data for the maps of Alaskan mineral resources at a scale of 1:250,000 which have been released in the miscellaneous field studies series or in open file.

Petroleum exploration drilling, the Powder River Basin

Data from 2,812 wells drilled during the period 1952 to 1968 in the Powder River Basin, Wyo., have been used in a model study by L. J. Drew who employed a variety of statistical techniques. General conclusions from an analysis of the model are that (1) the greater part of the drilling is done because of a nearby discovery rather than because of the findings of planned, ongoing exploration, (2) the majority of discoveries, however, result from ongoing exploration, (3) the probability of discovery and the total amount of oil to be expected increases with increasing amounts of exploration (number of wells drilled) whereas the probable amount discovered per well decreases with increasing amounts of exploration, and (4) in general, as the basin approaches exhaustion, larger exploration programs will become unprofitable before smaller efforts.

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 U.S. Geological Survey and the U.S. Bureau of Mines are making mineral 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 7.2 million acres. Reports on 31 of the areas have been published as Geological Survey bulletins, and reports on the remaining three areas will be printed during 1973 and 1974. Reports on primitive areas published in 1972 are summarized as follows:

High Sierra Primitive Area, California

The main geologic feature of the High Sierra Primitive Area is the Sierra Nevada batholith, comprising a group of Cretaceous granitic plutons separated by screens and masses of Mesozoic metavolcanic and metasedimentary rock. Limy rocks are interbedded with the metamorphic rocks, and both are associated with small areas of mineralization, particularly near contacts with the granitic rocks.

The High Sierra Primitive Area, in west-central California, was studied by J. G. Moore (USGS) and L. Y. Marks (USBM) (1972). The primitive area is at the eastern edge of a northwesterly trending group of tungsten-rich bodies on the west slope of the Sierra Nevada. There are two prospects in the area: one in the Middle Fork Canyon at river level and the other near the Obelisk in the northwest corner of the study area. The Middle Fork prospect contains small, noneconomic quantities of metals in sheared quartzite. The Obelisk prospect contains about 8,000 tons of tactite averaging 1 percent WO_3 as determined by diamond drilling. Limited additional reserves may be present; thus, a small economic deposit may be developed.

Salmon River Breaks Primitive Area, Idaho

The Salmon River Breaks Primitive Area is mostly underlain by intensely metamorphosed igneous and sedimentary rocks of Precambrian age which have been intruded and locally altered by at least four plutons of the Idaho batholith.

The mineral survey of the primitive area by P. L. Weis and L. J. Schmitt, Jr. (USGS), and E. T.

Tuchek (USBM) (1972) included extensive sampling and detailed studies in areas of old workings, mine claim locations, and areas of potential mineral deposits. More than one-third of Idaho's total gold production came from a broad northeasterly trending belt that lies just west of the study area. Consequently, more than 200 mining claims have been located in the area; nearly all are within 1 mi of the Salmon River.

Nevertheless, no important mineral resources were found in the primitive area although low-grade placer deposits are in gravels along the Salmon River. The Painter mine, in the extreme southwest corner of the study area, produced a small quantity of gold from a lode prior to World War II, but mineralization appears too sparse, erratic, and low in grade to constitute a significant resource. A deposit of fluorite in three ore shoots associated with a large quartz vein near Big Squaw Creek is estimated to contain 100,000 tons of commercial-grade ore, but the cost of extraction and transportation would exceed existing or probable future market values. A small area on Prospect Ridge contains small amounts of copper, lead, zinc, silver, and tin minerals.

Salmon-Trinity Alps Primitive Area, California

The mineral survey of the Salmon-Trinity Alps Primitive Area by P. E. Hotz (USGS) and H. K. Thurber, L. Y. Marks, and R. K. Evans (USBM) (1972), included about 450 mi^2 of the officially designated primitive area and 118 mi^2 of adjoining areas.

The area includes two lithologic belts. On the west is the western Paleozoic and Triassic belt underlain by fine-grained metasedimentary rocks and mafic to intermediate metavolcanic rocks. In the central part of the area is a belt of Salmon Hornblende Schist and Abrams Mica Schist, both Devonian or older Paleozoic in age, which has been thrust westward over rocks of the western Paleozoic and Triassic belt. In the eastern part of the area a large body of serpentinized ultramafic rock is thrust westward over the Salmon and the Abrams.

Gold and small amounts of silver, mercury, and chromium (as chromite) have been mined in the area. More than $5 million in gold has been produced from lode deposits, but the lode mines have been idle more than 30 yr. Some recent exploration and development have been carried on at the Globe mine and at some mines in the Coffee Creek area. The Globe, and possibly the Dorleska mine in the Coffee Creek south area, contain marginal deposits; the other lode gold deposits cannot be profitably mined now or in the foreseeable future. The placer deposits, which produced more than $500,000 in gold, can now support only small-scale operations. Anomalously high quantities of metals were found in many rock and stream-sediment samples, mainly in the western part of the area. Careful analyses of the geochemical and geophysical data, however, did not indicate the presence of undiscovered deposits of potential commercial interest.

WILDERNESS AREAS

Mineral surveys have been completed on 12 of the 54 wilderness areas that were established before or by the Wilderness Act of 1964. Reports on these areas are being prepared, and one will be printed during 1973. A report on the Pasayten Wilderness Area, Washington, which was established after 1964, was published in 1971.

STUDY AREAS

Mineral surveys on 29 of 237 areas being studied by the Forest Service for the Wilderness System have been completed. Investigations of 20 of the completed study areas are included in the reports on primitive areas. Reports on the remaining nine other areas were released in open file during 1973. Results of some of the areas are given below.

Cloud Peak study area, Wyoming

The Cloud Peak study area consists of the officially designated primitive area (137,000 acres) and contiguous areas (95,000 acres). The area is underlain mostly by igneous and metamorphic rocks of Precambrian age. Along the southwest boundary the Precambrian rocks are overlain by sedimentary rocks that dip westward into the Bighorn Basin.

The mineral potential of the area was evaluated by T. H. Kiilsgaard and G. E. Ericksen (USGS) and L. L. Patten and C. L. Bieniewski (USBM) (1972). Their investigations included the study of records of past mining activity, geologic studies and a search for mineral deposits, and extensive sampling and analysis of mineralized rocks and stream sediments. Geological, geophysical, and geochemical studies do not indicate that metallic mineral deposits of commercial value occur in the area, and none of the prospects that were seen warrants further exploration.

Teton corridor, northwestern Wyoming

Six anticlines of Laramide age (Late Cretaceous–early Tertiary), five trending northwest and one northeast, were mapped by J. D. Love and J. C. Antweiler in the Teton corridor between Teton and Yellowstone National Parks. All have Cretaceous rocks at the surface and contain seven or eight possible oil- and gas-producing horizons in a depth range of 1,000 to 9,800 ft. Some critical parts of each anticline that are covered with alluvial debris or Pleistocene rhyolitic welded tuff are subject to interpretation. None has been drilled and no detailed geophysical studies have been made. The east flank of one anticline has a small flammable gas seep. Anticlines similar to these, 60 mi to the east in the Bighorn Basin, generally produce oil and gas. However, even larger anticlines with larger closure, more extensive gas seeps, and more potential producing horizons, in Jackson Hole 10 to 25 mi southeast of the corridor, have been drilled but have not yielded commercial amounts of oil and gas. The reasons for this are not known and need to be explained before the economic potential of the anticline in the corridor can be considered of major interest.

Uncompahgre Primitive Area addition, Colorado

The mineral resource evaluation of three areas contiguous to the Uncompahgre Primitive Area in southwestern Colorado was made by T. A. Steven, P. W. Lipman, and F. S. Fisher (USGS) and C. L. Bieniewski and M. C. Meeves (USBM). They found three altered and mineralized zones, adjacent to the western margin of the easternmost area, that warrant further exploration. The mineralized areas are associated with monzonite intrusives that probably mark the roots of former volcanoes; all of them may be indicators of disseminated, porphyry-type deposits. On the north slope of Matterhorn Peak an intensely altered plug, 1,000 by 5,000 ft in cross section, contains anomalous amounts of copper, molybdenum, and other metals; the plug forms the core of an andesite central volcano that was active 30 to 35 m.y. ago. Farther south, in the Iron Beds area, there is a large mass of altered rock associated with several small monzonite plugs and dikes that irregularly cut the margin of the Uncompahgre caldera. Anomalous amounts of zinc and copper are present in the stream sediments derived from the altered area.

Mines in the old Capital City district, near the confluence of Henson Creek and its north fork, were developed in small veins in and peripheral to altered monzonite intrusions. Anomalous concentrations of metals in the altered rocks indicate widespread mineralization.

White Cloud study area, Idaho

The White Cloud study area, in White Cloud and Boulder Mountains, south-central Idaho, is underlain by intrusive, sedimentary, metamorphic, and volcanic rocks. The area contains the Stanley, Robinson Bar, Boulder, and East Forks mining districts and parts of the Bay Horse and Warm Springs districts. Past mineral production exceeds $3 million, and a mining company has announced the discovery of a molybdenum deposit in the area, valued at 100 times the past mineral production.

Field studies by C. M. Tschanz, D. A. Seeland, and T. H. Kiilsgaard (USGS) and R. Van Noy (USBM) indicate that other parts of the area also have mineral potential. The principal commodities, in approximate order of their potential value, are molybdenum, silver, lead, gold, zinc, antimony, tungsten, and copper. Past production has not included significant amounts of molybdenum and tungsten.

OFFICE OF MINERALS EXPLORATION

MINERALS DISCOVERY LOAN PROGRAM

The Geological Survey's Office of Minerals Exploration (OME) under Public Law 85–701 offers a program of financial assistance on a participating basis to private industry to explore deposits of certain minerals. To receive assistance, individuals or private firms must meet the eligibility requirements of the program. There must be a reasonable geologic probability that a significant discovery of ore may be made on a property by the exploration work specified in a contract, which is prepared for an approved application. Repayment of Government funds expended on a contract plus simple interest is made through a royalty of 5 percent on the value of mineral production from the property. If the Government issues a certification of possible production upon completion of work on a contract, 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. The Government is not obligated to purchase any minerals produced.

At present, Government financial assistance of 50 percent of the allowable costs may be granted for exploration of the following 27 minerals or metals:

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

Government financial assistance of 75 percent of the allowable costs may be granted for exploration of the following nine minerals or metals:

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

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

Activity on the OME program in calendar year 1972 and totals for the program through December 31, 1972, were as follows:

	Calendar year 1972	*Program totals, 1958 through 1972*
Application activity:		
New applications received	21	[1]918
Applications denied	11	384
Applications withdrawn	7	322
Processing completed	26	892
Total in process Dec. 31, 1972	14	
Contract activity:		
Contracts executed	8	204
Total value	$448,570	$12,957,440
Government share	$283,415	$7,466,004
Government share spent	[2]$122,616	$4,480,035
Repaid to Government through royalties on production	$7,124	$396,927
Estimated recoverable value of reserves in year discovered	$13 million	$108 million

[1] Total estimated cost of proposed exploration $88.4 million.
[2] Disbursements on all active contracts during the year.

Silver and gold exploration projects accounted for about 65 percent of the total value of contracts conducted on the program from 1958 through 1972 as shown in the following table:

Commodity	*Number of contracts*	*Total value of contracts*	*Percentage of total value*
Silver	73	$5,472,000	42
Gold	61	3,035,000	23
Mercury	17	1,162,000	9
Copper	14	858,000	7
Lead-zinc	7	682,000	5
Lead-zinc-copper	11	488,000	4
Molybdenum	3	384,000	3
Iron	3	200,000	2
Beryllium	3	127,000	1
All others			
All others (cobalt, fluorspar, mica, nickel, platinum, uranium)	12	550,000	4
Total (15 commodities)	204	12,958,000	100

GEOLOGICAL, GEOPHYSICAL, AND MINERAL-RESOURCE INVESTIGATIONS

NEW ENGLAND

USE OF REMOTE-SENSING DATA IN GEOLOGIC MAPPING

During the past few years, large areas of New England have been surveyed for geophysical purposes using a wide variety of remote-sensing techniques, and increasing numbers of maps and data banks displaying these data have been issued. During 1972 ERTS imagery of all New England and infrared and high-altitude visible-light photography covering much of eastern Massachusetts were acquired. These data, together with the previously obtained coverage of New England and offshore areas by aeromagnetic maps, airborne radiometric and gravity surveys, and coverage of southern New England by side-looking radar imagery, are providing new insights into the complex structure of the region. In New England where much of the bedrock is concealed, the various geophysical data are most helpful in integrating the known geology into an overall regional structural synthesis for this complex metamorphic terrane.

Geologic interpretation of the aeromagnetic map of southern New England

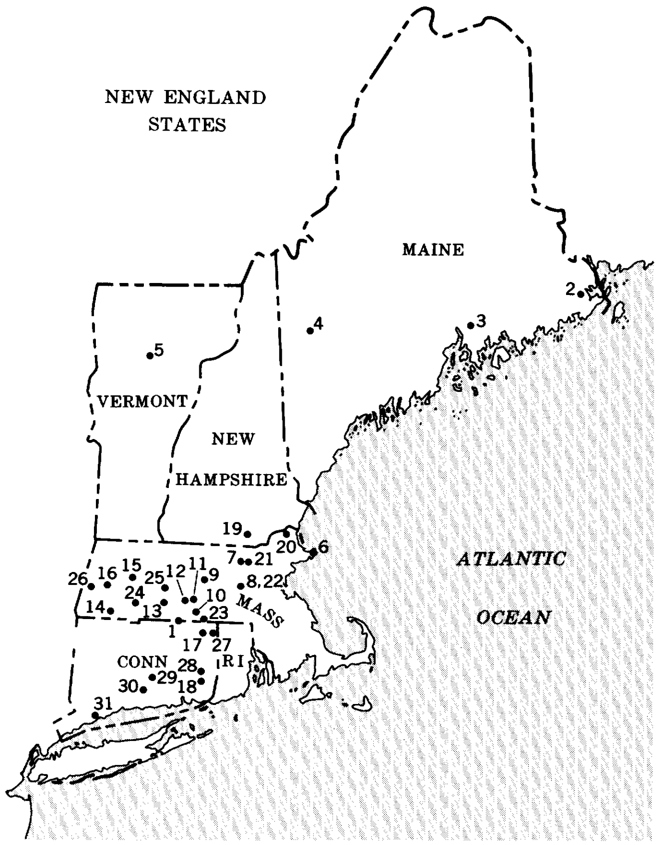
A new regional structural picture of southern New England that has many similarities with southern California has emerged from the studies made by P. J. Barosh, M. H. Pease, Jr., K. G. Bell, R. W. Schnabel, and J. D. Peper combining aeromagnetic data with geologic mapping. The aeromagnetic map of the region at 1:250,000, recently compiled by Isidore Zietz, shows a striking pattern of lineaments. Many of the lineaments coincide in whole or part with known faults, and many others with zones of geologic discontinuities that are now believed to be regional fault zones. The regional fault pattern that emerges is one of a series of large northeast-trending faults with subordinate north- and east-trending ones. No great transcurrent movement has yet been demonstrated, but many of the northeast-trending faults show apparent right-lateral offsets of up to several kilometers. A map showing this geologic interpretation is planned to accompany publication of the aeromagnetic map of southern New England.

Structural study of Rhode Island and southern Massachusetts as revealed by aeromagnetic data

A structural study of southeastern Massachusetts and Rhode Island by P. J. Barosh (1972) shows the region to be a distinct structural block bounded on the north by the southern border fault zone of the Boston Basin and on the south by the Honey Hill fault zone. The western boundary, in eastern Connecticut, is formed by a broad north-northeast-trending thrust belt that includes the Lake Char fault. A parallel magnetic and gravity lineament on the east, interpreted as a fault intruded by a mafic pluton, passes through the western part of Cape Cod and extends northward offshore for 50 mi. The major structures within this block are the composite gneiss dome forming most of western Rhode Island and the Narragansett basin to the east. Much of Narragansett basin appears bounded by north- and northeast-trending faults, the dominant fault trends within the block. A few northeast-trending faults cutting the composite dome have an apparent right lateral offset of as much as several kilometers where they cross the Precambrian (?) Blackstone Series.

Correlation of geology to aeromagnetic map pattern, eastern Connecticut

M. H. Pease, Jr. (1972), has found that geologic features of eastern Connecticut are clearly expressed on the 1:250,000-scale aeromagnetic map of southern New England. The Monson, Honey Hill, and Lake Char faults which separate blocks of distinctive geologic character are well delineated by prominent magnetic lineaments. Geologic features such as the Killingworth dome, the Bronson Hill anticlinorium, and the Colchester basin are clearly outlined on the aeromagnetic map. The correspondence of the aeromagnetic pattern to the geology is particularly close in areas of steeply dipping metamorphic rocks along the Bronson Hill anticlinorium in the Brimfield area, along the eastern border of Connecticut, and south of the Honey Hill fault. In the central part of eastern Connecticut, however, the aeromagnetic pattern does not reflect the complex structures of folded rocks exposed at the surface. A uniformly low magnetic susceptibility in these rocks probably accounts for much of this lack of correspondence, but the broad northeast-trending anomaly of low amplitude in this area may indicate that the rock exposed at the surface represents only a thin skin over a more uniform northeast-trending structure. Aeromagnetic data in the southeast part of the Killingsworth dome suggest that rocks of the Bronson Hill anticlinorium do not correlate, as previously believed, with rocks south of the Honey Hill fault. An exceptionally high intensity magnetic anomaly that lies south of the fault wraps around the south side of the dome and extends southwestward out to sea. It is conspicuously absent along the northeast side of the dome.



Aeromagnetic anomalies and stratigraphic and structural elements in central Massachusetts and adjacent Connecticut

Anomalies and lineaments on the aeromagnetic map of southern New England correspond closely to stratigraphic and structural elements in the Brimfield area (loc. 1) and provide a basis for general analysis of the unmapped parts of central Massachusetts. Analysis of the aeromagnetic data by J. D. Peper (1972) suggests a continuation into New Hampshire of the narrow north-trending zone of intense faulting that borders the Monson Gneiss on the east in southern Massachusetts and that forms a western boundary of northeast-trending rocks in the Merrimack synclinorium. Also suggested by trends of magnetic anomalies is the correlation of the sequence of rocks in the fault wedge in the Brimfield area of southern Massachusetts with the homoclinal sequence of Silurian and Devonian rocks on the southeast limb of the Merrimack synclinorium in New Hampshire.

Buried Reading Prong extends to Massachusetts-Connecticut boundary

The recent aeromagnetic map of southern New England includes adjacent New York and shows a high-amplitude positive anomaly extending from Beacon, N.Y., northeastward through Stissing Mountain to the vicinity of the Massachusetts-Connecticut border east of Copake, N.Y. The anomaly is asymmetrical with relatively steep northwest gradients and relatively gentle southeast gradients. Analysis of this anomaly by D. S. Harwood indicates the magnetic mass producing the anomaly is buried from 500 to 1,200 m below the lower Paleozoic quartzite, carbonate, and shale mapped by R. A. Balk in Dutchess County, N.Y. (Harwood and Zietz, 1973). The Beacon-Copake anomaly is similar in amplitude and lateral persistence to anomalies associated with Precambrian rocks of the Reading Prong found southwest of the Hudson River; therefore, it is inferred that the buried source of the Beacon-Copake anomaly is this type of Precambrian complex. The asymmetrical shape of the Beacon-Copake anomaly indicates the source has a relatively sharp boundary, probably a thrust fault, on its northwest side and that the magnetic source thickens and becomes more deeply buried toward the southeast. It is concluded that the source of the Beacon-Copake anomaly is a buried, parautochthonous slice of the Reading Prong. This Precambrian gneiss complex is overlain by lower Paleozoic rocks which, in turn, are overstepped by weakly magnetic Precambrian rocks of the Berkshire and Housatonic Highlands.

Relation of earthquake epicenters to regional fault patterns

Earthquake epicenters plotted for southern New England have been found by P. J. Barosh to correspond well with the regional fault pattern despite inaccuracies in epicentral locations and sparseness of data. Northeast-trending epicentral alinements occur across Rhode Island and western Massachusetts paralleling the major fault trends, and several epicenters have a roughly easterly trending alinement just south of and paralleling the Honey Hill fault and its eastward extension out to sea. The two most seismically active areas, the vicinities of Moodus, Conn., and Newburyport, Mass., lie near junctions of northeast-trending faults with others. The present seismic activity, however, does not necessarily imply that the stresses which formed the fault pattern are still active or that individual faults, even though they may be related to the epicenters, have more than local activity.

Gravity studies in the New England region

A comparison of Bouguer gravity levels of the Gulf of Maine with those of the surrounding northern Appalachian Mountains and with character of the rocks and structure onshore by M. F. Kane, M. J. Yellin, K. G. Bell, and Isidore Zietz (1972) indicates that the indurated bedrock underlying the Gulf may be largely of early Paleozoic or Precambrian age. A major discontinuity in the regional gravity field of New England extends along a northwest line from central Rhode Island to north-central Vermont (Kane, Simmons, and others, 1972), separating narrow north-trending elements of the field on the southwest from broad northwest-trending elements on the northeast. The discontinuity presumably marks a major division in the crustal rocks underlying the region. Analyses of detailed gravity profiles across the western edge of the Berkshire massif indicate that it is thrust-faulted over the stratified rocks of Paleozoic age which lie to the west.

Radar and regional geologic studies in southern New England

Further and more detailed analysis of the radar imagery of southern New England by P. T. Banks, Jr., has established a correlation between radar lineaments and certain large geologic features. Three Carboniferous sedimentary basins in eastern Massachusetts and the Triassic basin of central Massachusetts and Connecticut have been outlined by lineament analysis. Northeast-trending faults bordering the Boston, Norfolk, and Narragansett basins are sharply defined. Large, northeast-trending faults, such as the Clinton-Newbury and Bloody Bluff faults, are shown to extend from northeastern Massachusetts to south of Worcester where they join and possibly continue into eastern Connecticut. Northeast-trending lineaments characteristic of the Merrimack synclinorium sequence are sharply cut off on the west in east-central Connecticut and central Massachusetts by a zone of north-trending lineaments which coincides with the trend of the Bronson Hill anticlinorium sequence. This angular discordance, which is clearly defined on the radar mosaics of Massachusetts and Connecticut, marks the approximate trace of a major fault recently mapped in Connecticut and southern Massachusetts. The choppy lineament pattern just west of the Connecticut Valley shows the general configuration of the deeply eroded terrane of highly deformed and metamorphosed bedrock of this area. This pattern is interrupted on the west by the Berkshire, Housatonic, and Hudson massifs, which are characterized by more pronounced relief and arcuate lineament features. Farther west in Massachusetts and eastern New York, the allocthonous blocks of the Taconic sequence are clearly outlined on the radar mosaics.

Bottom-water circulation in Massachusetts and Cape Cod Bays

A general pattern of the bottom-water circulation in Massachusetts Bay and Cape Cod Bay has been determined by J. S. Schlee and R. N. Oldale using Richardson current meters moored 1 m from the bottom for 15- to 45-d periods at several locations in the bays. Ten km off the Boston Harbor entrance, the bottom flow is toward or parallel to the shore. No bottom flow seaward was observed. The limited amount of data suggests a weakly developed southerly drift for the basin comprising the Massachusetts and Cape Cod Bays. Average current speeds are 5 to 20 cm/s and maximum speeds are 20 to 40 cm/s. Minor seasonal changes in current speed and direction can be recognized.

STRUCTURAL AND STRATIGRAPHIC STUDIES

The USGS and various States have operated cooperative geologic mapping programs in New England since 1946, and one of the major purposes has been to issue revised intermediate-scale bedrock geology maps of New England based on information derived from detailed mapping. Substantial progress has been made on this objective, and in 1972 the progress continued to be satisfactory. Bedrock geologic maps of New Hampshire and Vermont at 1:250,000 and of Maine at 1:500,000 were published by these States several years ago. Mapping projects of the USGS contributed heavily to these maps. The USGS published a geologic map of Rhode Island, scale 1:62,500, in 1971. Compilation of the bedrock geology map of Connecticut at a scale of 1:125,000 is well advanced, 90 percent of the State having been geologically mapped at 1:24,000. Work is at an early stage on compilation of a geologic map of Massachusetts at 1:125,000; detailed mapping projects are presently being concentrated there so as to expedite compilation of this map. The relatively large scale of 1:125,000 for the geologic maps of Connecticut and Massachusetts was selected because these States, being urban and industrialized, require considerable detail for planning purposes. The USGS is presently engaged in cooperative programs with the States of Massachusetts, Connecticut, and New Hampshire. Results of the past year's research in New England, summarized below, show a concentration of effort in Massachusetts, the State with the greatest financial participation.

Chemical characteristics of volcanic rocks, eastern Maine coast region

Chemical analyses of 28 samples of typical Silurian and Devonian volcanic rocks collected by R. H. Moench (USGS) and Olcott Gates (New York State Univ., Fredonia) from the eastern part of the Maine coast volcanic belt (loc. 2) reveal two apparently significant relationships. First, the major-element compositions are strongly bimodal: basalt and mafic andesite on one extreme and silicic rhyodacite on the other. Compositions of lavas between 57 and 68 percent SiO_2 (volatile free basis) are conspicuously absent. This compositional gap is overlapped only slightly by tuffaceous rocks that show interlayering of the mafic and felsic types. Second, the major and minor element compositions change slightly from the older (Silurian and earliest Devonian) to the younger (Devonian) suites. The older basalts and andesites are tholeiitic, whereas the younger ones are alkalic. The younger felsic rocks (collected from the Eastport Formation of latest Silurian age) appear enriched relative to the older ones in most rare-earth elements, thorium, and several other metals.

Northeast-trending faults in Orland quadrangle, Maine

Major northeast-trending faults have been observed by D. R. Wones in the northwestern quadrant of the Orland quadrangle (loc. 3). These faults separate a block of second sillimanite grade gneisses from lower grade metamorphic rocks of Silurian and Devonian age (rocks near Kenduskeag and the Vassalboro Formation) to the northwest, and sulfidic schists of Ordovician age (Penobscot Formation) to the southeast. Abrupt changes in metamorphic grade, truncation of igneous bodies, mylonite zones, and mineralized areas mark the traces of the faults.

Characteristics of major transition zone in the Merrimack synclinorium, western Maine

Mapping by R. H. Moench and C. T. Hildreth in the Rumford quadrangle (loc. 4), western Maine, suggests that sedimentary and structural features characteristic of the central Maine slate belt to the northeast once extended the full length of the Merrimack synclinorium but were blurred to the southwest by successive periods of intense deformation and high-rank metamorphism. This quadrangle and adjacent quadrangles mapped by Moench (1971) are on a major structural and metamorphic transition zone in the synclinorium. The slate belt to the northeast is characterized largely by a rather straight beltlike pattern of low-grade metasedimentary rocks deformed by tight upright folds, subvertical slaty cleavage, and longitudinal premetamorphic faults (Osberg and others, 1968; Moench, 1970). In contrast, the region of the synclinorium to the south is characterized by greater structural complexity and by high-grade schists and gneisses. Across the transition zone in western Maine, sedimentary and early formed structural features of the slate belt are preserved. They are greatly modified, however, by large superposed folds of inconsistent trend, plunge, and amplitude, and by still younger map-scale kink band folds 3 to 5 km across. The kink band folds trend northwest and appear to have controlled emplacement of large plutons. Additional changes in western Maine include large migmatitic areas in which brittle, calcareous sedimentary units have been torn apart during successive deformations leaving disoriented blocks of granofels or calc-silicate rock in a matrix of migmatitic gneiss and intersecting patterns of late slip cleavage and schistosity which commonly have obliterated remnants of the early slaty cleavage. Most plutons appear to have been emplaced during a late stage of deformation in Devonian time. Although no cause-effect relation between emplacement and late stage deformation and high rank metamorphism is known, their contemporaneity is shown by map patterns and petrographic observations.

Isotopic evidence of Ordovician and Devonian metamorphic events in the Worcester Mountains area, northwestern Vermont

M. A. Lanphere (USGS) and A. L. Albee (California Inst. Technology) have obtained the ages of both major metamorphic events in New England on a single sample using the Ar^{40}/Ar^{39} age spectrum technique. In the Worcester Mountain anticlinorium of northwestern Vermont (loc. 5), coarse muscovite from a mineral assemblage of the kyanite-chloritoid metamorphic zone yielded an Ar^{40}/Ar^{39} spectrum with a plateau age of 439 m.y. Muscovite pseudomorphs after kyanite in the same hand specimen yielded an Ar^{40}/Ar^{39} spectrum with a plateau age of 354 m.y. These results indicate that the deformation and metamorphism in northwestern Vermont is Ordovician and that the extensive retrogradation of the higher grade assemblages of the Worcester Mountain anticlinorium and probably of the Green Mountain anticlinorium formed during the Devonian metamorphism.

Major unconformity beneath the type Marlboro and associated metavolcanic rocks and above the Dedham pluton and the rocks it intrudes

Continuation of mapping in eastern Massachusetts by K. G. Bell has revealed some previously unreported relations among the older rocks of the region. The oldest rocks are remnants of nonfossiliferous, metasedimentary, and metavolcanic formations. They are intruded by a metamorphosed plutonic series of which the Dedham Granodiorite is the most abundant phase. The stratified rocks are metamorphosed to amphibolite facies. The Dedham Granodiorite and associated plutonic rocks have undergone moderate pervasive brecciation and cataclasis of quartz and feldspar grains during regional metamorphism. The stratified metamorphic rocks also are intruded by unmetamorphosed gabbro, diorite, and granite of the Cape Ann pluton. The lowest stratified rocks are thinly layered biotite-quartz-feldspar gneisses of volcanoclastic origin occurring as xenoliths and pendants in the Dedham Granodiorite. Next is a sequence about 1,500 m (5,000 ft) thick of interlayered micaceous quartzite, argillite, slate, calc-silicate rock, quartzite, and amphibolitic gneiss. Much of the quartzite occurs as lenticular channel fillings. This sequence includes the Westboro Quartzite of Emerson (1917). Conformably overlying the quartzite-bearing sequence is a section of mafic metavolcanic rock about 1,500 m (5,000 ft) thick, formerly mapped as part of the Marlboro Formation of Emerson and LaForge (1932), but which lies several kilometers stratigraphically below the unit at the type locality of the Marlboro Formation. The above-mentioned stratified rocks probably correlate with the Blackstone Series of Rhode Island as described by Shaler, Woodworth, and Foerste (1899) and by Quinn, Ray, and Seymour (1949). Local omissions of part or all of the mafic metavolcanic sequence and even parts of the quartzite-bearing sequence that cannot be demonstrated as caused by faulting suggest a major unconformity exists between these rocks and the overlying thick sequence of predominantly metavolcanic rocks that includes the Waltham Gneiss, Woburn Formation, Marlboro Formation of the type locality, and many unnamed units. The overlying sequence is considered to be of pre-Silurian age. It is significant that the Dedham Granodiorite intrudes all the rocks below the suggested unconformity but does not intrude any of the rocks above it. Permissible ages from field evidence for the Dedham Granodiorite and the rocks it intrudes range from late Precambrian to early Paleozoic.

Field modal analysis on Cape Ann, Massachusetts

According to W. H. Dennen, field modal analysis of granitoid sialic rocks on Cape Ann, Mass. (loc. 6), allows their division into mappable units of less than 5 percent, 5 to 15 percent, 15 to 25 percent, and greater than 25 percent modal quartz. The areal distribution of these units coupled with aeromagnetic data suggests the intrusion to be layered and comagmatic with dioritic rocks upon which the sialic rocks rest.

Tectonic thinning in the Nashoba Formation

In the Westford, Billerica, and Concord quadrangles, Massachusetts (loc. 7), complexly interstratified metamorphosed volcanoclastic and epiclastic rocks of the Nashoba Formation have been subdivided into 16 lithostratigraphic map units with an aggregate thickness of 13,420 m (44,000 ft). According to D. C. Alvord, many of the map patterns of these rocks, formerly interpreted either as the result of folding or of facies changes, are the result of juxtapositioning and (or) removal of portions of the rocks by displacements within systems of subparallel east-northeast-trending high-angle reverse faults and related transverse faults. Along one such fault, mapping shows the southwesterly removal of 1,525 m (5,000 ft) of strata from its upper (northwest) plate in a distance of 7 mi. Three major subparallel zones of such faulting, together with some less extensive faults have, in a distance of 40 km (25 mi), progressively sliced out Nashoba rock, narrowing its outcrop belt gradually southwesterly from a 20-km (12-mi) breadth in the Westford-Concord area to a 6-km (3½-mi) breadth in the vicinity of the Wachusetts-Marlboro aqueduct where J. W. Skehan and A. Adel Abu-Moustafa found the stratigraphic thickness of the Nashoba to be 3,336 m (10,942 ft) (written commun., 1972). Thus, it is inferred that at least 75 percent or more than 10,000 m of section in the Wachusetts-Marlboro area has been removed from the Nashoba Formation by faulting.

Cataclastic rock along Bloody Bluff fault, Massachusetts

A zone of cataclastic rock has been mapped by A. E. Nelson along the northeast-trending Bloody Bluff fault in the Framingham and Concord quadrangles (loc. 8). This zone, which is locally 1.2 km (¾ mi) wide, is best demonstrated on the southeast side of the principal break of the fault. The cataclastic rock includes cataclasite, microbreccia, mylonite, mylonite gneiss, and blastomylonite. Granodiorite is the most common rock type exposed, but mafic lavas and tuffs as well as gabbro are present in lesser amounts.

Mineralized metavolcanics, Massachusetts

Anomalous amounts of base metals and silver have been found in samples taken across 156 m of a chloritized metavolcanic unit in Boylston and Clinton, Worcester County, Mass. (loc. 9). Samples collected by J. H. Peck from outcrops on the east shore of Wachusetts Reservoir consist of ten 4.5- to 9-kg (10- to 20-lb) lots of chips taken across 15.5-m intervals. The rock unit sampled is a chlorite schist altered from amphibolite and probably was a basic tuff or basalt flow originally. Average values across the 156-m sampled thickness of schist are 45.4 p/m Cu, 6.1 p/m Pb, 83.2 p/m Zn, and 3.0 p/m Ag. The range in values for each 15.5-m-long sample interval are Cu, 22 to 89 p/m; Pb, 2.9 to 11 p/b; Zn, 64 to 100 p/m; and Ag, 2.0 to 4.0 p/m. A selected sample of chips taken near the middle of the unit from rock which showed visible copper mineralization assayed 7,300 p/m Cu, 10 p/m Pb, 52 p/m Zn, and 5.0 p/m Ag.

The chlorite schist is greater than 160 m thick and has been mapped more than 1 km to the east. The unit is part of a metavolcanic and plutonic complex which forms part of the hanging wall of the Clinton-Newbury fault zone in the Clinton quadrangle. A subsidiary fault about 200 m north of the sampled exposures intersects the surface trace of the main Clinton-Newbury fault about 3 km to the northeast. The mineralization and the chloritic alteration of the amphibolite host rock may be from hydrothermal activity along the Clinton-Newbury fault system.

Metamorphic rocks of the Southbridge quadrangle, Massachusetts

G. E. Moore, Jr., reports that the Bigelow Brook Formation and rocks at Hamilton Reservoir in the Southbridge quadrangle (loc. 10) contain lime-silicate and metavolcanic units that were mapped separately from the more abundant quartz-feldspar-mica-garnet-sillimanite schist and gneiss. The Southbridge Formation is mostly quartz-feldspar-biotite gneiss and was not divided. All three formations contain many pods of coarse- to medium-grained quartz-feldspar pegmatite of two ages. The older pegmatites are foliated; younger ones are massive. North of the town of Southbridge the contract between the Bigelow Brook and Southbridge Formations is a fault; to the south the contact may diverge from the fault and be a gradational sedimentary contact. Both the sillimanite and the pegmatite are potentially of economic value.

Improper application of Rocky Quality Designation classification

Rock Quality Designation (RQD) classification was recently applied to cores taken for highway bedrock slope design in West Brookfield, Mass. (loc. 11). Preliminary design was based on poor or very poor RQD. Examination of the cores having a low RQD, existing roadcuts in the same rock, and determination of the near-surface seismic velocity of the rock indicated to J. H. Peck and C. R. Tuttle that the actual quality of the rock was consistently much higher than that indicated by the RQD values. Here the large discrepancies between

RQD values and rock quality determined by other methods were due to: (1) use of single-tube *AX* (1⅛ in.) core barrels and (2) poor drilling technique and (or) equipment. In this coring technique the specified criteria for use of RQD were not met, and design should have been based on other methods of classification.

Rock Quality Designation (RQD) is a rock-core classification scheme which is used to classify in situ rock for engineering purposes (Deere, 1968, p. 15–17). Simplified, the relation is $\mathrm{RQD} = \dfrac{C_R - C_f}{I}$

where C_R = total *NX* (2½ in.) or larger core recovered,
C_f = core in pieces less than 4 in. long, and
I = total interval cored.

The resulting percentage yields the following rock quality categories: Excellent (90–100), good (75–90), fair (50–75), poor (25–50), and very poor (0–25). Specifications require double-tube core barrels of a minimum *NX* size and close supervision of the drilling so as to recover as much intact core as possible and reduce breakage (Deere, 1968, p. 16).

Plutonic rocks of the Warren quadrangle

J. S. Pomeroy reports that there are two major foliated, syntectonic, and concordant intrusive bodies in the western part of the Warren quadrangle (loc. 12) Worcester, Hampden, and Hampshire Counties, Mass. The Coys Hill granite exhibits a porphyritic and an equigranular phase. The porphyritic phase is the more widespread and is largely quartz monzonite, but granite, granodiorite, and quartz diorite are common, whereas the equigranular phase is consistently a leucocratic quartz diorite. Major minerals in the porphyritic phase include calcic oligoclase to sodic andesine, quartz, microcline, and biotite. Equigranular phase rocks include intermediate andesine, quartz, and biotite with scarce potassium feldspar. Generally, the core of the porphyritic phase is higher in microcline and (or) quartz and lower in plagioclase and mafic minerals than are the flanks of the body. The other major plutonic body consists of medium-grained, equigranular diorite and meladiorite with less abundant quartz diorite and gabbro. Major minerals in the dioritic rocks are calcic andesine, green hornblende, brown biotite, and hypersthene with accessory minerals magnetic and apatite. Igneous textures are dominant, and retrograde or deuteric effects are generally minor in the two bodies. The magma must have originated at great depths and crystallized under stress, and the resultant foliation is considered to be primary.

Belchertown pluton, south-central Massachusetts

Petrographic study by G. W. Leo of the part of the Belchertown pluton within the Ludlow quadrangle (loc. 13) has revealed some new features. The pluton has a small core of pinkish, weakly foliated or nonfoliated quartz diorite to quartz-poor granodiorite with magmatic textures which contains clinopyroxene and hypersthene, red-brown biotite, and very sparse green hornblende. The outer zone of the roughly circular pluton consists of gray, gneissic quartz diorite to granodiorite with a strong foliation which generally parallels that of the adjacent middle Paleozoic metasedimentary and metavolcanic rocks. Chemical analyses obtained to date show that the outer zone gneiss is compositionally similar to the rock in the core, but it contains hornblende, green-brown biotite and locally epidote, and no pyroxenes. On the basis of textures and mineralogy, this rock ranges between essentially unmetamorphosed gneissic quartz diorite and recrystallized gneiss of epidote-amphibolite grade. The local metamorphism seems to be related to deep-seated shear zones (developed in the interior of the pluton as well as in the outer zone); indications are that the Belchertown pluton has undergone pervasive regional metamorphism.

Between the outer and inner zones of the pluton is a highly irregular transitional zone defined by L. M. Hall (unpub. data, 1970), as rocks containing clinopyroxene but no hypersthene. The transitional rocks, which in outcrop are very similar to rocks of the core, exhibit complex mineral reactions involving replacement of hypersthene and clinopyroxene by aggregates of tremolitic amphibole, green hornblende, and biotite. Such reactions could be late magmatic but may also have been enhanced by localized shearing. Field relations as well as petrographic features support the idea that the Belchertown pluton was forcefully intruded toward the end of the Acadian orogeny and that its fabric and mineralogy are chiefly due to magmatic and late-magmatic processes, locally modified by medium-grade metamorphism.

Recognition of mappable felsic gneiss units, central Massachusetts and Connecticut

Mapping by R. W. Schnabel in the Tolland Center and Otis quadrangles, Massachusetts and Connecticut (loc. 14), has resulted in the recognition of several distinctive lithologic units that can be traced for several kilometers along strike. All these units are parts of a complex series of quartz-plagioclase-microcline-biotite gneisses and are distinguishable mainly on the basis of different proportions of minor amounts of garnet, magnetite, hornblende, and muscovite. In addition, some units can be distinguished by textural differences including grain size variations and bedding structures. One unit, that occurs in the southwestern part of the Otis quadrangle and the northwestern part of the Tolland Center quadrangle, is dominantly calc-silicate rock with local beds of nearly pure marble. This unit gives the greatest promise of being a unique stratigraphic marker, and it has been traced along strike for nearly 3.5 km.

Granodiorite body is pegmatite

An areas of 10 to 15 km² in the Goshen quadrangle, Massachusetts (loc. 15), mapped as Williamsburg Granodiorite by Emerson (1917) is almost entirely muscovite pegmatite with minor muscovite granite and included mica schist according to N. L. Hatch, Jr. This area differs from surrounding areas of mica schist invaded by muscovite pegmatite only in the greater proportions of intrusive to intruded rock. The pegmatite and granite may represent the very top of what may be a large batholithic body at depth. Throughout all this and the nearby quadrangles to the west and south, the host schist, whether or not it constitutes a major or a minor proportion of the bedrock, does not appear to be disoriented by intrusion of the pegmatite and associated granite.

Refolded thrust plates in the Berkshire Highlands

S. A. Norton suggests that the Precambrian terrane in the Berkshire Highlands is composed of thrust plates and wedges. Fault traces in the eastern part of the terrane trend generally north whereas to the west they trend north and northwest. Refolding of thrust plates has resulted in klippes and fensters along the Becket–East Lee quadrangle border (loc. 16).

Two metamorphic events in Putnam quadrangle, Connecticut

Petrographic evidence for two metamorphic events has been found by H. R. Dixon in rocks of the Putnam quadrange (loc. 17). The earlier event was the strongest and recrystallized the rocks to sillimanite grade. The second event was less intense and downgraded the rocks to varying degrees. The calc-silicate gneiss of the Fly Pond Member of the Tatnic Hill Formation shows the second event well. To the south of the Putnam quadrangle, rocks of the Fly Pond Member contain a quartz-plagioclase-biotite-green hornblende-diopside assemblage. In Putnam, the green hornblende and diopside have been more or less completely recrystallized to pale-green actinolite, and only a few cores of the earlier minerals remain. Some plagioclase grains are completely replaced by epidote. Others contain small grains of epidote oriented in the plagioclase lattice, and in these, the host plagioclase is more sodic than in the unrecrystallized plagioclase. The calc-silicate gneisses show very weak or no indications of the cataclastic deformation which affected many of the rocks lower in the Tatnic Hill, but most likely the second metamorphism was of cataclastic generation. It is also possible that the K:Ar biotite ages of about 250 m.y. prevalent in the area in general reflect this second metamorphic event.

Deformation of the Preston Gabbro

According to H. R. Dixon field mapping and geophysical data substantiate earlier suggestions that the Preston Gabbro in Connecticut (loc. 18) is a fairly thin, westward-dipping sill (Loughlin, 1912; Longwell, 1943; Sclar, 1956). The mapping and preliminary petrographic study substantiate Sclar's conclusion that the gabbro was intruded after regional metamorphism and before cataclastic deformation. The gabbro at the border of the body is locally cataclastically deformed, especially in the southern part. Elsewhere it shows various types of deformation and alteration including amphibolization of mafic minerals and alteration of plagioclase but with little change in the original fabric (very common), local shearing accompanying the above alteration, or strong shearing and thorough alteration to a chlorite schist. The chlorite schist can, in places, be mapped for several thousand meters and probably indicates late faults that cut the gabbro. Inclusions of gneiss and a primary igneous fabric in the gabbro, even near the edge, indicate intrusion after regional metamorphism.

PLEISTOCENE GEOLOGY

Valley fill disappointing as water resource in Merrimack River valley, New Hampshire

Contours at 15 m (50 ft) intervals on the buried bedrock surface in the Merrimack River valley, Nashua North quadrangle, New Hampshire (loc. 19), indicate that few places have as thick an overburden as had been suspected. According to Carl Koteff, the contours indicate that the present Merrimack River is not too far from the course it occupied before the last glaciation. Because a large part of the thicker drift fill is fine sand, silt, and clay, the valley on the whole would not provide major ground-water resources, required by large towns or cities, without very careful drilling. For example, some excellent places exist, especially where eskers or ice-contact gravels are covered by clay, but their location cannot be predicted.

Relation of bedrock and surficial geology to environmental appraisals in northeastern Massachusetts

Mapping in the Newburyport West and adjacent quadrangles (loc. 20) of northeastern Essex County, Mass., has shown that the thickness and character of glacial deposits south of the Merrimack River closely reflect the underlying bedrock, according to A. F. Shride. Phyllite, underlying most of the town of West Newbury, resisted glacial erosion, and now cores a plateau that stands somewhat above plutonic terranes to the east and south. Drumlins composed of very clayey till derived locally from the phyllite surmount much of the plateau; except for the drumlins the till is only centimeters thick over broad areas, though phyllite outcrops are scant. Sand and gravel are nearly lacking, soils are thin, groundwater scant, and on-site waste disposal difficult due to impervious till and bedrock. Immediately to the east, in contrast, saussuritized granitoid rocks were eroded to form a lowland; little of the detritus scoured from the bedrock remains in the area. Gravelly and sandy outwash deposits accumulated in the lowland and may cover the bedrock to considerable depths. Sites for water wells are numerous in the thick sand and gravel as are potential gravel pits. South of the areas of phyllite and granitic rock, a high-standing rib 3 km (2 mi) wide of fine-grained diorite and associated resistant formations furnished granular fine and coarse detritus. Bedrock is widely exposed, and soils are so thickly strewn with erratics as to discourage land development. Compared with the phyllite area, drumlins and till deposits are sparse in both plutonic terranes, though in areas underlain by certain other types of bedrock farther south, drumlins are characteristic. These illustrations, from studies by A. F. Shride, indicate that data from bedrock and surficial geology considered in combination can lead to useful conclusions about geologic factors affecting land use.

Glacial deposits in Billerica quadrangle, Massachusetts

Mapping of surficial geology by A. V. de Forest has established that about 60 percent of the southern part of the Billerica quadrangle, Massachusetts (loc. 21), is underlain by till, bedrock, and swamp deposits. Two glacial-drainage sequences in the southwest display ice-contact features in the north and grade to finer grained sediments in the south. Extensive deposits of sand and gravel in a belt east of the town of Carlisle include ice-contact deposits in the west and glaciofluvial deposits along both sides of the Concord River. The extreme southern margin of the quadrangle is underlain by deposits of glacial Lake Concord commonly covered by 2 to 5 ft of loess.

New insights concerning Pleistocene geology of southern New England

Recent studies by C. A. Kaye of Pleistocene geology of the greater Boston area and nearby Massachusetts Bay are leading to new insights into the glaciation of southeastern New England. In the complex multiple-drift sequence of the Boston area, the separation of Wisconsinan from pre-Wisconsinan deposits is not clear. The evidence is compelling, however, that Wisconsinan ice was generally ineffective as an erosive agent. The bottom ice apparently moved rarely and then only locally; that is, the base of motion was a curved surface that only here and there impinged on the bed proper. This is shown by the general absence of curved striations on bedrock although striations of widely different orientation are found; instead striations of the several orientations are spatially grouped into domains with angular discordances between adjacent domains. One cannot, therefore, assume in this area a late Wisconsinan age for all surface glacial features or deposits, such as drumlins, outwash, or even till. The most effective glaciation (in terms of thickness of drift) seems to have been easterly flowing ice. Later, more southerly flowing ice reworked some of this earlier drift, carved drumlinoid forms, and redistributed clasts. Even the latest ice in the region, however, seems to have flowed easterly, not to the terminus as marked by the Cape Cod moraine on the south, but rather to some margin east of Massachusetts Bay.

Recessional stands of the last ice in southeastern Massachusetts

Several recessional stands of the last ice sheet (Woodfordian) have long been recognized in southeastern Massachusetts, including the terminal moraine of Martha's Vineyard and Nantucket, the Buzzards Bay and Sandwich moraines on Cape Cod, and several lesser moraines south of Plymouth. R. N. Oldale has postulated from recent mapping on inner Cape Cod other recessional stands, including a new interlobate moraine position. The interlobate moraine position is marked by high-level drift deposits along the southern shore of Cape Cod, a stagnant front position is marked by the head of the Harwich outwash plain, and another stagnant front position is marked by ice-contact deltas along the Cape Cod Bay shore. Two large proglacial lakes also existed, one in the area presently occupied by Cape Cod Bay. The data demonstrate that conditions along the ice front were varied, with active ice building a moraine in one place while debris from a stagnant front built outwash plains in others. Retreat from the terminal position was initiated in the Cape Cod Bay lobe, though later the Buzzards Bay lobe retreated faster.

Glacial lakes in the Framingham-Natick area, Massachusetts

Detailed mapping by A. E. Nelson has revealed that glacial Lake Charles and glacial Lake Sudbury successively occupied large parts of the Framingham and Natick quadrangles (loc. 22) during late Wisconsinan deglaciation. These lakes were the sites of deposition for most of the extensive stratified sand and gravel deposits presently exposed over much of the area. Ten lake levels or stages were identified for these lakes, each succeeding stage being lower than the previous one. Lake Charles had five stages and Lake Sudbury, which formed later, also had five stages. Three of the outlets, and a possible fourth, for Lake Sudbury are located within the Natick quadrangle; outlets for other Lake Sudbury stages and for all Lake Charles stages lie at a considerable distance from the area under study.

Two ages of drumlins

P. J. Barosh reports that drumlins in the Webster quadrangle (loc. 23) of Massachusetts and Connecticut form two groups having distinctly different trends which indicate two separate periods of drumlin formation. Southerly trending drumlins apparently were overriden by later ones trending S. 15° to 20° E. Neither group is noticeably dissected, and both were probably formed during the late Wisconsinan glaciation. One large composite drumlin trends anomalously S. 20° W., a trend that matches that of the underlying bedrock; a buried ridge has probably exerted local control over drumlin formation. The drumlins of the Webster quadrangle are part of the drumlin field that extends from Worcester, Mass., south into northern Connecticut. This field is coincident with a zone of relatively soft phyllite and schistose granulite and thus appears to be stratigraphically controlled.

Stages in deglaciation of Triassic lowland border

In mapping the surficial geology in the vicinity of Woronoco, Mass. (loc. 24), C. R. Warren has been able to distinguish 18 stages in deglaciation of the western border of the Triassic lowland. Deposits of some of these stages can be correlated over distances of several kilometers. The deposits suggest that the southward slope of the surface of the ice tongue in the Triassic lowland was less than 2 percent (20 m/km), even though the ice was subject to rather rapid ablation. The distribution of economically valuable gravel, sand, and brick-clay deposits relates to the successive positions of the ice margin.

Three tills in Belchertown, Massachusetts

J. A. Caggiano, Jr., reports three tills within the Belchertown quadrangle, Massachusetts (loc. 25). Three facies of the slightly silty, very fine sandy upper till have been mapped. These facies reflect mineralogy of the local source rocks and are distinguished on the basis of mineralogically induced color of the matrix. Well-indurated, stone-poor, highly weathered, silt- and clay-rich lower till lying at the base of one section has been exposed in two temporary excavations. A reddish-brown, stone-poor, well-indurated, silt- and clay-rich till in drumlins in the Connecticut Valley and on the north slope of the Holyoke Range may be a Connecticut Valley facies of the lower till derived from Triassic rocks. Sand and gravel in kame terraces, ice-channel fillings, kame deltas, deltas, and valley-train sediments were deposited by braided streams during episodes of melt-water drainage. While all melt-water eventually reached the Chicopee River and thence Lake Hitchcock, many temporary base levels controlled by masses of stagnant ice are recorded by kame terraces, deltas, and melt-water channels and spillways. Glaciofluvial sediments indicate initial drainage of melt-water to the southeast around the divide underlain by the Belchertown Tonalite. Melting of stagnant ice subsequently permitted drainage to the southwest out of the quadrangle.

Rapid deglaciation in western Massachusetts

Fieldwork by W. S. Newman shows that much of the lowland area of the Housatonic Valley within the Egremont quadrangle, Massachusetts and New York (loc. 26), contains valley-train outwash sand and gravel originating near the village of Alford; outwash literally buried much of the lower elevation topography. Except for ice-contact stratified drift deposits near Alford and South Egremont, the quadrangle exhibits little evidence of a slowly wasting and stagnant glacier. The dearth of ice-contact features, instead, attests to rapid deglaciation. Some of the stratified features are deltas built into glacial Lake Great Falls–Sheffield and smaller, shorter lived lakes and other fan deposits.

Pleistocene deposits along the Connecticut–Rhode Island boundary

D. A. Goulding reports that the surficial material in the uplands in the Thompson quadrangle, Connecticut and Rhode Island (loc. 27), consists chiefly of a thin blanket of till, though over Brandy Hill the till thickens to 100 ft. In the Five Mill River valley extensive and thick deposits of stratified drift and the dominance of hummocky collapse topography suggest a cycle of glaciofluvial deposition on and around stagnant ice masses that remained on the valley floor. High-standing remnants of the glaciofluvial deposits are represented by kames and kame terraces, especially east of Quaddick Reservoir; ice-channel fillings dominate the Whitman's Pond area to the northeast.

Valley fill in the lower Quinebaug River valley, Connecticut

An outwash chronology has been tentatively established for the lower Quinebaug River valley, east-central Connecticut (loc. 28), based on fieldwork by B. D. Stone and earlier investigations by A. D. Randall. Stratified drift and buried ice blocks filled the Quinebaug valley where it narrows 5 km (3 mi) south of Jewett City as the Quinebaug River turns sharply west. Adjacent to the filled gorge, a bedrock- and till-floored spillway controlled the melt-water levels in the valley to the north until the ice front had retreated 21 km (13 mi) upvalley to the vicinity of Wauregan. Valley-fill deposits graded to the water plane show progressive retreat northward. Altitudes of topset-foreset contacts in deltas indicate that postglacial crustal rebound amounted to about 0.8 m/km (4–4.5 ft/mi) in a northerly direction.

Pattern of deglaciation in the Colchester region, Connecticut

Preliminary work in the Colchester quadrangle, Connecticut (loc. 29), by R. M. Barker suggests that late Wisconsinan deglaciation occurred rapidly in southern parts of the quadrangle, and a series of short-lived melt-water streams fed minor quantities of sand and gravel to south-draining streams. Ice blockages in valleys to the west (Salmon River drainage) and east (Yantic River drainage) caused damming of proglacial lakes in west- and east-central areas, initially with outlets to the south. The easterly lake shortly began to utilize a southeasterly outlet through Gardner Lake lowlands in the Fitchville quadrangle. A stillstand of the ice that blocked easterly drainage for a considerable time prolonged its life appreciably. After it drained, a group of local outwash bodies were built north of the lake basin in tributary valleys to the Yantic River. The west-central lake maintained its southerly outlet for a longer period but increased in area considerably as the ice wasted north. Eventually the lake used an outlet to the west in the Moodus quadrangle, at an altitude not much lower than that of the southern outlet. When ice blockages along the Salmon and Jeremy rivers west of the quadrangle diminished, the lake drained. Melt-water streams then deposited outwash around ice blocks in valleys to the north until the glacier margin receded several miles north of the quadrangle.

Sudden draining of glacial lake may have deposited pink gravel on Connecticut River terraces

A discontinuous, major Pleistocene terrace level with a gradient of about 1 m/km (5 ft/mi) along the Connecticut River in the Deep River quadrangle, Connecticut (loc. 30), has been only slightly modified by post-Pleistocene stream cutting. Terrace segments, mapped by D. W. O'Leary, contain a variety of minor depositional units generally capped by coarse pink gravel derived from Triassic rocks. The layers underlying the pink gravel are markedly segregated by color and grain size; they consist chiefly of yellow to gray material of local origin or pinkish material from the Triassic valley rocks. Probably the terraces never formed a continuous valley filling in this stretch of the river; the highly variable bedding and composition, the general presence of ice-contact forms bounding the terraces, and the lack of erosional features along nonterraced stretches of the river suggest that the terraces were deposited as local ponded units, deltas, or gravel banks on and around blocks of residual ice. An abandoned channel of the Salmon River, cut into bedrock at Haddam Neck at elevations of 15 to 20 m (50–65 ft), suggests also that the present outlet of Salmon River (Salmon Cove) was ice dammed for a considerable period.

Scarcity of later stream-cut terraces and the prevalence of pink gravel capping the terraces suggest that the Connecticut River cut down to its present gradient in a single, possibly catastrophic event. The nearest source for pink gravel is near Middletown, about 16 km (10 mi) upstream. The sudden emptying of Lake Hitchcock could have been the event which both scoured residual ice out of the lower Connecticut River and deposited pink gravel on the remaining terraces.

Ice-flow change preserved in drumlins

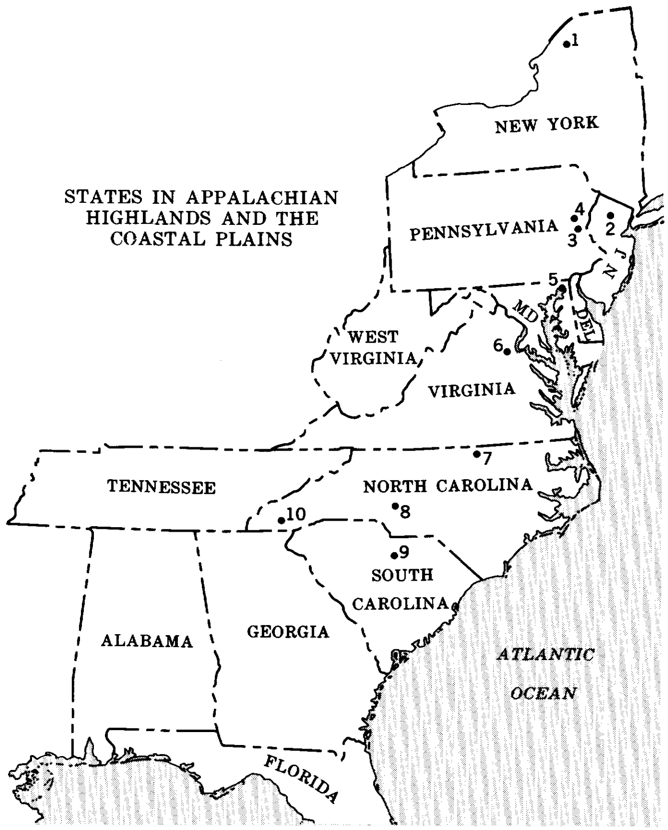
There are only a few drumlins in the Bridgeport quadrangle, Connecticut (loc. 31), but all exhibit a somewhat arcuate appearance when viewed in plan. Airphotographic analysis and ground checks by R. M. Barker verify that the arcuate appearances result from the consistent overprinting of later, more southeasterly flow trends onto earlier, more southerly oriented streamline forms. The earlier streamline forms were not appreciably eroded before deposition of the later material; the process seems to be mostly accretionary. In no drumlin is the change in trend much more than 15° to 20°. Opportunities for examining the drumlin materials is poor because they are heavily built over, but two, at least, contain lower till as the widespread near-surface deposit. The evidence, though meager, suggests that the drumlins are relicts of an earlier glaciation and that a change in ice-flow direction has been preserved in their form. Erosive power of ice of the last glaciation was not sufficient to change the drumlin shapes.

APPALACHIAN HIGHLANDS

ADIRONDACKS

Northeast-trending faults in Grenville Series, New York

In western St. Lawrence County, N.Y. (loc. 1, index map), C. E. Brown has recognized a set of curvilinear northeast-trending faults of regional extent that separate areas of Grenville Series metasedimentary rocks into large structurally and stratigraphically distinct lens-shaped panels. The continuous nature of the faults and their unknown displacements cause difficulty in stratigraphic and structural correlation in the area.



The Pleasant Lake fault is the westernmost fault that has been identified; it was first mapped near Pleasant Lake by J. R. Lewis (1969). Brown mapped the northeast extension of this fault in the Pope Mills quadrangle where recumbent east-plunging folds northwest of the fault are truncated by it. Southeast of the fault, folds in gneiss and impure marble are upright and have moderate plunges either to the northeast or southwest. Bounding this area on the southeast is a fault line valley occupied by Beaver Creek. The rocks southeast of

Beaver Creek are gneisses, calc-silicate paragneiss, marbles, and amphibolite in a doubly plunging recumbent anticline that is overturned to the southeast; it plunges both to the northeast and southwest and forms a large lens-shaped area on the map. The southeast part of the recumbent structure is bounded by a complex set of three low-angle faults dipping northwesterly. The easternmost of these was mapped by H. M. Bannerman (1972) who also mapped two high-angle, northeast-trending faults a few miles farther to the southeast. Six miles southeast beyond these is another subparallel fault near Balmat, N.Y., that was mapped by J. S. Brown (Brown and Engel, 1956). Total width of the zone between the Balmat and Pleasant Lake faults is more than 16 mi.

The faults apparently are penecontemporaneous with regional metamorphism because cataclastic and recrystallized metamorphic rocks occur along some, such as along the Balmat fault (Brown and Engle, 1956, p. 1620). Also, garnet and sillimanite-rich rocks locally are concentrated along the Beaver Creek fault and the thrust faults southeast of Beaver Creek. Some faulting is clearly younger than metamorphism and is manifested by thoroughly sheared and brecciated rock. A fault zone, subsidiary to the Pleasant Lake fault, south of Hickory Lake and faults mapped along the Oswegatchie River by H. M. Bannerman are of this type and may represent recurrent movement along old faults.

This movement may have been late enough to fracture the cover of overlying Paleozoic sedimentary rocks that is a few miles to the northwest. The late faulting might be responsible for the remarkably straight northeast-trending shoreline of Black Lake, which is the southeastern border of flat-lying Potsdam Sandstone. A few miles west of Black Lake, the St. Lawrence River leaves the granite of the Thousand Island region and enters an area of Potsdam Sandstone; it then flows in a straight narrow northeasterly course for more than 30 mi. Black Lake shoreline and the course of the St. Lawrence in this area are parallel to the northeast-trending faults.

The Pleasant Lake, Beaver Creek, and Balmat faults and the thrust faults southeast of Beaver Creek show clearly as lineaments on ERTS imagery as do the northeasterly lineaments in the Potsdam Sandstone to the northwest. The Beaver Creek fault can be traced for at least 20 mi, and the Pleasant Lake, Balmat, and other faults are visible for at least 15 mi on the imagery. Recognition of this set of northeast-trending faults helps in the understanding of some of the otherwise inexplicable geologic problems of the area.

TRIASSIC BASINS

Flow units in the basalts of the Watchung Mountains, New Jersey

The number of individual flow units which make up the three Watchung Basalt ridges in Somerset and Union Counties, N.J. (loc. 2), and the internal constitution of each of the flow units have not been previously established. G. T. Faust has found that there are two flow units in Third Mountain. The character of the jointing relations has been briefly described by Faust (in U.S. Geological Survey, 1961, p. A97). These two flow units are characterized by the uniformity of their internal structure and the very simple character of their thin vesiculate base. The two flow units of Second Mountain, on the contrary, have much more variable basal zones. Although the basal zone of the lower flow unit is chiefly a thin vesiculate layer overlying a thin layer of Newark rocks metamorphosed to hornfels, there are in addition areas of pillow lavas and some pahoehoe toes. These relations were observed chiefly in temporary road cuts, now largely landscaped. Similar but less variable characteristics have been observed for the base of the upper flow unit. First Watchung ridge, insofar as it has been mapped, consists of two flow units, the structure and constitution of which were briefly described by Faust (in U.S. Geological Survey, 1972f, p. A27).

VALLEY AND RIDGE

As a result of field investigations in eastern Pennsylvania, A. A. Drake, Jr., has more clearly identified the sequence of nappes and thrusts in the Allentown area, and J. B. Epstein has identified two generations of folds in the Lehigh Gap area.

Nappes in the Allentown area, Pennsylvania

At least four tectonic units contain Precambrian rocks in the Allentown area, Pennsylvania (loc. 3), according to A. A. Drake, Jr. These are, from lowest to highest and from west to east, the largely subsurface Lyon Station–Paulins Kill nappe, in part defined by aeromagnetic surveying and in part by studies in the large Paulins Kill window and smaller windows in the Catasauqua and Cementon quadrangles (A. A. Drake, Jr., in U.S. Geological Survey, 1969, p. A28; 1971a, p. A27; 1972, p. A23–A25); the very large Musconetcong nappe (A. A. Drake, Jr., 1970); the newly recognized South Mountain nappe, named for the prominent ridge of that name in the Allentown quadrangle; and, to the east, the Applebutter thrust sheet which brings Precambrian rocks onto a variety of lower Paleozoic rocks in the Saucon Valley.

The Lyon Station–Paulins Kill nappe lies beneath the Paleozoic rocks of the Musconetcong nappe in the Great Valley of easternmost Pennsylvania and western New Jersey. The South Mountain nappe overlies the Musconetcong nappe on an unnamed thrust fault that passes through Hellertown Gap, a narrow pass through the otherwise continuous massifs of Precambrian rock. The tectonic and temporal position of the Applebutter thrust in relation to the nappes is not completely clear as it is separated from the nappes by the enigmatic Colesville fault. Work in the Saucon Valley has shown that the Paleozoic rocks beneath the Applebutter thrust sheet are in a recumbent syncline (now an antiform) cored by Martinsburg Formation and Jacksonburg Limestone of Ordovician age. This recumbent structure is folded by the later Friedensville anticline. The above structural arrangement supports the suggestion by A. A. Drake, Jr. (1970), that the Colesville fault is a late steep thrust. If this interpretation is correct, the Applebutter thrust sheet is the tectonically highest unit recognized to date.

Multiple folding in eastern Pennsylvania

Analysis by J. B. Epstein (USGS) and W. D. Sevon and J. D. Glaeser (Pennsylvania Geol. Survey) of minor structures in the Martinsburg Formation of Ordovician age near Lehigh Gap., Pa. Lehigh and Northampton Counties (loc. 4), suggests that the dominant southwest-plunging folds with their axial-plane cleavage are superimposed on an earlier fold system that plunges more southerly. On the basis of map relationships, the earlier generation of folds is believed to be Taconic in age, and the later fold generation and its cleavage are believed to be Appalachian in age.

BLUE RIDGE AND PIEDMONT

A recently completed aeromagnetic map of New England and the Middle Atlantic States by Isidore Zietz (in U.S. Geological Survey, 1972, p. A27) has led to the formulation of several ideas concerning the geology of the northern Piedmont. Among these are the discovery of a hitherto unrecognized dome of Baltimore Gneiss and ideas concerning the tectonic development of the upper Chesepeake Bay reported by M. W. Higgins. Mapping in the past few years along the Rapidan and Rappahannock Rivers, Va., by Louis Pavlides has reached a stage in which insights into the geology of the Virginia Piedmont are being obtained. Work in the Carolina volcanic belt, also known as the Carolina slate belt, is continuing. Certain magmatic relations in the volcanic belt, reported by J. B. Hadley and A. A. Stromquist, suggest a geosuture is present in the Gold Hill district, North Carolina. Henry Bell III, has evidence to indicate that hydrothermal alteration of slate belt rocks is attributable to early volcanic rather than later plutonic events.

Magnetic anomalies suggest tectonic history of upper Chesapeake Bay

A large anomalously low magnetic anomaly coincides precisely with upper Chesapeake Bay (loc. 5), according to M. W. Higgins, G. W. Fisher, and Isidore Zietz. The anomaly is identical in amplitude and style with anomalies over some of the Baltimore Gneiss domes near Baltimore, except that it is much flatter. The steep straight gradient at the southeastern border of the anomaly is interpreted as a fault boundary between Baltimore Gneiss and mafic and ultramafic rocks. This fault also appears to have been active throughout much of the Tertiary and was probably responsible for the southwestward bend in the Susquehanna River before it was drowned to form the bay.

Stratigraphic relationships and metamorphism in the Fredericksburg area, Virginia

Mapping by Louis Pavlides in Stafford and Spotsylvania Counties, Va. (loc. 6), indicates that the metamorphosed volcanic Chopawamsic Formation of Cambrian and Ordovician(?) age and the Quantico Slate and Ordovician (?) age form a southeast-facing homoclinal sequence that strikes across parts of the Stafford, Storck, and Salem Church quadrangles. To the southeast of this homocline is a crystalline terrane, informally designated the Fredericksburg complex, that consists chiefly of granodioritic gneiss, quartz-plagioclase-biotite-hornblende gneiss, microcline augen- and flaser-gneiss, micaceous and quartzose schist, and coarse-grained microcline granite. All these crystalline rocks are cut by dikes and sills of weakly foliated biotite granite and pegmatite. The pegmatite cuts the granite dikes and sills as well as the country rock and is the youngest crystalline rock of this complex. This combination of dikes and sills of granite and crosscutting pegmatite is absent in the rocks to the northwest and is a characterizing feature of the complex.

A sample of quartz-plagioclase-biotite-hornblende gneiss from within the Fredericksburg complex, collected by S. K. Neuschel and T. W. Stern in 1962, yielded zircon analyzed by Stern that gave a Pb^{207}/Pb^{206} age of late Precambrian (606 m.y.). This is interpreted to be a minimum age; the true age of the rock is somewhat older, depending upon the time of Pb loss from the zircon. If recent Pb loss is assumed, the age is 740 m.y.; but if Pb loss occurred at an earlier time, the age of this gneiss would be still older. It is of interest that the 1928 edition of the Geologic Map of Virginia shows some of the gneisses near Fredericksburg as possible equivalents of the Baltimore Gneiss.

The Precambrian age of some of the gneisses in the Fredericksburg complex and the southeastward-facing direction of the Cambrian and Ordovician homoclinal sequence on its northwest side suggest that the contact between these two terranes is one of structural discordance.

D. L. Southwick, J. C. Reed, Jr., and R. B. Mixon (1971) defined the volcanic Chopawamsic Formation in the vicinity of Quantico, Va. They considered it to be correlative with the James Run Formation of Maryland that contains zircons which give a radiometric date of about 550 m.y., indicating an Early Cambrian age. Southwick and others considered the Chopawamsic of Cambrian and Ordovician(?) age to be in conformable contact with the overlying Quantico Slate of Ordovician(?) age. The large timespan that exists between the available ages of these formations suggests that unrecognized structural and (or) stratigraphic complications occur at this contact, or that the two formations represent a compressed section that spans a considerable segment of Cambrian and Ordovician time. Recent mapping in the Stafford quadrangle by Louis Pavlides has disclosed the presence of close folds within the Chopawamsic strike belt that are apparently absent in the Qauntico Slate terrane. Also, a lenticular mylonitic quartzite unit as much as 500 ft thick locally intervenes between the Chopawamsic and Quantico in both the Stafford and Storck quadrangles of Stafford County. These new structural and stratigraphic data suggest that the Chopawamsic and Quantico are probably separated by an unconformity, possibly the temporal equivalent of the Penobscot event of northern Maine.

The Quantico Slate, near its northern limit in northeast Virginia, commonly contains garnet and biotite as its characterizing metamorphic minerals. During geologic mapping to the southwest along its strike in the Stafford and Storck quadrangles, Louis Pavlides and K. A. Sylvester have found a rather widespread area of retrograded staurolite in biotite-garnet schists of the Quantico as well as local oval quartz knots within the schist that are sheathed by kyanite and staurolite. Chloritoid is also locally present in parts of this schist unit. Retrograded staurolite schist has also been found in layers within a sequence of silt- and sand-sized quartzitic schists along the Rappahannock and Rapidan Rivers in the southwest part of the Richardsville quadrangle in Culpeper County.

The discovery of these staurolitic and kyanitic schists is the first report of such high-grade metamorphic rocks in the outer Piedmont of northeast Virginia.

Magmatic relations in Carolina volcanic belt

Mapping by J. B. Hadley of a sequence of volcanic and intrusive igneous rocks in the volcanic-slate belt of Granville County, north-central North Carolina (loc. 7), indicates that gabbroic magma emplaced in a volcanic terrane yielded medium-grained plutonic rocks that began as pyroxene gabbro but completed crystallization as calcic hornblende-quartz diorite. Subsequent shallow intrusion of granitic rocks of sodic composition was followed by basaltic diking and regional metamorphism. Data from 25 new chemical analyses indicate that both volcanic and intrusive rocks were formed from separate gabbroic and granitic magmas with moderate contaminations of the gabbroic magma by ingestion of volcanic country rocks.

Subduction-zone model applied to Gold Hill area, North Carolina

Rocks of the so-called Charlotte belt of North Carolina west of the Gold Hill fault of central North Carolina (loc. 8) (P. B. King, 1955) are like the "slate belt" rocks east of the fault, but according to A. A. Stromquist the Charlotte belt rocks are more metamorphosed and largely invaded by igneous rocks. Interbedded mafic and felsic volcanic and sedimentary rocks have been metamorphosed to the albite-epidote-amphilobite facies and to a higher metamorphic facies in places farther west in the Piedmont. These schists and gneisses have been largely intruded by several generations of alaskite and possibly also by gabbros. The intrusions are similar in composition but geologic relations and isotopic-age dating indicated that they have crystallized at different times.

The geologic data on this area have been incorporated in line drawings (A. A. Stromquist and H. W. Sundelius, unpub. data) of A. E. Ringwood's (1969, fig. 5) version of a subduction zone indicating the ways in which several generations of mafic and felsic intrusions of similar compositions may be formed. Geologic relations and isotopic dates suggest that such a subduction zone existed from Precambrian through Triassic time off the east coast of the Carolinas.

Potassium-argon age of muscovite from hydrothermally altered rocks in South Carolina

Muscovite samples collected by Henry Bell III, from three areas of auriferous hydrothermally altered rocks in the Carolina slate belt, Chesterfield and Newberry Counties, S.C. (loc. 9), have yielded potassium-argon ages which average 415, 358, and 319 m.y. (Bell, Marvin, and Mehnert, 1972). These ages indicate that the hydrothermally altered rocks and ore deposits are not related to nearby granitic plutons of Permian or Pennsylvanian age but rather to early Paleozoic volcanic events.

Rutile province in the Blue Ridge, Macon County, North Carolina

Hypersthene-garnet-quartz-feldspar gneiss in an area of mafic gneiss of hornblende granulite grade contains disseminated rutile at several places in the Franklin area, Macon County, N.C. (loc. 10). The potential of the area as a source terrane for placer rutile deposits is good. In support of this E. R. Force has found rutile in concentrations under 1 percent in all but a few samples of flood-plain sands in parts of the Little Tennessee River and its tributaries which drain the province.

ATLANTIC PLAIN

Palynology and mineralogy

Palynologic and mineralogic studies in the Delmarva Peninsula, (loc. 11) have been made on three barrier, back-barrier sequences mapped in previous years by J. P. Owens, C. S. Denny, and R. B. Mixon, and on a probable fourth—a highly dissected older sequence. The palynologic studies by L. A. Sirkin of Adelphi College, N.Y., were concentrated on two of the back-barrier sequences ($\approx$ 31,000 radiocarbon years and $>$42,000 radiocarbon years). The pollen asemblages were significantly different between the two: one ($>$42,000 yr) dominantly a warm assemblage (oak-hickory) and the other (31,000 yr) a cooler assemblage (spruce dominant). Apparently high stands of the sea can be associated with significantly different climates.

Mineralogic studies were made by Karl Stefansson on the clay-size fraction of samples from three back-barrier facies older than the Holocene. The younger beds (31,000 yr) had all major clay groups present (kaolinite, illite, montmorillonite, and chlorite). The next older back barrier ($>$42,000 yr) had three of the four clay groups present with chlorite conspicuously absent. The oldest highest level back barrier ($>$42,000 yr) was also characterized by three clay types, again with chlorite absent but with the kaolinite highly disordered. The sediment tested in this facies appears to be unweathered, suggesting that the disordering in the kaolinite is a primary characteristic attributable to the source rock(s).

CENTRAL REGION AND GREAT PLAINS

ARKANSAS

Structure of the Ouachita Mountains, Arkansas

Geologic mapping by B. R. Haley (USGS) and C. G. Stone (Arkansas Geol. Comm.) demonstrates that the structure of the frontal belt of the Ouachita Mountains (loc. 1, index map) is characterized by thrust-faulted anticlines and relatively simple synclines. Structural complexity increases southward and decollements occur between competent and incompetent rock units. All thrust plates moved northward except in the southeastern part of the frontal belt where some appear to have moved southward.

The structure of the core area is characterized by complex structural belts of intensely folded rocks that are broken by unfolded and folded faults. Much of the folding along the northern side and all folding in the eastern two thirds of the core area suggest a southward translation. Thrusting of low-angle faults, however, appears to have been northward, and one thrust plate is displaced northward as much as 8 mi.

The structure of the south side of the Ouachita Mountains is characterized by high-angle thrust faults and generally vertically dipping strata. All thrust plates moved northward; some may have an eastward strike-slip component.

STATES IN CENTRAL REGION AND GREAT PLAINS

Base of Everton Formation mapped across Northern Arkansas

The base of the Everton Formation (Ordovician) has been mapped by E. E. Glick from the type area of the Everton in north-central Arkansas (loc. 2) eastward to the Missisippi Embayment, a distance of slightly more than 100 mi. The horizon is of special interest because it has been generally accepted as the boundary between rocks of Early and Middle Ordovician age in one of the few known areas where the interseries hiatus is only subtly marked within a fossiliferous sequence.

Areal mapping shows that the base of the Everton is a regionally recognizable lithologic boundary even though evidence for the pre-Everton hitaus diminishes eastward and southward along the outcrop. Structure contours on the horizon delineate a regional eastward trend and broad southward anticlines and synclines. Essentially all significant deposits of zinc ore that have been mined from pre-Everton and Everton units in the area are in localities that are anomalously low structurally.

The Everton is underlain by the Powell Dolomite (Lower Ordovician) in the western part of the area and by the Black Rock Formation (Lower Ordovician) in the eastern part. The upper part of the Powell appears to thicken and grade eastward into the Black Rock and subjacent Smithville Formation (Lower Ordovician). The fauna of the Smithville and Black Rock appears to be a facies fauna that is more widespread than previously assumed.

KENTUCKY

Geologic mapping of State

A cooperative project with the State, begun in 1960, was more than 73 percent completed by May 1, 1973, when 437 geologic maps had been printed (fig. 1), another 57 maps had been approved for

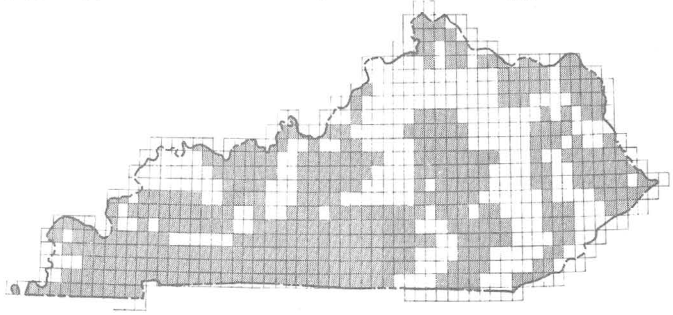


FIGURE 1.—Published geologic quadrangle maps (patterned area) of Kentucky as of May 1, 1973; small squares are 7½-minute quadrangles.

publication, and an additional 24 were undergoing editorial review. Geologic mapping was in progress in more than 78 quadrangles. About 710 maps will be published to cover the 763 7½-minute 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.

Sandstone body of Late Mississippian age in south-central Kentucky

A body of fine to very coarse grained sandstone in a dominantly limestone sequence of Late Mississippian age has been mapped in south-central Kentucky (loc. 3) by R. Q. Lewis, Sr., and A. R. Taylor. The sandstone, not previously recognized, is extensive in Rockcastle and Pulaski Counties and is a potential source of groundwater and hydrocarbons. Data to indicate its subsurface distribution are lacking.

MICHIGAN AND WISCONSIN

East Gogebic Range volcanic center

C. R. Van Hise (1892), following a reconnaissance field investigation, described a middle Precambrian (Huronian) volcanic center near the east end of the Gogebic Range, Michigan (loc. 4). In this same area mapping by V. A. Trent and W. C. Prinz shows a large-scale drag fold developed in Precambrian X and W (Animikie, Huronian, and Keewatin respectively) strata during the Penokean orogeny. As interpreted by Trent, several mafic sills were injected into the Ironwood Iron-formation from an 8-mi-wide mafic feeder dike swarm contemporaneous with a late dilation stage of fold development. A single thick sill 2 mi northwest of Wolf Mountain, was the feeder for gas-charged lavas which were extruded into water. Eastward the texture and lithology of the sill changes, and the sill grades through a transitional zone into about 300 ft of quenched pillow-structured flow breccias that lie athwart the Penokean fold structure. The main body of the breccia sequence, part of the volcanic complex along Emperor Creek, is north of Wolf Mountain; small outliers occur northeast of the mountain.

Axinite from the east Gogebic Range, Michigan

Axinite, a relatively rare borosilicate mineral characteristic of igneous contact zones, has been identified by V. A. Trent, M. E. Mrose, and Harry Klemic in rock from the east Gogebic Range, Mich. (loc. 4). It is the first reported occurrence of axinite in Michigan and on the Gogebic Range. The mineral was found by Trent 8 mi northwest of Marenisco, Mich., where it occurs as individual crystals and as coarse, close-spaced, bladed, crystal aggregates filling a tension fracture in a metamorphosed mafic lava flow. Several mafic flows and sills are interbedded with the lower Ironwood Iron-formation. Quartz, calcite, and sparse amounts of epidote, magnetite, and base metal sulfides occur in close association with the axinite. The mineral is typically brown-stained, but a few good crystals have a purple-gray hue on the weathered surface. The occurrence suggests boron was concentrated in siliceous, residual fluids of Penokean mafic sills rather than of Penokean granite. Axinite is generally considered to be of pneumatolytic-hydrothermal origin. Base metal sulfides found in trace and greater amounts are also products of this hydrotehrmal mineralization.

Geology near Pine Lake, Wisconsin, compared to Gogebic area

Exploratory drilling of 32 holes in a tract about 12,000 ft long and 600 to 1,800 ft wide near Pine Lake, Wis. (loc. 5) (T. 44 N., R. 3 W.), penetrated unexposed magnetic iron-formation and associated rocks that may be correlative with similar materials of Precambrian X (middle) age in the Gogebic area about 15 mi to the north. This proposal by C. E. Dutton is based on the following observations:

1. The iron-formation in both areas is composed of three sedimentary facies—oxide (magnetite and hematite), carbonate (siderite), and silicate (chlorite and minor stilpnomelane). Each facies has varying amounts of interbedded chert. Bedding in the iron-formation in both areas is either regular and thin or irregular and thick. The Gogebic area has five stratigraphic units—three units of wavy thick-bedded cherty iron-formation separated by two units of thin-bedded cherty carbonate iron-formation. Similar lithologies are at Pine Lake, but the fivefold succession is either not present or is less well developed.
2. Iron-formation in the eastern part of the Gogebic area and that at Pine Lake are overlain by mafic pyroclastics.
3. Iron-formation in the Gogebic area dips north and is underlain by argillite with some interbedded thin quartzites, which in turn is locally underlain by dolomite and quartzite formations. The Precambrian W (lower) complex includes a sedimentary and mafic volcanic sequence intruded by granite. The iron-formation at Pine Lake dips southward; the rock north of and presumably older than the iron-formation was penetrated by only one drill hole which passed through gouge and ended in brecciated fine-grained chloritic rock intruded by granite.
4. As indicated by local occurrences of small amounts of biotite, the iron-formation and associated rocks in both areas are at low-grade metamorphism.
5. Iron-formation in the western part of the Gogebic area in Michigan dips 50°, about 15° less steeply than the overlying sandstone and lavas of the Keweenawan Supergroup, ac-

cording to R. G. Schmidt and H. A. Hubbard (1972). Thus, the iron-formation in pre-Keweenawan time dipped gently southward and may have extended to the Pine Lake area, or correlative iron-formation may have accumulated separately in that area. Post-Keweenawan rise of the crystalline Precambrian W (lower) rocks may have draped the overlying strata causing reversal of dip along the north (Gogebic) flank and steepening of the dip along the south (Pine Lake) flank.

Preglacial erosion surface, northern Michigan

Data from water wells and outcrops compiled by J. W. Whitlow and J. F. Windolph in the area of the Sault Ste. Marie 2-degree quadrangle, Michigan (loc. 6) indicate a preglacial topography with about 600 ft of relief. Till and lacustrine deposits above the surface are as much as 400 ft thick at places. Local base level during erosion of the preglacial surface was at least 170 ft below the present local base level.

MINNESOTA

Paleomagnetic investigations in Minnesota

Paleomagnetic investigations by K. G. Books (USGS) and J. C. Green (Minnesota Univ.) (1972; Green and Books, 1972) in the western Lake Superior area (loc. 7) provide evidence to indicate the presence of lower Keweenawan rocks in addition to those previously reported. The reversed magnetic polarity common to the sedimentary rocks and lavas of the lower Keweenawan Sibley Series of Tanton (1927) near Ironwood, Mich., and Grand Portage, Minn., is also present in the basal Keweenawan Puckwunge Formation as used by Schwartz (1942) and overlying lava flows on Lucille Island and extends at least 30 mi inland from Grand Portage. Northwest of Hovland, Minn., the succession of lava flows superjacent to the Grand Portage lavas is also reversély polarized. Together, the Grand Portage and Hovland lavas comprise some 9,000 ft of flows lying between the northern and southern tongues of the Duluth Gabbro Complex in northeastern Minnesota.

Further south, in the wedge of lava flows west of Duluth, Minn., this reversed polarity occurs in the lower flows but changes to a normal polarity near the Duluth Gabbro intrusion. Probably the entire sequence of lava flows between the older Thomson Formation as used by Schwartz (1942) and the younger gabbro originally had a reversed polarity that was reset to that of the gabbro during its intrusion.

SOUTH DAKOTA

Emplacement of the Harney Peak Granite, southern Black Hills

Mapping in the Custer 7½-minute quadrangle, South Dakota (loc. 8), by J. A. Redden discloses boudinage structure in sillimanite schist in the Harney Peak area. The direction of the boudinage structure shows plastic stretching and doming of the metamorphic rocks and is consistent with the premise that the granite was forcefully emplaced. Locally in the pegmatite there are pseudomorphs of sillimanite after large (20 cm across) books of muscovite.

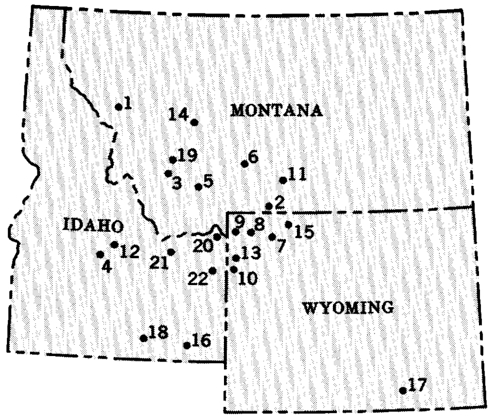
Metamorphic rocks similar to those of the nearby Bear Mountain domal area occur in the center of the Harney Peak dome. Tactite associated with marble in this part of the section contains some tungsten.

NORTHERN ROCKY MOUNTAINS

MINERAL-RESOURCE STUDIES

Stratabound copper in Belt rocks

Redistribution of diagenetic copper on both local and regional scales explains at least some of the anomalous concentrations and ores in the sedimentary rocks of the Precambrian Belt Supergroup. Chip samples collected by J. E. Harrison across copper-bearing green beds in several formations show that zones of anomalous copper tend to cut subtly across bedding, are not laterally persistent, and may occur at any position in the bed. Zones of depletion (less than normal background concentration) were found horizontally away from zones of enrichment, suggesting local redistribution of copper. Background geochemical data on the Revett Formation were collected in various parts of the Belt basin (centered at loc. 1, index map) by Harrison, J. D. Wells, D. A. Lindsey, G. B. Gott, and F. K. Miller. Analysis of these data indicates that the background copper content of the Revett Formation is at least 20 p/m higher regionally than it is locally in areas where the formation contains ore deposits. This, too, suggests redistribution of copper on a grand scale, as previously suggested (Harrison, 1972) on the basis of other geologic reasoning. The cause and timing of the redistributions are still enigmatic.



NORTHERN ROCKY MOUNTAIN STATES

Cooke City intrusive breccias

Field studies by J. E. Elliott near Cooke City, Mont. (loc. 2), suggest that much of the copper and gold mineralization is associated spatially and perhaps also genetically with intrusive breccias. Two masses of nearly monolithologic intrusive breccia are extensively altered and mineralized. In addition, two breccia pipes, one previously known and the other discovered during mapping this year, are locally altered and mineralized. The pipes are heterolithic, with fragments of several varieties of porphyry, Cambrian sedimentary rocks, and Precambrian gneiss; the fragments are displaced both up and down. The larger of the two pipes, informally named the Homestake breccia, is approximately 3,000 by 1,500 ft in plan and is exposed 1,100 ft vertically.

Iron phosphate ooids in the Phosphoria Formation of Montana

E-an Zen reports that a sample of oolitic phosphate ore from a prospect trench in the Phosphoria Formation of the Vipond Park quadrangle (loc. 3) contains no apatite; instead, the ooids are a mixture of strengite ($FePO_4 \cdot 2H_2O$) and its dimorph, metastrengite. Microprobe analysis shows no calcium. The rock has a sedimentary texture and, like the surrounding rocks, appears unmetamorphosed; the nearest exposed intrusive body is 3 km away and the nearest recognizable metamorphic rock is about 2 km away. The strengite could be either metasomatic or sedimentary; sedimentary strengite is well documented elsewhere. The geochemical environment of deposition of this ore must differ from that for the apatite-related ores of the Phosphoria.

Structural control of mineralization in central Idaho

A major anticline trends nearly north-south along the west side of the White Cloud Peaks, from the Salmon River about 25 km southward to Germania Creek (loc. 4). D. R. Seeland reports that the anticline is isoclinal, dips steeply west, and is complicated by faults parallel to its axis. The basal conglomerate of the Wood River Formation delineates the anticline and crops out in places along the entire known length. Much of the mineralization of the area is concentrated along the anticline, suggesting that its projection north of the Salmon River might be a fruitful exploration target.

Iron-formation in southwest Montana

H. L. James and K. L. Wier are continuing to map the very complex older Precambrian rocks of southwest Montana (loc. 5). Scattered exposures of iron-formation on the western slope of the Tobacco Root Mountains, east of Sheridan, are of a single 50-ft bed on the flanks and axis of a northerly-trending refolded syncline, which has been traced for about 6 mi. In the Ruby Creek area south of Ennis, several discrete belts of iron-formation on the eastern flank of the Gravelly Range also appear to represent a single bed, here repeated in a zone of imbrication a mile or more wide. The iron-formations of the two areas are thought to be separate, noncorrelative units.

IGNEOUS ROCKS

Chemical analysis of batholith rocks from the northern Pioneer Mountains, Montana

E-an Zen reports that chemical analysis of a suite of five rocks from an unnamed batholith in the northern Pioneer Mountains (loc. 3) show normal sodium but very low potassium. When the ratio of sodium to potassium is plotted on the alkali-ratio:silica diagram, the analyses conform with the trend for R. I. Tilling's sodic series for the Boulder batholith. On an $Na_2O:SiO_2$ plot, however, the trend conforms to Tilling's main series. The location of the batholith in the Pioneer Mountains is consistent with Tilling's observation that rocks of the sodic series tend to occur southwest of those of the main series.

Lower part of Livingston Group (Upper Cretaceous) is alluvial facies of Elkhorn Mountains Volcanics, Montana

The Upper Cretaceous Livingston Group comprises the Cokedale and Miner Creek Formations (lower part) and the Billman Creek and Hoppers Formations (upper part). Betty Skipp and L. W. McGrew (1972) report that the group totals 8,900 ft along the central western edge of the Crazy Mountains Basin near Wilsall, Mont. (loc. 6). The lower part consists largely of intermediate epiclastic and primary volcanic rocks. From more than 5,000 ft near Maudlow it thins to 3,500 ft near Wilsall 20 mi east, 2,900 ft near Livingston 30 mi southeast, and 2,800 ft near Lennep 25 mi northeast. Palynomorphs from the base of the lower part and ammonites from near its top indicate that the lower part of the Livingston Group here is late Santonian to late Campanian in age (83 to about 73 m.y.). It is thus temporally equivalent to the Elkhorn Mountains Volcanics to the west and represents its coarse-alluvial facies at Maudlow and its fine-alluvial facies farther east. The upper part of the group thickens northward from 3,555 ft at Livingston to about 5,400 ft at Wilsall and consists of volcanic mudstone and sandstone with minor vitric tuff and bentonite. The tuffs are of late Campanian and Maestrichtian Age; their source may be the Adel Mountains.

Hybrid origin of the absarokite-shoshonite-banakite series, Absaroka volcanic field, Wyoming

The texture and mineralogy of potash-rich basaltic rocks of the absarokite-shoshonite-banakite series in the Absaroka volcanic field (loc. 7) indicate that most of the large crystals and aggregates in these rocks are xenocrysts and microxenoliths—not true phenocrysts as was previously thought. H. J. Prostka (1973) proposes hybrid origin, involving assimilation of gabbro by hot syenite magma.

GEOLOGIC AND STRATIGRAPHIC STUDIES

Upper Grand Canyon of the Yellowstone River less than 100,000 years old

The Grand Canyon of the Yellowstone River from Artist Point to its head at Chittenden Bridge (loc. 8) is locally rimmed by old lake deposits and other sediments, capped by a sandstone about 20 ft thick. A pumice bed, found in the sandstone near Upper Falls by G. M. Richmond, has been potassium-argon dated by J. D. Obradovich as about 100,000 yr old; this means that the present canyon here is less than 100,000 yr old. Deposits of the last glaciation, the Pinedale, are found both in the canyon and on the terrain to either side. The canyon is thus older than the Pinedale Glaciation. Deposits of the next older glaciation, the upper Bull Lake, are not found in the canyon but occur beneath Pinedale deposits on the canyon rim. Cutting of the present canyon thus began after recession of the late Bull Lake ice. Upstream from the canyon head, Richmond has found flood gravels resting on upper Bull Lake deposits and overlain by Pinedale deposits. He believes that cutting of the present canyon was probably initiated by this flood 70,000 to 90,000 yr ago.

Late Illinoian(?) age of Bull Lake moraines, West Yellowstone

K. L. Pierce, J. D. Obradovich, and Irving Friedman report that Bull Lake moraines near West Yellowstone (loc. 9) have been dated by combined obsidian-hydration and potassium-argon dating at $150{,}000 \pm 30{,}000$ yr. This age is greater than previously thought, but it correlates well with the next-to-last major cold-glacial interval of the marine record. The moraines appear to predate the last interglacial stage (80,000 to 130,000 yr ago) dated by high sea-level stands and commonly correlated with the Sangamon. Thus the Bull Lake moraines near West Yellowstone do not appear to correlate with the lower Wisconsinan, but rather with upper Illinoian deposits if they can be correlated at all.

Pinedale age reassignment of the Burned Ridge moraine, Wyoming

Photogeologic mapping and study of the moraine-outwash complex in Jackson Hole, Wyo. (loc. 10), by J. C. Reed, Jr., have shown that the Burned Ridge moraine is of Pinedale rather than Bull Lake age. Outwash channels issuing from the Jackson Lake moraine 1 to 4 mi north are let down into kettle holes in pitted outwash behind the Burned Ridge moraine, indicating that stagnant ice masses left behind after retreat of the ice from the Burned Ridge moraine remained buried in outwash while the active ice front stood at the Jackson Lake moraine. Thus, little time could have elapsed between deposition of the Burned Ridge and Jackson Lake moraines. Outwash channels and terraces show that the Jackson Lake moraine is contemporaneous with fresh Pinedale moraines surrounding Jenny, Bradley, Taggart, and Phelps Lakes farther south in Jackson Hole. Partially obliterated outer loops in these moraines probably correspond to the Burned Ridge moraine.

Precambrian diamictite, Beartooth Mountains, Montana

In Precambrian metasedimentary rocks beneath the Stillwater Complex, southwest Montana (loc. 11), N. J Page and R. A. Koski found a metamorphosed diamictite similar to those in upper Precambrian and Lower Cambrian strata of Canada and the western United States. The diamictite consists of a quartz-cordierite matrix typically with 10 to 15 percent rock fragments of diverse size, shape, angularity, lithologic type, and texture. The diamictite is poorly sorted, crops out discontinuously for 14 mi, and locally has crude layers of dropstones. Its texture suggests a glacial origin. Minimum age of the diamictite is 2,750 m.y. based on uranium-lead determinations on zircons from younger quartz monzonite intrusions; maximum age is at least 3,140 m.y. based on zircons from metasedimentary interbeds.

Mississippian age of rocks called Milligen in the Bayhorse area, Idaho

A thick sequence of dark-colored, thin-bedded argillites, siltites, and silty sandstones with a few thin impure carbonate interbeds occurs between the western part of the Bayhorse area and the Idaho batholith in central Idaho (loc. 12). These strata were correlated by C. P. Ross (1937) with the type Milligen Formation of the Wood River district 40 mi to the south on the basis of lithologic similarities and relations to adjacent Wood River Formation of Pennsylvanian age. Fossils collected by S. W. Hobbs from a carbonate zone in Deepsprings Gulch and on Mill Creek 8 mi west of Clayton, Idaho, were studied by J. T. Dutro, Jr., and J. W. Huddle. Dutro reports that the collection represents an incomplete megafauna of Mississippian age, most probably middle or Late Mississippian. Huddle, on the basis of conodonts, reports that the collection could be as old as late St. Louis time or as young as early Chesterian time. The correlation of these strata with the type Milligen is invalidated, however, by work of W. E. Hall and C. E. Sandburg (oral commun.) who have established a Devonian age for the Milligen where it was originally defined on Milligen Creek east of Ketchum, Idaho. Application of the name Milligen to Mississippian strata in the Bayhorse areas is thus unsuitable, and correlative Mississippian units to the south are as yet undefined.

Pseudocoprolites in the Mowry Shale (Lower Cretaceous), northwest Wyoming

Thousands of spectacular intestine-shaped objects emboss the surface of a silicified marine sandstone bed in the Mowry Shale. Their origin, internal structure, composition, and external configuration are being studied by J. D. Love and D. W. Boyd. The stripped bedding surface extends for several acres about 2.5 mi south of Yellowstone National Park (loc. 13). The sandstone bed is about 120 ft below the top of the Mowry and is overlain by *Lingula*-bearing black shale. Most of the objects are 1 to 4 in. in diameter and several feet long. Many of them, some coprolites, occur in piles up to 6 in. high. The objects are composed of sandstone indistinguishable from that below, and most are extensions of it. Their large size, environmental context, and relation to the underlying sandstone suggest that they are not of organic origin but resulted from rapid extrusions of unconsolidated wet sand through orifices and cracks in a sandstone crust. The extrusions may be due to adjustment of clays beneath the sandstone. They were not eroded or deformed after extrusion and are not considered to be of tectonic origin.

STRUCTURAL STUDIES

Folded fault in the Montana disturbed belt

Geologic mapping by R. G. Schmidt in the disturbed belt north of Helena, Mont. (loc. 14), shows that the Nohrgang Ranch thrust is intensely deformed in a 6-mi-long belt in the Craig quadrangle; the thrust plane itself and the shales, siltstones, and sandstones of Late Cretaceous age that form its upper and lower plates are crumpled into a series of tight folds. This folded segment of the thrust lies east of, and is overridden by, a gently dipping slice of Mission Canyon Limestone (Lower Mississippian only) which forms the base of the Craig thrust sheet in this area. This rigid mass of limestone appears to be the cause of the intense deformation of the Nohrgang Ranch thrust. To the north and south, where the limestone slice is absent and much less rigid rocks have traveled over the Nohrgang Ranch thrust, the thrust is undeformed except for minor warping.

Heart Mountain fault, Wyoming

The Heart Mountain fault extends over 1,300 mi^2 in the northwest part of the Cody, Wyo., 1° × 2° quadrangle (loc. 15). If, as seems reasonable, the fault was originally a nearly horizontal plane, then a contour map of the present fault surface shows how much deformation has affected the fault and the adjoining rocks since the fault occurred near the end of the early Eocene. A structure contour map with contours drawn on one stratigraphic horizon shows the total deformation of the rocks in the area. At any point, then, the difference between the deformations shown by the two maps is the amount of deformation that occurred before Heart Mountain faulting. W. G. Pierce has thus determined that of the 7,000 ft of structural relief on the Rattlesnake Mountain anticline, 5,000 ft predates Heart Mountain faulting and 2,000 ft postdates it.

The Heart Mountain break-away fault at its type locality dips steeply through Eocene volcanic rocks and Paleozoic sedimentary rocks to the Heart Mountain detachment fault at the base of the Bighorn Dolomite. As the break-away fault is traced southeastward, however, Pierce has found that it becomes more complex and irregular. In Cache Creek valley it extends steeply downward through about 500 ft of volcanic rocks to a nearly horizontal secondary detachment surface covered by slightly younger volcanic rocks. Since the breakaway fault is presumed to extend all the way down to the primary Heart Mountain detachment fault at the base of the Bighorn, its termination here against a secondary detachment suggests that it descends in a series of steps. In cross section it would thus resemble stairs, with the risers representing the break-away fault and the treads representing secondary detachment faults.

Young faults in southeast Idaho

Very young north-trending range-front faults cut Cambrian through Devonian strata of the northern Malad Range, southeast Idaho (loc. 16). The faults also cut Miocene and Pliocene volcaniclastic strata but apparently do not cut the poorly consolidated sediments deposited in embayments of late Pleistocene Lake Bonneville that extended into adjoining intermontane basins. S. S. Oriel suggests that faulting in this northern part of the Wasatch seismic belt is younger than a few million years but older than 30,000 yr. The range-front set cuts several older fault sets, one of which is northwest-trending and also cut Miocene Pliocene strata. An east-trending set may be among the most extensive, for several of these faults have large throws and may connect with faults mapped on Oxford Mountain; minor late movements may have affected Miocene and Pliocene strata locally. The suspected presence of a still-older set of north-trending faults has not been confirmed.

Overturned(?) and folded layered mafic complex in the Medicine Bow Mountains, Wyoming

M. E. McCallum's detailed mapping of the eastern third of the Mullen Creek mafic complex (loc. 17) suggests that the complex has been folded, overturned, and refolded. A prominent arcuate zone of layered cumulate-textured anorthositic gabbro roughly parallels the southeast edge of the complex; the zone dips steeply west and is bounded on both sides by massive gabbroic to diabasic rocks. Rocks west of the zone appear to be slightly more mafic than those to the east and probably represent lower horizons. A tabular foliated granodiorite along the eastern margin of the complex also dips steeply west and appears to be comformable with mafic rocks above and metasedimentary rocks below. Other felsic rocks, mainly granodiorite to quartz monzonite, intrude the mafic sequence, roughly parallel to the mafic rock fabric. Contact relations are typically hybridized (dioritic), which may indicate that the mafic rocks were not completely solidified at the time of felsic intrusion. The felsic rocks may thus be products of late residual liquids concentrated near the top of the nearly crystallized mafic magma. Their concentration near the east side of the complex together with the trend toward more mafic gabbroic rocks westward suggests that the top of the complex is at the east, hence that its west-dipping layers have been overturned. Fabrics suggest that the complex is folded about a steeply plunging northwest axis. The tabular granodiorite and adjacent mafic and metasedimentary units are refolded into a shallow, west-plunging fold.

GEOPHYSICAL STUDIES

Gravity and magnetic anomalies in the Raft River area, Idaho

A gravity survey by D. R. Mabey has defined a low with a maximum residual relief of about 30-mGal in Raft River valley (loc. 18) The anomaly is interpreted as indicating that the valley is underlain by Cenozoic volcanic and sedimentary rocks up to several thousand feet thick overlying pre-Cenozoic rocks on a surface of considerable relief. The gravity data indicate concealed faults on the south and southeast sides of the valley and a complex pattern of faulting along the west and northeast sides. Coincident gravity and magnetic highs north of the hot wells near Bridge may reflect a concealed intrusive body. The gradients on the southeast edge of these anomalies suggest that the zone of thermal waters may be controlled by a fault trending east-northeast through The Narrows. In the Upper Raft River valley an approximately equidimensional gravity low of about 20 mGal suggests a collapse structure that may be related to the Tertiary volcanism.

Aeromagnetic studies in northwest Montana

In the predominantly Belt sedimentary rock terrane of northwest Montana (loc. 1), M. D. Kleinkopf, J. E. Harrison, and R. E. Zartman (1972) found that the most intense magnetic anomalies were of three types, representing igneous intrusives, major fault zones, and the sedimentary rocks of the Ravalli Group of the Belt Supergroup. In addition, field and laboratory studies have related geology, aeromagnetic data, and lead-isotope data to the vein-type of mineralization in the area.

Magnetization of Boulder batholith

Remanent magnetization data from the Upper Cretaceous Boulder batholith, Montana (loc. 19), obtained by W. F. Hanna, indicate that secondary magnetizations in many plutons intruded by the Butte Quartz Monzonite may be removed using alternating-field partial demagnitization. The resulting primary magnetizations indicate that during batholith emplacement (68–78 m.y.) the paleomagnetic field had at least four periods of reversed polarity and two periods of low inclination. The occurrence of reversed polarities after a long period of normal polarity serves as a convenient worldwide time marker for the Late Cretaceous Period. Of local geologic importance, the Unionville Granodiorite and the granodiorite from the Rader Creek pluton, once considered to be contemporaneous, cooled at distinctly different times in fields of opposite polarity. The magnetization data further imply that satellitic plutons were intruded throughout the timespan of batholithic emplacement.

ENVIRONMENTAL-GEOLOGIC STUDIES

Environmental-geologic studies along the northeast flank of the Snake River Plain, Idaho and Montana

Geologic studies by I. J. Witkind are currently directed toward gathering geologic data needed to make wise decisions about use of land along the northeast flank of the Snake River Plan (loc. 20), The area is dominated by the east-trending Centennial Range, which is astride the Idaho-Montana State line. The range is moderately to thickly forested along its lower flanks and has broad alpine meadows along its crest. Small unpolluted streams flow southward onto the plain and help replenish the aquifers beneath it. Although the mountains are used extensively for grazing sheep and harvesting timber, they offer as-yet-unrealized recreational benefits. Past geologic mapping by Witkind (1972b) in the Henrys Lake quadrangle, Idaho-Mont. (just east of loc. 20), has provided the basis for eight land-use maps. Three of these (Witkind, 1972i, g, d) are devoted to seismic hazards as the quadrangle is crossed by several known active faults and lies in NEIC seismic-risk zone 3, where "major destructive earthquakes may occur" (S. T. Algermissen, 1969). Others include a land-surface slope map (Witkind, 1972a), a construction materials map (Witkind, 1972c) on which the 51 mapped geologic units are grouped into 13 categories with a table summarizing their possible uses, and a related map (Witkind, 1972f) that distinguishes rock units easily excavated by bulldozer (common excavation) from those that require blasting (rock excavation). To anticipate waste disposal problems, a special map (Witkind, 1972e) emphasizes the geologic restraints on the placement of sanitary landfills. One other map (Witkind, 1972h), prepared in collaboration with local Forest Service personnel, identifies sites of possible snow avalanches for the protection of winter recreation enthusiasts.

Geology of southern Beaverhead Range, Idaho

D. L. Schleicher reports that carbonates and quartzites of the southern Beaverhead Range (loc. 21), west of Dubois, Idaho, seem to be much like Carboniferous rocks of southwest Montana. North-northwest-trending range-front faults are offset at least locally by northeast-trending cross faults, but the few observed fresh fault scarps again trend north-northwest. On the east, the range is flanked by tuffaceous basin deposits intercalated with silicic volcanic flows. Farther southwest, the range is flanked by carbonate fan gravels that interfinger in the upper part with welded tuffs and are overlain, in turn, by basalts. The gravels represent rich potential sources of water and, in their finer grained facies, potentially arable lands. The most obvious source of geothermal energy is Lidy Hot Springs which yields about 1,000 gal/min of hot water. Oxidized iron deposits in shear zones have been mined on a very small scale.

Young faults north of Caribou and Snake River Ranges, Idaho

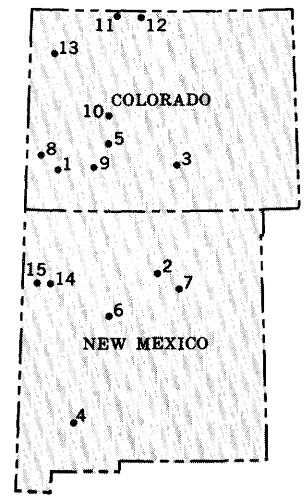
A belt of young northeast- and northwest-trending faults (loc. 22) extends from Idaho Falls to St. Anthony along the margin of the Snake River Plain, thence eastward to the Teton Range, where northwest- and north-trending faults become dominant. Reconnaissance field observations, photogeologic data, and reinterpretation of subsurface information gathered by H. J. Prostka, R. J. Hackman, and S. S. Oriel all point to recurrent deformation. Fault displacements are considerable—hundreds to more than 1,000 ft in rhyolitic ashflows less than 4 m.y. old, as much as 80 ft in 800,000 yr-old or younger basalt, and lesser but still significant amounts in loess that may be younger than 70,000 yr. Continuing deformation is confirmed by NEIC records of numerous earthquake epicenters in a belt extending north-northwest from the Caribou and Snake River Ranges. The evidence suggests tectonic instability and concomitant seismic hazards for the region.

SOUTHERN ROCKY MOUNTAINS

MINERAL-RESOURCE STUDIES

Copper in Wilson Mountains Primitive Area

C. S. Bromfield (USGS) and F. E. Williams (USBH) (1972) reported the discovery of a low-grade copper porphyry in the Wilson Mountains Primitive Area in southeast Colorado (loc. 1). Chalcopyrite is disseminated in porphyritic quartz monzonite high on the north slope of Navajo basin. The limits of the deposits have not been determined, but it extends horizontally for at least 1,000 ft. Bedrock is concealed by talus for a vertical distance of 600 to 700 ft downslope from the deposit. Copper content ranges from 480 to 9,000 p/m (0.048–0.9 percent) in chip samples of average quartz monzonite taken along the outcrop. In addition, all samples have low but anomalous gold content that range from 0.02 to 1.8 p/m.



SOUTHERN ROCKY MOUNTAIN STATES

Fossil gold placer in New Mexico

A. V. Heyl and C. N. Bozion discovered a fossil gold placer in central New Mexico while sampling the angular unconformity between Precambrian metavolcanic rocks and overlying Pennsylvanian sandstones. The deposit lies north of the Pecos massive sulfide mine 15 mi north of Pecos, N. M. (loc. 2). Gold occurs in the topmost weathered Precambrian rocks and in the basal foot or two of overlying Pennsylvanian sandstone. The gold was derived from the erosion of the massive sulfide deposit.

Hydrothermal minerals in the Silver Cliff–Rosita district, Colorado

Several zones of hydrothermal minerals have been discovered in the Silver Cliff–Rosita mining district in south-central Colorado (loc. 3). According to F. A. Hildebrand, abundant diaspore, alunite, quartz, and sericite are associated with lesser amounts of pyrophyllite, kaolinite, dickite, jarosite, goethite, scandium-bearing strengite, barite, and tourmaline in the hydrothermal assemblages. Plumbojarosites of different compositions occur in the same vein with normal potassium jarosite. Potassium jarosite and natrojarosite also occur in a single vein with low-lead plumbojarosites. Structural features indicate that the vein was formed in multiple stages. Silver halides, associated with vein jarosites at one place, contain significant amounts of iodine, chlorine, and bromine.

Geochemical reconnaissance in southwestern New Mexico

H. V. Alminas and K. C. Watts, Jr., report that three distinct types of mineralization have been delineated by geochemical sampling in the Hillsboro 15-min quadrangle, New Mexico (loc. 4).

The most widespread is that involving a lead, zinc, molybdenum, tungsten, and silver association. Areas which are anomalous with respect to these metals show a close spatial correlation. Distribution of the association appears to be controlled by major north-south trending faults. This mineralization is considered to be part of the major mineralized fracture zone extending from the north end of the Sierra Cuchillos through Cook Peak. The most intense geochemical expression of the Hillsboro portion of this mineralization is found along the western margin of the quadrangle in areas known to be in part underlain by a coarse porphyritic quartz monzonite of Tertiary age. A few samples of this intrusive show anomalous molybdenum values.

Although sporadic anomalous copper values were found at several locations within the quadrangle, the most intense and continuous copper anomaly overlies a known low-grade copper porphyry body at Copper Flats in the Las Animas mining district. Lead, zinc, bismuth, gold, silver, tin, and mercury are also found in this association. Lead and bismuth in stream-sediment concentrated produced the most intense and widespread anomalies of the four sample media tested (outcrop, soil, <80-mesh stream sediment, and stream-sediment concentrates).

Stream-sediment concentrates were also instrumental in defining a fluorite area in the southwestern corner of the Hillsboro quadrangle. The area was delineated on the basis of visual fluorite determinations on the nonmagnetic portion of the concentrate. Some evidence of fluorite veining was noted in the alluvium in Berenda Canyon.

Mineral investigations, Hillsboro and Kingston districts, New Mexico

D. C. Hedlund reports three target areas for mineral exploration in the vicinity of Hillsboro and Kingston, N. Mex. (loc. 4), between the crest of the Mimbres Range and the western margin of the Rio Grande trench. One area is the quartz monzonite pluton at Copper Flat with its accompanying radial dike system which is intrusive into weakly propylitized andesite lavas of Tertiary age and probably represents a denuded volcanic center. The mineralized monzonite locally contains chalcopyrite, chalcocite, bornite, pyrite, and molybdenite.

The second is associated with several north-striking faults which seem to control silver and base-metal mineralization. The Pierce Canyon fault has about 7,000 ft of throw and is the site of mineralization at the Silvertail, Log Cabin, and Ingersoll mines. The ore minerals, from oldest to youngest, include pyrite, sphalerite, galena, chalcopyrite, and argentite. The argentite is commonly present as veinlets and blebs 0.1 to 0.3 mm thick in sphalerite, pyrite, and galena. The Tierra Blanca fault near Seven Brothers Mountain may have as much as 10,000 ft of throw which has brought Precambrian granite into fault contact with lower Paleozoic limestones. Very minor silver mineralization within the El Paso Limestone has been observed along this fault. The Berenda fault has as much as 5,500 ft of throw. No silver mineralization is yet known along it, but its trace is largely concealed.

The third target consists of fluorspar anomalies along Berenda Creek, near Larkins Spring Mountain, indicated by panned stream fluorspar concentrates which probably are related to very thin vein fillings of fluorite in quartz latite (H. V. Alminas and K. C. Watts, Jr., USGS oral commun.).

GEOPHYSICAL AND STRUCTURAL STUDIES

Bouguer gravity map of Colorado completed

J. C. Behrendt and L. Y. Bajwa (1973) have recently completed a Bouguer gravity map of Colorado in cooperation with the Colorado Mining Industrial Board and the Colorado Geological Survey. This map at a scale of 1:500,000, was compiled using data from more than 12,000 terrain-corrected measurements. Gravity values were obtained from a number of sources including USGS published and unpublished surveys, the Air Force Chart and Information Center, and the University of Wyoming.

Several of the more interesting features on the new map are: extensive, approximately 50 mGal negative anomalies interpreted as representing granitic batholiths underlying the Colorado mineral belt and the San Juan Mountains; several northeast-trending positive and negative anomalies in eastern Colorado with several tens of mGal relief which is inferred to be caused by density contrasts in the basement underlying sedimentary rocks; and a difference of about 40 mGal between the Piceance basin (negative) and the White River uplift (positive).

Geologic interpretation of Colorado aeromagnetic map

An aeromagnetic map of Colorado has been compiled from flight lines spaced 5 mi apart over the Great Plains and northwest Colorado and 1 to 2 mi apart elsewhere and flown mostly at 13,000 to 16,000 ft barometric altitude. The map has been published in a black and white overlay edition at 1:500,000 (GP–836) and in a colored edition at 1:1,000,000 (GP–880).

Interpretation of the map by W. P. Pratt and Isidore Zietz indicates that, in the Rocky Mountains, most individual positive anomalies can be correlated with known units in the Precambrian: migmatites, amphibolites, and gneisses; mafic and alkalic intrusive bodies; and catazonal (Boulder Creek–type) and mesozonal (Silver Plume–type) granitic plutons. Significantly, no major positive anomalies are associated with epizonal plutons (Pikes Peak–type). A few positive anomalies are caused by Cenozoic volcanic or intrusive rocks.

Several intense negative anomalies are interpreted to indicate reversely polarized rocks either in the basement or in Cenozoic volcanic rocks. The extreme low over the Pikes Peak batholith suggests that the Pikes Peak Granite is underlain by a reversely polarized ultramafic body. A northwest-trending elliptical low centered about 25 km north of Gunnison, though of unknown origin, is of interest because it is the locus of several centers of silver-lead mineralization including Aspen, Tincup, and Pitkin.

Over western Colorado and the Great Plains, broad-wavelength positive anomalies indicate predominantly granitic gneisses at the surface of the basement, whereas magnetic lows indicate predominantly metasedimentary rocks.

Transcending the individual anomalies are several major through-going magnetic lineaments or zones that reflect major regional basement units or discontinuities as follows: (1) An east-northeast alinement of magnetic gradients and elongated anomalies extends across northern Colorado from Rangely to about 10 km south of Julesburg and is interpreted to reflect a major basement structural discontinuity that not only may have controlled the location of the Tertiary volcanic centers of the Rabbit Ears Range and the Never Summer Mountains but also indicates a northern limit to generation of Tertiary volcanic magmas in the Southern Rockies, (2) an east-west zone of positive anomalies, some 50 to 80 km wide, which traverses the State between lat 39° and 40° and continues into Utah, defines a major basement zone of gneissic granitic rocks, (3) a strong north-northeast alinement of positive anomalies in the eastern San Juan Mountains extends northeast as a zone of magnetic discontinuities to the Sawatch Range, where it includes the Mount Princeton batholith; this magnetic expression of an alinement of Tertiary igneous centers is interpreted to indicate a linear zone of weakness in the basement, and (4) a northwest-trending line of magnetic highs along the southwest side of the Uncompahgre front continues northwest into Utah at least to the vicinity of Great Salt Lake; extended southeast, the alinement marks the southwest limit of magnetic noise over the San Juan volcanic field and continues into New Mexico as a separation of magnetic highs and lows across the Sierra Grande arch; thus, the magnetic lineament relates the Uncompahgre–San Luis uplift to a major basement discontinuity at least 800 km long.

Structural geology of the Pueblo 1:250,000 quadrangle

Geologic mapping by G. R. Scott, R .B. Taylor, R. C. Epis, and R. A. Wobus shows that most major faults and folds in the Pueblo quadrangle trend N. 30° W., but some trend north. Minor faults crossing blocks between the major faults generally trend N. 55° W. or N. 30° E. Faulting began in Precambrian time at least 1.7 b.y. ago, and at least five erosional nonconformities in the sedimentary record between Cambrian and Cretaceous time near Canon City show later crustal instability. Two major structural episodes in more recent times involve uplift and folding in Laramide time and in early Miocene time. Laramide displacements along faults were as much as 25,000 ft, and early Miocene- to Holocene-time displacements were as much as 40,000 ft. Sharp drag folds along the eastern flank of the Wet Mountains lie east of high-angle reverse faults. Folds at the south end of the Front Range probably are a result of vertical uplift along faults that are not exposed at the surface.

Faulting in Gunnison and Saguache Counties, Colorado

Geologic mapping in the Powderhorn-Gunnison-Doyleville area of southern Gunnison and northwestern Saguache Counties, Colo. (loc. 5), by J. C. Olson has disclosed numerous faults in rocks as young as Cretaceous, but very few cutting the Tertiary volcanic rocks. The pre-Tertiary fault pattern is generally complex, but at least three major persistent faults, with displacements of at least several hundred feet, dip steeply and strike about N. 30° to

65° W. The northeast side is upthrown along all three faults. These faults are the Cimarron fault near Powderhorn, a fault zone along Sugar Creek that may extend from Iola to Cochetopa Creek, and the Powerline Spring fault crossing the lower part of Razor Creek and Quartz Creek valleys.

Holocene faulting in Rio Grande trench, New Mexico

Holocene faulting was reported in the Albuquerque–Belen Basin of the Rio Grande trench (loc. 6) by early workers. Work by G. O. Bachman in this area indicates that Holocene faulting is more extensive than previously recognized. Several fault scarps have been discovered that offset the Llano de Albuquerque surface southwest of Albuquerque.

Southern termination of Rocky Mountains

The prominent monoclinal fold characteristics of the east flank of the Southern Rocky Mountains of Colorado and New Mexico terminates abruptly at Montoya 12 mi south of Las Vegas, N. Mex. (loc. 7), as a gentle southeast-plunging anticline. R. B. Johnson reports that at Sheridan, 8 mi south of Las Vegas, the monocline has at least 2,100 ft of structural relief. At Montoya, the anticline has as much as 1,600 ft of relief on its steep eastern limb, but no trace of the anticline exists 8 mi southeast of Montoya where the beds are virtually flat.

Landslides on the northeast flank of the Dolores anticline, Colorado

Nearly all the southwestern part of the Dawson Draw 7½-min quadrangle (loc. 8) is underlain by a dip slope on the Dakota Formation. Dips are northeasterly 6° to 7° on the northeast flank of the Dolores anticline. D. E. Ward reports that where streams have cut canyons into this slope at oblique angles to the dip, landslides have formed updip from the streams. The largest landslide area of about 3 mi^2 occurs where Dawson Draw has cut through the Cretaceous Dakota and underlying Burro Canyon Formations which have slid downdip over the Brushy Basin Shale Member of the Jurassic Morrison Formation. The rough surface of the slide areas is clearly delineated by the contorted contours on the published topographic map.

IGNEOUS ROCKS

Revised volcanic history of four calderas in the western San Juan Mountains, Colorado

Recent studies in the western San Juan Mountains (loc. 9) by P. W. Lipman, T. A. Steven, R. G. Luedke, and W. S. Burbank (1973) indicate that the sequence of mid-Cenozoic volcanic events is closely analogous to that elsewhere in the volcanic field. Intermediate-composition lavas and breccias of the Lake Fork, Picayune, and San Juan Formations were erupted from a cluster of central volcanoes 35 to 30 m.y. ago. Dominant activity then shifted to ash-flow eruptions with accompanying caldera collapses. Uncompahgre and San Juan calderas, two distinct subsidence structures each about 20 km across, are separated by an uncollapsed rib of Precambrian granite; both formed during eruption of the 28-m.y.-old Sapinero Mesa Tuff. Collapse occurred concurrently with eruption, and intracaldera Sapinero Mesa Tuff (Eureka Member) accumulated to a thickness of more than 700 m. Variations in the thickness of later intracaldera lavas and volcaniclastic rocks, including the Burns and Henson Formations, indicate that both calderas were resurgently domed together. Uncompahgre caldera was then flooded by several 27- to 28-m.y.-old ashflow sheets from easterly sources and also by one apparently erupted from Silverton caldera nested within the older San Juan caldera. Lake City caldera, located within the older Unsompahgre caldera, formed about 22.5 m.y. ago in response to eruption of Sunshine Peak Tuff.

Thus, the "San Juan volcanic depression," to which eruption of the Silverton Volcanic Group previously had been related, is essentially equivalent to the combined San Juan and Uncompahgre calderas which formed during Sapinero Mesa eruptions. Rock units previously assigned to the Silverton Volcanic Group (Eureka Tuff, Picayune, Burns, and Henson Formations) and the Potosi Volcanic Group (Gilpin Peak Tuff) are correlative with other named units nearby in the volcanic field.

Italian Mountain intrusive complex, Colorado

Detailed mapping and petrologic studies by C. G. Cunningham, Jr., have disclosed that the Italian Mountain intrusive complex, Gunnison County, Colo. (loc. 10), consists of six plutonic phases emplaced at three adjacent intrusive centers along the Castle Creek fault zone. The intrusions range from quartz diorite to porphyritic quartz monzonite. A variant of the last intrusive phase is characterized by a partially aphanitic groundmass which was formed when the complex vented.

Fluid inclusion studies of quartz veins suggest that moderately saline fluids in the core boiled at

385°C±15°. Pressure constraints applied to a hydrostatic model suggest a depth of approximately 2,500 meters for this last event.

PRECAMBRIAN ROCKS IN COLORADO

New Colorado magnetic gabbros and peridotites

A previously unmapped mafic and ultramafic Precambrian intrusive body discovered by G. L. Snyder covers an entire 7½-min quadrangle in the northern Park Range of Colorado just south of the Wyoming line (loc. 11). Most of the body is a uniform medium-grained diabasic gabbro, but a variant exposed over several square miles along the continental divide in the northeastern part of the body consists of coarse-grained olivine gabbro and norite with inclusions of harzburgite and amphibole lherzolite. The possible presence of anomalous platinum-group elements in the more mafic phases of this body is being investigated. The age of the various gabbros and peridotites is unknown except that they are cut by small pegmatite and quartz-monzonite dikes of possible Boulder Creek (1.7 b.y.) affinity.

A new USGS aeromagnetic survey has been completed for the west side of the Park Range, and this survey shows a greater than 500 gamma positive anomaly over the above-mentioned gabbro body and indicates that the gabbro extends westward an unknown distance under Mesozoic and Tertiary cover. A previous aeromagnetic survey had mislocated this anomaly by more than 5 mi, and the anomaly was heretofore thought to be caused solely by Tertiary rocks which it was mistakenly thought to overlie.

Precambrian rocks in north-central Colorado

M. E. McCallum reports that lowermost Precambrian rocks in the Kings Canyon 15-min quadrangle, Medicine Bow Mountains, (loc. 12), are metasediments, locally of sillimanite grade, which have been intruded by a late phase of locally foliated quartz monzonite of the Boulder Creek Granite. In the northern part of the quadrangle a small stock of Sherman Granite intrudes the metamorphic sequence and is faulted and intruded by felsic and diabase dikes. Oldest Precambrian (pre-1.4 b.y.) faulting includes zones of mylonite and annealed faults trending northeast and northwest. Probable late Precambrian fault zones, also annealed, most commonly trend north-south and northeast and cut the Sherman Granite.

STRATIGRAPHIC STUDIES

Thinning of Paleocene beds on Douglas Creek arch

Mapping by W. J. Hail, Jr., in and near the Rough Gulch 7½-min quadrangle, Rio Blanco County, Colo. (loc. 13), shows a marked westward thinning of Paleocene strata. The Fort Union Formation, consisting of two mapped members, is about 1,500 ft thick at the east of the quadrangle but only about 400 ft thick at the west edge. Most of this thinning occurs in the lower member, and probably was caused by deposition against the rising Douglas Creek arch to the west. The Fort Union thickens to about 2,000 ft a few miles to the northeast, but it is entirely absent a few miles west of the Rough Gulch quadrangle.

Depositional units in the upper part of the Morrison Formation, McKinley County, New Mexico

Results of stratigraphic studies by C. T. Pierson in the western part of the Church Rock 7½-min quadrangle, near Gallup, McKinley County, N. Mex. (loc. 14), indicate that the upper part of the Morrison Formation of Late Jurassic age can be divided into two depositional units, neither of which corresponds completely with the Westwater Canyon Sandstone or Brushy Basin Shale Member. The two units probably were formed by differing modes of stream deposition or possibly by streams from different source areas.

The lowermost of the two units, consisting of the lower half of the Westwater Canyon, has a high sandstone-shale ratio throughout the area studied. The upper unit, consisting of the upper half of the Westwater Canyon and the entire Brushy Basin, decreases in the sandstone-shale ratio from high to moderate within about 2 mi in a south to north direction.

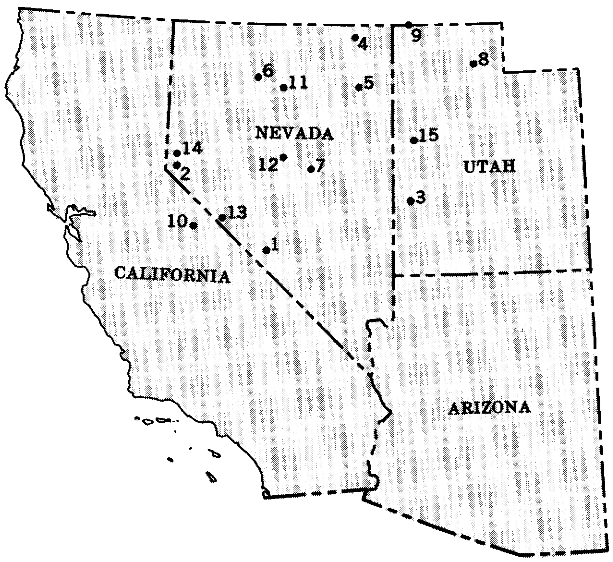
QUATERNARY GEOLOGY

Quaternary erosion cycles in the Gallup region, New Mexico

At least four major Quarternary erosion cycles and several minor cycles have been recognized near Gallup, N. Mex. (loc. 15), by J. F. Robertson. Evidence for these cycles includes remnants of graded erosional surfaces on the tops and sides of ridges and mesas, isolated deposits of weathered gravels and alluvium, remnant surfaces of early fans and pediments, stream terraces, gravel-capped benches, and flattened ridge spurs. In addition, a number of cut-and-fill sequences have been found in valley alluvium along recently incised arroyos.

The older erosion surfaces are fragmentary in the lower reaches of drainage basins and are generally better preserved in the upper reaches where lateral planation has been less active. They are also preserved in places where resistant rock barriers or abrupt escarpments have protected them from headward or lateral erosion.

The erosion surface that formed just before the present cycle of arroyo cutting is well developed along the main streams. It consists of wide valley floors. These features indicate a relatively long time interval (perhaps since the last ice advance) during which the base level or erosion was stable.



STATES IN BASIN AND RANGE REGION

BASIN AND RANGE REGION

MINERAL RESOURCE STUDIES

Preble Mountain anomaly near Goldfield, Nevada

R. P. Ashley and W. J. Keith have completed compilation of geochemical data for the entire Goldfield altered area, Nevada (loc. 1). Geochemical maps for arsenic, bismuth, copper, gold, lead, mercury, molybdenum, and silver have been prepared (Ashley and Keith, 1973a–h). The major ore deposits are reflected only by a gold anomaly, but areas of lesser production to the north and northeast of the main district show anomalous bismuth, gold, lead, mercury, and silver. Anomalous values generally occur over somewhat larger areas than those that were productive, and values obtained from both productive and nonproductive veins are similar, suggesting that small ore bodies may remain in these areas. The geochemical anomaly at Preble Mountain, about 3 mi east of Goldfield, which was discovered in the early stages of geochemical sampling, has been completely delineated. All the metals listed above except copper show anomalous values over an area of approximately 1 mi^2 centered on Preble Mountain. Scattered anomalous values appear in an area about 1 mi wide extending from Preble Mountain to a point about 2 mi east of Preble Mountain. Although no ore has been produced from this part of the area, the geochemical data suggest that further exploration may be justified.

Zonal alteration near Virginia City, Nevada

Examination of drill holes by D. H. Whitebread north of Virginia City, Nev. (loc. 2), discloses a zonal pattern of alteration that consists of an inner alunitic zone, an argillic zone, and an outer propylitic zone. Various mineral assemblages distinguished within these zones reflect the extent of hydrogen metasomatism outward from channelways. The zonal pattern is similar to that described at Goldfield, Nev., Summitville, Colo., and several other mining districts in the western United States.

Hydrothermal alteration, Fish Springs district, Utah

L. F. Hintze (Brigham Young Univ., Provo, Utah) reports that a zone of hydrothermal alteration just west of the active mining area in the Fish Springs mining district, Utah (loc. 3), has attracted geophysical and drill-hole prospecting in 1972, results of which are not available. In the vicinity of the Fish Springs mining district, which produced lead, silver, and gold between 1890 and 1930, small dikes of granite porphyry cut the dolomites and limestones that range from Late Cambrian through Middle Devonian in age. Although many minor normal faults transect the range, the main fault zone is along the east side. Scarps cutting recent alluvium attest to recent movement along this eastern fault zone.

Speculations on Nevada and California bedded barite and massive sulfides

The Meggen and Rammelsberg bedded barite and bedded sulfide deposits of the Devonian mineral belt in the Federal Republic of Germany were examined and sampled by F. G. Poole for the purpose of comparing them with Paleozoic bedded barite deposits in Nevada. The German deposits are sedimentary in origin and were deposited in a geosynclinal setting analogous to the Nevada bedded barites. Compositional, textural, and structural features suggest similar conditions of deposition within a geosynclinal environment, but paleontological data indicate that the German deposits probably formed in submarine basins in relatively shallow water. In addition to beds of relatively pure barite, the German deposits contain congruent layers of sulfide minerals including pyrite, chalcopyrite, galena, and sphalerite. The main sulfide ore bodies are lenticular and stratified with the sulfide minerals predominating in the flanks and upper part of the lenses. As bedded sulfide and barite occur together in eugeosynclinal-like strata of the Varsican geosynclinal in Europe, bedded sulfide deposits might be expected to occur in areas of bedded barite in the Cordilleran geosyncline in western North America, as well as elsewhere in the world.

STRATIGRAPHIC AND STRUCTURAL STUDIES

Extensive post-Early Triassic thrusting, northern Elko County, Nevada

Mapping in northern Elko County by R. R. Coats, L. D. Cress, and R. C. Greene has shown the considerable extent from west to east of post-Early Triassic southward-directed thrusting that was recognized by Riva (1970) south of the Contact district, in the HD Range, Nevada (loc. 4). Thrusts ascribed to this system have been recognized from the Owyhee quadrangle, west of the 116th meridian, to the Marys River basin, near 115°15′. The major thrust brings lower Paleozoic rocks of the western facies over probable Lower Triassic rocks, or over autochthonous upper Paleozoic carbonate rocks. Imbricate thrusting involving both Triassic and upper Paleozoic rocks has been mapped in the autochthon.

Tectonic zonation in northern Ruby Mountains, Nevada

In the northern Ruby Mountains, Nev. (loc. 5), three tectonic levels separated by distinct, mappable discontinuities in metamorphic grade, texture, and structural style are considered by A. W. Snoke to represent the framework of the Cordilleran hinterland. The lowest and essentially mobile core of the terrane is characterized by upper amphibolite facies metamorphism of lower Paleozoic sedimentary rocks coupled with synkinematic injection and remobilization of abundant granitic material. The dominant structures are large-scale recumbent folds with roughly north to northeast axes.

Overlying the mobile core terrane are allochthonous thrust sheets of high-grade metamorphic rocks that are stratigraphically equivalent to the metasedimentary rocks of the core terrane but are lower in metamorphic grade, in part cataclastic, and typically show well-developed linear structures and fold axes trending west-northwest. The character of the zone changes near its structural top with a further decrease in metamorphic grade, an increase in the orthogneiss component, and a more pronounced development of cataclastic textures.

The transition from metamorphosed lower Paleozoic rocks to unmetamorphosed upper Paleozoic rocks between the second zone and the suprastructural zone is incomplete due to the tectonic elimination of appreciable stratigraphic section. The unique character of this zone is the development of thrust-bounded slices of Paleozoic rocks typically fragmentary in regard to their original stratigraphic thickness but in the proper stratigraphic order. The younger-over-older thrusts predominate, but older-over-younger situations also have been identified. The features outlined for each tectonic level in the northern Ruby Mountains are not precisely repeated in all the metamorphic complexes of the hinterland. Local variations such as depth of erosion, the proximity of Tertiary plutons, and the role of old Precambrian basement may have a pronounced influence on the existing structural relations.

Two newly recognized Paleozoic deformations, Edna Mountain area, Nevada

Detailed geologic mapping by R. L. Erickson and S. P. Marsh of the four 7½-min quadrangles that make up the Edna Mountain 15-min quadrangle in Humboldt County, Nev. (loc. 6), has revealed two periods of deformation in Paleozoic rocks that are difficult to reconcile with either the Antler orogeny (Late Devonian to Early Pennsylvanian) or the Sonoma orogeny (probably the Permian-Triassic boundary). The Preble Formation and underlying Osgood Mountain Quartzite, both of Cambrian age, are regionally metamorphosed and folded into south-plunging asymmetric folds overturned to the west. The mechanism and time of this presumed westward directed deformation is uncertain, but it clearly predicts deposition of the Battle Formation of Early Pennsylvanian age. Genetic relation to the Antler orogeny and associated eastward-moving oceanic (?) thrust plates (Roberts Mountains thrust) of Late

Devonian to Early Pennsylvanian age does not seem reasonable because the principal westward movement of the Cambrian rocks is almost exactly opposed to the eastward movement of Antler orogenic plates.

The second previously unrecognized period of deformation was designated by Erickson and Marsh as the Iron Point thrust fault. The Battle Formation, Highway Limestone, and Antler Peak Limestone, ranging in age from Early Pennsylvanian to Early Permian, are asymmetrically folded, in places overturned, and ride over the Cambrian Preble Formation as a plate.

Displacement of this plate probably is of small magnitude—perhaps on the order of only a few miles. It is important, however, to record this period of movement, deformation, and erosion because it predates deposition of the Edna Mountain Formation of Late Permian age. The Edna Mountain Formation, underlying the Golconda thrust, is not folded—only tilted—and occurs in depositional overlap contact on an erosion surface cut across the older folded rocks in the plate; locally the plate has been completely eroded, and the Edna Mountain rests with angular unconformity on the Preble Formation. Thus this Pennsylvanian or Early Permian period of deformation followed by extensive erosion predates both the Golconda thrust and the Edna Mountain Formation.

Cauldron subsidence at Mount Lewis, Nevada

Studies by C. T. Wrucke and M. L. Silberman have shown that a ring fault outlines a cauldron subsidence structure 16 km in diameter at Mount Lewis in the Shoshone Range, Nev. (loc. 7). Thrust faults formed before collapse of Paleozoic and Mesozoic strata in the cauldron dip steeply inward near the ring fault but more gently in the interior where they form a concentric pattern around a centrally located cluster of plugs and breccia pipes. The plugs fed eruptions of rhyodacite and quartz latite flows and tuffs, remnants of which are preserved in the cauldron. Age dates by K:Ar show that volcanism and subsidence occurred during the interval 35.1 to 33.2 m.y. ago. The cauldron is therefore one of the oldest volcanic centers of Tertiary age in Nevada, and it may also be the most deeply eroded, as the majority of the rocks exposed lie well below the base of the original volcanic edifice.

Paleogeography of Precambrian Z tillites

Recent mapping of rocks above the Willard thrust near Ogden, Utah (loc. 8), and geologic reconnaissance in the area of the Great Salt Lake by M. D. Crittenden and M. L. Sorensen yields a more complete reconstruction of the paleogeography of Precambrian Z-age tillites than was possible heretofore.

Land areas apparently lay to the east, and subsiding basins to the west; this relationship has been disrupted by eastward thrusting of the basin sequences during the Sevier orogeny. Clast composition shows that source areas exposed gneiss, schist, pegmatite, and plutonic igneous rock; quartzite, argillite, and limestone, including stromatolites; and also both mafic and silicic volcanic rocks. To the east massive tills and associated sediments, including outwash lenses, were deposited in broad shallow valleys eroded into the underlying sediments. Farther west (basinward), massive diamictites give way to slumped and coarsely (particle size, 2–5 cm) reworked facies, the latter winnowed and locally redeposited in proximal graded sequences 1 to 3 m thick. Still farther west (basinward), distal graded sequences (particle size, 1–3 mm) contain sparse dropstones (1- to 2-m-size) indicative of floating ice in a deep-water setting. The normal sedimentary regimen in that area consisted of pyritic carbonaceous mudstone which is now black argillite and slate.

Lateral facies changes indicate the approximate temporal equivalence of tillite, boulder mudstone, black pyritic mudstone, graywacke, and siltstone. Deep-water facies can be distinguished by high content of organic carbon and pyrite; shallow-water facies are characterized by sediments weathering to tan to olive-drab.

Deformation in the Raft River Mountains

Mapping and petrofabric studies by R. R. Compton (Stanford Univ.) in the Raft River Mountains, Utah and Idaho (loc. 9), disclosed that quartzites of the Precambrian autochthon were locally deformed and metamorphosed a third time, in folds that trend northeast-southwest and overturned to the southeast. Fission track studies by Charles Naeser (USGS, written commun., 1972) indicate that temperatures of approximately 500°C affected underlying Precambrian granitic rocks as recently as 20 m.y. ago. In addition, the upper of two thrust plates (of Oquirrh Formation and Manning Canyon Shale) was found over upper Miocene or Pliocene sedimentary rocks.

Magnetic chronology

D. P. Elston and E. M. Shoemaker report that paleomagnetic poles measured in Precambrian rocks of the Grand Canyon and central Arizona allow a provisional correlation at the level of basaltic flows at the top of the Unkar and Apache Groups. The Troy Quartzite, which overlies the Apache rocks at some places, appears to have no correlative in the Grand Canyon and apparently predates rocks of the Namkoweap Group of Van Gundy (1934) of the Grand Canyon Supergroup.

The magnetic reversal chronology obtained from near the type section of the Moenkopi Formation (Triassic? and Triassic) near Gray Mountain, Ariz., has revealed that the beds here are entirely younger than sections of the Moenkopi Formation sampled to the northeast in the Navajo Reservation and in eastern Utah and western Colorado.

GEOCHEMICAL AND GEOCHRONOLOGIC STUDIES

Meteoric water–ore fluid, Bodie mining district, California

The results of an oxygen isotope and trace element study of the vein minerals, altered rocks, host rocks, and hot springs in the vicinity of Bodie mining district, California (loc. 10), by M. L. Silberman, J. R. O'Neil, and B. P. Fabbi (USGS) in cooperation with C. W. Chesterman (California Div. Mines and Geology) indicate that the fluid responsible for alteration and mineralization was locally derived meteoric water. This water was able to travel to depth by convective flow to a source material (possibly the upper part of an active magma chamber) rich in leachable K, Rb, SiO_2, Au, and Ag. The fluid after ascending attacked the dacitic host rocks, converting them to a potassium silicate alteration assemblage. Strongly increased K and Rb contents of the altered rocks vary inversely with the δO^{18}, and it is clear that introduction of K and Rb is in general correlated with interaction of the rocks with light meteoric water.

Trace element analyses (K, Rb) and O^{18}/O^{16} analyses show that there was a large quantity of alteration fluid of constant δO^{18}, K, and Rb content and temperature. Present hot spring waters in the Bodie area are anomalously high in Rb and have similar K:Rb to the altered rocks. The source of Rb in the present hot spring waters is unknown, but the similarity in K:Rb of these waters to the altered rocks, their low O^{18}/O^{16}, and the fact that they have the same salinity as fluids in inclusions in Bodie vein minerals suggest that they are very similar to the Bodie ore fluids.

Potassium-argon age relations at the Getchell mine, Nevada

In the Getchell mine area, north-central Nevada (loc. 11), M. L. Silberman and R. A. Koski (USGS) in cooperation with B. R. Berger (Continental Oil Co.) report that the granodiorite stock in Osgood Mountains intrudes complexly folded and thrust-faulted Paleozoic metasedimentary rocks. In the conspicuous thermal metamorphic aureole surrounding the pluton, the metasedimentary rocks are converted to cordierite, hornfels, and marble. Thirteen tungsten deposits have been mined in wolfram-bearing tactites which developed along the contacts of the granodiorite. Cutting the granodiorite stock and metasedimentary rocks along the eastern margin of the range is the Getchell fault along which the disseminated gold ore bodies of the Getchell mine are localized.

Three K:Ar ages of 89.9 ± 1.8 m.y. (biotite), 92.2 ± 1.8 m.y. (biotite), and 88.3 ± 1.8 m.y. (hornblende) were obtained from two samples of unaltered granodiorite. Two samples of wolfram-bearing ore from tactite yielded ages of 87.6 ± 3.4 m.y. muscovite) and 88.4 ± 3.3 m.y. (muscovite), respectively. Two samples of sericitized granodiorite from the gold ore zone along the Getchell fault at the mine gave ages of 92.2 ± 2.8 m.y. (muscovite) and 80.8 ± 3.3 m.y. (muscovite), respectively.

The K:Ar age of the second sample (80.8 ± 3.3 m.y.) has been lowered by Ar loss due to grain deformation from postmineralization movement on the Getchell fault, whereas the first sample (92.2 ± 2.8 m.y.) is undeformed. The K:Ar ages indicate that there is a genetic relationship between the pluton and the tungsten and gold mineralizations and that all are the result of the same thermal episode.

Possible age of mineralization, Austin, Nevada

E. H. McKee found a K:Ar age of 93 m.y. for adularia from a sample of sulfide-bearing, altered granitic rock from the Ogden incline at Austin, Nev. (loc. 12). The unaltered quartz monzonite host rock of the Austin pluton has a K:Ar age of 158 m. y. (Krueger and Schilling, 1971). The adularia and sulfide mineralization probably formed during alteration that also produced the rich silver sulfide ore in quartz veins near Austin. This age (93 m.y.) is the first radiometric date bearing on the time of mineralization in the district. Previous studies (Ross, 1953; Roberts and others, 1971) have indicated only that the veins cut granite rock assumed to be of Mesozoic age and are probably older than the Tertiary volcanic rocks in the area.

Age relations, Aurora mining district, Nevada

Based on mapping and geochronological studies by F. J. Kleinhampl and M. L. Silberman, four groups of volcanic rocks in the Aurora mining district, Nevada (loc. 13), are recognized. The oldest group—andesite flows, breccias, and plugs of 15.4 to 13.5 m.y. age—include the principal host rocks for the gold- and silver-bearing quartz veins which produced $30 million. To the west and south of Aurora, flows of coarse biotite-hornblende dacite prophyry (11.2 m.y.) lap onto the older andesites. The next younger (10.1–11.0 m.y.) group of rhyolite flows and intrusive rocks, crop out in the northern parts of the mining district and to the west of it where they are fault contact with the older andesites. The youngest rocks (250,000 yr to 3.6 m.y.) in the area are basaltic andesite flows and plugs, andesite and dacite flows and domes, and rhyolite plugs and domes which intrude and overlie the older andesites and the ore-bearing veins.

A K:Ar age of 10.3 m.y. was obtained from adularia separated from one of the major veins in the mining district. This age falls within the period of rhyolite activity (10–11 m.y.), and it is likely that fluids generated during this period were responsible for alteration and mineralization.

Lifetime of a hydrothermal system

Study of volcanic rocks and hydrothermal alteration by M. L. Silberman and D. E. White at Steamboat Springs, Washoe County, Nev. (loc. 14), indicate a minimum lifetime of the system of 3 m.y. From the previous work of White, it is known that hydrothermal activity has occurred at Steamboat Springs perhaps intermittently since at least the time when the Steamboat basaltic andesite flows of the Lousetown Formation were erupted. At about the same time, the Steamboat Hills Rhyolite domes were emplaced. An age of 3.0 m.y. was obtained on a sample of nonhydrated obsidian from one of the rhyolite domes, and an age of 1.0 ± 0.2 m.y. was obtained from adularized basalt of one of the Lousetown flows from a drill core in the Steamboat area.

The K:Ar work at Bodie, Goldfield, and Battle Mountain indicated that hydrothermal ore-depositing systems exist at least 1 m.y. and more likely on the order of 1 to 2 m.y. This establishes Steamboat Springs as the longest lived system yet investigated.

Radiometric dating of rocks associated with gold and silver deposits in Nevada

Radiometric dating of plutonic, volcanic, and hydrothermally altered rocks associated with gold and silver deposits in Nevada is used by M. L. Silberman and E. H. McKee to establish a partial time framework for igneous activity and mineralization.

Granite rocks were emplaced during three broad periods, 175 to 140 m.y. ago (Jurassic), 125 to 65 m.y. ago (Cretaceous), and 40 to 30 m.y. ago (Tertiary). The pulses are defined by approximately 100 published and unpublished K:Ar ages, mainly on biotite. When only concordant biotite and hornblende mineral pair ages are considered, the intrusive pulses appear to be much shorter, on the order of 10 to 20 m.y. duration.

Tertiary igneous activity in central Nevada began with abrupt localized eruptions of andesite lavas and intrusion of small granodiorite and quartz monzonite stocks about 40 m.y. ago. This was followed by eruptions of large quantities of rhyolite and some quartz latite ash-flow sheets from about 34 m.y. until about 20 m.y. ago. After a hiatus in igneous activity, volcanism resumed in central Nevada with eruption of rhyolite, basalt, and basaltic andesite flows between 16 and 5 m.y. ago.

The oldest Tertiary volcanic rocks in western Nevada are widespread ash-flow sheets of rhyolite and quartz latite composition that were erupted between 28 and 21 m.y. ago. Later Tertiary igneous activity in western Nevada is represented by a broad spectrum of volcanic types; of these the largest volumes are andesite flows which erupted from scattered volcanic centers between 21 and 8 m.y. ago. These are overlain by and interfingered with sedimentary rocks containing significant amounts of silicic tuff that accumulated in restricted basins between about 15 m.y. ago and the present. Locally, flows of alkaline olivine basalt and trachyandesite were erupted during this 15-m.y. interval.

Adularia in the following gold- and silver-bearing quartz vein deposits in pre-Tertiary host rocks have been dated: Imlay, 73 m.y.; Ten Mile, 16 m.y.; Manhattan, 16 m.y.; and Adelaide, 14 m.y. Adularia, alunite, or sericite from the following vein deposits in Tertiary volcanic rocks has been datel: Tuscarora, 38 m.y.; Midas, 15 m.y.; Buckhorn, 15 m.y.; Round Mountain, 25 m.y.; Tonopah, 19 m.y.; Goldfield, 21 m.y.; Aurora, 10 m.y.; Comstock, 13 m.y.; Rawhide, 16 m.y.; Talapoosa, 11 m.y.; Bodie, Calif., 8 m.y.; and Monitor, Calif., 5 m.y. Biotite and sericite from the disseminated gold deposits at Gechel and Gold Acres have been dated at 90 m.y. and 94 m.y., respectively. The replacement gold deposits at Copper Canyon (Battle Mountain) and Eureka contain biotite and sericite dated at 38 m.y. and 102 m.y., respectively.

Pre-early Oligocene tectonism, western Utah

Isotopic (K:Ar) dates on a subhorizontal series of volcanic rocks in the northern Confusion Range, Utah (loc. 15), show the oldest part to be 36.8 ± 1.3 m.y. old as reported by R. K. Hose. Since this gently dipping sequence overlaps the deformed conformable Paleozoic–Lower Triassic sequence, the tectonism that produced the Confusion Range structural trough is clearly pre-early Oligocene.

PACIFIC COAST REGION

Nature of rocks underlying the Sierra Nevada batholith, California

Alkaline basaltic to andesitic volcanic pipes at several localities in the western Sierra Nevada, California, have been found by J. P. Lockwood to contain sparse xenoliths brought up from levels below the granitic batholith. The most important of these localities is near the town of Big Creek, in the central Sierra Nevada near the axis of the Sierra Nevada batholith. The Big Creek xenoliths are found in an upper Miocene elliptical trachyandesite pipe about 300 m in maximum dimension. The pipe appears to be compositionally zoned, with the most alkalic rocks in the center. Xenoliths in this volcanic pipe range in composition from garnet lherzolite to granodiorite and have been torn by ascending magma from various levels ranging from the earth's upper mantle to the surface. Mantle rocks are sparse and commonly are intensely altered.

Mafic rocks from the lower crust constitute the most abundant xenolith types. These xenoliths all have strong metamorphic fabrics and include abundant garnet (almandine) pyroxenites, pyroxene-amphibole gneiss, and garnet amphibolites. Gabbroic and granulitic gneisses are other common crustal xenoliths. Partially fused granitic rocks are very common as large xenoliths and for the most part are more calcic than the porphyritic granodiorite cut by the pipe at the surface. The surrounding granodiorite has been melted and mixed with volcanic lava along contacts.

Although sub-batholith xenoliths are common only at one locality (Big Creek), enough other sites have been found to support the conclusion that the earth's crust underlying the Sierra Nevada batholith, at least to the west, consists of highly diverse, compositionally heterogeneous metamorphic rocks of mafic to intermediate composition. The strong metamorphic fabrics of these rocks reflect complex tectonic histories; elucidation of these histories will shed valuable light on the origin of the Sierra Nevada batholith and the tectonic development of western North America.

Early Jurassic ammonite from Sierra Nevada roof pendant

An early Jurassic ammonite has been found in metasiltstone of the Boyden Cave roof pendant, south-central Sierra Nevada, Calif. Although too poorly preserved to permit positive generic and specific identification, its general shape, coiling, and ornamentation are characteristic of Early Jurassic forms. Strata associated with the fossiliferous rocks in the pendant include quartzite, andalusite hornfels, and marble. This assemblage differs strikingly from nearby volcanic rocks to the east, some of which in the Ritter Range pendant also contain Lower Jurassic fossils. The presence of nonvolcanic Lower Jurassic rocks of the Boyden Cave pendant lying west of coeval volcanic rocks of the Ritter Range pendant is anomalous and may be the result of large-scale tectonic dislocations.

Eocene conglomerate and thrust faulting in western Imperial Valley, California

Distinctive continental conglomerate of probable Eocene age has been discovered by R. V. Sharp in the Vallecito and Fish Creek Mountains on the southwestern edge of the Salton Trough, California. These deposits, probably correlative with the conglomerate of the Poway Group of San Diego County, are the easternmost known exposures of conglomerate of this kind. They locally extend beneath other conglomerate beds of Miocene or Pliocene age that were generally considered to be the oldest sedimentary rocks within the Salton Trough.

The Eocene conglomerate beds in the Vallecito Mountains underlie an irregular thrust sheet of crystalline rocks belonging to the Southern California batholith. No rocks comparable in lithology to those in the thrust sheet have yet been found in any of the adjoining crystalline ranges, suggesting the possibility of very large-scale movement. Two important regional relationships are implied by these observations:

1. Thrust faulting that has been found at a number of locations in the eastern Peninsular Ranges of southern California was previously thought to be entirely pre-Eocene in age. A post-Eocene age of some of the thrusting could indicate that San Andreas-style strike-slip tectonics was restricted to post-Eocene time and did not start here in pre-Tertiary time, as suggested by relationships in the northern part of California.
2. The source terrane for the Poway conglomerate could lie under Cenozoic sedimentary fill in the Salton Trough, or, alternatively, the source may have been elevated by post-Eocene thrusting and largely eroded away prior to accumulation of the post-Eocene section in the trough.

Regional gravity anomalies, Los Angeles area

Complete Bouguer gravity data compiled by W. F. Hanna, J. D. Rietman, and Shawn Biehler on the Los Angeles 2-degree quadrangle map indicate that major gravity lows occur over all major areas of low-density Holocene and Tertiary sedimentary rocks, such as the Cuyama Valley, southernmost San Joaquin Valley, western Mojave Desert, northern San Fernando Valley, Santa Clara River valley, and northern Los Angeles Basin, except for the Oxnard Basin which has no negative gravity expression. Regional highs are restricted to areas of plutonic and metamorphic rocks in the San Emigdio Mountains and San Gabriel Mountains and to areas of Tertiary volcanic rocks in the western Santa Monica Mountains and on Santa Cruz Island. Gradients of the regional anomalies reflect major density barriers in the upper crust which approximately, but not exactly, coincide with mapped traces of many major faults. Very localized gradients, not easily discernible at the 1:250,000 compilation scale, occur directly over mapped traces of many faults not having a regional gravity expression.

Shallow origin for basaltic magma of the Conejo Volcanics

Preliminary examination of chemical analyses of 39 samples from the Conejo Volcanics (middle Miocene) of Taliaferro (1924) of the Santa Monica Mountains, Calif., by R. H. Campbell shows that these rocks, chiefly basalts, andesites, and dacites ranging in SiO_2 content from 45 to 73 percent, have consistently low $K_2O:SiO_2$ ratios. At 60 percent SiO_2, the intercept of the K_2O variation line is at about 0.5 percent; at 55 percent SiO_2, the intercept is at 0.3 percent K_2O. Comparison with arc andesites plotted by W. R. Dickinson and Trevor Hatherton (1967) suggests that the basaltic magma originated at much shallower depth in the mantle. This shallow origin is compatible with the structural model of Campbell and R. F. Yerkes (1971) which postulates crustal extension in the region during middle Miocene time.

Aeromagnetics and ophiolite belts in central California

In central California, M. C. Blake, Jr., Isidore Zietz, and D. L. Daniels report that a number of north-trending aeromagnetic anomalies are associated with linear belts of serpentinized ultramafic rock and overlying mafic intrusive and extrusive rock (ophiolite). Geologic data suggest that these ophiolite belts mark former subduction zones related to a westward-migrating consuming plate margin.

Extension of Hayward fault

Reconnaissance geologic mapping in the San Jose, Calif., area by T. W. Dibblee, Jr. (1973), has extended the Hayward fault as a zone of faults about 17 mi farther south than previously mapped. The mapping, in support of the USGS–HUD San Francisco Bay region environment and resources planning study, indicates that the Hayward fault zone and related landslides should be considered a hazard to urban development in the open space and grazing lands east of San Jose and Milpitas. The Hayward fault has had a long history of violent earthquakes and ground breakage. Right-lateral movement of the Hayward fault east of San Jose in late Quaternary or Holocene time is indicated by deflected streams. Vertical movement of the fault is suggested by scarps and by numerous landslides on the foothills flanking the east side of Santa Clara Valley in contrast to the more stable hills on the west side.

Landslide costs determined

The economic costs of landslides in the San Francisco Bay region have been determined for the first time. During the 1968–69 winter season which was slightly above average in annual rainfall, landslide damage in the Bay region amounted to at least $25,000,000 (F. A. Taylor and E. E. Brabb, 1972). Damage caused by just one landslide in northeastern San Jose was more than $1,200,000 (T. H. Nilsen and E. E. Brabb, 1972). Knowledge of this damage was the single most important factor in persuading the city of San Jose to allocate funds for a geologic study to assist in city planning.

Landslide analysis of San Mateo County

A map (E. E. Brabb and others, 1972) showing different areas of susceptibility to landsliding in San Mateo County is the first attempt in the San Francisco Bay area to deal with landslides and the area between landslides for regional planning purposes; it is the first map ever prepared in the United States that systematically integrates slope, geologic units, and the distribution of landslides. The landslide susceptibility map was prepared from a geologic map (E. E. Brabb and E. H. Pampeyan, 1972a), an inventory of landslides (E. E. Brabb and E. H. Pampeyan, 1972b), and an experimental slope map that was prepared photomechanically from contour negatives of the USGS topographic map series. The landslide failure record for each rock unit was established by comparing the total surface extent of the rock unit with the area that failed by landsliding. The rock units were then ranked in order of increasing area of landslide failure, and arbitrary numbers were assigned to express this failure record. The original slope of each landslide before failure was then estimated in order to determine which slope angles were critical for the formation of the slides. The information from the failure record and the critical slopes was combined in map form to express the average landslide susceptibility of slope-material units throughout the county. The landslide susceptibility map is being used by the San Mateo County Planning Department for proposed zoning and to indicate those areas where the development might be required to obtain an engineering geology report.

Bouger gravity, Cape Mendocino

The smoothly sloping gravity field of the Coast Ranges near Cape Mendocino, Calif., is interpreted by Andrew Griscom to mean that the bottom of the Franciscan Formation is a smoothly sloping surface, presumably an east-dipping décollement at the top of a former subduction zone containing oceanic crust. Gravity data south of Cape Mendocino do not support the idea that the fault at Shelter Cove is the main trace of the San Andreas fault but rather indicate that the main trace must lie at least 16 km offshore.

Digital topographic model of California put on magnetic tape

The average elevations of about 193,000 1-min and 51,000 3-min compartments in California and vicinity have been estimated visually and recorded on a nine-track magnetic tape (S. L. Robbins and others, 1973). The 1-min coverage extends about 15 mi and the 3-min about 100 mi in all directions beyond the California boundary. This digital model is being used by the USGS and California Division of Mines and Geology to compute terrain corrections to about 20,000 new gravity stations obtained in California over the last several years. The model is also being used by Ames Research and several air-pollution control districts to predict wind currents and other atmospheric phenomena.

About six man-years were required to complete the model; work was done under the supervision of H. W. Oliver and S. L. Robbins at the USGS, and R. H. Chapman at the California Division of Mines and Geology.

Ophiolite belts in Klamath Mountains

Dismembered suites of ophiolitic rocks occur in several rudely concentric arcs in the Klamath Mountains of California and Oregon. The ophiolites, consisting mainly of alpine-type ultramafics and associated mafic intrusives and volcanics, are considered to be tectonic slices of ancient oceanic crust. Ages of the ophiolitic rocks of the various slices are difficult to establish, but minimum ages are provided by the oldest paleontologically dated strata that are deposited on the ophiolite of the individual tectonic slice, W. P. Irwin (1973) points out that, on this paleontologic basis, the minimum ages of the ophiolites are successively younger westward (oceanward), ranging from Ordovician and (or) Devonian, through Permian and Permian-Triassic, to Late Jurassic (Kimmeridgian). The ophiolites of the Klamath Mountains are succeeded to the west by still younger ophiolite of the Coast Ranges. Isotopic ages are known for gabbroic components of a few of the ophiolites, and these ages are compatible with the sequence of relative ages indicated by the paleontologic data.

Roza Member of Yakima Basalt in southeast Washington

D. A. Swanson and T. L. Wright (1973) have mapped the Roza Member throughout a 10,000 km^2 area in southeast Washington. In this area, the Roza typically consists of one or two flows whose combined thickness increases westward to 50 m near Kahlotus; the thickness varies as much as 25 m locally due to underlying relief. At least 11 vent areas, marked by piles of spatter and pumice in places riddled by dikelets and interbedded with thin flow units, occur in a north-northwest-trending zone about 15 m wide between Potter White Hill near Peola and the vicinity of Winona, about 85 km to the north. Probable feeder dikes of Roza lithology and chemistry crop out within this zone of vent areas near Mayview. The Roza laps out against older flows to the north near Pine City and to the east near Colton; to the south, possible erosional remnants of the member capping the ridge west of Anatone suggest that it once extended over the crest of the Blue Mountains. In the eastern part of the area, the Roza commonly overlies thin layers of micaceous or woody sediments and a saprolite developed on aphyric or sparsely phyric flows probably correlative with the lower Yakima Basalt. To the west, the Roza overlies plagioclase-phyric flows, probably belonging to the Frenchman Springs Member, with no sediments or saprolite. One or more generally olivine-phyric flows and lenses of tuffaceous sediments overlie the Roza in the map area. Structure contour maps drawn on the base and top of the Roza define shallow northwest-trending folds west of LaCrosse superposed on the gentle west-dipping flank of the Columbia basin; they also suggest structural continuity between two large regional structures, the Blue Mountain uplift and the Lewiston monocline.

Discordant ages near Okanogan gneiss dome

From an evaluation by K. F. Fox, Jr., and C. D. Rinehart of 39 radiometric age determinations, the history of magmatism and metamorphism in the northern Okanogan Highlands, Wash., is complex and cryptic. These data, those from other workers, and field relations indicate that the gneiss dome of the Okanogan Complex of Royse (1965) cooled below the temperature at which radiogenic argon is lost or fission tracks erased from the most retentive minerals at about 60 m.y. ago, and less retentive minerals about 50 m.y. ago. The dome apparently was mobilized in the Late Cretaceous and cooled slowly through the early Tertiary.

The discordancy of ages of coexisting minerals from plutons lying west of the gneiss dome is tentatively attributed to thermal metamorphism associated with the mobilization and metamorphism of the dome. For example, the composite batholith of the Similkameen Granite of Daly (1906) shows markedly discordant hornblende (116–177 m.y.) and biotite (70–83 m.y.) ages. A (Ar^{40}/Ar^{36})-(K^{40}/Ar^{36}) plot of the biotite data suggests a 57 m.y. isochron, close to the thermal age of the gneiss dome. The age of intrusion of the Similkameen batholith is probably somewhat greater than the 177 m.y. hornblende.

Because of the polymetamorphism that is indicated in this area during the Mesozoic and early Tertiary by discordant mineral ages, firm conclusions as to the age of individual plutons requires more complete documentation than is currently available. Tentatively, the data indicate ages of about 50, 90, 115, 180, or 195 m.y.

Lower Tertiary thrust zone in the central Cascades of Washington

Geologic reconnaissance mapping by J. L. Gaultieri and G. C. Simmons in the area of Summit Chief Mountain in the central Cascade Range, Wash., has revealed a northwest-trending thrust fault zone which may be of regional extent. The zone is composed of several imbricate thrust plates of the Swauk Formation of Late Cretaceous to Eocene age, which have moved southwestward over pre-Eocene Easton Schist and other Swauk. The zone is about 1½ km wide at Summit Chief Mountain and has been traced for a distance of 4 to 5 km. It is suspected of extending at least 10 km farther south, and on the basis of available evidence it is believed to extend into the drainages of the Cooper and Kachees Rivers. Just north of Summit Chief Mountain the thrust zone is truncated by a lobe of the Snoqualmie Granodiorite of Miocene and Pliocene age, but farther northwest where the Easton Schist and Swauk are exposed, the geologic relationships suggest one and possibly more thrusts may be present.

The zone of thrust faults in the Middle Cascade Mountains, if extensive, gives the area a structural aspect strikingly similar to that of the Northern Cascade Mountains, where thrust faults occur along a belt 100 km in length. The relation of the thrust belts to other structural features in the respective areas is also similar; the southern part of the thrust zone in the northern Cascades and the zone in the middle Cascades lie just west of major northwest-trending high-angle faults.

Forty-mile displacement on the Newport fault zone

It appears that it may be possible to establish a minimum displacement on the Newport fault zone in northeastern Washington using K:Ar ages of the plutonic rocks involved in the faulting. A sufficient number of dates have been obtained west of the fault to establish a pattern of increasing discordance and decreasing apparent age from west to east. Within the area bounded by the U-shaped trace of the fault, however, several dates indicate there is no discordance and no reflection of the younger ages found west of the fault. East of the U-shaped trace of the fault the discordance and the young ages are found again. Apparently the older plutonic rocks are floored by the shallow-dipping fault zone, and since they show no effects of the younger thermal event, they must have been structurally transported to their present location. The younger plutonic rocks on either side of the U-shaped trace of the fault are presumably continuous beneath the fault. The minimum distance to which the concordant rocks within the U-shaped trace must be restored is about 40 mi.

Source of Tertiary sediments in northeast Olympic Peninsula

Geologic mapping in the northern part of the Cape Flattery area of the Olympic Peninsula, Wash., by P. D. Snavely, Jr., and N. S. MacLeod indicates that more than 6,000 m of deep-water marine sedimentary rocks, ranging in age from middle Eocene to late Oligocene, overlie pillow basalt and breccia of early to middle Eocene age. This sequence consists of massive to thin-bedded siltstone and fine-grained sandstone which commonly shows graded bedding and penecontemporaneous deformation. Interbedded in these fine-grained clastic rocks are thick lenses of cobble and boulder conglomerate and tabular units of turbidite sandstone and pebbly mudstone. Foraminiferal assemblages from the Tertiary rocks indicate bathyal to abyssal depths of deposition.

The conglomerate units are comprised principally of clasts of igneous and low-grade metamorphic rock types, but in places they contain siltstone clasts that exhibit soft-sediment deformation and sandstone clasts that contain displaced shallow-water mollusks. Analyses of sedimentary directional features (flute and groove casts) indicate a north or northwest source for the coarse clastic debris, probably Vancouver Island. The composition of the metamorphic and igneous rock types in the conglomerate units also supports a Vancouver Island provenance.

Studies suggest that the thick sequence of middle Eocene to upper Oligocene strata were deposited in a deep marginal basin that had a steep northern border formed by the pre-Tertiary metamorphic and igneous rocks of Vancouver Island. Coarse clastic debris was probably derived in part from active faults along this continental margin and was shed into the basin. Sand and gravel on the narrow shelf and coastal fans and cones at mouths of rivers that drained the rugged pre-Tertiary terrane were transported as submarine mudflows and as turbidity currents into the deeper parts of the basin. The lenticular shape and broad cross-stratification in some of the conglomerate units suggest that some of the coarse clastic material was transported into the deeper parts of the basin along submarine channels. In the Oligocene siltstone sequences, units up to 150 m thick comprised of ½ to 2 m-thick turbidite sandstone beds can be mapped across two quadrangles. They appear to represent longitudinal filling along the floor of the basin by turbidity currents.

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

Paleozoic corals widely distributed in Alaska

Paleozoic coral faunas in Alaska occur exclusively in structurally complex limestone and dolomite deposits of Ordovician through Permian age that are scattered widely through most of the geological provinces of the state according to Michael Churkin, Jr.

Ordovician corals are uncommon; according to W. A. Oliver, Jr., they occur in interior Alaska in the Porcupine River and Jones Ridge sections and in the Lake Minchumina area. In the Seward Peninsula, a sequence of coral faunas is of probable Middle to Late Ordovician age.

Silurian corals are known from the Seward Peninsula, in the Fairbanks-Rampart area of central Alaska, and in the Eastern Brooks Range but are especially abundant in thick limestones of southeastern Alaska.

Corals of Devonian age are those most commonly reported from Alaska. They are widely distributed in the Brooks Range, in the Porcupine River and Nation River areas of east-central Alaska, and in the Fairbanks-Rampart area, and smaller assemblages are known from southwestern Alaska to the eastern Alaska Range. In southeastern Alaska a succession of corals of Early, Middle, and Late Devonian age has been reported by C. W. Merriam.

Mississippian corals are common in the Brooks Range, in southeastern Alaska, and on St. Lawrence Island according to A. K. Armstrong. Pennsylvanian corals are known from the Brooks Range and probably occur also in the Alaska Range.

Permian corals are rare in northern Alaska but are abundant in the limestone sections interlayered with basaltic lavas in the Alaska Range and southeastern Alaska according to C. L. Rowett (Texas Christian Univ.). In the Alaska Range a sequence of coral zones extends through 6,000 ft of strata. Permian corals also occur in east-central and southeastern Alaska.

Coral reefs and reef breccia deposits are known in the Silurian, Devonian, and Carboniferous sections. Paleozoic corals of Alaska have their closest affinities to corals of Asia and provide clues to the former marine connections and paleoclimatic conditions in the Pacific and Arctic Ocean regions.

Modern tectonic analogs to the Cordilleran geosyncline

Lithologies and stratigraphic sequences of Paleozoic rocks of Alaska when compared by Michael Churkin, Jr., with modern deposits from the DSDP, Leg 21 (Fiji to Australia), indicate that the volcanic arc-marginal ocean basin tectonic system provides the best modern analog for the Cordilleran geosyncline in Alaska (Churkin, 1973). Detailed comparisons between these two regions, now underway, will help understand the geologic history of Alaska and point to specific areas most favorable for economic development.

NORTHERN ALASKA

Informal Russian-American cooperation yields new geologic data on Beringia

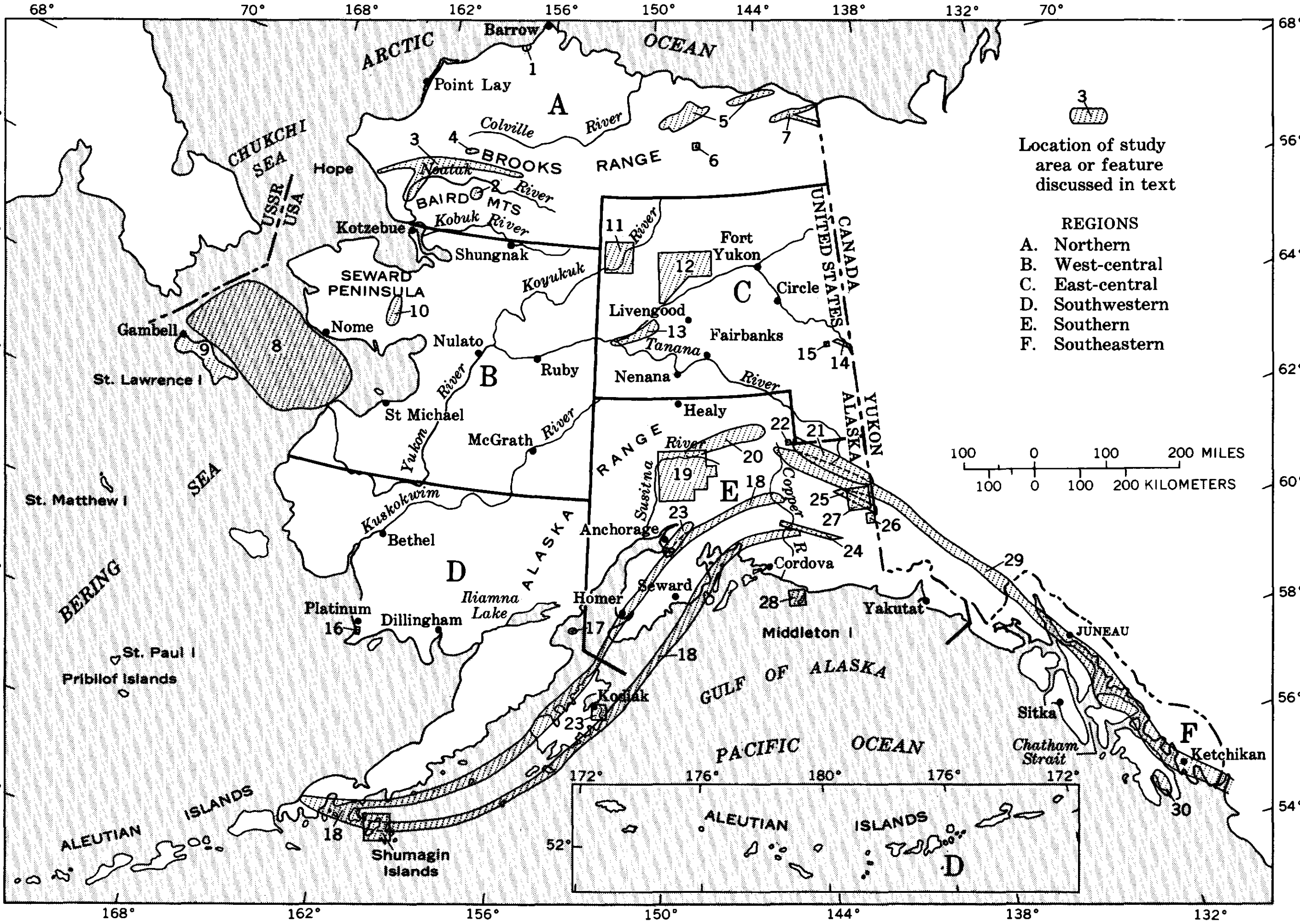
Cooperation between scientists of the USGS and the Geological Institute of the Academy of Science, USSR, in dealing with problems of the Quaternary geology of Beringia (Alaska, northeastern Siberia, and the intervening seas) has begun to produce concrete results. Exchanges of visits, of rock and fossil specimens, and of publications had already heightened ability to correlate stratigraphic units and to establish models of ancient climates, landscapes, and ocean circulation systems in the region. Recently, knowledge has been enlarged still further as a result of studies by Soviet paleontologists of materials collected in Alaska.

Mollusk-bearing Pleistocene marine sand and gravel beds at Skull Cliff, about 55 km southwest of Point Barrow (loc. 1, index map), were examined last summer by D. M. Hopkins (USGS) and O. M. Petrov (Geol. Inst. USSR), and a large fossil collection was made. After returning to Moscow, Petrov determined the fauna and provided a list of some 35 taxa—a tremendous increase over the 13 species listed for this locality in publication by C. E. Meek and F. S. MacNeil. The locality had been considered to be of early Pleistocene age, based on the presence of extinct *Neptunea leffingwelli* and *Astarte leffingwelli*, but it is now clear that both species are Arctic endemic species that persisted later than previously thought. *N. leffingwelli* is found in middle Pleistocene beds penetrated in boreholes offshore at Nome, and Petrov collected *A. leffinqwelli* in beds that are radiocarbon-dated as middle Wisconsinian Age near Point Barrow. Two other mollusk species present as fossils at Skull Cliff no longer live north of Bering Strait. Although the age of the Skull Cliff fauna cannot be firmly established, it seems more likely to be middle than early Pleistocene in age, and it may even be late Pleistocene (Sangamonian) in age.

A large contribution to understanding of paleoenvironments in Beringia was provided by pollen counts by R. E. Giterman (Geol. Inst. USSR) on seven species collected in northwestern Alaska by Hopkins and Petrov. The most significant specimens were five collected at various stratigraphic levels in the deposits of the middle Pleistocene Kotzebuan marine transgression on the shores of Kotzebue Sound near the Arctic Circle. Mollusks in these beds indicate extremely low water temperatures, and some features of the enclosing beds suggest that large glaciers may have been present on nearby land areas. Conversely, rich pollen floras indicate that, when sea level was rising, the adjacent land area supported shrub tunda rich in alder and dwarf birch and that, when sea level was at its maximum, spruce forest was present on the adjacent mainland. In other words, the vegetation on land was generally similar to the modern vegetation, which seems incompatible with encroaching glaciation.

Biostratigraphic record extended to Early Silurian or Ordovician in western Brooks range

Fragmentary graptolites collected by privately employed geologists from the northeastern Baird Mountains quadrangle (loc. 2) have been identified



as Early Silurian or Ordovician forms by Claire Carter and Michael Churkin, Jr. In subsequent investigations I. L. Tailleur (USGS) and G. H. Pessel (Alaska Div. Geol. and Geophys. Surveys) did not find more fossils but were able to confirm that the graptolite-bearing beds gradationally underlie dolomite in the lower part of the Baird Group. The graptolite remains, together with brachiopods collected in 1966 and assigned a Late Silurian age by J. T. Dutro, Jr., indicate that deposition of the Baird Group, which previously yielded fossils no older than Devonian, began at least in the Silurian and possibly in the Ordovician. Hundreds of meters of metaclastic sedimentary strata that appear to predate the Baird Group in the southwestern Brooks Range are therefore Ordovician or older.

Possible mantle-derived rocks in western Brooks Range

Infolds of gabbroic and partially serpentinized ultramafic rocks underlain by mafic shallow-seated layers and carbonate of the Devonian part of the Baird Group occur along the south edge of the De Long Mountains and across the west end of the Baird Mountains (loc. 3). These complexes appear to be remnants of a sheet that was allochthonous on several broadly dislocated thrust sequences consisting of magnetically flat Devonian (or older) to Cretaceous shelf and trough deposits. The sheet extended at least 200 mi eastward from the coast and may have connected with similar igneous rocks on the south edge of the Brooks Range. K:Ar dates on minerals related to the ultramafic rocks are 315±110 m.y. and 200 to 147±30 m.y.

Analogies with the model developed by the recent Penrose conference on ophiolites (Coleman, 1973) confirm previous suggestions that the igneous bodies are ophiolitic (Patton, 1973; Tailleur, 1970) and that the rocks may represent oceanic environments (Patton, 1970; Tailleur and Brosgé, 1970, p. E5). On a field trip to Red Mountain in the Diabolo–Mount Hamilton Range of northern California, I. L. Tailleur found rocks, indicated as deep-seated phases of the ophiolitic mass, that are markedly similar to ultramafic rocks that have been sketchily mapped in the western Brooks Range. Microscopic examination of the Alaskan specimens shows that they display features, such as olivine deformation-lamella and pyroxene "foliation" banding, indicative of mantle genesis (Loney and others, 1971).

If the Western Brooks Range ultramafic rocks originated in the mantle, a broad sheet of mantle has been transported to the top of the tectonic pile which is a few miles thick and telescoped from rocks that were spread 200 mi or more across a continental margin before middle Cretaceous time.

New interpretation of enigmatic Nuka Formation

Instead of including cyclically repeated rock units more than a mile in thickness as originally described, Nuka Ridge in the west-central foothills (loc. 4) is now interpreted as a stratigraphic sequence of late Paleozoic to Mesozoic age that has been stacked up by flat thrusts. Foraminifers identified by B. L. Mamet (Université de Montréal) and megafossils identified by J. T. Dutro, Jr. (USGS), from sections collected in detail by I. L. Tailleur in 1971, show that the fine-grained and arkosic units contain a Late Mississippian and Permian faunal succession that is repeated at least three times in the whole sequence.

Whether the stack of thrust sheets is itself allochthonous upon the rocks that crop out around Nuka Ridge and whether the detritus was shed from a microcline-bearing terrane to the north or to the south was not determined. Therefore, the potential of the Nuka Formation as a petroleum reservoir in the subsurface is still problematical.

Full Tertiary section present in northeastern Alaska

Completion of 1972 fieldwork permitted R. L. Detterman to construct an interpretive framework for Tertiary deposition in northeastern Alaska (locations numbered 5). Previously the relationships of the incomplete and spotty exposures of Tertiary were poorly understood. The recent work indicates that there was a fairly continuous deposition from Paleozoic to Pliocene with a general northeastward transgression. The older Tertiary sediments are typified by coarse conglomeratic, plant-bearing sandstones and siltstones, and coal beds. The somewhat younger Tertiary is characterized by light orange-yellow weathering silts and sands, some bentonite, and very minor coal. The youngest Tertiary is dominantly fine, thin-bedded to laminated silts and sands with a few unconsolidated pebble beds; very minor amounts of bentonite and coal are also persent.

Upper Lower Permian rocks discovered in northeastern Alaska

A concluding study of the Sadlerochit Formation in 1972 led R. L. Detterman to the discovery of the oldest Permian rocks yet known in northeastern Alaska. The late Early Permian age of these rocks is substantiated by a brachiopod fauna including *Attenuatella* sp. and *Anidanthus* sp. found on Flood Creek in the Sagavanirktok quadrangle (loc. 6). These rocks probably extend at least to the Canadian border and the south flank of the British Mountains (Joe Creek).

Age of carbonate unit in Demarcation Point quadrangle revised

A relatively thin, gray-weathering limestone, locally characterized by coarse-grained quartzitic beds, crops out over a wide area of the central and eastern Demarcation Point quadrangle (loc. 7). Detailed mapping by W. P. Brosgé and H. N. Reiser shows that these rocks are in normal depositional contact over volcanic graywackes of probable Late Ordovician age. This is significant as previous knowledge did not preclude a Precambrian age interpretation for these carbonates.

WEST-CENTRAL ALASKA

Benthic fauna of the Bering Sea

A study of the species composition, community structure, and ecological relationships of the benthic fauna of the Bering Sea (loc. 8) by R. W. Rowland defines five distinctive communities. Previous authors have doubted the existence of a shallow intertidal fauna in the subarctic and arctic because of the traumatic effects of winter sea ice. Rowland finds that although the intertidal zone on open coasts in barren, the lagoons have a distinctive intertidal community that includes taxa tolerant of brackish water. The other communities are in deeper water. Their distribution is mainly governed by substrate and is independent of depth, salinity, and temperature. The paleoecology of fossil assemblages of mollusks, brachiopods, echinoids, and barnacles can be interpreted on the basis of this exceptionally detailed study of the modern fauna, and the effects of environmental disturbance due to underwater mining can be predicted.

Evidence of oroclinal bending between Alaska and Siberia

Recent mapping on St. Lawrence Island by W. W. Patton, Jr., and Béla Csejtey, Jr., provides evidence that the Cordilleran foldbelt is buckled into a tight southward-looping oroclinal bend between Alaska and Siberia. Pre-Cretaceous miogeosynclinal deposits of the Brooks Range appear to swing in an arc southward across the Seward Peninsula to St. Lawrence Island and then northward into the Chukotsk Peninsula. The Paleozoic and lower Mesozoic stratigraphic sequence exposed on eastern St. Lawrence Island (loc. 9) is nearly identical to that found in the western Brooks Range, 250 mi to the north and also has counterparts on the Seward Peninsula and on the northern part of the Chukotsk Peninsula. The oroclinal bend is also reflected in the trends of upper Paleozoic–lower Mesozoic ophiolites and Cretaceous granitic rocks. The ophiolites appear traceable from the southern edge of the Brooks Range southward across the Seward Peninsula to St. Lawrence Island and then northward into the Chukotsk Peninsula. The Cretaceous granitic rocks likewise seem to be deflected southward in an arcuate belt stretching from west-central Alaska to St. Lawrence Island and then northward into the Chukotsk Peninsula. The oroclinal bending of Paleozoic and Mesozoic Cordilleran trends in the Bering Strait region is believed to be a consequence of east-west compression between North America and Eurasia in Late Cretaceous or Tertiary time.

Age of plutonic rocks and grade of metamorphic rocks in eastern Seward Peninsula

Laboratory studies of samples collected from the numerous large plutons of the eastern Seward Peninsula (loc. 10) together with previous geologic mapping by T. P. Miller and Donald Grybeck allow the delineation of separate intrusive suites of various ages. A wide variety of plutonic rock types, which range in composition from quartz monzonite to nepheline syenite and in age from 100 m.y. to 80 m.y., have been identified.

Petrographic studies also confirm an abrupt change in metamorphic grade along a north-south line west of the Darby Mountains. West of this line, the metamorphic rocks belong to the quartz-albite-muscovite-chlorite subfacies of the greenschist facies of regional metamorphism. East of the line, the rocks belong to the middle and upper almandine amphibolite facies.

EAST-CENTRAL ALASKA

ERTS–1 imagery provides clue to direction of movement on Kobuk fault zone

The Kobuk fault zone has been traced along the southern edge of the Brooks Range for 300 mi from the Kobuk River Delta on the west to the Yukon Flats on the east. The fault zone, which locally is as much as 20 mi wide, is made up of numerous, near-vertical, east-trending fractures. Major structural discontinuities in the bedrock along the fault zone suggest strike-slip movement, but until recently no evidence had been found to indicate the direction of movement. According to W. W. Patton, Jr., however, recently acquired ERTS–1 satellite imagery may provide a clue. An ERTS–1 image covering the Bettles region of central Alaska (loc. 11) clearly shows that the bedrock lying within the fault zone is sliced by closely spaced north-northeast-trending fractures. These cross-fractures had not been recognized previously either on the ground or in aerial photographs. If they are tension joints, left-lateral offset on the Kobuk fault zone is suggested; if they are shear fractures, right-lateral offset is indicated. The fact that they do not appear to offset the east-west trends in the bedrock suggests that they are probably tension joints, but additional fieldwork is needed to verify this.

Hodzana highland similar to southernmost Brooks Range

Rapid reconnaissance geologic mapping of the Beaver quadrangle by W. P. Brosgé, H. N. Reiser, and W. E. Yeend shows that the bedrock sequence on the southeast flank of the Hodzana highland (loc. 12) is similar to that on the south and southeast flanks of the Brooks Range. Quartz-mica schist and Cretaceous granite form the core of the highland and are flanked by successive belts of phyllite and lithic graywacke. Thin limestone beds that contain Paleozoic corals of probable Silurian or Devonian age occur in the phyllite and strike toward a zone of marble beds in the schist, thus indicating the same original age for the metasediments. The youngest extensive rock unit is an assemblage of mafic volcanic rocks, eclogite, and chert that strikes southwest toward the mafic rocks of the Rampart Group and northeast toward the Jurassic mafic complex in the Christian quadrangle.

Kaltag fault inferred in Yukon River valley between Tanana and Rampart

The Kaltag fault may be inferred to extend northeastward along the Yukon River valley between Tanana and Rampart (loc. 13) in the Tanana quadrangle on the basis of recent geologic mapping by R. M. Chapman, W. P. Brosgé, H. N. Reiser, and W. E. Yeend. The Kaltag fault has been traced eastward between Norton Sound and Tanana, a distance of 275 mi, by W. W. Patton, Jr., and J. M. Hoare (1968), and they suggest that it probably extends northeastward from Tanana. Right-lateral offset of 40 to 80 mi since Cretaceous time is postulated.

In the 60 mi between Tanana and Rampart, a major fault zone has not been identified in outcrops or as a positive trace in surficial deposits although it is probable that the northeast-trending belt of Tertiary sedimentary rocks was deposited in the fault trench and obscures the fault zone or zones. The southwesterly course of the Yukon River along the north side of this belt is probably controlled by the trend of the fault zone. The granitic pluton on the Yukon River at The Rapids and a belt of Tertiary (?) tuffs and rhyolitic rocks, southwest of Rampart, have a marked northeast elongation and are regarded as fault controlled. Known or inferred fault and shear zones that also trend northeast have been recognized in the area to the south as far as the Tanana River.

Right-lateral offset of 40 to 80 mi along the Yukon River valley is compatible with reconstructions based on recent mapping. A unit of Rampart Group rocks (Permian?) lying southwest of Rampart and a carbonate-bearing unit of metamorphic rocks (probably middle Paleozoic) south of the Yukon River appear to have been right-laterally offset by at least 30 to 40 mi from areally more extensive units of similar rocks on the north side of the Yukon River valley.

Tintina fault zone relocated in part of Eagle quadrangle

Investigations along the Tintina fault zone in the Eagle quadrangle, eastern Yukon-Tanana Upland, by H. L. Foster have led to a change in the mapping of the fault zone in part of the Eagle quadrangle (loc. 14). The finding of a breccia zone, along with topographic evidence and information from new mapping on the north side of the Seventymile River, suggests that the main fault zone may lie to the west of the trend as shown on USGS Miscellaneous Field Studies Map MF–358 (Foster, 1972). Also several semiparallel faults were mapped as possible splays of the Tintina system. A mass of marble containing echinodermal debris was found north of the fault zone where metamorphic rocks have not previously been found. Also unmetamorphosed Permian rocks were found south of the fault. These finds suggest that the pattern of faulting may resemble that in the Tintina fault zone in the Ross River area of Canada.

First Permian rocks found south of Tintina fault zone in Yukon–Tanana Upland

The first occurrence of definite Permian rocks south of the Tintina fault zone in the eastern Yukon–Tanana Upland was found in 1972 in the Eagle D–3 quadrangle by H. L. Foster. Brachiopod molds and casts were collected from a quartzite on the ridge west of Sutter Creek about 3 mi south of the Seventymile River (loc. 15). According to J. T. Dutro, Jr., the collection contained the genera *Megousia, Yakolevia, Anemonaria, Spiriferella, Neospirifer*, and *Tityrophora*? and a punctate spiriferoid. The brachiopods indicate a Permian age, probably about the same age as the Tahkandit Limestone and Step Conglomerate which occur north of the Tintina fault zone.

The zone of quartzite, argillite, and other slightly metamorphosed sedimentary rocks in which the fossils were found is believed to extend about 12 mi northwestward from Bryant Creek in a narrow, discontinuous band until it is cut off by faulting and an ultramafic intrusion near Flume Creek. The fossiliferous rocks are bordered on the northeast primarily by gneisses and schists of amphibolite facies and on the southwest by silicic to ultramafic intrusive and extrusive rocks and greenschist facies metamorphic rocks. Most contacts are probably fault contacts.

SOUTHWESTERN ALASKA

Platinum group metals in Red Mountain complex

The Red Mountain ultramafic complex (loc. 16), located near Goodnews Bay, is the source of platinum group metals recovered by a placer mining operation. Detailed mapping of the complex by A. L. Clark and Donald Grybeck has shown that it has a distinct border zone composed of dunite which grades successively to the margin through peridotite, pyroxenite, and hornblendite. Locally the surrounding greenstone and greenschist country rocks are metasomatically converted to amphibolite. The border zone of the complex is variable in thickness, ranging from 15 to 300 ft and locally is absent.

Detailed sampling on the southern flank of the Red Mountain ultramafic complex has shown the local occurrence of areas with a high concentration of chromite. The chromite is in discontinuous stringers, pods (locally up to 1 ft in diameter), or is disseminated throughout the dunite to peridotite host rock. Analytical results show that the highest concentrations of platinum group metals (5 p/m) are associated with the high chromite concentrations within the complex. In addition, the highest analytical values for platinum group metals and the corresponding associated chromite concentrations occur near the headwaters of the richest placer streams. Continuing studies will provide more data on the occurrence and distribution of platinum group metals within a known platiniferous ultramafic complex.

Late Mesozoic fossils discovered on Augustine Island

The first discovery of late Mesozoic fossils on Augustine Island was made on the south flank of Augustine Volcano (loc. 17) by R. L. Detterman and R. W. Imlay. *Diplomoceras notabile* and *Inoceramus* ex. gr. *I. subundatus* of Late Cretaceous age and *Buchia concentrica, B. rugosa,* and *B. Piochii* of Late Jurassic age were found in a section of sedimentary rocks, a few hundred feet in thickness, that underlies recent volcanic rubble and pumice flows. Previously only upper Tertiary rocks had been found on this island.

Gravity anomalies along south coast of Alaska

Gravity surveys by D. F. Barnes and others (1966) have revealed very long belts of gravity anomalies which almost parallel the southern coast of Alaska (loc. 18). Gravity surveys during 1972 now provide more data concerning the extent of the eastern and western ends of these belts. Data from the southwestern end of the Alaska Peninsula suggest that in this area two belts of gravity highs merge into the gravity high associated with the Aleutian volcanic arc, but the gravity high associated with the continental margin crosses the Peninsula between Port Moller and Cold Bay and trends northward along the edge of the Bering Sea continental shelf. Thus the Aleutian arc gravity feature seems to have been superimposed on a continental-shelf gravity feature. At the northeast end of the gravity belts, the new data suggest that the belts may not extend long distances east of the Copper River. The Prince William Sound gravity high definitely crosses the Copper River but was not detected in surveys along the upper Bremner River. Similarly a very extensive belt of highs that extends from the Semidi Islands along the north shore of Kodiak and to the south edges of Cook Inlet and the Copper River Basin may not penetrate far into the Chitina Valley before it is lost in the gravity minimum associated with the Wrangell Mountains.

SOUTHERN ALASKA

Paleozoic island arc in Talkeetna Mountains

Reconnaissance investigations by Béla Csejtey, Jr., in the Talkeetna Mountains (loc. 19) provisionally indicate that these mountains are underlain by two geologically dissimilar terranes of different ages and depositional environments. The two terranes are separated by a northeast-trending mesozonal batholithic complex of dominantly quartz monzonite, ranging in age from Jurassic to Cretaceous.

Rocks southeast of the batholith have been previously mapped as complexly deformed sedimentary and volcanic rocks of Early Jurassic to Tertiary age. Northwest of the batholith the dominant rocks form a thick, tightly folded sequence of low-grade metavolcanic and metavolcaniclastic rocks with a few interbeds of recrystallized cherty limestone. Lacking any fossil evidence, previous workers correlated this sequence with the Mesozoic rocks southeast of the batholith. Poorly preserved crinoid columnals, corals, and bryozoans from a newly discovered limestone locality strongly suggest, according to A. K. Armstrong, a late Paleozoic age for the sequence. On the basis of correlation with similar rocks in the eastern and west-central Alaska Range, this metavolcanic sequence in the northern Talkeetna Mountains is interpreted to represent a late Paleozoic volcanic island arc which was subsequently welded onto older continental crust.

Newly defined metamorphic belt in south-central Alaska

Recent studies by T. E. Smith (Alaska Div. Geol. and Geophys. Surveys, and USGS) demonstrate the continuity of a zonational metamorphic belt between the Alaska Range near the Delta River and the northern Talkeetna Mountains (loc. 20). This terrane, defined by mapping programs over the last 4 yr and referred to informally as the Maclaren metamorphic belt, extends northeastward over 80 mi from the Talkeetna Mountains near Tsusana Lake through the Clearwater Mountains and into the

Alaska Range where it is apparently truncated by the Denali fault system (J. H. Stout, 1972).

Bedrock along the belt consists mainly of pelitic sediments, deposited in Jurassic time and regionally metamorphosed in Late Cretaceous or early Tertiary time. A three-dimensional view of pressure-temperature conditions during progressive metamorphism is preserved in the lateral variation of index mineral assemblages along its length. Near the Delta River in the northeast the aluminosilicate pair, andalusite-sillimanite, is present in presumably stable equilibrium whereas farther southwest in the Clearwater Mountains, kyanite and sillimanite coexist. The lateral transition between these mineral pairs may be interpreted as a pressure transition across the Al_2SiO_5 triple point, with the deeper or higher pressure segment of the metamorphic belt being exposed at the southwest end.

A remarkably complete zonation between deformed metasediments of the pumpellyite-prehnite-quartz metamorphic facies and pelitic gneisses of the uppermost amphibolite facies is exposed in the Clearwater Mountains; there, metamorphic grade increases transversely across the belt to the northwest. Dynamothermal components of the metamorphic event have produced a textured gradation across the belt as well as a zonation of index minerals. Mildly metamorphosed pelitic rocks with primary sedimentary features grade through slates and phyllites to schists and gneisses with abundant rotational microtextures.

Plutonic rocks of the metamorphic belt include an intermediate magmatic series of Late Cretaceous age, which comprises most of the larger intrusive bodies, a small alkali gabbro stock of Late Jurassic age, and minor felsic bodies of middle Tertiary age near the Delta River. Field and textural relationships as well as K:Ar dates determined for the study suggest that many bodies of the Upper Cretaceous intermediate series were emplaced during the metamorphic event and were probably derived by anatectic melting of the pelitic sediments. Many of these plutons, though discordantly intruded into metamorphic hosts, retain contorted compositional layering suggestive of a paragneiss origin. These portions of the metamorphic terrane were apparently very near the igneous-metamorphic boundary and display facets of both, with attendant autoinjection of nearly molten material into slightly less mobile areas. K:Ar ages presently known from metamorphic and plutonic rocks near the Delta River appear to have been reset by post-Late Cretaceous thermal or tectonic events. Isotope studies and mapping programs in that region demonstrate an angular truncation of the metamorphic belt at the Denali fault.

Denali fault offset problem

Potassium-argon age determinations by D. L. Turner (Alaska Univ. and USGS) on samples collected by T. E. Smith (Alaska Div. Geol. and Geophys. Surveys and USGS), J. H. Stout (Minnesota Univ.), Turner, and F. R. Weber (USGS) from the Maclaren metamorphic belt (loc. 20), described by Smith in the preceding article, indicate that synkinematic metamorphism occurred between 65 and 70 m.y. ago. The Maclaren belt is cut by the McKinley strand of the Denali fault. To the north, a crescent-shaped block bounded by the McKinley and Hines Creek strands of the Denali fault contains slightly metamorphosed (greenschist facies) Devonian sediments, which have been intruded by a small granitic pluton dated at 90 m.y. The relatively young synkinematic age and compressed isograds of the Maclaren metamorphic belt (T. E. Smith and M. A. Lanphere, 1971) do not correlate with the regional greenschist facies terrane that characterizes the Birch Creek Schist of former usage north of the Denali fault or with the muscovite K:Ar ages between 112 and 115 m.y., determined for quartz-mica schists north of the fault near Canwell Glacier.

R. B. Forbes (Alaska Univ. and USGS), Turner and Stout have been searching for the offset segment of the Maclaren metamorphic belt, on the north block of the Denali fault (J. H. Stout and others, 1972). Synkinematic metamorphism of the Maclaren belt appears synchronous with development of the metamorphic belt on the west flank of the Coast Range in southeastern Alaska (R. B. Forbes, 1959; R. B. Forbes and J. C. Engels, 1970). K:Ar dates, lithologies, and regional outcrop patterns indicate that the Ruby Range metamorphic belt east of Kluane Lake, Yukon Territory, Canada, may have originally been a contiguous northwestern extension of the Coast Range metamorphic belt. The Ruby Range batholith and its adjacent metamorphic belt are truncated by the Denali fault along the Shakwak lineament. The Maclaren, Ruby Range, and Coast Range belts each include Barrovian metamorphic terranes, migmatite zones, late- and post-kinematic grandiorite and quartz monzonite plutons, and similar structural styles. A Kluane offset of the Maclaren belt would imply a right lateral offset of 250 mi along the Denali fault since latest Cretaceous time.

Aeromagnetic surveys aid geological interpretation in eastern Alaska Range

Aeromagnetic surveys of parts of Alaska, made by the State of Alaska in collaboration with the USGS, help to illustrate many of the geologic features delineated by the USGS reconnaissance field mapping programs. The aeromagnetic maps provide a valuable additional dimension for interpretive structural studies and have further beneficial applications in preliminary land-use planning and mineral resources exploration.

D. H. Richter reports that three distinct magnetic terranes are recognized in the eastern Alaska Range (loc. 21), each corresponding to a major unit of lithologically similar rock. North of the Denali fault the sequence of low-grade metamorphic rocks of Devonian and older age is characterized by moderate anomalies with a magnetic relief of generally less than 500 gammas. The anomalies are conspicuously elongate and subparallel to the pronounced structural trend of the metamorphic terrane. Immediately south of the Denali fault, a broad magnetic low, almost entirely devoid of local anomalies and with a maximum relief of less than a few hundred gammas, coincides with a clastic wedge of Jurassic-Cretaceous sedimentary rocks. South of the clastic wedge and over Pennsylvanian to Triassic volcanic and volcaniclastic rocks and limestone, the magnetic field increases with strong and extremely irregular anomalies commonly greater than 2,000 gammas.

Many of the local anomalies on either side of the Denali fault are apparently caused by Mesozoic granitic plutons. The magnetic expression of plutonic bodies north of the fault, however, is much subdued compared to those south of the fault.

Pennsylvanian age for late Paleozoic volcanic arc in Alaska Range

Detailed mapping and biostratigraphic studies in the east-central Alaska Range by D. H. Richter and J. T. Dutro, Jr., show that the Mankomen Formation, considered entirely of Permian age by Mendenhall (1905), consists of two distinct lithologies and contains both Pennsylvanian and Permian fauna. Re-examination of the type section in the Eagle Creek valley, Mount Hayes A–1 quadrangle (loc. 22), reveals approximately 3,100 ft of marine limestone and argillite of Permian (Wolfcampian and Leonardian) age conformably overlying more than 5,000 ft of volcaniclastic and volcanic rocks of Pennsylvanian (Atokan? and younger) and Permian (Wolfcampian) age. The investigators suggest that the name Mankomen Formation be restricted to the limestone-argillite sequence of Early Permian age and that the underlying volcanogenic sequence be provisionally assigned to the Tetelna Volcanics.

Recognition of this Pennsylvanian sequence shifts the timing of volcanic events in south-central Alaska. These new data suggest that the late Paleozoic volcanic island arc—proposed earlier by Richter and D. L. Jones (1971) to be largely Permian in age—developed during Pennsylvanian time and may have been virtually inactive by the Permian.

Late Cretaceous age established for extensive slate and graywacke belt

A thick sequence of highly deformed flysch-like meta-sandstone slate and argillite crops out in a belt extending at least 650 mi from northeast of Anchorage southwestward to the Shumagin Islands. Investigations in the Chugach-Kenai Mountains and on Kodiak Island (locations numbered 23) by D. L. Jones and S. H. B. Clark (1973) have shown that, although fossils are rare, the same types are present at widely scattered localities throughout this sequence of deep-water marine deposits that includes the Valdez(?) Group and the Kodiak and Shumagin Formations. These rocks that are lacking in fossils have long been considered Cretaceous in age because of scattered occurrences of fragmentary shells of *Inoceramus*. Mainly on the basis of new fossil collections by Jones and Clark, the age of some of these rocks can now be firmly established as Late Cretaceous (Maestrichtian), and the critical fossil is *Inoceramus kusiroensis* Nagao and Matsumoto. No evidence for other ages has been found in this extensive and thick rock sequence.

Inoceramus kusiroensis Nagao and Matsumoto also occurs in the much more fossiliferous and only slightly deformed Matanuska Formation that forms a parallel belt north of the Chugach Mountains. On the basis of faunal, lithologic, and bedding characteristics, this formation is the shelf equivalent of the deep-water, trench, or continental rise deposits of the Chugach and Kenai Mountains and islands to the southwest.

Major fault identified in Chugach Mountains

A 248-km-long segment of the Border Ranges fault, a major fault that can be traced for more than 1,000 km along the Pacific border of Alaska, was mapped in the Chugach Mountains by E. M. Mac-

Kevett, Jr., and George Plafker (1973). In the McCarthy and Valdez quadrangles (loc. 24), the fault separates the Valdez Group, a thick upper Mesozoic flysch sequence, from diverse upper Paleozoic rocks to the north. The upper Paleozoic rocks include metamorphosed volcanic and sedimentary rocks, subordinate gabbro and diorite, and rare ultramafic bodies; the rocks constitute the regional basement for much of south-central Alaska between the Denali and Border Ranges faults. They are interpreted as remnants of a late Paleozoic island arc and oceanic crust.

For most of its mapped length the Border Ranges fault is a northward-dipping thrust characterized by dips between 20° and 60° and the local development of nappes and klippen in the upper plate upper Paleozoic rocks. In its eastern part, throughout most of the McCarthy quadrangle, the fault dips vertically or steeply northward; it marks a plate boundary that developed during the late Mesozoic or early Tertiary.

Totschunda fault mapped in McCarthy quadrangle

During 1972 fieldwork, E. M. MacKevett, Jr., D. H. Richter, and D. L. Jones traced the Totschunda fault, a major fault described in the Nabesna quadrangle by Richter and N. A. Matson, Jr., across the northeastern part of the McCarthy quadrangle from the Nabesna quadrangle to the Canadian border. Throughout most of its extent in the McCarthy quadrangle (loc. 25), the fault dips nearly vertically and is characterized by a discrete lineament. In its southeastern portion the fault splays into subsidiary steep faults and thrusts that dip northward. The fault cuts rocks as young as the Wrangell Lava (Tertiary and Quaternary). The style of faulting exemplified by the Totschunda in the McCarthy quadrangle is an aid to tectonic interpretations in the region.

Devonian(?) marble section in McCarthy quadrangle

A thick, dominantly marble sequence has been recognized in the McCarthy B–1 quadrangle south of the Klutlan Glacier (loc. 26) as a result of reconnaissance mapping by E. M. MacKevett, Jr., D. H. Richter, and D. L. Jones. This sequence lies south of the Totschunda fault and is separated from the Wrangell Lava (Tertiary and Quaternary) on the northeast by a fault that probably is a strand of the Totschunda. In places the marble is unconformably overlain by Wrangell Lava or cut by monzonitic plutons, but most of its contacts are masked by snow and ice. The sequence is unlike any other lithologic assemblage in the McCarthy quadrangle. Although no fossils were found, the marble is lithologically similar to parts of the Kaskawulsh Group that have yielded Devonian fossils in nearby areas of Canada. These geologists conclude that the marble represents the northwesternmost extent of the Kaskawulsh Group, which correlates with parts of the Alexander terrane of southeastern Alaska. The recognition of Devonian(?) marble provides additional data for geologic interpretations of a region of great significance in regional tectonics. Of critical importance is the as-yet-unresolved relationship between the Devonian(?) rocks and the upper Paleozoic sequence that constitutes much of the regional basement between the Denali and Border Ranges faults.

Permian fossils and Middle Triassic rocks found in northeastern McCarthy quadrangle

Reconnaissance geologic mapping in the northeastern part of the McCarthy quadrangle by E. M. MacKevett, Jr., D. H. Richter, and D. L. Jones has revealed different faunules than those previously collected in Permian rocks of the region and more widely distributed remnants of Middle Triassic strata than have been known (loc. 27). Both elements are atypical when compared to previously mapped parts of the quadrangle. In the northeastern part of the quadrangle many of the Permian rocks contain abundant fusilinids and large rugose corals of the genus *Caninophyllum*. The Middle Triassic rocks consist chiefly of dark shale and siltstone, and they contain abundant remnants of the pelecypod *Daonella*.

Guides to interpretation of petroleum potential found in Kayak–Wingham Islands area

Detailed stratigraphic and structural studies by George Plafker in the Kayak-Wingham Islands area near Katalla (loc. 28) provide data critical to interpretation of the offshore petroleum potential in adjacent areas of the continental shelf. Bedded clastic sedimentary and pyroclastic rocks on the islands have a composite thickness of about 15,000 ft and range in age from late Eocene to early or middle Miocene. Much of the late Oligocene part of the sequence appears to have good source rock characteristics. Potential reservoir beds include sandstones in the upper Eocene and lower Oligocene section as well as sandstones and conglomerates in the lower to middle Miocene rocks.

The major problem for hydrocarbon accumulation appears to be the extreme deformation that has affected the entire sequence. All strata dip steeply or are overturned as a result of tight folding accompanied by imbrication on at least five major steeply-dipping reverse faults with the northwest blocks upthrown. Comparable structural complexity, if present beneath the continental shelf, would undoubtedly appear as acoustic basement on seismic profiles.

SOUTHEASTERN ALASKA

Gravina-Nutzotin belt—new key to late Mesozoic tectonics of southern and southeastern Alaska

Stratigraphic and structural studies originally based on work in the Annette-Gravina area near Ketchikan (Berg, 1972a, b; 1973) have led to an entirely new concept of southern and southeastern Alaska geology. This concept, which offers a unified hypothesis of the late Mesozoic tectonic history of the region, was formulated and published by H. C. Berg, D. L. Jones, and D. H. Richter (1972).

The concept is based on the recognition and documentation of the Gravina-Nutzotin belt, a sequence of upper Mesozoic flysch and volcanic rocks in southeastern Alaska. The belt crops out nearly continuously from southeastern Alaska through the St. Elias Range and into the eastern Alaska Range (loc. 29) and thus is the first documented link between the geology of these regions.

The definition of the Gravina-Nutzotin belt and an analysis of other rock sequences lead to the new interpretations. One is that the upper Mesozoic rocks in the belt are remnants of a magmatic arc that can be traced almost continuously for more than 700 mi, from the eastern Alaska Range to the southern tip of southeastern Alaska. The belt, together with two coeval shallow-marine and deep-marine assemblages in southern and southeastern Alaska, satisfies many of the criteria for an ancient tripartite arc-trench system. The other interpretation is that southeastern Alaska's myriad Paleozoic and Mesozoic rock units actually comprise only four or five main tectonic elements that are either crustal plates, fragments of plates, or terranes formed by the interaction of plates.

New evidence bearing on age of Wales Group

In its type area on southern Prince of Wales Island, the Wales Group comprises a thick, heterogeneous, mainly volcanogenic assemblage of low grade (greenschist and semischist) polymetamorphic rocks. Locally marble is interstratified with the schists in units ranging from less than 100 to 1,000 ft or more in thickness. The age of the group has been assigned by various workers to a range of pre-Ordovician to Devonian and even Carboniferous largely on the basis of lithologic analogy and gross, poorly understood field relations. The Wales Group has failed to yield any diagnostic fossils despite considerable diligent searching at numerous places where lithologic characteristics favor their occurrence and preservation.

Detailed mapping of G. D. Eberlein and Michael Churkin, Jr., along the southwest coast of Prince of Wales Island (loc. 30) has demonstrated the existence of an angular unconformity, probably folded, between the Wales Group and overlying unmetamorphosed marine sedimentary rocks of late Early or possibly early Middle Devonian age. From this and other field relationships it is evident that the Wales Group was deposited, metamorphosed, locally intruded by trondhjemite, and exposed to erosional processes before Early Devonian time. Further, the finding of Zone 9–10 (Middle Orodovician) graptolites in unmetamorphosed beds in Klakas Inlet that appear to be at least 20,000 ft stratigraphically above the Wales Group strongly supports a pre-Middle Ordovician age assignment. Inferentially, the presence of such a thick section of unmetamorphosed, thin-bedded, rhythmically layered, graded siliceous siltstone and fine-grained sandstone, sedimentary breccia, and conglomerate beneath the horizon represented by the Middle Ordovician fossil locality suggests the Wales Group may be at least as old as Cambrian, and probably Precambrian.

PUERTO RICO

Stratigraphic relationships in the San Germán Formation

Detailed field investigations in the San Germán quadrangle by R. P. Volckmann have shown that the San Germán Formation of Mitchell (1922), previously mapped as undivided volcanics, can be subdivided into three mappable units that could be important keys to unraveling the complex structure of the area. A lower purple volcanic sequence and an upper brown tuff are separated by a massive gray limestone. More detailed lithologic description of these field designations awaits thin-section and analytical studies.

The purple volcanics are at least 1,000 m thick and are a series of fine- to medium-grained, porphyritic, reddish-purple to purplish gray, massive, and agglomeratic andesitic flows and flow breccias. The rock is composed essentially of plagioclase and hornblende phenocrysts set in a hematite-rich matrix of plagioclase and hornblende.

The purple volcanics are overlain conformably by gray limestone, a massive to thick-bedded reef-type deposit which consists principally of skeletal debris. Whole gastropods and, notably, whole rudistids are present in some localities, and in places the limestone grades to a dense, dark gray calcilutite. Thin, brown, tuffaceous calcarenites occur irregularly within the limestone; the unit varies greatly in thickness from 10 to 70 m.

Brown tuff conformably overlies the massive gray limestone and consists of an interbedded series of volcanic conglomerates (some containing abundant limestone clasts), agglomerates, and epiclastic tuffs with local beds of skeletal gray limestone, well-bedded foraminiferal calcilutites, and tan calcarenites. The brown tuff is at least 800 m thick.

Recognition and mapping of this sequence elsewhere in southwestern Puerto Rico may provide some important clues to the nature of the complex tectonic history of the area.

Volcanic stratigraphy of the Humacao quadrangle

Volcanic rocks in the Humacao quadrangle occur in two distinct provinces separated by a west-northwest-trending transcurrent fault zone. Three volcanic units in the northern province correlate with the Lomas and Fajardo Formations of northeastern Puerto Rico and with a third unnamed group of rocks that appear to lie stratigraphically below the Figuera Lava of northeastern Puerto Rico.

Two major volcanic rock groups in the southern province probably are correlative with the Torrecilla Breccia and with the formation informally designated as formation A or J in east-central Puerto Rico. The volcanic rocks of east-central Puerto Rico are not contiguous wth those of the Humacao quadrangle, as the San Lorenzo batholith intervenes. Hence, this correlation will probably remain speculative.

Significance of dendritic drainage patterns in karst terrane

Between Ciales and Florida, Puerto Rico, many of the sinkholes are in karst valleys that form dendritic drainage patterns. The valleys have limestone walls and in many places a limestone floor interrupted by smaller holes. The pattern of these valleys shows that the limestone was once covered by middle to upper Tertiary alluvial material on which normal drainage systems developed. After the streams cut through the alluvial material, they disappeared into the porous limestone, and today the drainage is entirely underground. The original valleys have been deepened by solution of the limestone and by cliff-forming collapse of oversteepened slopes.

A Tertiary olistolith in south-central Puerto Rico

Geologic mapping in the Ponce quadrangle of south-central Puerto Rico by R. D. Krushensky indicates that an allochthonous plate composed of the Cuevas, Monserrate, and Anón Formations of Eocene age overlies the Maravillas Formation of Late Cretaceous age. The fault plane is marked by a breccia composed of tabular clasts of the Maravillas and rounded clasts of the overlying Cuevas Limestone in a slickenside-riddled, hematitized, clay matrix. The fault plane dips at about 35° SW. and cuts across the Cuevas in the Ponce quadrangle. In the Jayuya quadrangle to the north, the fault also cuts the base of the Monserrate Formation. Emplacement of the allochthon predates formation of the southwest Puerto Rico fault zone as it is cut by that fault zone, and it may postdate deposition of the Guayo Formation as that unit locally forms the footwall of a reverse fault in which the hanging wall is the allochthon. The absence of a root zone or highland to the south and the south-southwest dip of the fault plane and of paleoslopes in the Tertiary rocks indicated by penecontemporaneous slump features suggest emplacement of a southward moving gravity glide plate or olistolith off the rising magmatic arc of central Puerto Rico.

Widespread copper mineralization found on Island of Vieques, Puerto Rico

Anomalous copper concentrations in soils have been found in several areas on the Island of Vieques, Puerto Rico, and copper mineralization has been observed in outcrop at several sites on the island. These findings, reported by R. E. Learned, resulted from a geochemical survey conducted at the request of the Puerto Rican government. Although the findings are of interest, the geochemical and geologic characteristics of the mineralization do not appear to indicate targets of economic importance.

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 Geological Survey, and the completion of geologic maps of the country at scales that will fulfill foreseeable needs and uses is a long-range goal.

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

LARGE-SCALE GEOLOGIC MAPS

Large-scale geologic mapping, principally at scales of 1:24,000 and 1:62,500, constitutes 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 of 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 also are used as the basis for exploration for economic mineral deposits and for the preparation of reserve and resource estimates.

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

INTERMEDIATE-SCALE GEOLOGIC MAPS

Geologic mapping at a scale of 1:250,000 makes up an increasingly important part of the USGS geologic investigations program. The 1:250,000 and smaller-scale geologic maps generally are compiled from available large-scale geologic maps and supplemented by reconnaissance geologic mapping at intermediate scales. Mapping at 1:250,000 has now expanded to a point where it constitutes more than one fifth of the geologic mapping program of the USGS. Many State geological surveys also have 1:250,000-scale geologic mapping programs which are 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 the present time nearly 40 percent is covered. Figures 2 and 3 show the areas of the United States for which 1:250,000-scale maps have been published.

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

FIGURE 2.—Index map of the conterminous United States, showing 1:250,000-scale geologic maps published as of June 30, 1973.

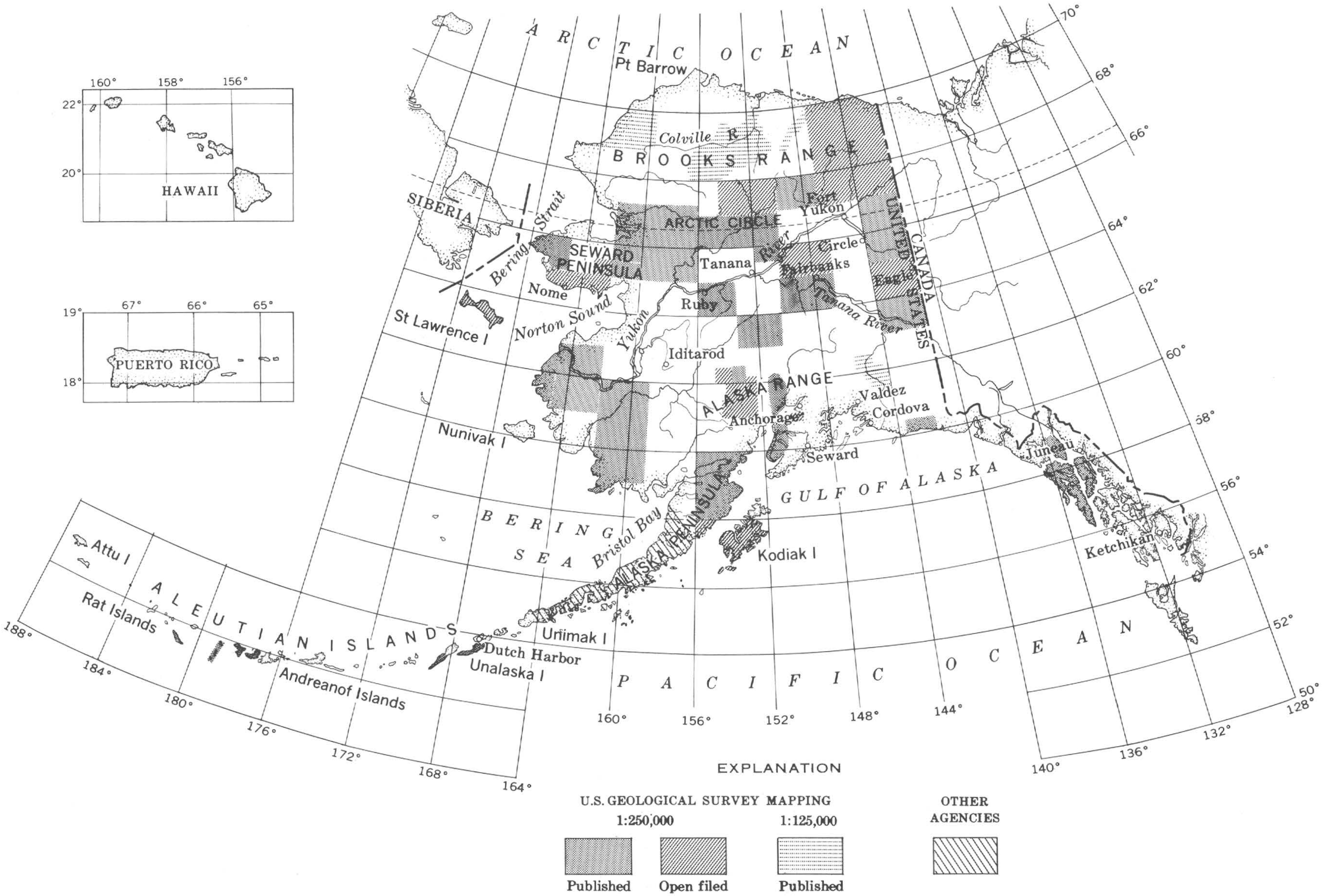


FIGURE 3.—Index map of Alaska, Hawaii, and Puerto Rico, showing geologic maps published or on open file as of June 30,1973.

MAPS OF LARGE REGIONS

Several maps of individual States or of all or large parts of the United States currently are in preparation. 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.

Compilation of the new geologic map of the conterminous United States has been completed. This map, which has been in progress of compilation since 1967, will illustrate the vast increase in knowledge and concepts of areal geology of the United States that have accrued since 1932 when the existing but now outdated map was published. Many areas, such as New England and the Pacific Northwest, are now better mapped and better understood, and stratigraphic correlations have been more nearly perfected so that a unified picture of the whole country can be presented. Aside from conventional paleontological correlations, notable assistance in this unification has been obtained from radiometric dating of the Precambrian rocks and of the Phanerozoic plutonic and volcanic rocks. A text to explain the map in additional detail is now being prepared.

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, and 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 B. R. Haley and E. E. Glick of the USGS and W. V. Bush, B. F. Clardy, C. G. Stone, and M. B. Woodward of the 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, compilation of which began in 1971, will supersede the existing map published nearly 40 yr ago and will depict the numerous advances in knowledge of the geology of Colorado made since that time. Geology will be plotted on a new four-color base that will show highways and 500-ft topographic contours as well as geographic features.

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, is nearing completion. The compilation draws on data from about 500 large- and small-scale maps, many of which have previously been used 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.

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

This 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 (H. J. Zwart and others, 1967) suggested metamorphic facies map explanation.

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 virtually completed and include maps showing total thickness of rocks of the two systems, thickness and lithofacies of divisions of the systems, and geologic maps showing 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.

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

Research is conducted to improve the scientific basis of investigations 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, salt-water instrusion, 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 relationship, (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, 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 salt water, (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, synthetic rubber industry, and water requirements, (13) agriculture, irrigation, and pesticides—movement in streams and ground water of pesticide, water requirements, and water spreading, (14) water management—flood control, and management of ground- and surface-water resources, (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-water disposal—radioactive waste disposal and waste 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-resources studies—appraisals, computer applications in water research, data processing, evaluation, hydrologic data, infrared applications, 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, (22) water cycle.

A significant part of USGS water-resources activities is providing scientific and technical assistance to other Federal agencies. When USGS interests are related to the interest 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 1973, data on streamflow were collected at about 8,400 continuous-record discharge stations and at about 9,600 lake- and reservoir-level sites and partial-record streamflow stations. About 7,000 maps of flood-prone areas in all States and Puerto Rico have been completed to date, and about 1,500 pamphlets covering areas susceptible to flooding have been prepared. Studies of quality of surface water were expanded; there were approximately 5,000 water-quality stations in the United States and 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 most of the water-quality stations. Sediment data were obtained at over 900 locations.

Annually, almost 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 current water-resource studies, about 350 studies are related to urban hydrology problems. Areal and research studies are being carried out in about 1,300 locations. Ground-water studies have been made or are currently in progress for about two-thirds of the Nation. In 1973, 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 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 1973. Records of about 255,000 station-yr of streamflow acquired at about 10,000 regular streamflow stations are stored on magnetic tape, and data on about 40,000 wells and 25,000 chemical analyses of water from them have been coded in machine format. Digital-computer techniques are used to some extent in almost all the research projects, and new techniques and programs are being developed continually.

The water-resource activities selected by the USGS as its contribution to the IHD were continued in 1973, and a résumé of certain activitis in the IHD program for 1973 concludes the water-resource section of this chapter. More detailed reports on some of the activities appear, where appropriate, in other sections.

The principal publications devoted to basic hydrologic data are in the following series of 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) detailed, descriptive reports on noteworthy floods for each year.

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 in 1973 by the USGS for administering the water-resource program. These regions differ considerably from those used and illustrated in all Geological Survey research summary volumes since 1963.

NORTHEASTERN REGION

Disaster struck the northeastern region in 1972. Tropical Storm Agnes devastated many parts of Pennsylvania, New York, Maryland, and Virginia between June 21 and 24 and also caused moderate to severe flooding in parts of six adjacent States. Damage in excess of $3 billion has been estimated, and 122 persons have been reported dead as a result of the storm. The flows of many streams were highest for periods of record exceeding 100 yr. Flooding was worst in Harrisburg and Wilkes-Barre, Pa.; Corning, Elmira, and Wellsville, N.Y.; and Richmond and Roanoke, Va. Shortly after the storm, USGS scientists were engaged in data collection in the stricken areas. At its peak, the work force included 160 hydrologists.

An earlier disaster struck West Virginia on February 26, 1972, when a flood swept through Buffalo Creek valley, in the southwest corner of the State. Shortly before 8:00 a.m., a coal-waste dam collapsed on the Buffalo Creek tributary of Middle Fork, suddenly releasing 132 Mgal of impounded water. The water passed through two more piles of coal waste blocking the Middle Fork in its one-half of a mile run to Buffalo Creek 250 ft below. The resulting flood wave, 10 to 20 ft high, traveled through the 15-mi-long valley and reached the town

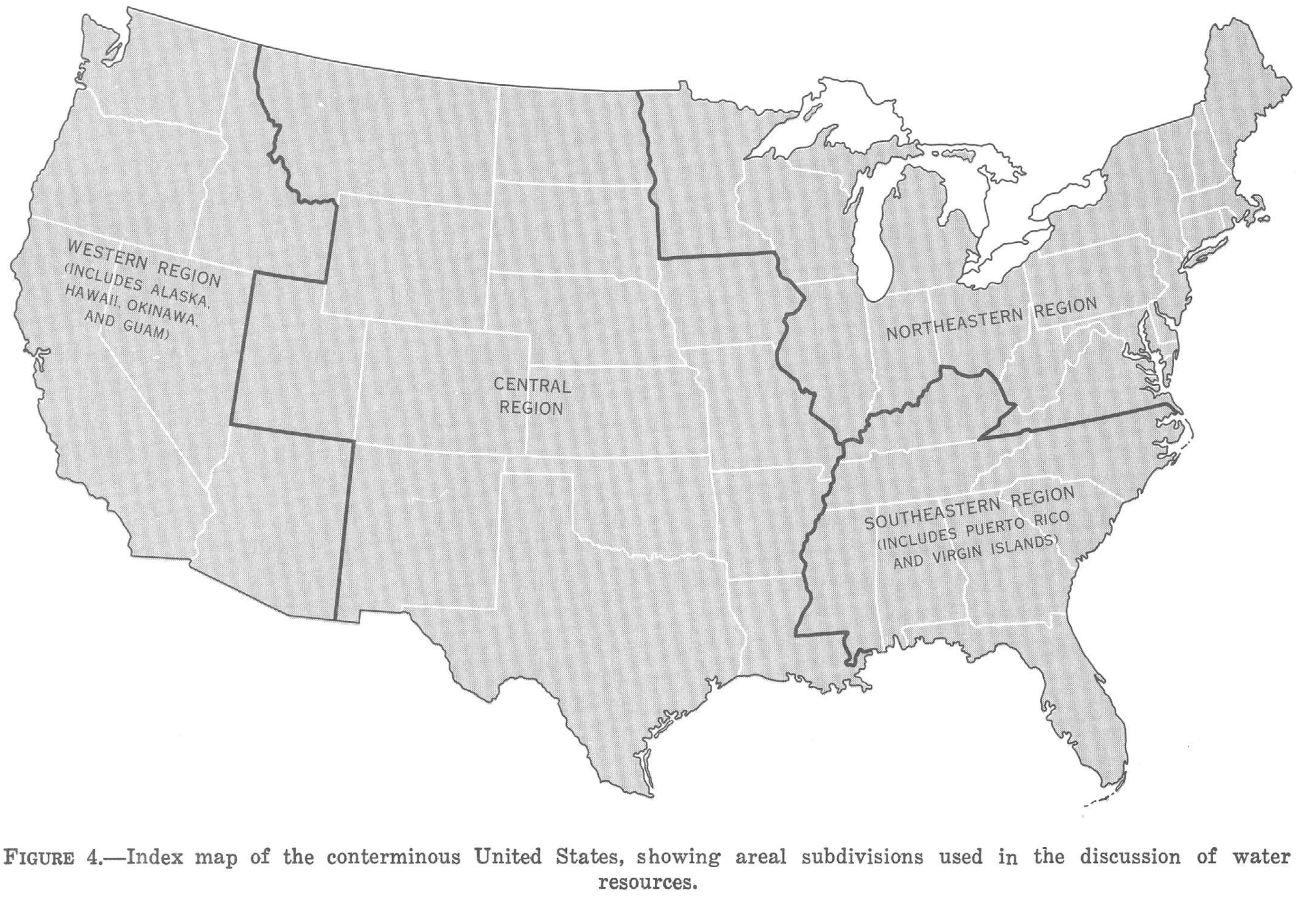


FIGURE 4.—Index map of the conterminous United States, showing areal subdivisions used in the discussion of water resources.

of Man, at the creek's mouth, around 11:00 a.m. During those 3 h, at least 118 lives were lost, 500 homes were destroyed, 4,000 people were left homeless, and property damage exceeded $50 million (highway damage alone exceeded $15 million).

Water-quality activities in the northeastern region included eutrophication assessments in parts of the Finger Lakes region of New York, which indicated natural input of nitrogen and phosphorus to be far in excess of the concentrations needed for accelerated growth of undesirable plants. Preimpoundment studies in Pennsylvania are being conducted to evaluate controls on water quality for locating multipurpose reservoirs and for reservoir management. A pilot study in the upper White River basin of Indiana is scrutinizing all factors bearing upon the total quality of an aquatic system to guide future comprehensive environmental evaluations. Fresh water was successfully stored underground in a salt-water aquifer and later recovered through a well near Norfolk, Va.; 80 percent of winter-surplus water stored for high summer use can be recovered from the aquifer.

Hydrologic modeling of coastal-plain aquifers from Long Island to Virginia continued. In Long Island, a five-layer analog model was utilized in studies relating both to the original condition of the ground-water system and to stresses imposed by development. Digital-model studies of aquifers in New Jersey included simulations of the Englishtown, Wenonah-Mount Laurel, and Potomac-Magothy-Raritan aquifer systems. Digital modeling of Pleistocene aquifers in Morris County, N.J., was also begun. In Maryland, the Aquia aquifer system was analyzed by digital model, and a report was completed on earlier analog studies of the Magothy aquifer in the Annapolis area. In Virginia, Cretaceous aquifer systems in the Franklin area were analyzed by digital models. Effects of utilizing coastal plain aquifers for an emergency water supply for the greater Washington area were also analyzed by digital model. The digital studies all incorporated single-layer models, and numerous questions have arisen concerning interaquifer leakage. Some form of three-dimensional modeling seems to be needed to answer these questions.

CONNECTICUT

Water inventory, lower Connecticut River basin

A study of the quality of water from the Triassic sedimentary rocks indicates that the hardness of water from the East Berlin Formation is consistently greater than 120 mg/l, regardless of the depth of uncased saturated bedrock penetrated, whereas water from the Portland Arkose differs widely in hardness, depending on the location and the depth of uncased saturated bedrock penetrated.

A unit hydrograph study was made of two small, closely spaced tributaries of the lower Connecticut River. The tributaries are comparable in size and geology but differ in that one drains a rural area and the other drains an urban area. The lag time (time from center of mass of excess rainfall to runoff) for the rural stream was 6 h, whereas the lag time for the urban stream was only 2 h. In the urban basin, downstream increases in chemical and biological constituents were caused by industrial effluents, sewage, and leachates from poorly drained solid waste. Suspended-sediment studies of seven small estuarine streams draining directly to Long Island Sound close to, but outside of, the basin of the major waterway, the Connecticut River, showed that substantial loads of estuarine sediment moved upstream and downstream, although the incoming fresh-water load from upstream was small.

Stream-aquifer models, southeastern Connecticut

R. L. Melvin used simple analytical models to estimate the long-term yields of nine stream-aquifer systems in southeastern Connecticut previously delineated by reconnaissance mapping and test drilling. Estimated long-term yields range from 0.5 to 10 Mgal/d. The models indicate that the Quinebaug River valley south of Jewett City ranks with the lower parts of the Pawcatuck and Shunock River valleys as the most favorable areas for the development of large sustainable supplies. The estimated yields are based on hydrologic conditions prevailing when data for the models were collected, and these estimates require verification.

Water study of Long Island Sound area

The USGS is cooperating with the New England River Basins Commission in a multidisciplinary and multi-agency study of Long Island Sound and surrounding land areas. R. L. Melvin, F. P. Haeni, and E. L. Burke are preparing maps showing the occurrence and quality of surface water and ground water in parts of southern Connecticut near the sound. The maps are similar to those already prepared by Ellis Koch for use in resource planning on Long Island.

DELAWARE

Water-table aquifer in central and southern Delaware

Pleistocene deposits of central and southern Delaware form a regional water-table aquifer, which supplies about one-half of the ground water pumped in the State. R. H. Johnston prepared a transmissivity map of the aquifer, using data from pumping tests and data obtained by several reconnaissance methods. The map indicates wide variations in transmissivity (T), reflecting changes in lithology (from fine sand to coarse sand and gravel) and changes in saturated thickness. However, the average T (7,000 ft^2/d) and hydraulic conductivity (90 ft/d) indicate that the Pleistocene deposits effectively act as a medium- to coarse-sand aquifer. Six areas of above-average transmissivity where T ranges from 10,000 to 22,000 ft^2/d have been identified.

Average ground-water runoff from the aquifer, about 800 Mgal/d, was determined by separation of streamflow hydrographs. By comparison, present pumpage is small (33 Mgal/d), and the aquifer is capable of yielding much more water. The easiest and most efficient method of obtaining large yields is to construct wells in areas of high transmissivity adjacent to streams characterized by high base flow.

ILLINOIS

Network of thermal recorders in Illinois

C. R. Sieber reported that the Illinois network of water-temperature recorders has been extended. The network, maintained in cooperation with State and Federal agencies, increased from one station in 1966 to 13 stations in 1973. The increase is attributed to concern for potential thermal pollution in specific areas and to a need to enlarge the base record for evaluation of future environmental changes.

Water-quality monitoring in Fulton County

The Metropolitan Sanitary District of Greater Chicago has undertaken an ambitious program of land reclamation and disposal of digested sludge in a strip-mined area in Fulton County. To ensure that no objectionable material leaves the project area in surface waters, C. R. Sieber reports that the USGS is monitoring discharges, specific conductivity, sediment, and temperature of Big Creek, the major stream that flows through the project area. The sanitary district concurrently is monitoring the chemical and biological constituents in the surface water and ground water.

Mixing of thermally different waters

The navigation locks and dams on the Illinois River provide an indirect benefit by mixing waters of different temperatures. This was noted during an investigation on March 16 and 17, 1972, to determine the velocity and temperature distributions in the river. The observations were made immediately downstream from the confluence of the Kankakee and Des Plaines Rivers and about 1 mi upstream from Dresden Island Lock and Dam. According to C. R. Sieber, the temperature of water from the Des Plaines River, which flows through the highly industrialized area around Chicago, averaged about 6.6°C, and the temperature of water from the Kankakee River, which is influenced by a relatively small amount of industrialization, averaged about 4.2°C. The mixed waters at the downstream side of the lock and dam had a temperature of 5.0°C. Discharge of the Illinois River at the Marseilles gaging station, about 25 mi downstream, was 22,500 ft^3/s. Discharges of the two tributaries were about of the same magnitude.

INDIANA

Quality assessment of the upper White River

According to W. J. Shampine, the quality of a river may be described by five characteristics—physical, chemical, biological, esthetic, and cultural. Traditionally, water-quality studies do not include all these characteristics. A pilot study on the White River tests the feasibility of quickly and economically assessing a river's quality using available data and collecting a minimum number of samples. The data currently under study are from many sources and include information on the physical setting; climate; land, cultural, and water resources; and potential sources of pollution; some of these data were collected in the late 1800's. The major objectives of the study are to describe the current quality of the river, to establish long-term trends, and to predict future quality.

MARYLAND

Hydrology of Triassic rocks, west-central Maryland

Water in arkosic sandstone, siltstone, and shale of the Triassic lowland in Maryland occurs chiefly in joints, faults, and bedding-plane partings. According to L. J. Nutter, most of the wells with the highest yields in the Triassic rocks tap a limestone-pebble conglomerate, where solution cavities have developed along fractures. The Triassic rocks are a reliable source of water for small to moderately large supplies. Extremely low-yielding wells are much less common in the Triassic rocks than in carbonate, metamorphic, and igneous rocks of the Piedmont.

The regolith overlying the bedrock is fairly thin in many areas in the Triassic lowland. Water-quality data indicate that nitrate concentration is fairly high in some areas that have both individual wells and septic systems.

MARYLAND, DELAWARE, AND VIRGINIA

Water resources of the Delmarva Peninsula

Precipitation on the Delmarva Peninsula averages 43 in./yr, and average runoff is 15 in./yr. Data presented by E. M. Cushing, I. H. Kantrowitz, and K. R. Taylor (1972) indicate that about 6½ in. of average runoff is overland flow, and the remaining 8½ in. is ground-water discharge. The streams are generally perennial but, because of the flat terrain, there are few opportunities to store water in surface reservoirs. Ten regional coastal-plain aquifers furnish nearly all the water used. Ground water is generally of good chemical quality; however, saline water exists in the deeper parts of the aquifers and also in the shallow parts adjacent to saline surface-water bodies. The amount of fresh water that can be developed perennially is estimated to be 1,500 Mgal/d. Large long-term water supplies will probably have to be developed from the Quaternary aquifer which is the most areally extensive and productive fresh-water aquifer.

MASSACHUSETTS

Ground water in the Connecticut River lowlands of central Massachusetts

Most of the Connecticut River lowlands are underlain by fine-grained sediments that yield little water. However, the fine-grained sediments are underlain by and interbedded with bodies of sand and gravel that are good aquifers. Sediments of coarser texture, capable of yielding large amounts of water, are concentrated mainly along the margins of the lowland, according to E. H. Walker, W. W. Caswell, and S. W. Wandle, Jr. The sand and gravel that constitute the good aquifers were deposited near the edges of the lowland by streams of melt water before and during the time when glacial Lake Hitchcock occupied most of the lowlands.

MICHIGAN

Flowing wells of Michigan

Flowing wells yielding fresh water from glacial drift and bedrock in Michigan have been studied by W. B. Allen (1973). Most known flowing wells are in the Lower Peninsula where many wells have been drilled to meet the needs of the large population. A comparison of flowing-well areas in 1900 with those in 1970 shows a probable decline in head in the glacial drift and in the Marshall and Saginaw Formations in the central and southern parts of the Lower Peninsula. Wells having the greatest reported flows tap the Marshall and Saginaw Formations; those having the greatest heads tap Cambrian-Ordovician and Silurian rock units. Water from flowing wells in Michigan is mainly used for domestic water supplies, but some is used for municipal and industrial supplies. In general, water from flowing wells is suitable for domestic use; however, high iron and chloride content and hardness impair water quality in places.

Ground-water resources of Baraga County

Results of a study by C. J. Doonan (USGS) and J. R. Byerlay (Michigan Geol. Survey) indicate that most ground water in Baraga County is obtained from beds of sand and gravel in morainal and lake-bed deposits or from the Jacobsville Sandstone. Although yields of wells range from a few gallons per minute to as much as 115 gal/min, most wells probably yield less than 10 gal/min. Large areas where igneous and metamorphic rocks crop out or are covered only by thin drift do not yield enough ground water for domestic supply. Water from most wells is satisfactory for use, although hardness and high iron content impair quality in places. Some deeper wells in the Jacobsville Sandstone may yield salty water. Most large public water supplies are obtained from Lake Superior, but some small supplies are obtained from wells and springs.

Geology and hydrology related to sanitary landfill in Washtenaw County

Using data obtained in a recently completed water-resource study of Washtenaw County and available geologic data, W. B. Fleck prepared maps delineating information useful in selecting sanitary-landfill sites. The maps show where wells in glacial drift yield less than 3 gal min^{-1} ft^{-1} (of drawdown), where thicknesss of the uppermost confining layer is greater than 50 ft, and where depth to bedrock exceeds 50 ft. Maps showing urban areas, distribution of surface water and mineral deposits, and places where permeability of the upper 30 ft of glacial material is low have also been prepared.

A summary map, showing the relative suitability of areas for landfill, indicates that a broad belt from the northeast corner to the southwest corner of the county is generally more suitable. This belt includes areas adjacent to the major population center, Metropolitan Ann Arbor.

MICHIGAN AND WISCONSIN

Hydrology and trout populations of cold-water rivers

In a study of hydrologic influences on recreation values of 112 stream segments of cold-water rivers in Michigan and Wisconsin, G. E. Hendrickson and R. L. Knutilla found that trout populations increase with decreases in annual maximum water temperatures and streamflow variability, and with increases in hardness, percentage of gravel bottom, bottom vegetation, and discharge per unit drainage area. Most hydrologic parameters were significant only when evaluated collectively. Analyses of stream segments restricted to certain limits of hardness, temperature, or percentage of gravel bottom improved correlations. Analyses of trout populations, in pounds per acre and pounds per mile, and of hydrologic parameters resulted in regression equations from which trout populations could be estimated with standard errors of 89 and 84 percent, respectively.

MINNESOTA

Agricultural areas affected by drainage projects

Results of an investigation by D. B. Anderson show that agricultural lands affected by artificial drainage in the Minnesota River basin increased 26 percent, from 3.51 to 4.44 million acres, during the period 1960–72. The drainage basin of the Minnesota River (above the last downstream gaging station at Jordan) is 16,200 mi^2 in area, 6,935 mi^2 (42.8 percent) of which is affected by manmade drainage projects. More than 75 percent of the area of three adjoining counties—Redwood, Renville, and Sibley—in south-central Minnesota is affected by drainage projects. The investigation of drainage projects is continuing for the remainder of the State.

Water resources of river basins in southeastern Minnesota

Results of studies by H. W. Anderson, Jr., show that all 94 municipal water systems in southeastern Minnesota use ground water. Of the 71 municipal systems in the watersheds of the Cannon, Zumbro, and Root Rivers, 72 percent tap the Prairie du Chien–Jordan aquifer. In the Cedar River watershed only three of 23 municipal systems tap the Prairie du Chien–Jordan aquifer, and all except one are supplied, at least in part, by the upper carbonate aquifer (Cedar Valley, Maquoketa, Dubuque, and Galena Formations).

Water budgets prepared by D. F. Farrell for the above four watersheds indicate a close correlation between precipitation and evapotranspiration. Runoff, however, is more directly related to topography. Runoff is less in the west in the rolling hills of thick glacial drift and is greater in the east, where the drift is thin and streams have cut deeply into bedrock.

The quality of ground water throughout the Cannon River watershed generally shows only minor variations. W. L. Broussard reported that the maximum dissolved-solids content of 21 samples was 750 mg/l. Excluding the maximum, the dissolved-solids content was less than 500 mg/l and averaged 392 mg/l. Analysis of geophysical logs and water samples from a 2,050-ft test hole showed a progressive change from fresh to saline water as depth increased. Dissolved-solids content was 450 mg/l in the Ordovician Prairie du Chien aquifer at about 400 ft and 8,200 mg/l in Precambrian red clastic rocks at 2,000 ft.

Water resources of the Crow River watershed

G. F. Lindholm, D. F. Farrell, and J. O. Helgesen determined that glacial drift, ranging in thickness from 100 to 500 ft, is the main source of water supply in the Crow River watershed. Surficial outwash in some areas is capable of yielding several hundred gallons per minute to individual wells. In the eastern third of the watershed, Precambrian sandstone underlying the drift is a proved source of water, making that area highly favorable for ground-water development. Two buried-outwash aquifers, each over 50 mi^2 in extent, were mapped. Streamflow in the North and Middle Forks of the Crow River is sustained during low flow by ground-water discharge from surficial outwash aquifers. Most of the water is hard, moderately to highly mineralized, and of the calcium magnesium bicarbonate type.

Water resources of Lake of the Woods, Big Fork River, Little Fork River, and Rainy Lake watershed units

Flowing wells occur in some areas of the northern part of the Lake of the Woods watershed and in the central parts of the Big Fork and Little Fork River watersheds. According to G. F. Lindholm, J. O. Helgesen, and D. W. Ericson, lake clay of glacial Lake Agassiz, 30 to 50 ft thick, forms the confining unit. Water from flowing wells is generally higher in dissolved solids than ground water elsewhere.

The distribution of glacial drift is highly irregular in the Rainy Lake watershed. Where drift is thin or absent, wells are commonly drilled into the crystalline bedrock, and yields are generally less than 10 gal/min.

In the late summer of 1972, smallest low-flow measurements in these watersheds were in the western third of the Lake of the Woods watershed, where the total runoff from approximately 800 mi^2 was about 3 ft^3/s.

Ground water near Alexandria

M. S. McBride reported that 170 test holes drilled in the outwash plain near Alexandria show an average sand thickness of 50 ft and an average saturated thickness of 40 ft. The drilling revealed that the plain is divided into five parts by narrow bands of clay till. In some places, particularly northeast of Parkers Prairie and east of Carlos, the saturated thickness is more than 90 ft, and the water table is within 20 ft of the surface. Transmissivity was calculated to be 160,000 gal $d^{-1}ft^{-1}$ from a pumping test near Carlos, where the prepumping saturated thickness was 80 ft. In other places, the sand is too thin for development of irrigation supplies, but a partial inventory of wells indicates places where irrigation supplies possibly can be developed from sand and gravel layers within the clay till underlying the sand.

NEW JERSEY

Digital model of the Mount Laurel and Wenonah aquifer

Bronius Nemickas is using a mathematical model to simulate the Mount Laurel and Wenonah aquifer in the Coastal Plain of New Jersey. Preliminary results indicate that the major cause of head decline in the aquifer is pumping from the underlying Englishtown aquifer of Cretaceous age.

Head declined most in the areas of Avon by the Sea and Freewood Acres between 1959 and 1970. In this 12-yr period, maximum head decline was approximately 100 ft. Pumpage is about 1.2 Mgal/d. The digital-model simulation indicates that head decline should be about 30 ft.

The Englishtown aquifer, which is separated from the Mount Laurel and Wenonah aquifer by a confining unit 20 to 190 ft thick, is being pumped at about 12 Mgal/d. Heads in the Englishtown aquifer declined as much as 130 ft between 1959 and 1970.

Decline of potentiometric heads of the Potomac-Raritan-Magothy aquifer system

An investigation of the Potomac-Raritan-Magothy aquifer system in north-central Camden County by G. M. Farlekas indicates an average decline of the potentiometric surface of approximately 2 ft/yr during the period 1968–70. Mass measurements in 1968 and 1970 and a selected few in 1972 suggest that the rate of decline is about the same as that during the period 1956–68 and about twice that during the period 1898–1956. Total head decline from 1898, before ground-water diversions, to 1972 was greater than 100 ft.

Test-drilling program in Cumberland County

Seventeen observation wells were drilled at six selected sites in Cumberland County for monitoring water-level trends, water quality, and possible saltwater intrusion in several aquifers, according to L. D. Carswell and Bronius Nemickas. Ten undisturbed cores were taken from the confining units to determine hydraulic properties for input to digital models.

Interpretation of the well data by Nemickas indicated that the Piney Point Formation is a well-developed former sand bar. It has a northeast trend, parallel to the Delaware River, and is not exposed. The formation is locally more than 100 ft thick. Glauconite concentration is least in the thickest part of the formation. The lithology indicates a high-energy depositional environment. Quartz is predominant in the thickest part, and glauconite concentration increases as the formation thins to the northwest and southeast. This can be attributed to less winnowing action in a lower energy environment.

The Piney Point Formation has not previously been considered for water supply in New Jersey, but it is tapped in Delaware. Geophysical logs indicate good water quality, and the formation may be the deepest aquifer containing fresh water in Cumberland County.

Farrington Sand Member traced from outcrop in Middlesex County downdip into Monmouth County

G. M. Farlekas used geophysical logs obtained at new wells in Monmouth County to trace the Farrington Sand Member downdip into areas where stratigraphic control was previously lacking. With the further aid of water-level data, the Farrington, the basal sand member of the Raritan Formation, was traced as a continuous aquifer from its outcrop in Middlesex County into Monmouth County for a distance of 12 mi.

Recent water samples from wells tapping the Farrington Sand Member in Sayreville, Middlesex County, show continued downdip movement of salt water. Salt water enters the aquifer at the Washington Canal, which is near the outcrop. Continued pumping over many years has moved the salt water downdip. Although pumpage from wells just downdip from the interface between the salt water and fresh water has been reduced or discontinued in recent years, the downdip movement of salt water is continuing.

NEW YORK

Lake Ontario Plain surface drainage

From April 1972 through February 1973 the Lake Ontario Plain surface drainage, as determined in the IFYGL program, was significantly higher than normal, according to G. K. Schultz. Heavy snows earlier in the year produced a high spring runoff. Very heavy rains occurred during Tropical Storm Agnes. Rainfall was also above normal during late Spring 1972 and from November 1972 through February 1973. The months of least rainfall during the period of study were July and August. The heavy rainfalls (other than Tropical Storm Agnes) covered all areas of the Lake Ontario Plain.

Soil moisture in Black River basin

W. N. Embree used neutron-scattering logging equipment to monitor soil-moisture changes at 11 sites in the Black River basin as a part of the Terrestrial Water Budget Program for IFYGL. Data collected from March 1972 through February 1973 indicate that soil-moisture content was greatest (54 in.) in April and least (41 in.) in July. Depth to water was greatest (18 ft) in March and least (15.6 ft) in May. Water content of the unsaturated zone of the Lake Ontario basin in New York will be determined by use of data from this project, as well as from other IFYGL-related projects.

OHIO

Ground water in western Ohio

Continuing studies of carbonate-rock aquifers in southwestern and central Ohio, by S. E. Norris and R. E. Fidler, indicate that relations between ground-water quality and areas of recharge and discharge, previously reported for the southwestern part of the State, hold true for much of the northwestern part. Thus, the relations are applicable to virtually the entire outcrop area of the limestone and dolomite in western Ohio. Water from wells in the principal recharge areas, tapping the regional flow system, has a relatively high bicarbonate content, compared with total anions, whereas water from wells in discharge areas contains a relatively low percentage of bicarbonate. The delineations of the principal recharge and discharge areas should permit reasonable predictions of ground-water quality in advance of drilling.

Ground-water availability and base flow in southeastern Ohio

Reconnaissances by A. C. Sedam have shown that ground-water availability is markedly different between the northwestern and southeastern parts of southeastern Ohio. In the northwest, well yields are generally good because permeable glacial deposits and relatively permeable bedrock are tapped. Well yields in the southeast are generally meager because the area is unglaciated and permeability of the bedrock generally is low. Base-flow values for the smaller drainage areas, likewise, are greater in the northwestern part than in the southeastern part, although some are anomalous. In the northwest, base flow exceeds 0.25 $ft^3\ s^{-1}\ mi^{-2}$ in some places while in other places it is only 0.03 to 0.04 $ft^3\ s^{-1}\ mi^{-2}$. The disparity can probably be attributed to differences in the glacial deposits. Low base flows (0.002 to 0.030 $ft^3\ s^{-1}\ mi^{-2}$) in much of the southeast are consistent with the low ground-water yields. There is, however, a several-basin area in which the base-flow values are relatively high (0.052 to 1.46 $ft^3\ s^{-1}\ mi^{-2}$), although geologic conditions seem to be similar to the rest of the area in which yields to wells are low.

PENNSYLVANIA

Study of the Cussewago Sandstone aquifer

Geologic mapping and analysis of well data by G. R. Schiner and J. T. Gallaher indicated that the principal bedrock aquifer in western Crawford County is the Cussewago Sandstone. The formation is present in the southern two-thirds of western Crawford County and is as thick as 80 ft. A structure contour map of the Cussewago shows that it crops out in the northern part of western Crawford County and is as deep as 450 ft in the southern part.

Yields of wells that penetrate the Cussewago are 2 to 20 times that of most wells finished in bedrock formations above or below the Cussewago. Many low-yielding wells can be deepened to penetrate the Cussewago, with a resultant increase in yield.

VIRGINIA

Data collected for rainfall-runoff model of the Holiday Creek basin

E. H. Nuckels reported that recorders were installed in September 1971 in the Holiday Creek basin, south-central Virginia. Records collected by these continuous recorders and at a regular network gaging station provide stage and rainfall data at three sites and ground-water levels at four sites. In addition, soil-moisture data are collected at seven sites. Data collected over several years will be used to define parameters for a rainfall-runoff model of the basin.

Triassic rocks penetrated in Nansemond County test well

In a study of drill cuttings from a deep test well in Nansemond County (lat 36°34′08″ N., long 76°35′00″ W.) drilled by the Virginia Bureau of Water Control Management in 1971, W. F. Lichtler found that sedimentary rock of Triassic age was penetrated at a depth of 1,874 ft (alt −1,818 ft). The finding was confirmed by P. M. Brown, J. A. Miller, and F. M. Swain (1972) and substantiates an earlier report (Am. Assoc. Petroleum Geologists and U.S. Geol. Survey, 1967) of buried Triassic rocks in this area.

Ground-water conditions in the Franklin area

G. A. Brown and O. J. Cosner reported that heavy industrial pumpage from aquifers of Early Cretaceous age in the Coastal Plain continued near Franklin during 1972. A potentiometric map for November 1972 indicates that levels remained about the same as they were in November and December 1971 in wells near the center of the cone of depression at Franklin. Outside of the immediate vicinity of Franklin, water levels declined 1 to 3 ft as the cone of depression continued to approach equilibrium with the withdrawals at Franklin. However, between Franklin and Courtland, levels declined 3.0 to 6.5 ft.

WEST VIRGINIA

Causes of failure of coal-waste dam No. 3 on Middle Fork

The failure of coal-waste dam No. 3 on the Middle Fork tributary to Buffalo Creek caused the disastrous flood of February 26, 1972, in Buffalo Creek valley, in the southwest corner of the State. According to an investigation by W. E. Davies, J. F. Bailey, and D. B. Kelly (1972), causes of the dam failure were:

1. The dam, primarily a coal-waste pile, had not been designed to contain as much water as could accumulate behind a stronger structure.
2. There was no spillway; the only water-level control was a 24-in. pipe which was too small to handle large flows and placed so high that water rising to it greatly decreased the stability of the dam.
3. The sludge foundation was inadequate. Excessive seepage through the weak foundation encouraged extensive piping and caused slumping and subsiding that led to the initial breach and overtopping.
4. The great thickness of the dam in relation to its height decreased its stability because through seepage was impeded. The high phreatic surface was reflected in dam saturation, and the resulting buoyancy accelerated the failure.
5. The dam was constructed of coal waste (including fine coal), shale, clay, and mine rubbish—material that is high in soluble sulfates, which reduce bonding strength, and does not compact uniformly.

WISCONSIN

Recharge to a ground-water reservoir in the Rice Lake–Eau Claire area

E. A. Bell and S. M. Hindall estimated recharge to the ground-water reservoir in the Chetek–Rice Lake area of Barron County, northwestern Wisconsin. The major aquifer is as much as 300 ft thick. It is a clean, well-sorted sand and gravel aquifer, with a transmissivity, as determined from aquifer tests, as high as 5 Mgal d^{-1} ft^{-1}. To determine how much water can be withdrawn from the aquifer, a reliable recharge figure had to be determined. A network of observation wells and precipitation gages was installed to determine effects of precipitation on the potentiometric surface. Using the storage coefficient for the aquifer, the rise in water surface, and the amount of precipitation, recharge was estimated. Because the estimating method (hydrograph) has many uncertainties, a flow-net analysis was made. Similar results were obtained by both methods, values obtained by the hydrograph method being slightly higher. An additional check, using streamflow data from a gaging station, was also made. The amount of recharge was estimated to range from less than 1 in./yr, where Precambrian rocks are at or near the surface, to 10 in./yr, on the flat glacial outwash plains. The average was 6.6 in./yr, which compares closely with the 7.1 in. average estimated from streamflow data.

Digital-computer model study of the hydrologic system in Dane County

The digital-computer model for aquifer evaluation developed by G. F. Pinder was reformulated by R. S. McLeod, in terms of drawdown, for solving problems of confined-aquifer flow. Both computer core storage and computation time were reduced. In addition, rates and volumes of leakage from streams and from confining beds created by these drawdowns are now provided as optional output from the model.

The revised computer model was used to model the sandstone aquifer in Dane County. Results indicated that the aquifer would be adequate to meet the water needs of the county through 1990.

Ground water susceptible to pollution in Door County

According to M. G. Sherrill, water infiltrating the Niagara Dolomite in Door County moves downward in the unsaturated zone through nearly vertical joints. It moves nearly horizontally in the saturated zone through solution-enlarged bedding-plane partings. The resulting rapid water movement and lack of time for natural filtration increases the possibility of ground-water pollution from surface sources. Test drilling and exploration by bore-hole geophysical methods indicate zones of greatest permeability along bedding-plane partings, particularly at or near formational contacts. These conclusions are substantiated by analyses of well records and by results of aquifer tests.

Hydrologic data for proposed impoundment

A water-quality study on the Kickapoo River at the LaFarge Dam site, southwestern Wisconsin, was begun in October 1971 by E. L. Skinner and S. M. Hindall. Water-quality data are being collected at two stations. One, below the dam site, monitors discharge and temperature continuously and monitors conductance, temperature, and sediment daily. The other, approximately 3 mi upstream but within the impoundment, monitors sediment and temperature daily; pH, conductivity, turbidity, DO, BOD, and total and fecal coliform bacteria weekly; ions and nutrients monthly; biota, pesticides, 24-hour DO, suspended sediment and bed material, and particle-size analysis quarterly; and minor elements annually. The stations are operated as part of a preimpoundment study and will be continued throughout the construction period. Data collection at the station below the dam will be continued after the reservoir is filled.

A station was established in December 1972 on the river above the inundated area. This station monitors discharge and temperature continuously. The remaining parameters and frequency of monitoring are the same as at the station 3 mi above the dam. This station will be monitored through the construction and filling period and will be used as a permanent station to collect data for reservoir management.

SOUTHEASTERN REGION

Water-resource studies in the southeastern region emphasize the quantity and quality of water resources available for use and are often designed to fulfill the data requirements to resolve problems arising from competition of groups or individuals who share or are interested in the same water. There is an ever-increasing need to develop a better understanding of the interrelation of the aquifer system and the surface-water bodies to provide an insight into data needs involving water-management problems. Land-use studies that are underway in Florida will provide an understanding of the relationship of the hydrologic system to land use and are needed for beneficial resource and land management.

FLORIDA

Problems occasioned by changes in land use and increase in population in Palm Beach County

Land-use changes coupled with rapid growth in population have precipitated numerous problems in the hydrologic environment. Definition of and alternatives to the problems were studied by L. F. Land, H. G. Rodis, and J. J. Schneider (1973). Drainage of agricultural lands for urban construction has considerably decreased aquifer storage and has caused water-level declines of as much as 5 ft, resulting in salt-water intrusion in coastal areas and necessitating the deepening of some wells in interior areas. Canals, lakes, streams, and waterways contaminated by excessive nutrients and coliform bacteria have been delineated, and this has precipitated action for a centralized sewage-treatment and disposal system. Benchmark data on water use, water quality, and water availability for backpumping to Lake Okeechobee have been collected and analyzed.

Recharge to unconfined aquifer estimated

Estimates of a plausible range in average annual recharge to the unconfined aquifer in the Peace River basin area of Charlotte County were deduced from a water-budget approach. J. J. Hickey reported that values from two different water-budget models were consistent, ranging between 0.1 and 1.0 in. per yr. These values appear low, but when depth to the water table is considered, the results are plausible. The water-table depth averages 3 ft below land surface, and it is always within a zone where the processes of evapotranspiration are active.

Nutrients and trace metals in bulk precipitation

Rainfall-dry fallout sampling conducted by A. G. Lamonds, Jr., as a part of the water-quality monitoring of Lakes Faith, Hope, and Charity at Maitland, Fla., found concentrations of 1.9 mg/l nitrogen, 0.22 mg/l phosphorus, and from 10 to 30 μg/l of aluminum, copper, iron, lead, and zinc. The composite sample of rainfall and dry fallout, which was collected during the period July 7–August 23, 1972, contained higher concentrations of inorganic nitrogen, phosphorus, copper, and lead than the three lakes, which were sampled on August 1 and 8, 1972.

Oil-field activities not adversely affecting water quality in the Big Cypress Swamp

E. T. Wimberly reported that surface waters in and around the Sunniland oil field have been sampled to determine the effects that the oil field has had on water quality in the Big Cypress Swamp. Preliminary findings, based on analyses for chloride, organic carbons, and hydrocarbons, indicate that surface waters in the area around the oil field have not been adversely affected by oil-field operations. Organic carbons were determined by a Beckman Analyzer and hydrocarbons were determined by gas chromatography. Potential oil-exploration areas were sampled for background data prior to exploration and for comparison with data from the developed area.

Heavy pumping causes water-level declines in Tampa area

A 350-mi^2 area, incorporating parts of Hillsborough, Pinellas, and Pasco Counties, contains three well fields which supply the bourgeoning urban centers of St. Petersburg, Clearwater, and Tarpon Springs in Pinellas County. During 1972, pumpage from the Floridan aquifer was as much as 80 Mgal/d during dry periods. To keep pace with demands for fresh ground-water supplies for Pinellas County and the City of Tampa, two additional well fields, each with a potential capacity of 30 Mgal/d, are being developed.

Maps prepared by C. B. Hutchinson show 15 to 30 ft of drawdown in the potentiometric surface in the Floridan aquifer in the well fields. At one of the well fields, water level at the center of the cone of depression was below sea level, thereby presenting the threat of salt-water intrusion. The contours also show cones of depression developing in the water-table aquifer as a result of the increased head differential between the Floridan aquifer and the shallow water-table aquifer. Levels of lakes, which are hydraulically connected with the water-table aquifer, have declined more rapidly in the vicinity of the well fields than have the levels of lakes away from the pumped areas.

Streamflow conditions in Dade County during drought

Changes in hydrologic conditions in Dade County during 1971 were reported by J. E. Hull and E. T. Wimberly (1972). The combined average discharge from the five major canals that flow into Biscayne Bay was only 540 ft^3/s, about 30 percent of the previous year's average of 1,755 ft^3/s. Documentation of the effects of this extreme drought include (1) a map showing the extent of salt-water intrusion, (2) physical and chemical analyses of water samples from 9 stations, (3) results of nutrient surveys, (4) organic-carbon, pesticides, and PCB analyses of water samples from 14 stations, and (5) radiochemical analyses of water samples from 6 stations.

Effects of changes in land use in southern Dade County

K. E. Vanlier and J. T. Armbruster predict that, if present population and urbanization trends continue in southern Dade County, most of the readily developable land—land that is well drained or drainable—will be urbanized in the next few decades. Most of this land is used presently for agriculture; thus future urbanization will result in a decrease in the acreage available for crop production. If development in natural wetlands is restricted, future urbanization will sharply decrease the areas available for quarrying construction aggregates. Critical water-supply problems would result from a reduction in wetlands, and urbanization would aggravate the already serious problem of waste disposal.

Deep test well completed at Jacksonville

Investigations of a new source of soft water from the Floridan aquifer are nearing completion. G. W. Leve and R. W. Fairchild reported that a 1,200-ft-deep test well was completed and logged, and aquifer tests were conducted to provide the city of Jacksonville, Fla., with information on how to utilize this new source of supply.

Fresh water available for Charlotte County

Horace Sutcliffe, Jr., reported that future water-supply needs of the urban coastal area in Charlotte County can be met by developing shallow aquifers in the eastern part of the county, desalting moderately saline ground water underlying the county, importing ground water from counties to the north and east, and importing water from surface-water reservoirs developed outside the county.

Urban development at Naples may be controlled by water supply

H. J. McCoy (1972) reported that the maximum withdrawal capacity of the coastal aquifer at Naples in western Collier County would probably be reached by 1979. However, more recent data indicate that the continued rapid increase in population and the consequent increase in water demand will probably cause the maximum withdrawal capacity of the aquifer to be reached several years earlier than 1979. Thus, the rate and type of urban development of the coastal region near Naples will be largely determined by the rate of development of additional water supplies inland.

Salinity monitoring at Riviera Beach

L. F. Land installed a salinity monitoring well in the shallow aquifer at Riviera Beach, Fla., to locate the top of the salt-water wedge which extends inland from the coast at a depth of 270 ft, 900 ft inland from the shoreline. The nearest producing well in the Riviera Beach well field is over 4,000 ft from the coast and is 250 ft deep. Recharge to the well-field aquifer is principally from rain falling within a 3-mi^2 area centering around the well field. Because of immediate recharge in the well-field area and the location of the salt-water front, salt-water intrusion probably is not an immediate problem.

Relation of ground-water quality to surface-water quality in Osceola County

A water-quality survey by J. M. Frazee, Jr., of 146 surface-water sites in Osceola County may have provided data for a method using chloride content and conductance values to delineate areas where wells are flowing. Preliminary investigations indicate that surface-water chloride values greater than 30 mg/l define areas affected by local flowing wells tapping the Florida aquifer, particularly in the St. Johns River basin of eastern Osceola County. Partial checks of such areas have shown a large concentration of either uncontrolled flowing wells or irrigation-stock wells which have been in use for long periods. Delineation of quality of water boundaries in the Okeechobee inflow area (Kissimmee River basin) is underway for western Osceola County.

Southeastern Florida's last natural river threatened by salt-water encroachment

The middle reach of the Loxahatchee River is the last remaining river in southeastern Florida to retain its natural fresh-water environment. Land drainage by canals to make new land available for urban development and agriculture has diminished the flow of the river and transformed its lower reach into an estuary. The river channel in the upper reach has been so altered by filling and diversion that the river, as such, cannot now be recognized. Results of a study by H. G. Rodis indicated that the middle reach can be maintained in its natural state by supplying the reach with a minimum flow of 50 ft^3/s. This flow is possible by diverting fresh water from inland canals and water-storage areas to maintain the required flow during low-flow periods and (or) by preventing upstream movement of salty water from the estuarine reach by constructing a salinity barrier, dam, or lock near the downstream end of the middle reach.

Modifications to bypass canal will reduce ground-water drawdowns

Floodwaters of the Hillsborough River will be diverted at a point upstream from areas of flood-plain encroachment in the cities of Tampa and Temple Terrace into nearby McKay Bay by means of the Tampa Bypass Canal, which is being built through an area east of Tampa by the U.S. Army Corps of Engineers. L. H. Motz states that construction of the canal, as presently designed, will lower water levels in the Floridan aquifer 1 ft or more over an area of about 130 mi^2 and will increase the discharge from the aquifer about 8 to 15 Mgal/d. Adding an additional water-level-control structure to raise the pool level in part of the canal will reduce the area affected by drawdowns by 60 to 80 percent, and the ground-water discharge to the canal can be reduced about 60 percent.

Shallow aquifer provides supplemental water supply

Five shallow wells in the city of Sarasota's Verna well field yield 1 Mgal/d of water to the city to supplement water obtained from deeper limestone aquifers. Water from the shallow wells is of a better quality than that from the limestone aquifers. Horace Sutcliffe, Jr., reported that testing is continuing to determine whether the 30 to 40 ft of unconsolidated sand of the shallow water-table aquifer can be developed and whether, when developed, the aquifer can be used to store storm runoff from a nearby stream.

Hydrology of Oklawaha lakes area

Detailed depth contours on maps of eight of the nine major lakes (from 400 to 27,000 acres in area) in the upper Oklawaha basin, prepared by P. W. Bush and P. W. Potter, show that the lakes are relatively shallow (10 to 15 ft deep), generally with flat bottoms except near shorelines where slopes are steep. Lake Apopka, which consists of 31,000 acres and is the largest lake, has not been mapped. Stage-duration curves for nonregulated and regulated periods of record for the lakes are practically coincident, but flow-duration curves for the watercourses connecting the chain of lakes differ considerably between regulated and nonregulated periods. Regulation of lake levels by controlling flow through these channels apparently has had little effect on the percent of time the lakes remain at given levels. Discharge into the lakes of nutrient-rich water from muck farms (truck crops) bordering some of the lakes, particularly Lake Apopka, is the principal cause of the rapid decline of lake-water quality in recent years. Lake Carlton (400 acres) appears to be the most eutrophic of the lakes, probably because flushing, or exchange of water, in the lake is difficult. Lake Carlton has a single small inlet and therefore acts as a nutrient sump.

Conversion of coastal farmland to urban use has water-conservation potential

In order to protect large tracts of coastal farmland south of Miami, Fla., from flooding each year, control structures in drainage canals are adjusted to periodically discharge fresh water to the ocean for several weeks during the early part of the dry season. Howard Klein and J. T. Armbruster have noted that, because water levels approach or decline below sea level late in each dry season, the area is subject to sea-water intrusion. The fact that fresh water must be discharged during the dry season suggests that the coastal agriculture is not compatible with water conservation. Were the farming tracts converted to urban use, land elevations would be raised by filling to elevations above those of storm-tide flooding. Increased land elevations near the coast would permit reduction of discharge of fresh water and maintenance of higher coastal ground-water levels. The resulting overall rise in water levels would benefit interior wetlands and would alleviate the threat of sea-water intrusion.

Prospects for irrigation in De Soto County

W. E. Wilson III reported that hydrogeologic conditions at a citrus grove, 42 mi^2 in area, in northeastern De Soto County can be generally represented by a mathematical model for leaky artesian-aquifer systems. Results of aquifer tests and analyses of early well-field history suggest that ground-water withdrawals for irrigation will probably result in small drawdowns near the grove. Pumping rates may exceed 100 Mgal/d during spring irrigation periods, but during nonirrigating seasons the potentiometric surface will probably recover nearly fully from the effects of pumping. Thus long-term net declines due to pumping for irrigation will also be small.

Water in Biscayne aquifer suitable for public supply in Hallandale

Evaluation of test-drilling data by H. W. Bearden in the northwest part of Hallandale revealed that water in the 70 to 100 ft zone of the Biscayne aquifer was suitable for public supply in both quality and quantity. Just north of the Oleta River, in the southwest part of the city, sea-water contamination was detected at a depth of 160 ft in the Biscayne aquifer.

Quality of water backpumped to storage from Broward canal system

The Central and Southern Florida Flood Control District backpumps water from South New River Canal into Water Conservation Area 3 regularly in the wet season and intermittently in the dry season. H. J. Freiberger and C. B. Sherwood, Jr., reported that exceptionally low DO concentrations (sometimes as low as 0.2 mg/l for a 24-h period) in South New River Canal result from ground-water discharge to the canal after pumping. The effects of low DO were apparent in the canals of Water Conservation Area 3 as far as 3 mi from the pumping station, but effects were rarely seen in the marshes of the water-storage area. Concentrations of nutrients in both South New River Canal and Water Conservation Area 3 were generally low. Phosphorus concentrations were very low and no trends could be observed. Concentrations of ammonia increased in the conservation area after pumping, and nitrates decreased for short periods of time until mixing with water of better quality restored original conditions.

MISSISSIPPI

Areal extent of Gordo Formation studied

Recent test drilling near the proposed Tennessee-Tombigbee Waterway in northeastern Mississippi has shown that the Gordo Formation, an important aquifer in the upper part of the Tuscaloosa Group, is more extensive than previous maps indicated. In this area, the Gordo unconformably overlies rocks of Paleozoic age and is overlain by the McShan Formation. On a contour map, made by B. E. Wasson, showing the configuration of the top of the Paleozoic rocks, a large depression in west-central Tishomingo County is evident. The thickness of the Gordo is as great as 250 ft in the area of this depression, and fresh-water-bearing sand and gravel make up about 100 ft of the total thickness. Downdip to the west the Gordo pinches out, and within 10 mi it is generally absent or no more than 20 ft thick. This extensive area of outcrop of the Gordo Formation in Tishomingo County is separated from the main exposure of the formation to the south by an outcrop of Paleozoic rocks in the southwest corner of Tishomingo County.

NORTH CAROLINA

Water-resources investigation in northeastern North Carolina

K. L. Lindskov (1973), in a preliminary investigation of the water resources of northeastern North Carolina above Cape Lookout, estimates that about 16 Ggal/d of water is available for use in the 17-county area. Current utilization is only a small part of this resource.

The investigation shows about 5,500 Mgal/d is left from precipitation in the area after losses to evapotranspiration. In addition, the flow of major rivers entering from the west is about 11,000 Mgal/d. Present water use, including 55 Mgal/d withdrawn for dewatering mining operations, is only 90 Mgal/d. Utilization of this resource may be sharply limited, however, by water-quality problems, including brackishness, acidity, color, hardness, and iron content.

PUERTO RICO

Maunabo Valley alluvial-aquifer model

In Maunabo Valley in southeastern Puerto Rico, the principal aquifer consists of alluvium which occupies 3.5 mi^2 of the valley's 18.5 mi^2. A preliminary finite-difference digital model of the alluvial aquifer is being prepared by T. M. Robison. The first computer run will be a trial-and-error test to reconstruct the existing water table. By noting the amounts and locations of input (recharge) and output (discharge) required to maintain the water table, it can be determined whether or not the model is reasonable. If the model is satisfactory, various amounts and configurations of pumpage will be simulated to provide results that will serve as guides for exploration and development of the valley's ground-water resources.

SOUTH CAROLINA

Low-flow characteristics of South Carolina streams

W. M. Bloxham studied 70 ungaged streams in South Carolina's inner Coastal Plain and determined several low-flow characteristics of each, including the average 7-day minimum flows of the 10-yr recurrence interval. Values range from less than 0.1 to more than 0.7 $ft^3s^{-1}m^{-2}$; the average yield is approximately 0.25 $ft^3s^{-1}m^{-2}$. Streams near the center of the inner Coastal Plain generally afford better sustained low flows. The 7-d, 10-yr low flows plotted on a map indicate a broad areal conformance with geologic and physiographic features; however, the map shows several watersheds of disproportionately high or low dry-weather output. Probably the anomalies are attributable to the degree of stream-valley incisement rather than to the specific inconsistencies of the geologic regimen.

Hydrologic environment of the Santee Rediversion Canal

C. A. Spiers reported that a project to study the effect on the hydrologic environment of the Santee Rediversion Canal, during and after canal construction, was started in July 1972. Twenty observation wells and four gaging stations will make up the data-collection points for studying the hydrology. Existing core holes with geophysical logs will be used to determine the geology of the study area.

Sixteen new core holes drilled parallel to the Santee River and about 2 mi south of St. Stephens resulted in the discovery of an old river channel which runs nearly parallel to the present Santee River channel and which is buried under silts and fine sands. It is composed of gray-brown sands with wood fragments and some gravels. The significance of this old streambed is that it may be a point of discharge for the two aquifers being studied. The channel intersects both the shallow sands and the limestone and may provide a conduit for aquifer discharge to the river.

Test drilling near Charleston

A deep test hole, drilled adjacent to the Atlantic seaboard about 20 mi southeast of Charleston, S.C., provided for testing most water-bearing zones in the area. P. W. Johnson reported that firmly consolidated rock was encountered at a depth of 2,696 ft. A core revealed this rock to be a well-indurated, fine-grained quartz sandstone with some black minerals; its depth is 300 to 600 ft shallower than was previously estimated for such rock from surface geophysical surveys.

The well was drilled for the purpose of penetrating the full thickness of the Tuscaloosa Formation, the major regional aquifer, which was estimated to be about 600 ft. However, the Tuscaloosa Formation was only 150 to 200 ft thick and consisted mostly of the typical varicolored clays with none of the coarse-sand layers that are present elsewhere in the formation. A good water-producing zone was found between 2,040 and 2,260 ft in the lower Black Creek Formation of Late Cretaceous age. Water under an artesian head of 120 ft flowed at the surface. After development, the well flowed 600 gal/min and was pumped at about 1,600 gal/min. The quality of the water was good with the exception of a high fluoride content and a temperature of 98°F. The chloride content was less than 100 mg/l.

TENNESSEE

Bentonite a barrier to ground-water movement

In the Normandy, Tenn., area of the Duck River basin, C. R. Burchett identified a 4.5-ft-thick bentonite layer in the Ordovician limestone. In 12 test holes, ground water was above the thick layer of bentonite. Burchett concluded that the bentonite acts as a barrier to the downward movement of ground water and that, in this area, water wells should not be drilled below the bentonite layer.

CENTRAL REGION

The water-resource studies of the USGS in the central region, broadly generalized, are of three types. One is the continuing, systematic collection of data on streamflow, on ground-water levels, and on the quality of surface and ground water. Another is the application of these and other related data to the specific water-resource planning, development, and management problems of an area such as a city, a county, or a river basin. The third type of study is the collective research effort needed to support and improve data collection and the application of these data to water-resource problems.

The USGS has undertaken and essentially completed an appraisal of the ground-water resources of three Water Resources Council Regions—the Upper Colorado River, the Western Missouri (a subregion), and the Rio Grande basins.

Many research studies in the central region emphasized methods of predicting flows of water and quantities of solutes and sediment. In addition, studies were made of basic chemical transformations, artificial-recharge problems, and methods of measurement. These research investigations primarily have a common goal of improving or advancing the facts needed for more effectively predicting the consequences of water extraction and use.

Ground-water development in the upper Colorado River basin

A tremendous volume of ground water is stored in ground-water reservoirs of the upper Colorado River basin. Ted Arnow and Donald Price estimated the volume of recoverable storage in the upper 100 ft of saturated rocks to be as much as 115 million acre-ft. This is almost four times the total active storage of all surface-water reservoirs in the region. Yet, at the 1970 level of development, total annual ground-water withdrawal for various uses was estimated to be less than 2 percent of total water use in the upper Colorado River basin. The ground-water reservoirs receive an estimated 3.8 million acre-ft of recharge a year.

Much of the ground water is saline and natural discharge of the water to streams is contributing to the salinity of the Colorado River. It is concluded, therefore, that the increased use of ground water (with demineralization if necessary) would not only lead to optimal use of the total water resources of the region but would help to reduce the salinity of the Colorado River.

ARKANSAS

Digital model of the hot springs at Hot Springs National Park

A digital model of heat flow and ground-water flow near the hot springs of Hot Springs National Park was used to determine the distribution of recharge, permeability, porosity, and heat flux that will simulate the observed discharge and temperature of the springs. According to J. E. Reed, model results indicate that, for the ground-water circulation indicated by present knowledge of the hydrologic system, vertical heat flow through the rocks is greater than the normal flow of 1.5 heat-flow units (1×10^{-6}cal cm^{-2} s^{-1}).

COLORADO

Undeveloped ground water in upper Arkansas River basin

According to P. A. Emery, about 20 million acre-ft of ground water is stored in extensive valley-fill aquifers located between Salida and Buena Vista and in the Wet Mountain Valley. Geophysical data indicate these aquifers are as much as 6,700 ft thick in some parts of the upper Arkansas River basin. The dissolved-solids concentration of the water is generally less than 520 mg/l.

Ground water also occurs in the Dakota-Purgatoire aquifer of Cretaceous age that underlies the eastern part of the study area. The dissolved-solids concentration averages about 2,400 mg/l.

Minor ground-water supplies can also be obtained from pre-Cretaceous aquifers and from volcanic and crystalline rocks.

Hydrology of oil-shale terrane in Piceance basin

A study of the Piceance basin in northwestern Colorado is being made to determine the availability of water to supply an oil-shale industry and the effects of such an industry on the hydrology of the area. Data from more than 50 wells are being used in the development of a digital model of a three-layered aquifer system. The system basically consists of two aquifers of relatively high permeability that are separated by the oil shale. Measured transmissivities range up to 1,000 ft^2/d in the upper aquifer, and are as high as 2,000 ft^2/d in the lower aquifer. Values of specific conductance in the upper aquifer generally are less than 3,000 μmhos per cm and in the lower aquifer may exceed 20,000 μmhos per cm. Fluoride concentrations as high as 74 mg/l occur in water in the lower aquifer.

Preliminary studies by J. F. Ficke, J. B. Weeks, and F. A. Welder indicate that most waters leaving the basin exit as discharge of Piceance and Yellow

Creeks. Water discharge and quality of Piceance Creek are affected by irrigation practices. Diversion of water for irrigation substantially decreases streamflow during late summer, and the quality of water is degraded by increased total dissolved solids in return flow to the stream.

Computer model predicts water-level declines by the year 2000

The hydrologic system in part of the northern High Plains of Colorado was modeled by W. E. Hofstra and R. R. Luckey using a finite-difference technique. The model was verified by comparing observed and computed changes in water levels that occurred during 1964–70. The verified model was used to predict declines in the water table by the year 2000, based on the 1973 rate of ground-water withdrawal. The predictions indicated declines in excess of 80 ft in Kit Carson County and 90 ft in Yuma County.

Water-management analyses of lower Arkansas River valley

O. J. Taylor and R. R. Luckey (1972) used a mathematical model to analyze 24 comprehensive water-management plans for the irrigated lower Arkansas River valley in Colorado. The model simulates the interrelations among ground water, streamflow, surface reservoirs, losses, water importation, and various existing water-distribution rules as defined by Colorado water laws. The analyses indicated that an integrated water-management plan is more beneficial than a plan employing any single approach. For example, one plan simulated the combined benefits of salvage of water from phreatophyte evapotranspiration, modified reservoir-operation regulations; additional use of ground water in the area, use of imported ground and surface water, a new reservoir, and recharge of excess streamflow to the aquifer. The resulting dependable supply would thereby be increased from a normal 610,000 acre-ft per yr to 870,000 acre-ft per yr. The resulting 43-percent increase in the dependable supply should produce a substantial increase in the present annual revenue of $25 million from irrigated crops. The estimated water requirement for the area is 1,100,000 acre-ft per yr.

Aquifer units of the Green River Formation in the Piceance Creek basin

J. E. Weir, Jr., reported that four discrete aquifer units can be differentiated in the Green River Formation of the Piceance Creek structural basin in northwestern Colorado: (1) the near-basal part of the Evacuation Creek Member, (2) a part of the upper Parachute Creek Member including the upper part of the Mahogany ledge zone, (3) a part of the Parachute Creek Member immediately beneath the Mahogany ledge zone, extending up into the ledge zone in some places, and (4) the sandy facies near the base of the formation, usually all or part of the Douglas Creek Member. These are differentiated on the basis of hydraulic head, quality of the water, and permeability range.

Evaluation of two drill-stem tests of 500-ft sections of drill hole below the Mahogany ledge zone showed a very low permeability for the lowermost zone and a moderately high permeability for the uppermost zone. Hydraulic head was greatest in the lowermost zone by slightly more than 40 ft.

KANSAS

New ground-water supply discovered

J. R. Ward and H. G. O'Connor (Kansas Geol. Survey) have located a new ground-water supply near Kansas City, Kans. Glacial deposits of Pleistocene age and underlying sandstone of Pennsylvanian age together will yield 5 to 50 gal/min to wells in an area of about 75 mi^2 in Leavenworth and Wyandotte Counties, Kans. Surrounding areas are underlain by limestone and shale that yield very little water to wells.

LOUISIANA

Soft water discovered in the Chicot aquifer, southwestern Louisiana

Preliminary results of test drilling confirm the existence of an anomalous zone of fresh soft water in the Chicot aquifer in southwestern Louisiana, according to R. L. Hosman. The Chicot aquifer is a vast reservoir of Pleistocene age that extends across all of southwestern Louisiana westward from the Atchafalaya River. Water in the Chicot aquifer is generally characterized as hard where it is fresh, grading to salty downward and downdip toward the gulf. The anomalous soft water is in a basal sand that is separated from the main body of the Chicot aquifer by a clay of limited areal extent and highly variable thickness.

The zone containing the soft water is in an irregularly shaped area that trends generally southward in the vicinity of Bayou Teche in St. Martin

Parish. The area appears to be at least 20 mi long and varies greatly in width. Depth to the top of the basal sand ranges from about 600 ft to slightly more than 800 ft. Thickness of the aquifer that contains soft water is variable, from a few feet to about 200 ft, as it is both flanked by and underlain by salty water. There are indications that the soft water moved upward into the basal Chicot sand from an upper sand of the underlying Evangeline aquifer system. The two sands appear to be in hydraulic connection in a small area immediately south of St. Martinville. Additional test drilling should provide data that will enable more accurate definition of the zone containing soft water.

Central Louisiana terrace aquifers

New information on the availability of water from terrace deposits in central Louisiana has benefited many small municipal and rural water districts. The terrace deposits, which generally are less than 100 ft thick, were mapped with the aid of data obtained in a test-augering program, according to T. H. Sanford.

A new source of water was discovered in the terrace deposits in La Salle Parish northeast of Jena. The terrace deposits in this area were previously believed to be too thin to furnish adequate water for the town. However, they were found to consist of about 40 ft of saturated sand and gravel capable of yielding an estimated 100 to 200 gal/min to individual wells at this location.

In western Grant Parish the terrace deposits are thin and discontinuous. However, data obtained verified the occurrence at a depth of about 100 ft of a coarse Miocene sand that can be used for rural water-district supply in this area.

Water quality in the Mississippi River alluvial aquifer

Mapping of the Mississippi River alluvial aquifer in northeastern Louisiana has disclosed several salt-water occurrences, according to M. S. Whitfield. This aquifer, which consists of fine to coarse sand and gravel, ranges in thickness from 80 to 200 ft. In most of the study area, the aquifer contains fresh water. However, salt water occurs within the aquifer at 11 known localities. Most of these occurrences are attributed to leakage from former salt-water disposal pits or wells and to oil-well drilling mishaps. Underflow from the underlying Cockfield Formation at the contact with the confining clay of the Jackson Formation may account for some of the salt-water occurrences. During the past 9 yr a decrease in chloride concentration of 5 to 50 percent has occurred in water from some wells screened in these salt-water bodies.

Effects of navigation structures on the Red River

A. H. Ludwig reported that a preliminary investigation of the effects of proposed navigation structures on the Red River downstream from Shreveport, La., as far south as Avoyelles Parish, La., indicates that water in the Red River Valley will be raised to a level at or near the land surface in places in the vicinity of the proposed locks and dams, and the effects of the increased river stage will be measurable to a distance of at least 5 mi from the river. Principally involved will be nine parishes in Louisiana and two counties (Marion and Harrison) in Texas. Of the parameters used in the analysis, the rate of change of evapotranspiration with respect to depth to water ($\Delta ET/\Delta H$) was most critical. Using values of $\Delta ET/\Delta H$ ranging from 6×10^{-6} to 1×10^{-4} produced a variation of from 4 to 6 ft in projected water levels.

MISSOURI

Flood-volume design data for Missouri streams

By regression analysis, regional flood-volume equations applicable to ungaged sites with drainage basins as small as 0.2 mi² have been defined for the plains and Ozarks regions of Missouri, according to John Skelton. Four basin characteristics (drainage area, mean basin elevation, mean runoff, and soils infiltration index) were statistically significant in defining flood volumes.

The major problem for the designer in generalizing flood volumes in the Ozarks is economics. Gross overdesign of structures is possible in those basins where significant amounts of storm runoff are diverted to natural underground flood-detention reservoirs and gradually released in the springs and seeps of the region.

Missouri stream characteristics

John Skelton reported that preliminary investigation of the relationship between basin drainage areas and the 7-day Q_{20} (7-day low flow with recurrence interval of 20 yr) in the plains and southeastern lowlands regions of Missouri has led to the following general conclusions:

1. In the plains, the 7-day Q_{20} is zero for practically

all basins with drainage areas less than 250 mi^2. Eighty-five percent of the basins with drainage area of 250 to 1,000 mi^2 have 7-day Q_{20} of zero, and the remainder have 7-day Q_{20} of 0.1 to 1.0 ft^3/s. A small percentage of basins with drainage areas greater than 1,000 mi^2 have 7-day Q_{20} of zero, but most of the values are 0.5 ft^3/s or greater.

2. In the southeastern lowlands, basins with drainage areas less than 100 mi^2 have 7-day Q_{20} of zero to 0.5 ft^3/s. For drainage basins greater than 100 mi^2, these values are generally greater than 1.0 ft^3/s.

MONTANA

Ground water in the Libby area

Results of a ground-water investigation near Libby, Mont., by A. J. Boettcher indicate that much of the recharge, which causes high water levels in June and July, is from snowmelt in the adjacent mountains. Streams from the mountains lose much of their flow upon entering the valley. The alluvium and other valley-fill deposits transmit the water to lower reaches of Libby Creek and to the Kootenai River where the ground water is discharged.

The concentration of nitrate in water from wells tapping the alluvium ranges from 27 mg/l in heavily populated areas to less than 1 mg/l in sparsely populated areas. Effluent from septic tanks mixes with the ground water, especially during June and July when the water table in the alluvium is near land surface. Although the concentration of nitrate in ground water is below generally accepted standards, the levels are high enough to warrant additional sampling to define variations with time and to define increases in concentrations as new septic tanks are added.

Potential ground-water source in Glacier National Park

Test drilling in Glacier National Park by A. J. Boettcher and R. D. Feltis revealed an unusually well sorted lakeshore deposit adjacent to Lake McDonald. The deposit, more than 40 ft thick, is composed of round, flat (disk-shaped) black limestone pebbles with a maximum diameter of about 3 in. The limestone was derived from rocks of the Belt Supergroup by glaciation. Fluctuations of lake level, wave action, and sorting by lake currents have caused the unusual deposit.

The hydraulic conductivity of the deposit is at least 1,500 ft/d, and the deposit is hydraulically connected to the lake. Properly constructed wells tapping the deposit will produce at least 1,000 gal/min.

Ground-water reservoir management

The undeveloped artesian limestone aquifer of the Madison Group of Mississippian age in Judith Basin, Mont., provides a rare opportunity for water users to manage and monitor a ground-water reservoir from its initial development to its optimum utilization, according to R. D. Feltis. Recent interest in large-scale irrigation systems has focused attention on the aquifer; however, excessive drilling depths and cost and lack of knowledge of hydrologic characteristics of the aquifer have deterred development. Management of the ground-water reservoir could include measures to increase recharge as well as control withdrawal of water. Results of seepage runs of streams crossing the cavernous limestone show losses ranging from 16 to 164 ft^3/s. Infiltration could be increased by removal of obstructions or enlargement of solution openings in the limestone, by development of a system of recharge wells, and by diversion of surface water into the aquifer. A large quantity of the water that leaves the basin during spring runoff thus could be diverted to the ground-water reservoir to be withdrawn later in the year.

Ground water in coal-bearing Fort Union Formation

Wells and springs that obtain water from the coal-bearing Fort Union Formation are essential to ranch operations in south-central Montana. None of the springs and few of the wells that have been inventoried yield more than 10 gal/min, according to W. B. Hopkins. Accumulated data will serve as a benchmark against which changes in water level, quality, or yield can be evaluated.

NEBRASKA

Irrigation-seepage losses cause water table to rise

C. F. Keech (1972) reported that seepage losses have caused the water table beneath irrigated uplands in Sherman and Howard Counties in central Nebraska to rise as much as 45 ft since the mid-1960's when water from Sherman Reservoir first was applied to the land for irrigation. The largest area affected is about 70 mi^2 in west-central Howard County, west of the city of St. Paul, Nebr. It may be expected that eventually some local areas will become waterlogged.

Hydrogeology of Banner County, western Nebraska

According to F. A. Smith (Nebraska Univ., Conserv. and Survey Div.), test drilling in the western two-thirds of Banner County revealed that groundwater supplies may be adequate for irrigation in much of the southwestern part of the county. Eighteen test holes, ranging in depth from 120 ft to 665 ft and averaging about 300 ft, were drilled along three north-south lines across the county. Saturated silt, siltstone, and sandstone of Miocene and Pliocene age that ranged in thickness from less than 1 ft to more than 200 ft were found. In localities where the saturated deposits are thickest, large-capacity wells may be obtained. In a large part of the county, however, the saturated sediments are not capable of yielding enough water for irrigation purposes. Depth to the water table under the uplands is about 200 ft below land surface.

NEW MEXICO

Roswell basin valley-fill and base-flow studies

Valley-fill sediments in the Roswell basin have maximum thicknesses of about 300 ft in large depressions near Roswell, Hagerman, and Artesia, according to F. P. Lyford and G. E. Welder. The depressions result from the solution of underlying Permian carbonates and evaporites. Maximum saturated thicknesses of the valley fill are about 250 ft in the depressions near Hagerman and Artesia and about 300 ft near Roswell.

The base flow in the Acme-Artesia reach of the Pecos River, which is sustained in part by ground water from the Roswell basin, was determined for the period 1957–71. Base flow in the reach declined erratically from 1957 to about 1963, but was fairly stable from 1964 through 1971. The annual base flow has ranged from a high of 36,640 acre-ft in 1958 to a low of 15,250 acre-ft in 1964.

NORTH DAKOTA

Quality of water in the Fox Hills Sandstone and glacial-drift aquifers in Emmons County

C. A. Armstrong reported that the quality of the water in aquifers in the Fox Hills Sandstone and glacial drift is closely related to the lithology and thickness of near-surface materials. Wells in areas where sand or sandstone crop out in east-central Emmons County generally yield water that contains less than 500 mg/l dissolved solids. Wells in areas that are covered with silty clay beds or thin patches of clayey till generally yield water containing from 500 to 1,500 mg/l dissolved solids. Wells in areas that are covered with about 50 ft or more of clay till yield water with 1,500 mg/l to nearly 4,000 mg/l dissolved solids. The higher concentrations of dissolved solids generally are in areas where a large percentage of the material in the clay till was derived from the Pierre Shale.

Fox Hills and lower Hell Creek aquifers

Ground-water investigations in Adams and Bowman Counties by M. G. Croft indicate that five major aquifers occur within the Cretaceous and Tertiary rocks. The aquifers are fine grained and have low transmissivities. The most important aquifer is in sand beds of the Fox Hills Sandstone and the lower part of the Hell Creek Formation. The water from this aquifer is clear and has a specific conductance of 1,600 to 2,000 μmhos. The overlying aquifers contain lignite that colors much of the water. Water from these aquifers is also high in sulfate and generally has a higher specific conductance than does water from the Fox Hills and lower Hell Creek aquifers.

High yields from Fox Hills Sandstone in Dunn County

R. L. Klausing reported that some wells tapping the Fox Hills Sandstone in the northwestern part of Dunn County will yield more than 600 gal/min. One well, which penetrated 92 ft of medium to coarse sand in the Fox Hills section, had an estimated flow of 600 to 700 gal/min through an open drill hole. Pressure measurements made on the well after the casing was set indicated that the head was 191 ft above a land-surface datum of 1,940 ft.

Buried glacial-valley aquifers in Morton County

A study of the geology and well data by P. G. Randich has revealed the presence of two large buried valleys in Morton County. Both of these valleys are west of and generally parallel to the present Missouri River valley. They are probably the result of the earliest glacial advances in North Dakota.

One of the buried valleys, located in western Morton County, trends southeastward from Hebron and Glen Ullin toward Almont and Flasher. It is deeper than the present Heart River valley and was formed by an ice-marginal stream similar to the present Missouri River. The second buried valley, located in southeastern Morton County, extends from St. Anthony southeastward toward the confluence of the Cannonball and Missouri Rivers. Preliminary data indicate these valleys contain some of the largest and potentially most productive aquifers in Morton County.

Geohydrology of Cretaceous and Tertiary formations in Grant and Sioux Counties

A study by P. G. Randich of subsurface data indicates considerable variations in geohydrologic conditions of the Tertiary and Upper Cretaceous formations in Grant and Sioux Counties. The formations dip northwest at a rate of about 10 ft/mi, except in northwestern Grand County, where the dip increases to about 14 ft/mi. Aquifers in the Hell Creek Formation and Fox Hills Sandstone of Late Cretaceous age consist of very fine to medium-grained sandstone, which ranges in thickness from 10 to more than 100 ft. Potentiometric contours show an eastward movement of ground water through these aquifers toward discharge areas in outcrops near the Missouri River and its tributaries. Aquifers in the Tertiary formations (Tongue River and Cannonball) consist of very fine to medium-grained sandstones with limonitic concretions. In some places the sandstone beds grade into siltstone and silty shale. Ground-water movement in these aquifers is controlled primarily by topography and has a strong downward component. Aquifers in the Tertiary formations appear to contribute considerable recharge to the underlying Cretaceous aquifers.

OKLAHOMA

Availability and chemical quality of ground water in north-central Oklahoma

A reconnaissance study by R. H. Bingham of the water resources of the Enid quadrangle shows that several geologic units have considerable potential for development of adequate quantities of ground water for irrigation, municipal, and industrial needs.

Wells in alluvium and terrace deposits along major streams commonly yield 100 to 400 gal/min, and locally where the basal gravel is 25 to 30 ft thick, yields of 1,000 gal/min may be obtained. Water in the terrace deposits generally contains less than 500 mg/l dissolved solids. Quality of water in the alluvium is highly variable; dissolved-solids content ranges from about 400 mg/l to 6,000 mg/l. However, dissolved solids of 500 to 1,000 mg/l are more common.

The Vamoosa Formation of Pennsylvanian age has considerable potential for development of ground-water supplies in northern Creek County. Wells in the Vamoosa Formation yield 75 to 150 gal/min in areas where wells penetrate the entire thickness of the formation. Yields of 200 gal/min may be obtained locally from the Vanoss, Ada, and Vamoosa Formations combined. Water from the Vamoosa Formation generally contains less than 500 mg/l dissolved solids. The water is hard and locally is the sodium bicarbonate type.

Appraisal of ground water in west-central Oklahoma

A reconnaissance study by J. E. Carr and D. L. Bergman of the water resources of the Clinton quadrangle shows that several geologic units have considerable potential for development of ground-water supplies. Well yields of 25 gal/min or more are possible from about one-half of the quadrangle. In Caddo, Blaine, and Custer Counties, the Rush Springs Sandstone yields as much as 1,000 gal/min to wells, and yields from 300 to 600 gal/min are common. The Ogallala Formation yields as much as 300 gal/min in northern Roger Mills County; however, yields in other areas generally range from 25 to 50 gal/min. Well yields from alluvium and terrace deposits in Roger Mills and Custer Counties are as much as 1,400 gal/min; in other areas these deposits generally yield from 100 to 600 gal/min. Sandstone of the Elk City Member of the Quartermaster Formation in Washita County yields as much as 300 gal/min, and yields from 60 to 200 gal/min are common. The Blaine Formation in southern Beckham County yields as much as 600 gal/min locally from solution channels.

Streams in the area have limited base flow, and most go dry each year. During base-flow periods, excessive sulfates and dissolved solids limit the use of the water for many purposes; in a few streams chloride concentrations are excessive. For some areas, reservoir storage has been developed to furnish a dependable year-round surface-water supply.

Water-level declines in the Oklahoma Panhandle

D. L. Hart, Jr., and G. L. Hoffman reported that water levels in the Ogallala Formation have continued to decline at a rate of 1 to 8 ft/yr in heavily pumped areas in the Oklahoma Panhandle. In a few areas, water levels declined as much as 5 to 20 ft during the 1972 agricultural season. Declines have been large enough in some areas to affect adversely well discharge. Many of the approximately 1,900 irrigation wells in the Oklahoma Panhandle are clustered in several relatively small areas. The greatest concentrations of wells are in the vicinity of Guymon and Goodwell in Texas County and near Boise City and Felt in Cimarron County.

Recent development has been quite rapid in northwestern Texas County, an area that has shown substantial water-level declines. Water levels outside the heavily pumped areas have shown little change in the past few years.

Irrigation water for Kickapoo Indian Lands

Test-drilling data obtained by M. V. Marcher and G. L. Hoffman indicate that alluvium underlying lands of the Kickapoo Indian Tribe near Jones, Okla., has an average thickness of 46 ft and consists of fine to medium sand grading downward to very coarse sand. Based on an average saturated thickness of 24 ft and a specific yield of 15 percent, approximately 2,300 acre-ft of ground water per mi^2 is available from storage. An additional 300 to 500 acre-ft per mi^2 is available from annual recharge. Approximate allowable well yields at different sites in the study area range from 100 to 400 gal/min.

In most of the area, water from the alluvium is of good quality, has a low sodium hazard, is borderline between medium- and high-salinity hazard, and is excellent in boron concentration. Water in the southwestern part of the study area is too highly mineralized for irrigation or domestic use, possibly due to improper disposal of oil-field brine.

Bedrock of the Garber Sandstone and Wellington Formation, underlying the alluvium, probably will yield up to 250 gal/min to wells. Water from upper zones of the bedrock is chemically suitable for irrigation except in the southwestern part of the area. The quality of water in deeper zones in bedrock is unknown; however, the depth to the top of saline water ranges from 400 to 500 ft below the surface.

SOUTH DAKOTA

Pahasapa Limestone is potential source of large ground-water supplies in west-central South Dakota

Information obtained from an inventory of wells tapping pre-Cretaceous formations in west-central South Dakota indicates that the Pahasapa Limestone of Mississippian age is a potential source of large ground-water supplies. The 7,500 mi^2 area, under study by D. G. Adolphson, is bounded by the Missouri River, the White River, the Moreau River, and the Black Hills.

Wells tapping the aquifer are from 2,700 to 4,500 ft deep. Flowing wells that yield 25 to 1,500 gal/min can be obtained in parts of the area; pumped wells yield from 50 to 1,000 gal/min. Total dissolved solids range from 1,000 to 2,000 mg/l, and temperatures range from 54°C to 67°C.

Water-supply site studies for the National Park Service

Investigations of water-supply sites in Wind Cave National Park and in the Rockyford area of Badlands National Monument were made by D. G. Adolphson.

In the eastern part of Wind Cave National Park the Pahasapa Limestone is an excellent aquifer and will yield an adequate supply of ground water for large demands. The many springs and seeps in the valleys and ravines are not considered to be large potential additional sources of water supply. A few of the springs flow throughout the year and provide quantities of water sufficient for development to supply picnic areas and campgrounds.

Investigation of the proposed Rockyford addition to the Badlands National Monument indicated that the alluvial deposits in the White River valley are the best sources of ground water. Large variations in the character and the saturated thickness of the alluvial deposits occur locally. The chemical quality of water from the alluvial deposits is generally poor, except where the aquifer is in direct hydraulic contact with the White River; there, the quality of the water generally is similar to that in the stream. The deep artesian aquifers yield water of poorer quality than do the alluvial aquifers.

Buried outwash aquifer in north-central South Dakota

The little-used James-Grand aquifer, 50 to 100 ft of outwash sand and gravel in north-central South Dakota, has been penetrated by 50 test holes along a 90-mi channel that is buried beneath as much as several hundred feet of clay till, according to L. J. Hamilton. The aquifer enters the southwestern part of McPherson County from the west and then trends southeastward through Edmunds and McPherson Counties. A 24-h pumping test of the aquifer near Faulkton, where it is 50 ft thick, indicated a transmissivity of 13,000 $ft^3d^{-1}ft^{-1}$ and a storage coefficient of 1×10^{-4}. The water generally is a sodium bicarbonate type with a conductivity of about 2,500 μmhos per cm.

Deep James aquifer

The Deep James aquifer is an interconnected system of channel deposits extending from southwestern Brown County in a northerly and northeasterly direction across the county. The aquifer underlies about 250 mi^2 in Brown County and extends into North Dakota and into Marshall and Spink Counties, S. Dak. Test drilling by N. C. Koch and W. L. Bradford indicates that the aquifer ranges in depth from 150 to 380 ft below land surface. The channel sands and gravels are composed mainly of outwash and alluvium of preglacial and glacial deposition. Water in the aquifer occurs under artesian conditions, and water levels range from 5 to 32 ft below land surface.

Extensive aquifers in the alluvium and outwash deposits in northeastern South Dakota

Jack Kume reported that well inventory and preliminary test drilling in Deuel and Hamlin Counties in northeastern South Dakota have revealed several extensive aquifers. The largest aquifer occurs in an alluvium-and-outwash deposit underlying the Big Sioux River valley. These deposits attain a considerable thickness in several areas with the maximum of 96 ft found 2.5 mi west of Dempster. The thickness of the deposits generally ranges from about 25 to 50 ft and the depth to water is commonly about 9 ft.

Other extensive aquifers occur in buried outwash deposits that are generally overlain by till. These deposits of sand and gravel occur at various depths and are as much as 600 ft deep in the areas 1.5 mi south of Gary and 6 mi east of Castlewood. The sand and gravel layers range from about 15 to 60 ft in thickness.

UTAH

Ground-water flow system in Curlew Valley

Ground water for irrigation in Curlew Valley is pumped from three major aquifer systems. Most of the recharge enters the system in Idaho, and about 48,000 acre-ft of water per year enters Utah in the subsurface.

According to C. H. Baker, Jr., water levels in the Kelton aquifer system, on the west side of the valley, have declined nearly 25 ft since pumping began in 1953. The concentration of dissolved solids in water pumped from this system, initially less than 1,500 mg/l, has more than doubled since 1953.

Water levels have declined 10 to 15 ft in the Juniper–Black Pine aquifer system, in the central part of the valley, since pumping began there in 1955. The concentration of dissolved solids in water from a small area in the eastern part of this system has increased slightly since 1955, but water quality in other parts of the system has not changed.

Locomotive Springs, near Great Salt Lake at the eastern side of Curlew Valley, discharge from the Holbrook-Snowville aquifer system. No effect of withdrawals on the flow of these springs has yet been detected. However, increased withdrawals up valley will ultimately reduce the discharge of these springs.

Water-budget analysis in Box Elder County

L. J. Bjorklund and L. J. McGreevy reported that tentative results of a water-budget analysis of about two-thirds of the lower Bear River drainage basin in Box Elder County, north-central Utah, indicate that during the period 1960–71 about 1,667,000 acre-ft of water annually entered the area—surface-water inflow (1,171,000 acre-ft), precipitation (457,000 acre-ft), and ground-water inflow (39,000 acre-ft). A similar amount left the area—streamflow (1,160,000 acre-ft), evapotranspiration (504,000 acre-ft), and ground-water outflow (3,000 acre-ft). Ground water in the 492 mi^2 budget area is generally fresh at the upstream end and slightly to moderately saline at the downstream end.

Pumping in Milford area affects quality of water

The water needs of the Milford area are supplied by the Beaver River and by wells constructed in the unconsolidated materials underlying the valley. According to R. W. Mower and R. M. Cordova, the 1914–71 average annual inflow of the river was 27,600 acre-ft. Pumpage from wells for irrigation increased from 60 acre-ft in 1918 to 56,000 acre-ft (more than 98 percent of total well discharge) in 1971, resulting in significantly lower water levels, land subsidence, and large-scale polygonal fracturing of a surficial clay zone. Average annual recharge was estimated at 58,000 acre-ft and average annual discharge at 81,000 acre-ft for the 2-yr period 1970–71. The average dissolved-solids concentration is 880 mg/l for well water and 700 mg/l for spring water. The dissolved-solids concentration of ground water in the unconsolidated materials decreases slightly with depth, but has increased by approximately 50 percent between 1950 and 1972, apparently as a result of the increased pumpage.

WESTERN REGION

Among the activities in the USGS water-resource program in the western region, several were particularly noteworthy.

In Idaho, in cooperation with the Corps of Engineers, a program was initiated for sediment sampling on the Clear Water and Snake Rivers in the Lewiston area. The project included the design and construction of a new bedload sampler which has an opening twice that of previous models, allowing for a considerable increase in the range of material collected.

In cooperation with the Washington State Department of Ecology, the USGS increased its efforts in the study of the lakes of Washington. At the present time, data are available for only a small percentage of the State's 7,800 lakes. A general reconnaissance study, including aerial photography, bathymetric maps, and water-quality sampling, has been undertaken on many of the lakes. A broad classification will be made of the lakes according to degree of eutrophication.

The U.S. District Court for the District of Columbia has issued an order for the Secretary of Interior to formulate operating criteria that will provide maximum inflow to Pyramid Lake, in Nevada, consistent with all existing court decrees, orders, and valid water rights. The Truckee-Carson Operating Criteria and Procedures Committee of which the USGS is a member has formulated operating criteria which it believes complies with the court order. This program is being initiated and will require considerable effort on the parts of the Bureau of Reclamation and the USGS to analyze outflow records for detection of waste attributable to uncoordinated water deliveries and usage.

The program of investigation of geothermal resources remained in high gear throughout the year. Studies of parts of Idaho, Nevada, and California were emphasized.

The USGS scientists involved in the ongoing program of the San Francisco Bay region environment and resources-planning study continued to collect, analyze, and publish data on surface and ground water and on water quality.

ALASKA

Surface-water investigations at Barrow

A study was made by S. H. Jones (1972) and J. P. Hale, Jr., of the availability of surface water and the temporal and areal distribution of runoff for a water supply at Barrow. Hydrologic data collected from two small basins in the Arctic Coastal Plain show that 90 percent of the total annual runoff occurs during the month of June from snowmelt. The surface water was found to be of good quality with dissolved-solids concentrations ranging from 38 to 97 mg/l.

Hydrologic reconnaissance of springs in the Brooks Range

Discharge, temperature, and specific conductance of eight selected springs were measured during a hydrologic reconnaissance of the eastern Brooks Range, and water samples were collected for chemical analysis. According to J. M. Childers, C. E. Sloan, and J. P. Meckel, water from the springs is of the calcium bicarbonate type and has a low dissolved-solids content. Discharge, at the time of measurement, ranged from about 4 to 36 ft^3/s and temperature ranged from about 3°C to 9°C. All but one of the springs discharge from limestone bedrock or associated colluvial and alluvial deposits. Results indicate significant ground-water movement in an Arctic area previously considered to be underlain by continuous permafrost.

ARIZONA

Availability of ground water in the Navajo and Hopi Indian Reservations

Preliminary guidelines have been established by E. H. McGavock and R. J. Edmonds to determine the feasibility of developing large ground-water supplies for irrigation, municipal, and industrial uses in the 25,000 mi^2 of the Navajo and Hopi Indian Reservations. The areas in which 25, 75, 200, and 500 gal/min of ground water can be obtained from aquifers were delineated. The approximate pumping level necessary to obtain the desired yield and the estimated amount of dissolved solids in the ground water also were determined. The study indicated that at least 25 gal/min of water can be obtained in about 75 percent or 18,750 mi^2 of the area but that only 15 percent (3,750 mi^2) of the area is underlain by aquifers capable of yielding 500 gal/min. The chemical quality of the water varies greatly from aquifer to aquifer and may change laterally within an aquifer; in about 20 percent (5,000 mi^2) of the reservations all known aquifers yield water that contains more than 1,500 mg/l dissolved solids.

CALIFORNIA

Occurrence of ground water in the Modesto-Merced area, San Joaquin Valley

Results of an investigation by R. W. Page and G. O. Balding indicate that at least three ground-water bodies underlie the Modesto-Merced area: (1) The unconfined water body, (2) the confined water body, and (3) the water body in consolidated rocks. The unconfined water body lies above and east of the confining bed that is equivalent to the Corcoran Clay Member of the Tulare Formation (Pleistocene) (W. R. Hotchkiss, 1972). The confined water body lies below the confining bed and has heads less than those in the unconfined water body. The water body in consolidated rocks underlies most of the area and consists of a group of poorly defined perched and confined water bodies.

Hydrology of Sagehen Creek basin

R. G. Simpson reports that Sagehen Creek, in Tahoe National Forest near Truckee, has an average discharge of 12.2 ft^3/s. Annual peak flows range from 27 to 765 ft^3/s, and minimum daily flows are generally about 1.0 ft^3/s. Results of analyses for coliform bacteria in water samples indicated no pollution, and surveys of plant and animal life suggested a healthy stream environment. Sediment concentration and conductivity of water samples analyzed ranged from 1 to 126 mg/l and from 40 to 135 μmhos.

Water quality in the Middle Fork Feather River

According to A. E. Dong and R. L. Tobin (1973), various physical, chemical, and microbiological measurements indicated that the water quality in the reach of four major sampling stations on Middle Fork Feather River is good and meets recommended criteria for most fresh-water organisms and for recreational use. Water quality in the upper reach of the river downstream from Sierra Valley is less desirable; turbidity and color have rendered the water esthetically less pleasing in this reach. Water quality improves downstream because of dilution by better quality water entering from tributaries.

Ground water in marine terrace deposits, Montara Beach

Results of geologic mapping and test drilling indicated that marine-terrace deposits at Montara Beach are not capable of receiving, transmitting, or discharging large volumes of treated wastewater to the ocean, according to K. S. Muir. Ground-water storage in the terrace deposits was at or near maximum in December 1972. The ground-water basin, in a nearly natural state, was full. Ground water was discharging from the basin into stream courses, along the beach cliffs, and beneath the beach into the ocean. Any additional ground-water recharge to the terrace deposits would increase the surface discharge. The terrace deposits have a maximum thickness of about 90 ft and a coefficient of permeability of about 25 to 40 gal $d^{-1}ft^{-2}$.

Hydrologic models for San Luis Rey River ground-water basins

J. A. Moreland reported that digital hydrologic models have been constructed for Pauma and Pala ground-water basins of the San Luis Rey River watershed. Steady-state conditions have been modeled and verified for both basins. In addition, the period 1958–68 has been simulated as five pumping periods for Pauma basin and as two pumping periods for Pala basin. Annual pumpage for the two basins, computed from land-use maps and verified by the hydrologic models, is approximately 6,500 acre-ft for Pauma basin and 2,500 acre-ft for Pala basin.

Geohydrologic map of southern California

W. R. Moyle, Jr., reported completion of a map showing water-level contours for most of the large alluvial valleys in southern California. It shows the altitude and direction of flow of ground water and shows how water that falls as rainfall moves through the ground until it finally reaches the ocean, rivers, or inland seas, or is discharged from a playa surface in a closed basin.

Ground-water quality investigated in Mesquite Flat area of Death Valley

According to G. A. Miller, data from eight shallow test holes augered in the western and northern part of Mesquite Flat indicate that most of the ground water along the west side of the flat contains more than 2,000 mg/l of dissolved solids. Ground water at the north edge of the flat contains as little as 630 mg/l of dissolved solids.

Geohydrology and artificial-recharge potential of the Irvine area, Orange County

The Irvine area is in hydraulic continuity with the rest of the coastal plain in Orange County. According to J. A. Singer, factors that distinguish the aquifer section in the Irvine area from that in other parts of the coastal plain are a low permeability, a high clay and silt content, and a thin alluvial sequence, all factors that resist artificial recharge. Rapid facies changes and the large percentage of silt and clay in the section result in confining conditions. The aquifer, most of which is included in the Fernando Formation, is as much as 1,300 ft thick beneath parts of the plain. The alluvium overlying the Fernando Formation averages about 200 to 250 ft in thickness and also contains significant amounts of silt and clay.

Transmissivities range from 25,000 to 100,000 gal $d^{-1}ft^{-1}$ in the Irvine area, values which are much lower than those in the rest of the coastal plain in Orange County.

Water levels have recovered as much as 60 ft from the low levels of the early 1950's. Water-level maps indicate that, in the winter nonpumping season, water tends to move toward upper Newport Bay and the rest of the coastal plain. During the summer pumping season, a cone of depression develops, reversing the winter gradient.

The average dissolved-solids content of the ground water is about 800 mg/l. The most prevalent cations are sodium and calcium; the most prevalent anions are bicarbonate and sulfate. No long-term degradation of water quality has occurred, with the exception of a slight increase in dissolved solids.

Ground-water quality in Indian Wells Valley

J. W. Warner determined that Indian Wells Valley has no immediate ground-water quality problems. He found no indication that the increasing pumping depressions in the Inyokern, Intermediate, and Ridgecrest areas have significantly altered the natural flow pattern (toward the China Lake playa) of the poor-quality water in the shallow aquifer.

The recharge of sewage effluent from the U.S. Navy sewage ponds and golf course has not reversed the natural direction (toward the China Lake playa) of ground-water underflow across a northwest trending fault near China Lake as was previously suspected. It is important to maintain the natural direction of flow in the shallow aquifer across the fault to prevent the naturally poor-quality water of the shallow aquifer from migrating towards the well fields and degrading this source of public water supply.

There is no indication that recharged sewage effluent from the Ridgecrest Sanitation District sewage ponds is migrating towards the well fields. However, because the Ridgecrest well field is only about 2 mi from the Ridgecrest Sanitation District sewage ponds, the direction and rate of movement of the recharged sewage effluent should be continually monitored.

As water levels in wells in the pumping depression continue to decline, a greater proportion of the water pumped from these wells will come from the deeper part of the aquifer, causing a trend toward a slight increase in dissolved-solids concentration.

Chemical analyses indicate the aerial extent of poor-quality ground water has not increased in the past 25 yr.

NEVADA

Bathymetric surveys in Nevada

F. E. Rush (1973) and T. L. Katzer and Lynn Harmsen (1973a, b) completed bathymetric surveys of 16 lakes and reservoirs in northern Nevada. During 1973 they determined: (1) The area of Lake Tahoe is 124,000 acres, and the volume is 125 million acre-ft, (2) the area of Wild Horse Reservoir is 2,830 acres, and the volume is 73,500 acre-ft, and (3) the area of Weber Reservoir is 900 acres, and the volume is 10,700 acre-ft.

OREGON

Perched water zones provide domestic water

Perched ground-water bodies underlying a fast-growing suburban area southeast of Oregon City are small but important local domestic-water sources. There, the Boring Lava forms an area of rolling hills several hundred feet higher than the adjacent Willamette Valley lowland. Recent studies by A. R. Leonard show that domestic wells about 100 to 350 ft deep commonly tap permeable zones in the Boring Lava that contain perched water. Water levels in these wells generally are about 100 to 200 ft higher than levels in nearby wells that are drilled through the Boring Lava to the regional water table in the underlying Troutdale Formation. Some wells tapping perched-water bodies yield less than 5 gal/min, but the median yield is about 20 gal/min—adequate for a good domestic supply.

WASHINGTON

Streams, lakes, and ground water on the Colville Reservation

The principal perennial streams available to the 2,200-mi^2 Colville Indian Reservation are the Columbia, Sanpoil, Nespelem, and Okanogan Rivers; each of these streams has numerous perennial and intermittent tributaries. The primary source of streamflow is from snowmelt occurring in the mountainous headwater reaches of the rivers during the spring and early summer. Minimum flows usually occur during the fall, although some of the smaller streams freeze and cease to flow in winter. Many small streams are dry for several months in summer. The sanitary quality of the stream water is generally excellent except in parts of basins heavily occupied by livestock.

According to R. E. Harkness, G. C. Bortleson, and D. A. Myers, water in numerous lakes in the study area contains a wide range of dissolved solids and nutrient concentrations, oxygen regimes, and phytoplankton. Omak and Soap Lakes are closed-basin saline lakes in a semiarid part of the reservation; five lakes in the mountainous parts of the area had good quality water with dissolved-solids concentrations ranging from 51 to 92 mg/l. The average inorganic nitrogen concentrations in the epilimnion were less than 0.20 mg/l in eight lakes; however, the average total phosphorus concentrations were moderate to high (greater than 0.02 mg/l) in six lakes, even though the lakeshore development is sparse to light. Agricultural runoff may account for a substantial part of the phosphorus. Owhi Lake, which receives runoff from grazed land, had the highest average total phosphorus concentration (0.12 mg/l) and the highest amount of phytoplankton of all the lakes on the reservation. The trace-metal concentrations in the saline lakes were generally higher than in the nonsaline lakes.

The reservation is underlain by igneous and metamorphic rocks in the mountains and by unconsolidated glaciofluvial sediments in the valleys. Ground water is derived primarily from the latter and is used mostly for domestic supplies. Pumpage for irrigation is chiefly from glacial deposits in the western part of the reservation. Well yields range from less than 1 gal/min from bedrock to more than 5,000 gal/min from the coarse glacial deposits. No evidence of ground-water overdraft has been observed.

Digital model of basalt-aquifer system, Walla Walla River basin

Recent completion of a steady-state digital model of the primary basalt-aquifer system underlying the Walla Walla River basin in southeastern Washington and northeastern Oregon has established the various constant-flux parameters required for the forthcoming transient model, while refining previous gross budgetary estimates for the system. According to R. D. MacNish and R. A. Barker, comparison of final computed potentiometric heads with historical data verifies the steady-state solution as being within 25 ft over 90 percent of the modeled area and within 10 ft in the areas of greatest control and importance.

PACIFIC NORTHWEST

Computer model developed for determining bank storage

A computer model has been developed by T. H. Thompson (1972) for determining the change in bank storage at Hungry Horse Reservoir in northwestern Montana. Changes in bank storage have been computed from the beginning of operation of the reservoir in 1951 through September 1972.

Tests of the model using theoretical water-surface elevations indicate that if the reservoir were drawn down to minimum pool over a 2-yr period or longer, an estimated 5.8 percent of usable reservoir-storage volume would be available from bank storage. This additional water could be used for onsite power generation and for downstream benefits such as irrigation or additional power generation.

The model is being modified for use at other reservoirs in the Pacific Northwest where bank storage may be significant.

SPECIAL WATER-RESOURCE PROGRAMS

SALINE WATER

Sea-water intrusion in southeastern Florida

Continuing investigation of the movement of the fresh-water–salt-water interface in the coastal area of Dade County, Fla., by J. E. Hull (1972) has shown a general, slow, seaward movement of the interface during the period 1961–72. During 1971 and 1972, however, the salt front moved inland in the vicinity of the Miami, Miami Springs–Hialeah, and Homestead Air Force Base well fields as a result of deficient rainfall and consequent high pumpage.

Sources of saline water identified on Sanibel Island, Florida

Sources of saline water and the mechanisms through which this water enters the interior fresh-water system of Sanibel Island have been identified by D. H. Boggess. Sources of saline water include the adjacent tidal water bodies, evaporite beds within the shallow aquifers, and unflushed remnants of sea water in the deeper artesian aquifers. The adjacent surface sources of saline water have been able to intrude the system largely by leaking through and overtopping two control structures which separate the tidal and nontidal waters on the island. Saline water, pumped during dewatering of ponds, lakes, and canals (during their excavation), is dumped into the interior drainage way and has caused a large increase in the chloride concentrations in this system. Upconing of saline water from the shallow artesian aquifer in response to the pumping rates required to dewater excavations is also a source of contamination. Some natural leakage of this saline water upward into the lower part of the water-table aquifer also occurs. Discharge of saline water at the surface from improperly cased wells and test holes drilled into the deeper artesian aquifers has also caused an increase in chloride concentrations in the interior fresh-water system.

Restricted circulation of water affects salt balance in Great Salt Lake, Utah

Continuing studies of the permeable rock-fill causeway across Great Salt Lake show that it has caused a shift of 0.26 billion tons of dissolved-salt load from the south to the north arm of the lake during the 1970–72 water years. Predictions by K. M. Waddel and E. L. Bolke, using a digital model of the hydrology of the causeway, indicate that the salt balance in the lake is near equilibrium for a continued rising lake stage; however, if the lake stage falls, large quantities of sodium chloride may precipitate in the north arm, and an additional dissolved-salt load may be lost from the lake's south arm to its north arm.

Water supply for brine production in Searles Valley, California

A brief exploratory water-resource study of Searles Valley, Calif., was made by W. F. Hardt, L. C. Dutcher, and W. R. Moyle, Jr. The study forms the basis for a comprehensive geohydrologic investigation of the area which will provide the necessary information for administration of mineral leases, determine the maximum recovery of valuable brines, and establish fluid-basin management objectives.

A conceptual model or hydrologic working hypothesis was formulated from available information. This model indicates that the valley is separated into a brine aquifer (fluid density 1.300) in the center and a peripheral fresh-to-brackish water aquifer (fluid density 1.000 to 1.050). Water in each aquifer has a different mode of occurrence, recharge, and discharge and a different chemical composition. The availability of water is the limiting factor in brine production and a water supply that can be used for this purpose may exist in the peripheral aquifer along the east side of the brine lake.

DATA COORDINATION, ACQUISITION, AND STORAGE

OFFICE OF WATER DATA COORDINATION

A contract was issued on January 8, 1973, by the USGS to the PRC Systems Sciences Co. of Los Angeles, Calif., for the formulation of an implementation plan for a National Water Data Exchange (NAWDEX). The contract is to run for 1 yr and calls for the development of an overall design and financial structure for NAWDEX, as well as a survey of potential NAWDEX members.

The PRC study plan calls for accomplishing the objectives of the contract in seven steps: (1) Defining NAWDEX attributes, (2) designing a preliminary NAWDEX, (3) identifying potential participants, (4) conducting a survey using the preliminary NAWDEX design, (5) analyzing the results of the survey, (6) redesigning NAWDEX on the basis of the survey results, and (7) formulating an implementation plan for the redesigned NAWDEX.

The Willamette River basin of Oregon is the subject of an intensive river-quality investigation by the USGS with the assistance of the ad hoc Working Group on River Quality Assessment from the Advisory Committee on Water Data for Public Use. The project began in January 1973 and is to last 2 yr. The work plan was approved at the September 22, 1972, meeting of the Working Group and the investigation is currently underway.

The primary purpose of the intensive river-quality assessment program is to develop comprehensive approaches and the methods and techniques needed to evaluate planning alternatives. The following specific aspects will be emphasized in the Willamette River basin investigation:

1. The definition of existing river quality.
2. The presentation of trends in river quality.
3. The projection of river quality under various alternatives of basin development.

The Office of Water Data Coordination released for general distribution the preliminary report, "Recommended Methods for Water-Data Acquisition," of the Federal Interagency Work Group on Designation of Standards for Water-Data Acquisition. The report documents the results of more than 2 yr of interagency effort to designate recommended methods. The report consists of six chapters and covers the following areas of concern: (1) Surface-water stage and quantity, (2) chemical (inorganic) and physical quality, (3) bacteriological, biological and chemical (organic) quality, (4) sediment, (5) ground water, and (6) automatic water quality monitoring.

An ad hoc subcommittee of the Federal Advisory Committee on Water Data has developed a plan for the continuation of the work on designation of standards. The plan was presented to the Committee at the eighth meeting and will be implemented by the USGS.

A report on Water Resources Investigation 2–72, "Water-Temperature Data Acquisition Activities in the United States," by F. H. Pauszek, was prepared and distributed by the Office of Water Data Coordination. The report presents information by Federal and non-Federal agencies on the collection of temperature data.

Acquisition of water-temperature data is analyzed by means of tables and illustrations preceded by brief explanations. The report also includes a bibliography listing 194 references to publications containing water-temperature data that are available in major public and university libraries as well as in libraries of Federal and non-Federal agencies.

The "Summary of Plans for Acquisition of Water Data by Federal Agencies, Fiscal Year 1974" was released for distribution in April 1973. This is the third in a series prepared by the Office of Water Data Coordination in cooperation with other Federal agencies. In addition to a digest of plans for water-data acquisition in each of the 21 water-resource regions, the summary contains information regarding activities of national scope as reported by officials at headquarters level.

Coverage was broadened during this field coordination cycle to include ground-water-quality stations as well as surface-water stations. Specifically, the summary contains information on Federal plans for acquisition of stage and flow data at long-term surface-water stations and for water-quality data on both long-term surface- and ground-water stations.

The field coordination effort covering fiscal year 1975 was initiated in April and will cover the same activity as the preceding year. Updating of the "Catalog of Information on Water Data" will be conducted as part of the field coordination process.

To meet an expressed need to have water-data acquisition activities listed on a regional basis, the format of the 1972 edition of the "Catalog of Information on Water Data" has been revised. The contents of the former surface-water section and water-quality section of the catalog are presented in 21 separate volumes. Each volume covers a water-resources region as established by the Water Resources Council in July 1970 for the National Assessment of Water and Related Land Resources.

Information in each of the 21 volumes of the catalog reflects activities as of January 1, 1972, for those stations being operated on a recurrent basis for a period of 3 yr or more. Each volume has three parts containing information about stations in a particular category as follows: "Part A—Streamflow and Stage," "Part B—Quality of Surface Water," "Part C—Quality of Ground Water." Stations in parts A and B are arranged in downstream order, whereas stations in part C are grouped primarily by States, by counties within each State, and by agencies within each county.

The eighth meetings of both the Federal Advisory Committee on Water Data and the Advisory Committee on Water Data for Public Use were held. The meeting of the latter committee was in Portland, Oreg., and included a field inspection of activities constituting the Willamette River basin investigation.

A hydrologic base-map series was prepared by the Office of Water Data Coordination, using the standard USGS 1:500,000 State base. Hydrologic boundaries for the water-resource regions, subregions, National Water Data Network accounting units, and cataloging units are portrayed. Boundaries are consistent, with smaller units nesting in larger units.

WATER-DATA STORAGE SYSTEM

The USGS uses a digital computer to process, store, retrieve, and display water-resource data.

The computer is also used in conjunction 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 Washington, D.C., and remote terminal facilities located in 25 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 255,000 station-yr of record. This covers more than 73 percent of all streamflow data collected under this program. 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 used 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.

The USGS has coded hydrologic data in machine format for about 40,000 water wells and for about 25,000 chemical analyses of water from these wells. The file, which uses the latitude-longitude system for locating wells, includes information relative to State, county, use of water, use of well, depth, drilling method, yield, water levels, physiographic data, and aquifer characteristics.

URBAN WATER PROGRAM

During 1973, more than 350 USGS projects were considered by W. J. Schneider as related to urban water problems. These projects give impetus to designing many of the new hydraulic instruments and to formulating new techniques for collecting hydrologic data under special conditions found in the urban environment. Determining storm runoff in a 42-in. storm sewer in Denver, Colo., for example, required both new instruments and techniques.

Simultaneous recording of several types of data is frequently required in urban areas, and according to G. F. Smoot, an instrument package has been designed to record urban rainfall-runoff data. The instrument is basically a six-channel type recorder with an additional provision for recording time by a digital clock. The six channels provide for various combinations of data, such as two head measurements, three rain gages, and a water-quality sampler. The instrument is capable of recording data at approximately 2-s intervals; a complete set of hydrologic data can be recorded at intervals as short as 1 min if necessary. Housing requirements are a 4- by 4-ft shelter for rainfall-runoff stations and a 6- by 8-ft shelter if water-quality data are also obtained. Where only one rain gage is installed in a basin, the two additional channels on the recorder can be used for continuous recording of water quality parameters such as conductivity, temperature, and DO.

G. F. Smoot reported that a water-quality sampler is ready for field installation and testing. The sampler is capable of collecting twenty-four 2-l samples during a storm event on a time-integrated or discharge-integrated basis. The sampler is activated by the recorder, and storm water is then pumped continually during the event. The bottles are rotated at the preselected intervals and fill in about 10 s. When the bottles are not being filled, the water is wasted and returned to the storm sewer. The samples are housed in a refrigerated unit in order to keep them as biologically inactive as possible. After each storm event the bottles must be removed and new bottles must be installed so that the sampler is ready for the next storm event. A 110-volt power source is required for operation of the system.

URBAN WATER-RESOURCE STUDIES

Alaska

In Alaska ongoing hydrologic studies of the Anchorage Borough have been directed toward determining the availability of ground water in the Anchorage, Girdwood, and Eagle River areas. According to W. W. Barnwell, a new well just completed in the North Fork Campbell Creek well field is capable of a yield of 2 to 3 Mgal/d. Similarly, L. L. Dearborn determined that adequate ground water is available from the glacial sediments in the foothills area east of Anchorage. The ground-water potential in the Girdwood area, 40 mi south of Anchorage, also appears to be good, according to Chester Zenone, but availability of ground water in the Eagle River area, 15 mi north of Anchorage, may be somewhat limited.

In a study of the effects of urbanization in the Anchorage area, R. S. George and W. W. Barnwell have completed a pollution-susceptibility map of the area. This was done by integrating on a rating system factors such as sorptive capacity and permeability of soils, slope of land surface, depth to water table, distance to surface-water features, and thickness of unconsolidated sediments overlying impermeable zones. Surface drainage, water-table contour, and depth-to-water maps were also compiled. L. L. Dearborn reported that the susceptibility to pollution is high in the foothills area east of Anchorage.

To evaluate the long-term availability of ground water in the Anchorage area, the feasibility of artificial recharge using summer streamflow from Ship Creek is being studied. Preliminary studies by W. W. Barnwell and R. S. George indicated an infiltration rate of 300,000 gal/d into a ½-acre recharge pond on an alluvial fan near Ship Creek. A 10-acre pond is now under construction in the same area to further evaluate the effects of artificial recharge.

Proposed industrial development and highway improvement will greatly alter the distribution of population and the water informational needs of the City and Borough of Juneau. An ongoing program to study the water resources of the area and to meet these needs includes a basic-data collection and monitoring program, detailed studies of rapidly developing areas, and preliminary studies of areas proposed for development. To anticipate the water needs and as part of the proposed plans for a central water system, the Salmon Creek Reservoir is being evaluated as a potential source of water. In the event it may be available to the city-borough after the completion of the Snettisham power project, hydrologic data will be required for management decisions. According to G. O. Balding, studies of the reservoir thus far indicate that the quantity and quality of the water is excellent. The rapid development of Mendenhall Valley has required a continuous updating of the hydrologic information needed to assess the availability of water in this area and the effects of urbanization on water resources. In addition, more basic hydrologic data are needed for the Lemon, Eagle, and Herbert River valleys, the Lena-Cove-Tee Harbor area, and northern Douglas Island.

G. S. Anderson and S. H. Jones (1971, 1972) recently completed a 5-yr water-resources investigation of the Kenai-Soldotna area. They concluded that water is abundantly available throughout the area, but its poor quality in some areas and the high cost of development either present restrictions or interpose economic consideration on its use. The principal source of water is from artesian aquifers of glacial outwash. Artesian wells less than 350 ft deep yield as much as 1,400 gal/min of generally good quality water. Large amounts of water are also available in some areas from water-table aquifers but the water has a high iron content. The Kenai River, which has a mean annual discharge of 5,700 ft^3/s, flows through the area but is heavily laden with glacial flour. Total water use during 1970 was approximately 1,260 Mgal/d. Over one-half of this total was used by industry in North Kenai. Water levels in wells and lakes declined in the North Kenai area from 1967 to 1970 principally because of drought conditions but possibly also from the effects of industrial pumpage. Additional water can probably be developed from water-bearing deposits underlying the cities of Soldotna and Kenai and from the Beaver Creek and the Kenai River valleys. Also, it may be possible to develop more ground water near North Kenai. The Kenai River remains the largest untapped source of water but would require treatment. Optimum development of water in the area would result from a unified system using ground water in conjunction with surface water.

Arizona

Thermal stratification has caused recurring water-quality problems in Upper Lake Mary—the principal water supply for Flagstaff. Studies by E. H. McGavock and J. W. H. Blee show that air bubbling conducted at one site in the 15,000-acre-ft reservoir eliminated the stratification for a distance of more than 2 mi. Natural oxygenation of the entire reservoir following air bubbling changed the hypolimnion from a reducing environment to an oxidizing environment and significantly improved the quality of water withdrawn from the reservoir. The dissolved-iron content decreased from an average of 1.0 to 0.03 mg/l, the dissolved manganese decreased from an average of 0.5 to 0.01 mg/l, and the objectionable odor and color of the water were eliminated. DO in the hypolimnion had ranged from 0- to 20-percent saturation before air bubbling and ranged from 40- to 70-percent saturation after the thermocline was destroyed. The improvement in the quality of the water in Upper Lake Mary, an attendant effect of the air bubbling, was accomplished at a net saving to the city; the cost of purchasing, installing, and operating the air-bubbling equipment was more than offset by the savings in electricity and chemicals previously used at the water-treatment plant.

Connecticut

An 18-sheet folio of environmental maps of the Hartford North quadrangle, published as USGS Miscellaneous Geologic Investigations Maps 1–784 (A–R), depicts land-surface information, the character of materials making up the surface of the earth, and availability and character of water and other natural resources. The maps present earth-resource information in a nontechnical format for easy understanding and direct use by those involved in land use and resource management. In addition to the folio, bedrock contour maps have been published for the Windsor Locks, Broad Brook, and Manchester quadrangles. Basic geologic, topographic, and hydrologic mapping being done under ongoing Federal and Federal-State cooperative programs provides a base for the preparation of environmental maps.

Florida

Curtailment of water use during the record drought of 1971 in southeastern Florida demonstrated the need for implementation of water-management plans to alleviate detrimental effects of drought on wetlands and of sea-water intrusion. Results of analyses by Howard Klein and J. T. Armbruster indicated that backpumping surplus storm water to interior water-storage areas, increasing storage schedules of Lake Okeechobee, and storing surplus storm water by deep injection into the upper part of the Floridan artesian aquifer are expedient methods of water management. However, plans to increase storage in Lake Okeechobee and the water-conservation areas can evolve only if the water to be backpumped and stored is relatively free of pollution. Injection into the Floridan aquifer can proceed only after deep-well exploration and adequate injection and recovery tests to determine the feasibility of this alternative.

R. N. Cherry reported that withdrawals from the Floridan aquifer in the Clearwater-Dunedin area have not lowered the potentiometric surface significantly during the last 20 yr. Recharge of 10 Mgal/d to the aquifer has equaled natural discharge and withdrawals. Salt-water encroachment, which has been an inherent problem with water development from the aquifer in this peninsular area, can be minimized by careful management of withdrawals.

L. V. Causey and G. W. Leve delineated areas of possible recharge to the Floridan aquifer in western and east-central Duval County. The recharge area in the east-central part of the county is in a section of the City of Jacksonville where urbanization is increasing rapidly. The local governing agencies are utilizing the map as a basis for zoning and drainage ordinances to protect the recharge areas and the future water supplies of Jacksonville.

Construction of the South Dade sanitary-sewage deep-well injection system has been delayed pending EPA's approval of the master plan. F. W. Meyer evaluated the suitability of the proposed well sites, and a shallow-well monitoring network was established to gather background information on the Biscayne aquifer.

H. J. McCoy reported that the C–13 Feeder Canal contributed about 5 Mgal/d of water as recharge to the aquifer in the Prospect well field at Fort Lauderdale from May 1971 to May 1972. This canal was designed to convey water from the regional water-management system into the Prospect well-field area to replenish the aquifer and to retard sea-water intrusion. Flow into the canal averaged about 12 Mgal/d for the study period. Modification and improvements to the canal and the connection with the regional system will increase this flow to the design criterion of 50 Mgal/d and will significantly increase recharge to the aquifer.

H. W. Bearden and H. J. McCoy reported that local and regional management efforts in Broward County have been effective in mitigating problems of sea-water itrusian and in meeting rapidly increasing water needs. During the major drought of 1970–71, further sea-water intrusion was minimized even though record-high withdrawals caused record-low water levels in coastal areas for several consecutive months. However, the ever-increasing demands on the water resources and the growing threat of contamination from effluent wastes will necessitate continued refinement of management practices in order to meet future needs. Necessary improvements are (1) increased fresh-water storage, (2) reduction of fresh-water losses to the sea, and (3) improved methods for treatment and disposal of effluent wastes.

Recharge from the Miami Canal system accounted for almost 100 percent of the dry-season pumpage in the 1940's; however, since 1961, peak pumpage has caused the cone of depression to expand beyond the recharging canals, thus removing water from storage during the dry season according to F. W. Meyer (1972) and J. E. Hull. The rate of recharge by the canal is limited by bottom sediment in the canal and by a 15-ft-thick bed of sand at shallow depth. Due to effects of the 1970–71 drought, well-field pumpage was approaching the recharge capability of the canal system. Samples of water from the canal and monitor wells were analyzed to determine the filter effect of bottom sediments and the sand bed on the quality of the recharging canal water. Water-quality profiles showed that bacterial, organic, and pesticidal concentrations decreased significantly due to filtration.

Despite the 60 in. or more of annual rainfall, municipal well fields in northeastern Palm Beach County are endangered by salt-water intrusion. During periods of drought, salty water moves landward into the shallow aquifer causing many municipal and domestic wells to yield water with excessive chloride content. H. G. Rodis suggested that water resources west of this area might be available to augment present supplies. Also, the use of treated sewage and storm runoff could meet certain fresh-water needs and thereby extend the life of the present well fields.

Test wells drilled in the area of a proposed well-field site in Hollywood showed the water to be of generally good quality, except for an iron content of 2.2 mg/l below a depth of 100 ft. However, this undesirable constituent can be easily removed by aeration. In an existing well field in the Hollywood area, a salt-water front was located by H. W. Bearden at a depth of 200 ft in the Biscayne aquifer near the eastern edge of the well field. This salty water is moving from the highly saline Hollywood canal toward the well field.

An evaluation of the ground-water resources of the Venice area by Horace Sutcliffe, Jr., indicated that the existing fresh ground-water supply will be adequate to meet the city's needs until about 1975. The area is underlain by an aquifer that contains water with a dissolved-solids content of 3,000 mg/l. Wells less than 400 ft deep that tap this aquifer yield more than 500 gal/min. There are plans to desalt this water by the reverse-osmosis technique and to use the desalted water to supplement the fresh-water source after 1975.

Because of the rapid urbanization of the Englewood area, its water-supply needs have increased by 1 Mgal/d. Evaluation of the ground-water resources in the vicinity of the existing well fields indicates that additional water to meet immediate needs can be obtained by expanding these fields. Horace Sutcliffe, Jr., is evaluating the ground-water resources of the area adjacent to Englewood.

Permeability of the aquifer is the most important factor directly related to the effect of septic-tank effluent on water quality at sites investigated in Dade County, according to W. A. Pitt, Jr. High permeabilities have both positive and negative effects; the greater the permeability the greater the waste dilution, but also the greater the ease with which bacteria can move through the aquifer. No significant differences were observed in the ground-water quality in areas with one to three septic tanks per acre. In the Biscayne aquifer the effects are almost totally confined to the top 30 ft and are confined to the top 10 ft for most parameters. Polio virus has not been found at any level, and no significant adverse effects were observed at any of the sites investigated.

C. H. Tibbals reported that results of a series of double-mass curve analyses of rainfall versus ground-water levels indicate that, in southwestern Seminole County (Greater Orlando metropolitan area), the cause of low ground-water levels is deficient rainfall. The analyses further indicate that, in the Orlando area of Orange County, increased ground-water withdrawals have resulted in a lowering of ground-water levels in excess of that which can be attributed to deficient rainfall.

Louisiana

Investigation of the water resources in the Ruston area, by T. H. Sanford, revealed that ground water is adequate to meet the present and projected needs through the year 2000, despite the proposed large increase in ground-water use at the nearby village of Hodge. The principal aquifer is the Sparta Sand, the only aquifer capable of yielding large quantities of fresh water in this area. The water level at Ruston has declined 175 ft since 1920; 90 percent of the decline is attributed to industrial pumpage at El Dorado, Ark., and at Monroe, Bastrop, and Hodge, La. Aquifer dewatering, which began in the mid-1960's, will greatly increase the storage coefficient and thus decrease the rate of water-level decline. The quality of water from the Sparta Sand is generally good, but treatment is required for a "red-water" problem believed to be caused by a combination of slightly corrosive water and iron bacteria in the water system. As an alternative to ground water, Lake Bayou D'Arbonne, 15 mi northeast of Ruston, can supply water of good quality. The lake has a capacity of 130,000 acre-ft (42.4 Ggal) and can supply about 200 Mgal/d.

The availability of water-bearing sands and the suitability of the water for public supplies were tested at 72 sites in Louisiana during 1972, according to J. E. Rogers. The USGS and the Louisiana Department of Public Works drilled test holes for geologic data and installed temporary wells for hydrologic data, including collection of water samples for chemical analysis. During 1972, tests were made to a depth of 2,685 ft; in prior years, tests were made to depths of more than 3,100 ft. At many of the sites, the water in one or more sands was suitable for public supply without treatment. Some of the tests provided data for mapping areas or sand zones where excessive amounts of chloride, iron, fluoride, or sulfate occur.

Massachusetts

Continued monitoring of wells adjacent to Massachusetts highways shows increasing concentrations of chloride in ground water caused by highway deicing salts. According to L. G. Toler and S. J. Pollock, use of deicing salts, mainly sodium chloride, on State-maintained highways increased to 231,000 tons, a 10-percent increase, in the winter of 1971–72. Maximum concentration of chloride at a test site 15 ft from the highway increased from a high of 380 mg/l in 1971 to 518 mg/l in 1972. Preliminary data suggest that concentration of chloride in the unsaturated zone adjacent to a highway is held in soil moisture at a relatively constant level that is reached soon after salting of the highway begins. In fine sand and silt the amount of chloride retained in the unsaturated zone is a function of the grain size of the soil materials.

Michigan

F. R. Twenter, R. L. Knutilla, and J. O. Nowlin estimated that by the year 2000 about 70 Mgal/d of water will be used in Washtenaw County. More than 70 percent of the water will be used in the Ann Arbor–Ypsilanti metropolitan area. Ground-water and surface-water sources are capable of meeting the needs of most areas in the county for the next 10 yr; glacial deposits and bedrock, the prime sources of water for all areas except Ann Arbor, yield more than 50 gal/min to individual wells, especially in the central and western parts of the county, and the total discharge of all streams in the county averages more than 700 ft^3/s. However, streamflow is variable, and during drought periods, many streams recede to low rates of discharge. Median annual 7-day low flows are generally less than 0.15 ft^{3}s^{-1}mi^{-2}. Water supply may be a problem in the densely populated Ann Arbor–Ypsilanti area in the near future. In this area surface-water sources are almost fully utilized. Sand and gravel in the glacial deposits underlying the area, although capable of yielding large quantities of water, may not yield sufficient water to meet additional demands. If present trends in water use continue, the water supply of the Ann Arbor–Ypsilanti area during the next 10 to 20 yr will have to be supplemented from sources outside the area. The quality of surface water and ground water from glacial deposits is generally suitable for most uses. Water from both sources is normally of the calcium bicarbonate type. However, ground water from bedrock is of the sodium bicarbonate or sodium chloride type.

Minnesota

In 1970 water use in the Twin Cities metropolitan area, exclusive of that used for powerplants and sewage-effluent assimilation, was 133 Mgal/d (210 ft^3/s) of surface water and 194 Mgal/d (300 ft^3/s) of ground water. According to R. F. Norvitch, projected water needs for the year 2000, based on present trends, are 220 Mgal/d (340 ft^3/s) for surface water and 600 Mgal/d (388 ft^3/s) for ground water. Estimated future water demands on Mississippi River flow for sanitary effluent reduction range from 3,500 to 3,800 ft^3/s. Based on conditions similar to those of the droughts that occurred in the area in the 1930's (or the 100-yr, 30-d low flow), streamflow above the metropolitan sewage treatment plant would be only 840 ft^3/s. Presently, the 7-d, 10-yr low-flow probability above the sewage treatment plant is about 1,400 ft^3/s. Although average flow in the Mississippi River downstream from the Minnesota River exceeds 10,000 ft^3/s, the flow is not enough to satisfy all demands, now or in the future, during low-flow periods. This problem can be partially alleviated by greater use of ground water, especially as a supplement during periods of low flow. Five aquifer systems underlie the Twin Cities area—glacial drift, St. Peter Sandstone, Prairie du Chien Group, and Jordan Sandstone (as a unit), Ironton and Galesville Sandstones (as a unit), and Mount Simon and Hinckley Sandstones (as a unit). Estimated sustained yields of 845 Mgal/d can be obtained from the Prairie du Chien–Jordon and Mount Simon–Hinckley, the two major aquifers. Estimated sources of recharge are 375 Mgal/d from precipitation (captured aquifer discharge), 350 Mgal/d from induced streamflow, 100 Mgal/d from artificial recharge, and 20 Mgal/d from incidental recharge such as leaking water mains, sewers, and septic tanks.

Nevada

J. R. Harrill obtained water-level data from several hundred wells in Las Vegas Valley in February 1971, 1972, and 1973 for evaluating changes in ground-water conditions as increased importation of Colorado River water resulted in reduced ground-water withdrawal. A compilation of water-level data through 1972 by Harrill indicated that the maximum net decline in head for the period February 1955 to February 1972 was slightly more than 160 ft. The maximum net decline in head for the 1-yr period, February 1971 to February 1972, was about 15 ft. These large declines in head occurred along the west side of the valley. Little net change in head occurred in the southwestern part of the valley, and water levels in shallow wells generally have risen. The first year of large-scale importation of water by the Southern Nevada Water Project was 1972. Water-level data collected in February 1973 indicated that water levels rose in the central part of the valley, but not in the southwestern part.

New York

In continuing studies of Long Island, Ellis Koch and E. J. Koszalka used published data to construct hydrologic maps and cross sections of the island. Maps showing the following subjects have been completed: Altitude of the water table; potentiometric surfaces of the middle and deep aquifers; tops and isopachs of aquifers and major confining beds; hydraulic conductivity, transmissivity, and general chemical quality of waters in the aquifers; and surficial geology. The maps and cross sections were constructed for the New England River Basin Commission as part of the data inventory for its Long Island Sound study.

Studies by R. C. Prill and D. A. Aronson at a surface-controlled recharge basin, used for the recharge of storm runoff on Long Island, illustrate some principles involved in predicting infiltration rates. Ponding tests run with constant hydraulic load and water temperature gave infiltration rates that ranged from ± 30 percent of the mean value. When tests were run several days apart, differences in rates were almost as great as seasonal differences. This indicates there is no unique value for infiltration rate. Thus, predictions of infiltration rates should be considered as general approximations. An evaluation of the flow pattern in the unsaturated zone during ponding indicates that a one-dimensional, steady-state model should be appropriate for prediction of infiltration rates. An analysis of the sensitivity of the parameters required in the model shows that the critical hydrologic parameters are the saturated hydraulic conductivity of the surface stratum and the pressure head-hydraulic conductivity relationship of the subsurface stratum. Measurement of the latter is critical, as it provides an estimate of the pressure head at the boundary of the two strata. Pressure-head values indicated by use of laboratory-test data approximate values observed during ponding. Hydraulic-conductivity values of the surface stratum obtained by the shallow-well pump-in test were more reliable than values obtained by means of laboratory analyses of core samples. The shallow-well pump-in test values were only slightly less than values determined from ponding-test data, whereas the core-samples analyses values were several times as great as ponding-test values.

According to H. M. Jensen and Julian Soren (1973), the geohydrology of the north shore of Long Island is complicated by buried valleys that apparently resulted from ice scour. These valleys contain glaciofluvial sediments that in places consist of alternating beds of stratified sand and gravel as much as 700 ft in thickness and elsewhere consist of clay and sandy-clay deposits as much as 400 ft in thickness. The movement of ground water in buried valley deposits depends largely on the continuity of different glaciofluvial units in both the vertical and the horizontal directions. Therefore, a knowledge of physical and hydraulic characteristics of buried valley deposits is needed to locate additional ground-water supplies in the northern part of Suffolk County.

URBAN RUNOFF AND FLOODS

California

The Stanford watershed model was used to simulate the effects of urbanization on the discharge from five watersheds in the upper Santa Ana Valley with drainage areas ranging from 3.72 to 83.4 mi^2. According to T. J. Durbin, the historical record of streamflow for each watershed was reconstructed to represent various degrees of urban development. Examination of the reconstructed records indicated that urbanization has the following effects on streamflow in the upper Santa Ana Valley: (1) Annual runoff from a watershed that has 10-percent effective impervious area is approximately 2 in., and the annual runoff increases 2 in. for each increase in impervious cover equal to 10 percent of the drainage area, (2) urbanization can increase the magnitude of the 2-yr peak discharge and the 2-yr daily mean discharge by a factor of four or more, and (3) peak discharges and daily mean discharges that have recurrence intervals of 50 yr or more are little affected by urbanization.

R. F. Middelburg, Jr., is monitoring storm runoff from three separate drainage basins tributary to San Francisco Bay to determine their contribution to pollution of the bay. These basins, Peralta Creek in Oakland, Castro Valley in Hayward, and Rose Creek in San Jose, are heavily urbanized. Samples are collected at the beginning, peak, and recession of selected storms and are analyzed for nutrients, major ions, heavy metals, pesticides, oxygen demand, phenols, and bacteria. Wide ranges of concentration have been noted for most of the constituents. The total lead concentration ranged from 50 μg/l to as much as 3,100 μg/l. The total cadmium concentration was as high as 80 μg/l, arsenic was 10 μg/l, and mercury was 6.4 μg/l. Total nitrogen concentrations as high as 13 mg/l and phosphorus concentration of 2.6 mg/l indicate the possibility of extremely high nutrient loading of the bay.

North Carolina

Prior to delineating floodways based on the 100-yr flood as affected by urbanization in Charlotte, W. H. Eddins estimated the percentage of impervious cover (pavement and roofs) of basins with certain kinds of urban development. A. L. Putnam (1972) published relations for determining the 100-yr-flood discharge based on basin parameters and the percentage of impervious cover that is an index of the degree of urbanization affecting the magnitude and frequency of flooding. To apply Putman's results, Eddins needed a method for estimating the percentage of impervious cover of large basins based on maps showing expected development in a basin. Using aerial photographs and field checking his results, Eddins found the percentages of impervious cover for the expected, or ultimate, development conditions under Charlotte's long-range land-use plans were much greater than anticipated.

Kind of development	*Percent impervious cover*
Urban core (downtown)	88.0
Arterial commercial	68.8
Industrial park (high density)	56.5
Office-regional shopping	48.9
Urban node	47.1
Industrial park (medium density)	44.0
Residential (high density)	34.0
Industrial park (low density)	23.8
Residential (medium density)	21.6
Residential (low density)	15.0
Rural	1.3

Putman's report indicates that once impervious cover reaches 20 percent, additional impervious cover has comparatively little effect in increasing the magnitude and frequency of floods. Even medium-density residential development has sufficient impervious cover to make it one of the types of developments having strong hydrologic effects.

Pennsylvania

Flood-plain mapping in southwestern Pennsylvania by several Federal agencies has been described in a report by R. M. Beall (USGS) and A. C. Lardieri (U.S. Army Corps of Engineers) (1972). The flood plains of more than 300 stream miles within the six-county Greater Pittsburgh region have been or are in the process of being outlined. These reaches have been symbolized on a status map which accompanies the report. The listed references include flood-prone area maps by USGS, flood-plain information reports by the U.S. Army Corps of Engineers, and flood-risk maps by SCS. Notes about the status of flood studies and protection works for 141 urban places within the region are also given.

Texas

S. L. Johnson and D. M. Sayre used rainfall and runoff data for drainage basins in the Houston metropolitan area and a 60-yr rainfall record from the National Weather Service to simulate 60 annual flood peaks at 26 sites. Selected frequency characteristics, based on these simulated annual peaks, are related to drainage area and percentage of impervious area. These relations, which may be used to estimate the flood characteristics at ungaged sites, indicate that in the Houston metropolitan area, complete urbanization increases the magnitude of a 2-yr flood nine times and increases the magnitude of a 50-yr flood five times.

Wisconsin

Discharge in eight storm sewers is being monitored by E. E. Zuehls, Jr. Three gaging stations at Waupaca and five gaging stations on storm sewers at Madison measure urban runoff. The monitoring at Madison is an integral part of an International Biological Program research project related to effects of urbanization on a small watershed. The drainage areas for the stations range in size from 3 acres to about 2 mi^2. The storm sewers range from 10- to 60-in. diameter to 8- by 4-ft box culverts. An H-flume, two Palmer-Bowlus flumes, and several weirs form the artificial controls at the stations. Five bubble gages and three stilling wells are used to operate digital recorders. Because of the rapid rise and fall of stage in storm sewers, a 5-min punch interval is used. Current-meter measurements, a Parshall flume, and venturi meters on city hydrants have been used to adjust theoretical ratings computed for the controls.

EROSION AND SEDIMENT

A study of small streams designed to evaluate the effectiveness of sediment control in urban construction areas is being continued in Montgomery County, Md. T. H. Yorke reported that data collected between 1968 and 1970 indicate a decreasing trend in the sediment-load to water-discharge relationship for the Northwest Branch Anacostia River near Colesville. The decrease in the sediment load, even though the average amount of construction during the period was greater than that for the period 1963–67, is believed to be attributable to the implementation of sediment controls at some construction sites within the basin. Although the decrease was relatively small, about 13 percent, it does indicate that sediment controls can be effective and substantial improvements in sediment conditions will be realized with improved control techniques established uniformly throughout the county.

HYDROLOGIC EFFECTS OF WASTE DISPOSAL

Florida

Results of an investigation conducted by D. H. Boggess indicate that contamination of the water-table aquifer, resulting from leachates from a landfill operated by the city of Fort Myers, has spread to the northwest. Water samples from a test well about 700 ft north of the landfill showed substantially higher concentrations of calcium, sodium, sulfate, chloride, and dissolved solids than were in samples from control wells in other parts of the area. The increase in chemical concentrations are similar, although of lesser magnitude, than those determined in water from a well immediately adjacent to the landfill.

Effect of the Cross-State dump, west of West Palm Beach, on ground-water quality has been minimal in the 75- to 200-ft zone tapped by most producing wells in the vicinity. J. J. Schneider found that water at very shallow depths beneath and immediately adjacent to the dump is somewhat adversely affected. The water contaminated by the dump generally stays near the top of the saturated zone and moves toward the perimeter canals. Also, sandy materials act as filters, removing some contaminants as the ground water flows away from the dump.

J. W. Stewart and A. D. Duerr studied inactive and active landfill sites to determine the effects that solid-waste disposal, in a sand aquifer having a high water table, would have on the water resources in the Tampa area. The sites investigated are underlain by the Floridan aquifer (highly permeable limestone), the source of most ground-water supplies in west-central Florida. At inactive landfill sites 8 to 11 yr old, water hardness and concentrations of chloride, sodium, calcium, potassium, and iron in water in the shallow water-table aquifer showed slight increases over the previous year and were as much as 2 to 70 times greater than background levels. At active landfill sites that have been in operation for 3 yr, no significant changes in conductivity, hardness, chloride, and iron were observed in wells near an oxidation pond and a perimeter canal. No noticeable changes in chemical quality of the water in the Floridan aquifer have been observed to date at either the inactive or active landfill sites.

A study of the effects of land disposal of solid wastes and septic-tank sludge on the water resources is being conducted at St. Petersburg's Toytown landfill. Solid-waste trenches and sludge reservoirs are in a surficial aquifer with a high water table. The surficial aquifer is a 23-ft-thick fine sand, which grades downward to a 27-ft-thick dense clay bed. The clay, which is the confining bed for the underlying limestone (Floridan aquifer), hydraulically separates the two aquifers. According to J. W. Stewart and C. B. Hutchinson, the lower two-thirds (10 ft) of the filled trenches and reservoirs are saturated with ground water from the surficial aquifer. Concentrations of chloride greater than 5,000 mg/l and specific conductance values greater than 19,000 μmhos were observed in some shallow wells at the landfill. Water in some peripheral ditches has a total coliform count of 10,000 individuals per 100 ml of sample. Although the landfill has been in operation for several years, no contamination from the solid waste or sludge has been detected in the water of the Floridan aquifer.

Hawaii

K. J. Takasaki assessed the practice of subsurface disposal of wastes in Hawaii. The assessment included an inventory of information on the waste, disposal sites and methods, receiving aquifers, and related water quality. An inventory of surface waste-disposal sites and an outline of areas in sugarcane irrigation were also made because the generally pervious surface rocks in Hawaii allow leachates from these sources easy access to underlying ground-water bodies. There were about 200 surface and subsurface waste-disposal sites in use at the end of 1972, and about 110 additional sites were under consideration. Most of them are subsurface disposal sites for small volumes of treated and untreated sewage in areas where there are no municipal sewer facilities. However, municipal sewer facilities planned for many of the areas where development has been heavy will eliminate the necessity of maintaining many of the disposal sites. Irrigation reuse and onsite subsurface disposal of the treated sewage effluent from municipal sewage-treatment plants are being contemplated for many of the dry areas. In one area, subsurface disposal of 6 Mgal/d by injection wells is planned.

Kansas

Geologic mapping by H. G. O'Connor and J. R. Ward (Kansas Geol. Survey) delineated two areas near Kansas City that meet geologic and hydrologic criteria for sanitary landfills. The areas are (1) underlain by 50 ft or more of unsaturated loess and glaciofluvial deposits, (2) easily excavated because the material is mostly silt and clay, (3) not subject to flooding, and (4) accessible from good all-weather roads.

New York

At Catskill, leachate beneath 25 ft of municipal landfill about 6 mo old had a specific conductance of 18,000 μmhos per cm (at 25°C) and COD of 22,400 mg/l, according to A. D. Randall. The leachate contained various trace metals whose concentrations ranged from 10 to 4,500 μg/l, but it contained no detectable pesticides. Flow through underlying glacial gravel and sand carried leachate at least 400 ft in less than 12 mo. At this distance, concentrations of most constituents were 0.25 to 5 percent of the concentrations under the landfill.

LAKES

J. F. Ficke and T. W. Danielson completed a reconnaissance of lakes in the northern Front Range urban corridor of Colorado. The area contains more than 280 lakes with surface areas greater than 2 hectares (5 acres). Samples and field measurements from the 117 lakes greater than 10 hectares (25 acres) showed that the waters of 28 have specific conductance greater than 1,500 μmhos/cm and that seven have specific conductance greater than 4,500 μmhos/cm. Specific conductance of more than one-half of the lakes is less than 750 μmhos/cm. Almost all of the lakes are alkaline, and about two-thirds contain water with a pH greater than 8.5. Secchi disk transparency ranges from 0.05 m (0.16 ft) to 3.6 m (11.8 ft). A transparency of less than 1.0 m (3.3 ft) was found in about two-thirds of the lakes larger than 10 hectares.

Algal counts on samples from the 23 largest lakes ranged from 77 to 13,000 cells per ml. *Oscillatoria* was the most common dominant genus and usually dominated the lakes with the larger algal populations.

WATER USE

Supply-demand relationships of water in the United States

C. R. Murray (1973) analyzed water-use records collected for 1970 (C. R. Murray and E. B. Reeves, 1972) to establish empirical relationships between supply and demand for water in water-resource regions in the conterminous United States. By more precisely determining present use and dependable supply, future water-supply development necessary to meet optimum levels for the various regions of the United States can be determined. An important element in determining the extent to which the dependable supply can be increased is the evaluation of the amount by which the supply will be augmented by increasing reservoir capacity. C. H. Hardison (1972) determined the amount of storage required for a given draft rate combined with a given probability of deficiency. Hardison also evaluated effects of water price on development.

An assessment of the 1970 water-use–water-supply relationships in the United States showed that in the eastern regions sustained, dependable streamflow is generally the most important element in meeting demands, whereas in the western regions, where the level of development is generally high because of lack of dependability of streamflow, storage is especially important in meeting demands. This difference of importance of streamflow in relation to storage results in fairly low values for the ratio of withdrawal to dependable streamflow, with accompanying high values of the ratio of withdrawal to dependable supply, in the East (20 and 44 percent, respectively, for the New England region); the opposite is generally true for the western regions where the ratio of withdrawal to dependable streamflow is high and the ratio of withdrawal to dependable supply is comparatively low (720 and 360 percent, respectively, for the Lower Colorado region). In the Southwest, high ratios of ground-water withdrawals (Texas Gulf, 30 percent; Arkansas-White-Red, 55 percent; Rio Grande, 38 percent; Lower Colorado, 62 percent; and California-South Pacific, 38 percent) to surface-water withdrawals have permitted withdrawals far in excess of both dependable streamflow and dependable supply.

Ground-water use in parts of west-central Florida

The quantity of ground water withdrawn in the upper Peace and upper Alafia River basins in Florida during 1971 was about 120 Ggal. This quantity represents a reduction of about 16 percent from the total withdrawn in 1968 when withdrawals were the highest ever recorded. A. F. Robertson and L. R. Mills reported that industrial water use accounted for 63 percent of the total. Irrigation and municipal withdrawals accounted for 27 percent and 10 percent of the total 1971 withdrawals, respectively.

Revised estimate of water use in Georgia in 1970

R. F. Carter and A. M. F. Johnson reported that a revised estimate of water use in Georgia in 1970 indicates that withdrawal use was nearly 5,560 Mgal/d. Of this amount 3,940 Mgal/d (71 percent) was used by thermoelectric powerplants for cooling, 930 Mgal/d (17 percent) was used by self-supplied industry, 560 Mgal/d (10 percent) was used for public supplies, and 120 Mgal/d (2 percent) was used for rural purposes.

Water used by thermoelectric powerplants was withdrawn mainly from surface-water sources; for other withdrawal uses, 920 Mgal/d was withdrawn from surface-water sources and 690 Mgal/d was withdrawn from ground-water sources.

Total industrial use of water, excluding thermoelectric powerplant withdrawals, is estimated as 1,130 Mgal/d. More than half of this amount, 720 Mgal/d, was used by industries manufacturing paper and chemical products.

Effects of irrigation development in western Kansas

S. E. Slagle (USGS) and E. C. Weakly (Kansas Geol. Survey) reported that 30 percent of the original ground-water reserves have been mined in parts of Greeley and Wichita Counties, western Kansas. Records from 1,020 large-capacity wells in the area indicate that about 200,000 acre-ft of water is pumped annually for irrigation. The water is withdrawn from the Ogallala Formation, which yields as much as 1,700 gal/min to individual wells.

Use of ground water for irrigation in area west of Lincoln, Nebraska

E. K. Steele, Jr., reported that records of pumpage for selected irrigation wells in Seward, York, Hamilton, and Clay Counties indicate that ground-water withdrawals during 1972 totaled about 640,000 acre-ft. The resultant net lowering of water levels in wells from spring to fall averaged 2.24 ft. How much ground-water storage was depleted by the pumping cannot be determined until water-level measurements are made in the spring of 1973, when water levels will have had time to recover from the summer withdrawals and again become stabilized. As precipitation during the 1972 irrigation season was more favorable than during the 1971 irrigation season, depletion of ground-water storage due to pumpage in 1972 probably was less than in 1971, when pumpage of 874,000 acre-ft reduced storage about 268,000 acre-ft. The number of irrigation wells in the four-county area continues to increase. New installations—209 in 1971 and 233 in 1972—have increased the total number of registered wells to 5,452.

INTERNATIONAL HYDROLOGICAL DECADE, 1965–74

The USGS continued its participation in the 10-yr program of cooperative IHD studies in scientific hydrology. The network of 82 river stations for observing and recording streamflow, chemical quality, and suspended-sediment load was maintained. This network provides a general index of the discharge of surface water and of dissolved and suspended material from the continent to the oceans. Collection of hydrologic data also was continued at 23 lake and reservoir stations and at 34 selected observation wells; these stations provided information on the chemical quality of lake, reservoir, and ground waters and on water levels.

Hydrologic benchmarks were established early in the decade and 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 tritium in precipitation at 16 localities, are being used to evaluate the effect of precipitation on the chemical character of inland waters.

Hydrologists of the USGS participated in international symposia, seminars, meetings of working groups, intercountry exchange of experts, discussions of selected activities chosen for particular years, and hydrologic research at selected areas in the United States where the results are expected to have international interest or application.

E. L. Hendricks, Chief of the U.S. delegation, participated in the eighth session of the Coordinating Council for the IHD in Paris in May 1973.

R. L. Nace participated in the second session of the Sub-Group on Hydrological Maps of the IHD Working Group on Water Balances, in Paris, Nov. 27–Dec. 1, 1972. As a member of the U.S. National Committee for the IHD, Nace also represented the United States at a meeting of the Canadian National Committee for the IHD in Charlottetown, Prince Edward Island, in early June 1973.

G. H. Davis continued his activities for the IHD as chairman of the Working Group on Ground-Water Studies.

R. L. Cory continued water-quality monitoring and studies of the epifauna in South River, Rhode River, and West River—small estuarine tributaries on the west side of Chesapeake Bay in Anne Arundel County, Md.

Allen Sinnott and R. L. Nace continued bathymetry and bottom-sediment studies in the Rhode River estuary.

Under the direction of M. F. Meier, monitoring of selected glaciers in Alaska and in the Western States was continued by L. R. Mayo, W. V. Tangborn, and R. M. Krimmel. Meier and Krimmel presented papers at the International Symposia on the Role of Snow and Ice in Hydrology, sponsored by UNESCO, the World Meteorological Organization, and the International Association of Hydrological Sciences, held at Banff, Alberta, in September 1972.

O. M. Hackett and R. W. Carter participated in the fourth session of the Commission for Hydrology, World Meteorological Organization, as members of the U.S. delegation in April 1972 in Buenos Aires, Argentina.

International Field Year for the Great Lakes

Additional progress was made during the year on studies related to the IFYGL—a joint contribution by the United States and Canada to the IHD. E. C. Rhodehamel, G. K. Schultz, and W. N. Embree continued hydrologic observations in the sector of Lake Ontario basin that lies within the United States.

MARINE GEOLOGY AND HYDROLOGY INVESTIGATIONS

MARINE AND COASTAL GEOLOGY

Wide-ranging investigations of the character and resources potential of offshore areas of the Nation and other selected marine regions were pursued during fiscal year 1973. Areas studied were the Atlantic continental margin, the Gulf of Mexico, Caribbean Sea, and the Pacific continental margin including Hawaii and Alaska. Other studies were conducted in the Pacific Ocean, Red Sea, offshore Liberia and Peru, and for the United Nations as an international seabed assessment. Tools for the studies included shipboard oceanographic, geological, and geophysical surveys, laboratory analyses, and aerial and ERTS photographs.

The possibility of an energy shortage for the United States focused attention on the offshore regions of the country and their potential for supplying additional petroleum and natural gas. To provide publicly available information on the geology, structure, and energy potential of the outer continental shelf, exploration of the Atlantic continental margin was intensified, initially in the vicinity of Georges Bank. Geological, geophysical, and associated environmental investigations are intended to help provide a background of information useful in assessing leasing questions as well as environmental problems and risks. Many investigations involved cooperation with other Federal agencies, State governments, universities, oceanographic institutions, and international organizations.

ATLANTIC CONTINENTAL MARGIN

Gravity measurements in the vicinity of Georges Bank

J. D. Hendricks, J. M. Robb, and J. C. Hathaway found that gravity measurements confirmed the presence of mafic and felsic intrusive bodies along the northern edge of Georges Bank. These bodies are inferred to be elongate in a northwest-southeast direction concurrent with regional trends and are at least 20 km in minimum lateral dimension. Readings on the bank show a Bouguer low which corresponds to the Georges Bank trough (Maher, 1965); the low can be reproduced theoretically using published data concerning the densities and configuration of the rocks involved. The thinning of the crust from continental to oceanic is noted by an abrupt change in the gravity gradient near the southeast edge of Georges Bank.

The present gravity data are not adequate to confirm or reject the hypothesis of a major fault along the northern edge of George Bank. The change in the gravity field from the anomalous area of alternating highs and low with gradients up to 1.5 mGal/km north of the bank to the smoother field with gradients ≥ 1 mGal/km on the bank is fairly abrupt and occurs over the north edge of the bank. This result would support the suggestion of a fault.

Detailed seismic profiling of Georges Bank

Sites for potential test borings on Georges Bank were evaluated by J. C. Hathaway and co-workers by means of detailed continuous seismic profiles. The use of a pulse shaper on a 40 in.^{3} air gun permitted high resolution profiling on a 1-mi spacing of lines in several areas along the inner, or northern, margin of the bank. Stratigraphic interpretation is presumptive because of the lack of outcrop or subsurface control, but a wedge of presumed Cretaceous beds which dip gently southeastward emerge from a cover of flat-lying presumed Tertiary beds on the western end of the inner edge of the bank and toward the eastern end where the inner edge of the bank curves to become the Northeast Channel. All the subcrops of presumed Cretaceous and Tertiary beds, although covered by a banket of Pleistocene deposits, should be within easy reach of shallow core drilling.

Petroleum possibilities on the continental shelf, northeastern United States

Geological and geophysical studies by R. Q. Foote have identified geologic structures on the continental shelf of the northeastern United States. Sedimentary rocks are considerably thicker (more than 10 km in the Baltimore Canyon area and 8 km on Georges Bank) than previously recognized beneath parts of the shelf. Major deltaic sequences of Cretaceous age are recognized on the coastal plain and probably extend across the shelf. Marine sandstone and carbonate rocks interfinger with fluvial rocks of the deltas. These relations may provide both structural and stratigraphic traps for the accumulation of petroleum.

Continental rise sedimentation

Under contract to the USGS, M. E. Field and O. H. Pilkey (Duke Univ.) (1971) compared piston cores obtained on two portions of the North Carolina continental rise. In the Hatteras Canyon vicinity turbidite sands are an important component of the sediment column. Within a short lateral distance, usually less than 10 mi, these sands essentially disappear, and the rise appears to have been formed by bottom rather than turbidity currents. Extrapolating these results to the entire Atlantic continental margin and considering the wide spacing of submarine canyons, it is probable that bottom currents are the major process responsible for rise formation.

The shape of turbidites

B. D. Bornhold and O. H. Pilkey (Duke Univ.) (1971) mapped six individual turbidites on the floor of the Columbus Basin, a deep reentrant in the southern Great Bahama Bank. The study is based on 30 closely spaced piston cores. The flows have occurred in Columbus Basin with a frequency of about one every 3000 to 6000 yr and have resulted in turbidites with volumes of the order of 10^8 m^3. The individual flows are tongue shaped. Since the areal extents of single flows have not previously been mapped, a unique basis is afforded for calculation of the dynamic characteristics of turbidity currents.

GULF OF MEXICO

Bands of turbid water along the Texas coast

Water analyses, NASA aerial photography from an altitude of 60,000 ft, and ERTS–I imagery were coordinated to describe water turbidity off the south Texas coast during August 1972. This work by R. E. Hunter showed that plumes of turbid water were being formed by ebb-tidal discharges from the bays through tidal passes and were being diverted southward by the coastwise drift. For a distance of more than 36 mi south of Aransas Pass, high suspended-sediment concentrations were found in a zone extending from the shoreline to about 1.5 mi offshore and in another zone from 4 to 7 mi offshore. These turbid zones were separated from each other and bounded on the seaward side by zones of relatively clear water. The outer band of turbid water impinged on the shore about 75 mi south of Aransas Pass.

The occurrence of the bands of turbid and relatively clear water suggests the existence of large-scale helical circulation cells having axes almost parallel to shore. The impingement of a turbid water mass onto the shoreline suggests that some, and perhaps most, of the suspended sediment in nearshore waters may not have been stirred up from the nearshore sea floor but may have traveled long distances in the water mass, perhaps even having remained in suspension from the time of its entry into the gulf through tidal inlets such as Aransas Pass.

Nearshore mapping and sedimentology, south Texas coast

The Gulf of Mexico sea floor off Padre Island, Tex., was sampled to a depth of 20 m by R. E. Hunter and G. W. Hill as part of a project to map the offshore area of the South Bird Island quadrangle on a scale of 1:24,000. The sampling resulted in the definition of several depth-related geomorphic zones, sediment facies, and infaunal and epifaunal benthic communities.

The most prominent geomorphic feature seaward of the nearshore bar-and-trough system in this area is a terrace at a depth of 11 to 15 m that interrupts the otherwise smoothly concave profiles. A seaward transition from sand to sandy mud occurs near the seaward edge of this terrace. The terrace may not mark a former stand of sea level but rather may result from differing resistance to reworking on the part of sands and muds deposited since the sea reached nearly its present level.

The upper 1 to 2 m of sediment in the sandy mud facies consists of bioturbated sandy muds interbedded with undisturbed silty clays, some of which grade downward into sand. The silty clay beds and graded units rest with sharp contacts on bioturbated sandy muds and are interpreted to be storm deposits.

Major salt-dome province off Texas and Louisiana

On the basis of interpretation of seismic reflection profiles from a cooperative USGS-Navy cruise of the USNS *Kane* and later from the USNS *Keathley*, R. G. Martin, Jr., reported that an area of more than 100,000 km^2 on the Texas and Louisiana slopes in water depths ranging from 200 to 3,000 m contains a high density of salt domes and related structures that have a high potential for oil and gas entrapment. The structures are closely spaced (6–16 km) in the area east of long. 94° W. but are much less numerous in the slope south of Galveston and east of Corpus Christi, Tex., possibly because of the influence of the seaward extension of the San Marcos arch. East of long. 94° W. the domes appear to be interconnected at subbottom depths shallower than 2 km (2 seconds). The diapiric structure of the slope is abruptly terminated along the Sigsbee Escarpment, which is lobate in outline along the foot of the slope but which strikes abruptly northeast from near long. 91°30′ W. upslope into the upper Mississippi fan where the domes seem to be concentrated only in water depths shallower than 2,000 m. In the region south of the Louisiana coast, the domal structures appear to have a crude northeast–southwest lineation; west of long. 93° W. the domes are more randomly oriented with a suggestion of north–south trends.

These preliminary findings suggest that the central part of the Texas and Louisiana slope between long. 9° W. and 91° W. may have been the site of an upper Cenozoic submarine fan which placed sufficient load on underlying sediments and Louann Salt so that massive diapiric intrusions resulted. This is consistent with the evidence of a major late Tertiary to early Quaternary depocenter beneath the adjacent outer shelf and evidence adapted from JOIDES drilling that Pliocene and Pleistocene beds thicken appreciably into the slope adjacent to the Sigsbee Escarpment. The area of concentrated domes in the upper Mississippi fan may indicate that either sufficient loading to produce diapirism lower down on the fans has not yet occurred or that salt is not present there in sufficient thickness to behave diapirically or a combination of both.

Bouguer anomaly map, Gulf of Mexico

H. L. Krivoy, H. C. Eppert, Jr., and T. E. Pyle are compiling a gravity map of the Gulf of Mexico at the same scale (1:2,500,000) and with the same density assumption (2.67 g/cm^3) as that of Woollard and Joesting's Bouguer anomaly map of the United States. The Bouguer field of the Gulf of Mexico appears to be similar to that found in other small seas, but an accurate comparison must await more complete mapping over other small ocean basins. The greatest positive Bouguer contour in the gulf basin is +250 mGal whereas large basins exhibit Bouguer maxima more than 100 mGal greater.

Regional tectonic implications of the gravity map of the Gulf of Mexico include a relatively uncomplicated relationship between continental and oceanic crust around the western gulf. The eastern Gulf of Mexico has a complex gravity pattern, particularly beneath the west Florida shelf and beneath the Yucatan Peninsula. On both regions, the continental margins seem to be partly underlain by areas of thin crust. The gravity pattern over the central and northern region of the Yucatan Peninsula displays a north-south tectonic axis but trends northeasterly over eastern Yucatan which appears to rest on a plate having quasi-oceanic geometry. A well-formed Bouguer trough between the Yucatan Peninsula and Cuba provides a clear geophysical division between the Gulf of Mexico and the northwestern Caribbean Sea.

Distribution of metals in estuarine sediments

C. W. Holmes reported the distribution of zinc, cadmium, and lead in sediments and water of Corpus Christi Bay as determined by atomic absorption and polarographic methods. Large concentration gradients exist across the bay with the highest values near the harbor. Superimposed on these gradients are secondary patterns which reflect the prevailing currents active in the bay. Measurements of the dissolved metal content of the harbor water reveal that these elements exist in high concentration (50–200 p/b) in the surface oxidized water which is apparently the primary metallogenic effluent entering the bay. A secondary source of metals, in particular lead, that enter the bay is from storm drains.

Mercury content insignificant in sediment of Florida Bay

According to a reconnaissance survey by J. G. Palacas, mercury in the uppermost layer of sediment from Florida Bay ranged from <0.01 to 0.03 p/m as a percentage of dry weight of sediment. Two samples of peat and lower sediment contain 0.04 to 0.06 p/m mercury. Three of the most prominent marine plants, the marine grass, *Thalassia,* and two algae, *Penicillus* and *Halimeda,* in Florida Bay and in the Florida "reef tract," contain 0.01 to 0.02 p/m mercury.

The mercury contents in the surficial sediments of Florida Bay are indeed very low when compared with those of other aquatic environments near urban areas. For example, the average mercury content in the uppermost sediments of southern Lake Michigan and San Francisco Bay are 15 to nearly 40 times greater than the average concentration in Florida Bay (approx 0.01 p/m). Therefore, the mercury content in the sediments of Florida Bay are considered as background levels and are not due to manmade mercury pollution.

CARIBBEAN SEA

Tectonic map of the eastern Greater Antilles region

A preliminary tectonic map was completed by L. E. Garrison, R. G. Martin, Jr., and H. L. Berryhill (USGS) in cooperation with M. W. Buell, Jr., and H. R. Ensminger (U.S. Naval Oceanographic Office) and R. K. Perry (U.S. Naval Research Laboratory) (1972). The map combines 200-m bathymetric contours, stratigraphy, igneous geology and tectonics, and a residual magnetic anomaly map to include Puerto Rico and the Greater Antillean islands. Several offices of the Commonwealth of Puerto Rico also cooperated in providing data for the compilation.

Caribbean tectonic study indicates major structures extend from offshore to onland areas

J. E. Case and E. A. Silver indicate that a major foldbelt of Tertiary sedimentary rocks extends from Curacao Ridge, north of the Netherlands Antilles, west-southwest along the continental margin of Colombia. The foldbelt strikes onshore near Cartagena and forms the Sinu-Atlantico basin of northwest Colombia.

J. E. Case discovered that the basement rocks of eastern Panama are pillow basalts with associated deep-sea sedimentary rocks. The basement highlands are the site of strongly positive gravity anomalies, and the basement is interpreted to be a raised segment of oceanic crust. O. L. Bandy (Univ. of Southern California) and R. E. Casey (Rice Univ.) identified Campanian(?) Radiolaria from cherts associated with the basalts. The Campanian basement is essentially an exposure of seismic reflecting horizon B which is widespread in the Caribbean Sea.

PACIFIC COAST

Southern California borderlands—reactor site and other studies

H. C. Wagner (USGS) and S. C. Wolf (Atomic Energy Comm.) interpreted a large, nearly continuous anticlinal structure offshore from a proposed reactor site near Point Conception. A fault associated with this structure intersects and may displace a southwest-striking fault that is shown by J. I. Ziony to have had late Quaternary movement onshore. The structural relations at the offshore junction of the two faults are not clearly shown by the available geophysical data, but the tectonic pattern requires late Quaternary left lateral movement on the fault block to the north of the east-west fault. Preliminary interpretations farther south and east of Point Conception suggest that the east-west offshore tectonic pattern extends southward to and slightly beyond the Channel Islands and eastward to the Santa Monica area onshore. (See also U.S. Geological Survey, 1971a, p. A167.)

Monterey Bay, California

H. G. Greene (Greene and others, 1973) continued a study of the geology of Monterey Bay and adjacent continental shelf and slope with emphasis on detection and mapping of active faults and geologic hazards.

Results of analysis and interpretations of bedrock samples and data collected in Monterey Canyon by a research submersible and cores obtained from the axis of the canyon indicate that the headward part of the canyon is not active, as there is no evidence to suggest active sediment transport down the canyon. Sedimentary structures, such as current ripples and (or) scour depressions, were not observed in the canyon axis during the submersible dives, and no turbidite units were identified in the gravity cores. Seismic profiles across the canyon show numerous slumps on the canyon walls, many of which have slid across the canyon axis. It appears that some of the slumps have blocked the axis of the canyon, thereby effectively curtailing down-canyon transport of sediments by damming and pooling any sediments that may enter the canyon head.

New geophysical data substantiate the existence of a fault buried beneath, and running parallel to, the headward axis of Monterey Canyon and suggest that the canyon, in part, is structurally controlled. These new data also make it possible to map the granitic basement surface underlying Monterey Bay. Basement is deepest in the center of the bay, on the north side of the canyon, where it lies buried approximately 5,000 to 6,000 ft beneath upper Tertiary sediments.

To the north and south of Monterey Bay several generally north-south trending bedrock ridges and shallow (1,000 ft thick) linear sedimentary basins have been mapped. To the south of Point Sur these structural basins and ridges are fault controlled with some faults showing substantial (20–30 ft high) sea-floor scarps. Recent seismicity in this area suggests some of these faults are active today.

Central California: Geophysical study of Santa Lucia Bank

E. A. Silver, R. E. von Huene, and H. G. Greene report that geophysical profiles between Point Conception and Point Sur show a major northwest-trending group of faults, the longest of which is termed the Lucia fault. Maximum offset of the sea floor is 150 m along this fault. A major unconformity on the bank separates highly deformed rocks below from unfolded sediment above. The age of unconformity is not known, and it now lies 600 m below sea level.

Chloride in rainfall

The detailed variation of chloride in rainfall was studied by V. C. Kennedy, R. J. Avanzino, and G. W. Zellweger for a single large storm which occurred in the period January 19 to 23 in the Mattole River basin of northern California. Sequential samples representing successive 0.25 cm of rainfall were analyzed and commonly found to contain 0.5 to 3 mg/l chloride when the rate of precipitation was less than about 0.25 cm/hr. When the rate of precipitation exceeded about 0.25 cm/hr, the chloride concentration decreased to less than 0.02 mg/l chloride. A short-duration hailstorm occurred at the end of the major storm period, and precipitation then had a concentration of approximately 38 mg/l. The position of the collection station about 6.5 km east of the Pacific Coast line, varying wind direction, and great turbulence associated with the hailstorm are thought to account for the 38 mg/l chloride value. Nevertheless, the difficulty of getting representative samples of average rainfall in the area is evident when a single constituent, such as chloride, can vary by more than two orders of magnitude during one storm period.

Phytoplankton-zooplankton abundance and estuarine stagnation, San Francisco Bay, California

Investigation of plankton productivity by D. H. Peterson and T. J. Conomos show that maximum populations in the San Francisco estuary occur where the landward-flowing density current and the seaward-flowing Sacramento and San Joaquin River currents result in stagnation. During summer, the period of highest phytoplankton-zooplankton abundance, river inflow is low and the nontidal river current is weak (<2 cm/s) relative to the density current (5–15 cm/s); that is, the influence of density currents on water-replacement time (residence time) seems greater than the influence of the estimated river current. Assuming that water-replacement time significantly increases with density current stagnation, water-replacement time may be a major control on the distribution of phytoplankton-zooplankton populations in northern San Francisco Bay. Investigations of phytoplankton indicate higher populations for low riverflow summers (1968, 1972) than for a summer of high riverflow (1971).

Holocene and Pleistocene tidal flat sediments, Willapa Bay, Washington

H. E. Clifton and R. L. Phillips studied the texture, composition, structure, and fauna of exposed tidal flats and submerged tidal channels in Willapa Bay as well as emergent Pleistocene terrace deposits enclosing three sides of the bay. Both tidal material and terrace deposits show similar assemblages of lithology and fossils. This combination of modern and ancient deposits affords an opportunity to develop a detailed facies model for an estuarine deposit in which the individual facies can be related to originating processes within the estuary.

Sedimentation in small stream mouths, southern Oregon

Depositional structures and processes in the mouths of small streams indicate that these structures reflect the magnitude of stream discharge. The studies by H. E. Clifton, R. L. Phillips, and R. E. Hunter also demonstrated that systematic changes occur on a seasonal basis. These changes not only control the nature of deposition and the orientation of directional structures but also the distribution of fauna, including benthic forms, and the discharge of effluents within the estuary.

Geologic study in the Straits of Juan de Fuca

Participants in a cooperative study—P. D. Snavely, Jr., N. S. MacLeod, H. G. Greene, and J. E. Case of the USGS, and D. L. Tiffin and other members of the Canadian Geological Survey—completed a 12-d cruise aboard the Canadian RV *Parizeau.* Preliminary interpretation of selected seismic reflection profiles and magnetic data indicate that the top of the lower and middle Eocene Metchosin

Volcanics can be traced from their outcrop along the southern part of Vancouver Island into the Straits of Juan de Fuca; in the central part of the straits they lie at shallow depths beneath the sea floor. Upper Oligocene sedimentary rocks that fringe the south side of Vancouver Island can be traced southward where they are gently folded beneath the straits and appear to be truncated by a major fault near the coast of the Olympic Peninsula. South of this fault along the Olympic coast, a much thicker (>6,000 m) marine clastic sedimentary sequence ranging in age from middle Eocene to middle Miocene crops out. Magnetic data contoured by D. L. Tiffin show that a major fault extends southeast from Victoria across the eastern part of the straits, and another fault trends obliquely across the western part of the strait near Cape Flattery, Wash. These two faults appear to be eastern and western seaward extensions of the Leech River fault of southern Vancouver Island which separates Eocene Metchosin Volcanics from pre-Tertiary phyllites that lies north of the fault. Although a major offset of basement rocks along this fault can be demonstrated, upper Oligocene and younger sedimentary rocks on the Vancouver coast and beneath the straits do not appear to be deformed along the trace of the fault. High resolution CPS (continuous seismic profiling) records show the detailed stratigraphy and structure of upper Pleistocene glaciofluvial deposits. Units interpreted from the records include till sheets, moraines, bedded outwash gravels, prograded deltaic deposits, channel fills, ice collapse and submarine landslide features, beach and constructional terrace deposits, and large asymmetric sand waves.

ALASKA-ARCTIC INVESTIGATIONS

The role of sea ice in the marine geological environment of the Beaufort Sea Shelf, Arctic Alaska

Fieldwork by Erk Reimnitz, P. W. Barnes, S. C. Wolf, C. A. Roderick, T. C. Forgatsch, and C. W. Gustafson revealed that sea ice is an important agent in the marine geologic environment of the Arctic shelves (Erk Reimnitz and others, 1972).

Forces of the Arctic pack ice are commonly transferred to the sea floor and coast, and during the open season the movement of solitary ice pieces by wind and current is often retarded or stopped by bottom contact. Bathymetric, side-scan sonar, and high-resolution seismic records, coupled with extensive diving observations and surface observations, were evaluated in this investigation. Pressure ridge ice and ice islands gouge the sediments to a water depth of at least 60 m; smaller pieces of pack ice similarly affect the inner shelf and beaches. According to direct bottom observations on the inner shelf, sediments plowed up into ridges are unstable. In this area the bottom is reworked frequently by ice and other marine agents. In cohesive sediments of the outer shelf, gouges are better preserved. As a result of the gouging, bedding in the Holocene marine sediments appears disrupted in seismic records, and internal sedimentary structures generally are disturbed in box cores. Evidence for ice rafting is scarce. Where currents move ice, the flow of water around grounded chunks is intensified and turbulent, and rapid reworking and resuspension of bottom deposits results. The formation of permafrost by conductive heat transfer through ice probably occurs largely inside the 2-m-depth contour, where seasonal fast ice rests on the bottom (Erk Reimnitz, 1971; Erk Reimnitz and K. F. Bruder, 1972; and Erk Reimnitz and P. W. Barnes, 1972).

Arctic coastal processes elucidated by ERTS—1 imagery

P. W. Barnes, Erk Reimnitz and J. V. A. Trumbull used ERTS-1 images to show that active sedimentological processes along the Arctic coast are initiated by the melting, flooding, and eventual overflow of rivers onto sea ice. It is now apparent that only minor amounts of sediments are transported offshore at this stage; however, scouring of the bottom is significant beneath the strudels (drain holes) which develop in the fast-ice canopy in the region of overflow (P. W. Barnes and Erk Reimnitz, 1972).

Later during the period of maximum sea-ice melt (late June and July), temperatures and turbidities decrease offshore while salinities increase and then decrease as the pack ice is approached offshore. Patterns of salinity and turbidity as shown by the imagery conform with a consistent influx of colder, clearer, saltier water to the coast just east of the Colville River. Strong (up to 3 knots) bidirectional but intermittent currents often manifest themselves as wakes behind grounded ice. Ice movement vectors generated from repetitive images indicate that drift is closely associated with wind direction especially in shallow bays where displacements of 4 to 22 km were noted in 24 h. Nearshore topographic highs serve as loci of grounded ice whose keels are of sufficient depth. Side scan sonar data confirm these areas to have been intensively gouged by ice.

Baseline sediment data for the Beaufort Sea

Sediment samples gathered from shipboard along the Arctic coast of Alaska during the past 3 yr by P. W. Barnes, Erk Reimnitz, and J. V. A. Trumbull constitute a suite of samples which form a baseline data bank for the sediments of this little known region.

Textural analyses indicate that the coastal zone out to a depth of 15 m is one of complex sediment types due to the compound influence of river sedimentation, a thin to nonexistent Holocene layer, and probably most important, the churning and bulldozing action of ground ice. The central shelf is dominated by modern silt-size material. Along the shelf break at depths of 50 to 70 m, angular gravels are abundant, primarily as an admixture of silts and clays; sediment-laden ice carried almost exclusively silts and clays.

Geochemical studies of selected elements reveal no indication of anomalous values of copper, lead zinc, cadmium, arsenic, and mercury. In fact, many values are near or below the detection limit of the techniques used. It appears that the areal distribution is partly related to sediment type and partly to the nearness of source areas. The organic chemistry shows bitumen content averaging <0.004 percent of sediment dry weight and a humate content of <0.25 percent of sediment dry weight, indicating low background values relative to other oceanic areas.

River flooding of sea ice on the Beaufort Sea shelf, north of Alaska

In the spring of 1972, Erk Reimnitz, P .W. Barnes, C. A. Roderick, and T. C. Forgatsch investigated the unique effects of the Kuparok River on the marine environment along northern Alaska's coast near Prudhoe Bay. The rivers of northern Alaska start flowing prior to the melting and breakup of sea ice, and the phenomena associated with the overflow significantly influence the sedimentary processes of the inner shelf. The Kuparok River discharges into a shallow lagoon behind a chain of barrier islands. River water advanced along a lobate front from the delta and inundated the sea ice at rates of 15 to 30 cm/s, with higher velocities in the constrictions between the barrier islands (P. W. Barnes and Erk Reimnitz, 1972). This rapidly advancing sheet of fresh water was up to 1 m deep and carried little sediment and virtually no ice, sand, or gravel. Upon passing the 2-m-depth contour, where the ice is not supported by the sea bottom, the weight of water depressed and broke the ice, forming major cracks. Draining of the melt water occurred at drain holes, or strudels (Erk Reimnitz and K. E. Bruder, 1972), which initially developed along these cracks, and at seal holes and ice fractures seaward. Steep-sided depressions, up to 4 m deep, were secured in the sea floor below strudels. These formed mainly outside of the 2-m-depth contour. Similar but less pronounced scour depressions develop later in the lagoon as the ice lifts off the bottom. As draining proceeded, ice in the channel between barrier islands oscillated vertically in a wavelike pattern in response to load changes and swift overflow and underflow. Little if any ice movement is associated with the overflow and melting phenomenon.

Alaskan continental shelf north and west of Point Barrow

Marine geophysical studies in the northern Chukchi Sea and adjacent Arctic Ocean were conducted by Arthur Grantz, B. D. Ruppel, and J. W. Cady (USGS); M. L. Holmes (Washington Univ.), and D. C. Riley (Stanford Univ.) during the 1972 open season. These studies were carried north to 74° lat and onto the continental slope north of Point Barrow and have now covered the entire continental shelf north of Bering Strait and west of Point Barrow that would come under United States jurisdiction through application of the various formulas that have been proposed for defining continental shelf boundaries.

A large province of presumably shale diapirs intrusive into generally flat-lying Tertiary and probably Cretaceous sedimentary rocks was found north and west of Point Barrow. A zone of broad folds and buttress unconformities in sedimentary rocks lying along the projection of the Barrow arch separates the diapiric province from gently southdipping Upper Cretaceous and older petroliferous rocks that underlie Alaska's North Slope.

The continental shelf north and northwest of Point Barrow is underlain by gently north-dipping sedimentary rocks that are thrown into a gentle anticline (in places only a structural terrace) beneath the outer continental shelf. At least two generations of massive slump deposits mantle the north-dipping beds that underlie the continental slope north of the broad shelf-edge structure.

Trace metal content and displacement of surface relict sediments

C. H. Nelson reported that Holocene sandy silt of major Alaskan rivers is being highly dispersed offshore, bypassing much of the Bering Shelf to be deposited in the Chukchi Sea. Box core stratigraphy indicates that offshore sediment from the Yukon and Kuskokwim Rivers forms only very thin (25 cm) layers in the Bering Sea. Rhythmic thin sand interbeds in Yukon sediment of Norton Sound suggest that storm waves over this shallow shelf intermittently resuspend bottom sediments, leaving thin lag layers of sand. Strong northerly currents then displace the suspended sediment northward to the Chukchi Sea. In contrast to the extensive marine dispersal and displacement of Holocene river sediments, anomalous contents of heavy metals in the bottom sediments have not been widely dispersed by normal fluvial and marine processes. Although numerous large cinnabar lode deposits occur along the Kuskokwim River, high mercury content in sediments nearby is rapidly diluted downstream by incoming sediment and (or) lack of heavy particle movement. Within a few tens of miles of large mercury deposits, the mercury content of river sediments is normal. Consequently, normal mercury content is found throughout shoreline and offshore sediments of Kuskokwim estuary and bay. Likewise, where shoreline bedrock sources are nearby in Seward Peninsula, mercury is concentrated on modern beaches but not offshore. The extremely rare, low anomalies of mercury offshore in the Bering Sea can be attributed to Pleistocene continental and valley glaciers that pushed mineral-bearing till offshore into the northern Bering Sea. Transgressions and regressions of the shoreline reworked the glacial moraines to concentrate mercury-bearing minerals in a few local areas of the relict gravel, a process similar to the formation of placer gold deposits

Benthic fauna of the Bering Sea

A study of the species composition, community structure, and ecological relationships of the benthic fauna of the Bering Sea by R. W. Rowland defines five distinctive communities. Previous authors have doubted the existence of a shallow intertidal fauna in the subarctic and arctic because of the traumatic effects of winter sea ice. Rowland finds that although the intertidal zone on open coasts is barren, the lagoons have a distinctive intertidal community that includes taxa tolerant of brackish water. The other communities are in deeper water. Their distribution is mainly governed by substrate and is independent of depth, salinity, and temperature. The paleoecology of fossil assemblages of mollusks, brachiopods, echinoids, and barnacles can be interpreted on the basis of this exceptionally detailed study of the modern fauna, and the effects of environmental disturbance due to underwater mining can be predicted.

Results from deep sea drilling in the Gulf of Alaska

R. E. von Huene participated as co-chief scientist in Leg 18 of the Deep Sea Drilling Project. Cores recovered off Kodiak revealed younger ages and higher rates of sedimentation than previously estimated. Gray-mud turbidites (middle Pliocene to Holocene) that compose more than 75 percent of the first 270 m in hole 178 were deposited rapidly (160 m/m.y.) on the Alaska abyssal plain. Abundant ice-rafted debris in the mud extends back to middle Pliocene time. Below the grey mud the section accumulated much more slowly (about 16 m/m.y.), and it consists of interbedded mud, diatomaceous sediment, and silt and sand turbidites. Sediments of similar lithology fill the trench at site no. 180. From the cores it would be difficult to differentiate by lithology the lower section in hole 178 from the trench fill recovered in hole 180. The overall rate of sedimentation at the present trench axis is 1,000 m/m.y., on the basis of the maximum age (0.9 m.y.) of trench-filling sediment.

On the steep 2,000 m ridge of the lower continental slope (hole 181), the drill first penetrated a sequence of deposits 169 m thick, similar to those normally found on the lower continental slope. Drilling then became difficult, as the bit suddenly entered very hard, deformed mudstone which also contained abundant ice-rafted lithic clasts. This sediment, which yielded Pleistocene diatoms, appears to have undergone extensive dewatering. Its original site of deposition is difficult to recognize because the sediments recovered from the abyssal plain, the trench, and the lower slope cannot as yet be differentiated with confidence by their lithologies. The lithology of the mudstone, however, is significantly different from the pebbly muds and sands that accumulated on the upper continental slope.

The major conclusion from these data is that steep slopes of acoustic basement commonly seen in seismic records across the landward wall of the Aleutian Trench need not be composed of older lithified sediment but may instead be young trench or abyssal plain sediment that has been highly deformed. Brief summaries of the data have been reported. (R. E. Von Huene and others, 1971)

Younger volcanic rocks in the Aleutian-Bering sea region

D. W. Scholl reported the discovery, by dredging, of a submerged field of upper Cenozoic dacite domes west of Buldir Island, the westernmost upper Cenozoic Aleutian volcano. Scholl also reported finding andesitic flows of early Pliocene age at the westernmost tip of the 2,200-km-long Aleutian Ridge. Late Cenozoic volcanism had not been suspected west of Buldir Island. Potassium-argon dating of feldspar microlites in tholeiitic basalt recovered by drilling (DSDP site 191) in Kamchatka Basin, western Bering Sea, indicated that mafic magmatism last took place here in the middle Oligocene. This occurred after the adjacent Aleutian Ridge had formed. Dredging revealed that Shirshov Ridge, which flanks the basin to the east, is underlain by andesitic rock and ceased growing volcanically in early or middle Miocene time. Thus, volcanism along the Aleutian Ridge has been sporadic but generally continuous since at least the early Tertiary, but north of the ridge, beneath the floor of the deep Bering Sea, magmatism has not been widespread since about the middle Miocene. Emplacement of mafic magma north of the ridge does not appear to have involved significant crustal dilation or southward migration of the Aleutian Ridge.

GENERAL OCEANIC AND INTERNATIONAL STUDIES

Transatlantic geophysical profiles, Liberia to St. Thomas

Survey members of the Woods Hole Marine Geology office, led by J. M. Robb, reported continuous bathymetric, seismic reflection, magnetic, gravity data, and 18 wide-angle seismic reflection and refraction lines on a route from Monrovia, Liberia, to St. Thomas, U.S. Virgin Islands. Geomorphic features crossed included the African continental margin, the Sierra Leone Basin and rise, southeast Cape Verde Basin, Mid-Atlantic Ridge and fracture zone, and northern Guiana Basin.

Geophysical surveys made from the RV *Unitedgeo I*, combined with earlier surveys and available geologic information, provide the basis for interpreting the structure of the continental margin of Liberia. The work was carried out by J. S. Schlee (1972) and co-workers.

The Cape Palmas and Grand Cess fracture zones, identified in the area southeast of lat 9°30′ W. on the basis of magnetic and gravity data, had not been reported previously. Possibly, the three major fracture zones exist only near Africa and are really part of the same transform fault crossing the Atlantic (the St. Paul fracture zone). The magnetic anomalies associated with these fracture zones, which probably originated in Cretaceous time at the opening of the South Atlantic Ocean, are continuous with magnetic anomalies over crust of Eburnean age (about 2,000 m.y.) in southeast Liberia and its continental shelf, suggesting that Eburnean age structures may have been zones of weakness reactivated in Cretaceous time.

A positive gravity anomaly ($\approx$50 mGal) along the coast and continental shelf of Liberia is attributed to deep crustal rocks uplifted and exposed in Pan African (about 550 m.y. ago) time. The land boundary of this anomaly coincides with a shear zone that marks the boundary between the Pan African and the Liberian-age (about 2,700 m.y. ago) province; the shearing (in a thrust fault sense) may be the result of compressive stress associated with the closing of a proto–Atlantic Ocean. Magnetic data indicate a thick section of sedimentary rocks, possibly as great as 8 km on the continental slope. Liberian age magnetic anomalies in the area northwest of about lat 9°30′ W. cross the Pan African province, and the positive coastal gravity anomaly, and continue over the continental shelf and slope to about the 3,000-m bathymetric contour; the seaward limit of the anomalies is interpreted as representing the seaward limit of the old continental crust (J. C. Behrendt and others, 1972, 1973; J. S. Schlee and others, 1972).

Interstitial waters of marine sediments, worldwide

Study of the chemical composition of interstitial waters from drill cores recovered by the Deep Sea Drilling Project has been concluded. The program, beginning in 1968, obtained analytical data from nearly 200 drill sites in the world's oceans, as well as the Gulf of Mexico, Mediterranean Sea, and Red Sea (F. T. Manheim and others, 1972, 1973; F. L. Sayles and others, 1972a and b, 1973; L. S. Waterman and others, 1972; F. T. Manheim, 1972a and b; F. T. Manheim and K. M. Chan, 1973).

The studies indicate that interstitial fluids are sensitive indicators of bulk fluid flow, water-rock interactions (diagenesis), changes in sea floor regime, organic production and decomposition, rate of sedimentation, and presence of evaporite bodies. Salt diffusion from buried salt deposits penetrates more than 3 km into enclosing or overlying sediments and furnishes reliable indicators of the presence of such bodies in undrilled strata. Anomalous chloride concentrations (gradients) have indicated evaporite bodies in the Gulf of Mexico, off West Africa, in the Mediterranean Sea, off Brazil, and off southern Australia, as well as in the Red Sea.

Other mechanisms which seem to affect pore fluid chemistry are dolomitization, authigenic silicate formation, sulfate reduction, methane synthesis, igneous rock weathering, and recrystallization and precipitation of calcite.

Near some continental areas submarine discharge of fresh or brackish fluids permeates sediments below the sea floor. The offshore pools of fresh water may be important in providing a partial barrier to salt water intrusion which could occur as a result of ground water use by coastal communities.

Regional offshore prospecting in East Asia

A final analysis was made by C. Y. Li of the United Nations and F. H. Wang (USGS) on the past 6 years' work of the CCOP (Committee for Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas 1968–72), which covered large oceanic areas in East and Southeast Asia, extending from the Yellow Sea around Japan and Korea in the north to the Indonesian archipelago in the south. The investigations involved about 39,600 km of deep-penetration seismic-reflection surveys, 6,800 km of high-resolution shallow-penetration sonic profiling, 1,050 km of seismic refraction surveys, 7,400 km of shipborne gravity profiling, 44,100 km of shipborne magnetic profiling, and 105,400 km of aeromagnetic surveys. The results of these reconnaissance surveys were published by the United Nations and have stimulated and assisted private companies in their detailed offshore exploration for petroleum and hard minerals (F. H. Wang, 1972).

Experimental drilling in the Red Sea

A U.S. Geological Survey team contributed to a special Red Sea Leg (23B) of the Deep Sea Drilling Project. F. T. Manheim coordinated geochemical work of shipboard personnel and collaborating shore laboratories. D. F. Siems completed more than 5,000 semi-quantitative spectrographic analyses on rock and sediment samples onboard ship. R. G. Coleman examined the petrologic character of basalts and detrital minerals recovered from the five drill sites and compiled new regional facies maps. The expedition was led by Robert Whitmarsh (Natl. Inst. of Oceanography, United Kingdom), and D. A. Ross (WHOI) (D. A. Ross and others, 1973).

Major results include the finding that the Red Sea appears to be floored with evaporite-rock salt at a depth of a few hundred meters below sea floor. A vanadium-molybdenum rich suite of black shales occurs in the Pliocene sections of the cores, whereas Miocene black shales within the evaporite sections are variably enriched in zinc (to 5 percent). Stratigraphic relationships preclude significant spreading of the Red Sea floor during much of post-Miocene time. Salinity of interstitial waters in the cored strata increases continuously with depth, reaching over 250 g/kg in the evaporite rocks. Some brines are enriched in magnesium (to 18 g/kg) and boron.

Holocene marine phosphorites off Peru

Studies by F. T. Manheim (USGS), G. T. Rowe (WHOI), and Dan Jipa (Institute of Geology, Romanian Ministry of Mines and Geology) have found evidence for the formation of Holocene phosphorites off Peru at depths of 100 to 1,000 m. The phosphorite is localized as replacement of carbonate in benthonic Foraminifera of Holocene age by carbonate fluorapatite. The deposits occur in sites of upwelling of cold, nutrient-rich water, resulting in intense productivity of organic matter. Detrital sedimentation in the area is low, owing partially to the desertlike nature of nearby continental areas. Phosphatization appears to occur in the interstitial water of the organic and diatom-rich sediments, where calcium and phosphate are abundant, rather than in the water column. This phosphatization appears to be separate from preexisting (fossil) phosphorite which has been noted in the literature and confirmed by recent sediment samplings.

Late Oligocene change in Pacific plate motion

Previous analyses utilizing seamount paleomagnetic pole positions have indicated a northward component of motion of 30° latitude for the Pacific plate during the Cenozoic. Independent biostratigraphic evidence obtained by the Deep Sea Drilling Project from a series of sites near the East Pacific Rise between lat 20° N. and 12° S. supports a northward motion of approximately 20° since early Eocene time. David Bukry (Bukry and others, 1973) reports that the lines of maximum biogenic sedimentation, reflecting deposition at the Equator, have been offset northward since the time of deposition. The thickest Holocene to middle Miocene section is near the present Equator, 1 to 3° N.; lower Miocene, 3 to 4° N.; upper Oligocene, 4 to 6° N.; lower Oligocene, 8 to 11° N.; upper Eocene, 11 to 14° N.; middle Eocene, 15 to 20° N.; and lower Eocene, 20° N. A rapid early Cenozoic northward rate of 0.5°/m.y. indicated by these data versus only 0.1°/m.y. for the late Cenozoic may reflect the same change in Pacific plate motion as is indicated by the bend in the Emperor and Hawaiian Seamount chains. Thus, a late Oligocene change from north-northwesterly to west-northwesterly motion is supported by sedimentation data from the eastern Pacific.

ESTUARINE AND COASTAL HYDROLOGY

Estuarine water quality and biota

Maryland.—On June 21, 1972, rain from Tropical Storm Agnes caused a 22-yr record flow in the Susquehanna River. In the Rhode River estuary, in Maryland, influxes of freshened bay water were first noted by a USGS monitor on June 26, when salinity gradually began to decrease from 7.0 p/t to a July 15 minimum of 2.0 p/t. During this 3-week period, water temperatures rose from about 25.0°C to a maximum of 32.6°C, a 3-yr record high. Studies, by R. L. Cory, of the benthic fauna indicated that mass mortalities occurred as a result of the freshened water and higher temperatures. A survey of the commercial clam *Mya arenaria* showed a 100-percent mortality in the Rhode and West Rivers and adjacent bay areas.

Monitored DO measurements and metabolism estimates indicated that, as an aftermath of this storm, biostimulation of the system resulted in daily changes of oxygen as great as 13.1 mg/l (from 3.6 to 16.7 mg/l) compared with a maximum of 10.7 mg/l during the previous 2-yr period. Daily net production of carbon by green plants was estimated in excess of 4 g m^{-2} d^{-1} at the monitor site with a high of 3.2 g m^{-2} d^{-1} being observed the previous year. The system approached anaerobicity the second week of September when the DO concentration dropped to 0.5 mg/l. Fishkills were observed in adjacent small embayments during the last week in August and the first 2 weeks in September.

Mississippi.—A study in Mississippi of the tide-affected reaches of the Escatawpa River and the east and west forks of the Pascagoula River, by D. E. Shattles, related fresh-water inflow and tidal conditions to the chemical, bacterial, and physical characteristics of the water. Initial results show that above river-mile 17 on all three streams, the water is of good quality for domestic, industrial, and agricultural uses and for the propagation of fish and aquatic life. Conversely, poor conditions with little or no DO exist below mile 13 in the East Pascagoula River and below mile 6 in the Escatawpa River. DO levels on the West Pascagoula River, however, are near saturation levels. The discharge of industrial and municipal waste has reduced the water quality in a 13-mi reach of the East Pascagoula River and in an 8-mi reach of Escatawpa River.

Estuarine- and coastal-sediment transport

R. H. Meade, Jr., reported that sediments brought by rivers to the Atlantic coastal zone are not being transported across the continental shelf to the deep sea. Neither the distribution of bottom sediments nor that of inorganic suspended sediments shows any convincing evidence of cross-shelf transport. To the contrary, the circulation of shelf-bottom waters, the migration of beach sands, and the mineral composition of bottom sediments suggest that river sediments that reach the shelf (as well as material from offshore and littoral sources) are eventually transported back into the estuaries and coastal wetlands.

The most likely sites for accumulation of river sediment are the coastal marshes, which have been growing upward in response to rising sea levels along the Atlantic seaboard for at least the last 3,000 yr. Meade has calculated that the marshes of the Atlantic coast, if they are to keep pace with rising sea level under present conditions, require an annual increment of sediment that is equivalent to the total annual input supplied by the rivers. Between Cape Cod, Mass., and Cape Lookout, N.C., most of the river sediment accumulates in coastal wetlands inside the large estuaries. South of Cape Lookout, much of the river sediment is discharged onto the continental shelf, but it eventually accumulates in the large marsh areas behind the barrier beaches of the outer coast.

From measurements of tidal flow and suspended-sediment discharge in or near the inlet to Bolinas Lagoon, Calif., J. R. Ritter determined that the highest flows and suspended-sediment discharges occurred during the major daily ebbtide. Computations based on a relationship developed between suspended-sediment discharge and tidal range indicated that the annual suspended-sediment discharge of ebbtides exceeds that of floodtides by 9,000 tons. The highest concentration of suspended sediment occurred near the eastern shore of the inlet, which is at the end of a sandspit. Most transported sediment was sand, and most sediment deposited in the lagoon was sand.

The measured volume of water moved by a tide in Bolinas Lagoon ranged from 180 to 2,740 acre-ft, and the maximum flow measured was 7,900 ft^3/s. The highest average velocity for a measurement was 4.9 ft^3/s. The maximum average velocity in the inlet occurred within 1 h after midtide during a floodtide and 2 h before midtide during an ebbtide. The relation of average tidal velocity ($\bar{u}_t$) to tidal range (R) for Bolinas Lagoon is $\bar{u}_t = 1.21R^{0.508}$; the average flow for either a floodtide or an ebbtide can be estimated by multiplying this calculated average velocity by the average cross section of the inlet.

Estuarine simulation using numerical models

J. D. Stoner and W. L. Haushild have applied a circulation and water-quality model to the highly stratified estuary of the Duwamish River in Seattle, Wash. The model is the product of research by H. B. Fischer. DO field measurements in the salt wedge from June to September of both 1970 and 1971 were successfully simulated in the model, using an oxygen-demand coefficient that did not vary with time. Model results indicated that, for salt water entering the wedge from Elliott Bay, depletion of oxygen in the salt wedge was higher and DO content was lower from 1967 to 1969 than in 1970 and 1971. During the 3-yr period prior to 1970, waste-disposal discharge was changing from predominantly untreated industrial and municipal wastes at many outfalls along the estuary to secondary-treated effluent at one outfall.

A preliminary version of the Tampa Bay, Fla., digital simulation model is operational. A detailed, automated bottom survey of the channel and spoil areas has been completed to finalize the model boundary. Initial results of the bottom survey indicate that less material may need to be removed to deepen the ship channel than was previously estimated to be necessary. C. R. Goodwin reports that savings of $20 million may be realized. Storm-surge data from 14 time-synchronous tide gages in Tampa Bay during Hurricane Agnes may be the most detailed and accurate ever collected. The surge amplified from 3½ ft above normal at the mouth to 4½ ft above normal at the head of the bay. These data are valuable for calibration and verification of the high-water characteristics of the model. Similar data for extreme low-water periods will also be used during the calibration procedures.

Tsunamis in the San Francisco Bay region

Areas of the San Francisco Bay region that might be inundated by a tsunami creating a 20-ft runup along the coast were delineated by J. R. Ritter (USGS) and W. R. Dupre (Stanford Univ.). The likelihood of occurrence of such a tsunami is about once in 200 yr, but smaller tsunamis, while not causing widespread inundation, could produce currents damaging to boats and be dangerous for people participating in shoreline recreation activities.

Application of ERTS data in turbidity observations

ERTS remote-sensing data were collected over Tampa Bay, Fla., on August 2, 1972, while a shell-dredging barge was operating in the bay. These data were processed for turbidity recognition and unique spectral signatures representative of type and amount of material in suspension. Stratification and settling depth were observed for several different spectral bands. A. E. Coker, A. L. Higer, and C. R. Goodwin reported that the processed data, integrated with the Tampa Bay estuarine model study, will provide a method for synoptically observing the dynamics of turbid material. The three-dimensional aspect of the turbidity plume was achieved by superimposing parts of the plume recognized in each spectral band. These data provide a background for computer processing of ERTS data and three-dimensional modeling of turbidity plumes.

MANAGEMENT OF NATURAL RESOURCES ON FEDERAL AND INDIAN LANDS

The Conservation Division is responsible for carrying out the U.S. Geological Survey's role in the management of the mineral and water resources on Federal and Indian land including the Outer Continental Shelf; that role includes, in particular, the conservation, evaluation, and development of the leasable mineral resources and waterpower potential of these areas. Primary functions are (1) mapping and evaluation of mineral lands, (2) delineation and preservation of potential public-land reservoir and waterpower sites, (3) promotion of orderly development, conservation, and proper utilization of mineral resources on Federal lands under lease, (4) supervision of mineral operations in a manner to assure protection of the environment and the realization of a fair value from the sale of leases and to obtain satisfactory royalties on mineral production, and (5) cooperation with other agencies in the management of Federal mineral and water resources.

MAPPING AND EVALUATION OF MINERAL LANDS

The organic act creating the U.S. Geological Survey gave the Director the responsibility of classifying and evaluating the mineral resources of the public domain lands. There are about 250 million acres of land for which estimates of the magnitude of leasable mineral occurrences have been only partly made. Such appraisals are needed to reserve valuable minerals in the event of surface disposal and to assist in determining the extent of our mineral resources. Estimates are based on data acquired through field mapping and the study of available geologic reports in addition to spot checks and investigations made in response to the needs of other Government agencies. As an aid to this assessment for certain minerals, guidelines have been prepared setting forth limits of thickness, quality, depth, and extent of a mineral occurrence that are necessary before land is considered to be mineral land.

Classified land

As a result of 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.

Geologic maps and studies developed to assist in mineral land classification are published in the regular USGS publications series.

During fiscal year 1973, examination was completed of more than 110,000 acres in the State of Colorado, and the land was formally classified with respect to coal. This classification was mainly a result of the leasable mineral mapping program of the USGS. Most of these lands were previously withdrawn to prevent alienation of the leasable minerals until an examination and classification could be made. More than 20,000,000 acres remain withdrawn for coal; 1,600,000 acres, for phosphate; and 9,000,000 acres, for potash.

Producing oil and gas structures

By the provisions of the Mineral Leasing Act of 1920, the Secretary of the Interior is authorized to grant to any applicant qualified under the act a lease to prospect for oil or gas on any part of the mineral estate of the United States that is not within any known geologic structure of a producing oil or gas field. Lands within such known structures are leased to the highest bidder. During fiscal year 1973, over 249,000 acres of onshore Federal land were determined to be in known geologic structures.

Drilling for coal in northwestern Alaska

A cooperative drilling and sampling program conducted by the USGS and the USBM has resulted in the addition of about 175 million tons of coal to the resources in the Cape Beaufort–Corwin Bluff coal field east of Cape Lisburne in northwestern Alaska. The drilling program and guidance in drill-site selection was based on geologic mapping of the Corwin Formation of Cretaceous age by geologists of the USGS. Engineers of the USBM directed drilling operations. Drilling equipment was designed to provide maximum environmental protection during the project.

WATERPOWER CLASSIFICATION—PRESERVATION OF RESERVOIR SITES

The objective of the waterpower classification program is to identify, evaluate, and segregate from disposal or adverse use all reservoir sites on public lands which have significant potential for future development. Such sites are an increasingly scarce and valuable natural resource. 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 Federally owned 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, the land is released for return to the unencumbered public domain for other possible disposition. During fiscal year 1973, about 100,000 acres of previously classified lands were released, and the review program was carried on in 12 river basins in the Western States and Alaska.

The USGS conducts a limited specialized mapping program to aid in classification of potential water resource development sites in areas not covered by maps of standard accuracy in the topographic quadrangle series. Reservoir sites are usually mapped at a scale of 1:24,000 and damsites at a scale of 1:2,400. During fiscal year 1973, fieldwork was completed on damsites and reservoir sites for potential pumped storage development in Washington. Maps of several damsites in Oregon were published during the year.

SUPERVISION OF MINERAL LEASING

Supervision of competitive and noncompetitive leasing activities to develop and recover leasable minerals in deposits on Federal and Indian lands is a function of the U.S. Geological Survey, under delegation from the Secretary of the Interior. It includes (1) geologic and engineering examination of applied-for-lands to determine whether a lease or a permit is appropriately applicable, (2) approval of operating plans, (3) inspection of operations to insure compliance with regulations and approved methods, and (4) verification of production and the collection of royalties. (See table 1.)

Before recommending a lease or permit, USGS engineers and geologists consider the possible effects upon the environment. Of major concern are the esthetic value of scenic and historic sites; the preservation of fish and wildlife and their breeding areas; and the prevention of land erosion, flooding, air pollution, and the release of toxic chemicals and dangerous materials. Consideration is also given to the amount and kind of mining-land reclamation which will be required.

Louisiana and Texas Outer Continental Shelf lease sales for oil and gas

Three sales of Federal Outer Continental Shelf leases for oil and gas were held in fiscal year 1973. During sales held in September and December 1972, 210 tracts comprising 826,195 acres were offered. High bids worth $2,251,347,556 were accepted for 178 of the tracts. Results of the June 19, 1973, sale were not final at the end of the year, but of the 129 tracts comprising the 697,643 acres offered, at least 104 tracts were leased for high bids worth $1,587,595,780. Thus, during fiscal year 1973, at least 282 tracts were leased for high bids totaling at least $3,838,943,336. The highest accepted bid was $21,870 per acre. USGS geologists, geophysicists, and engineers prepared evaluation studies and reports leading to minimum acceptable bids for each lease block offered.

COOPERATION WITH OTHER FEDERAL AGENCIES

The U.S. Geological Survey acts as a consultant to other Federal agencies in land-disposal cases. In response to their requests, determinations are made as to the mineral character of specific tracts of Federal lands under their supervision which are proposed for sale, exchange, or other disposal. More than 15,000 such reports were made during fiscal year 1973.

TABLE 1.—*Mineral production, value, and royalty for fiscal year 1973*[1]

Lands	Oil (barrels)	Gas (thousand cubic feet)	Gas liquids (gallons)	Other[2] (tons)	Value (dollars)	Royalty (dollars)
Public	168,404,000	938,364,000	535,875,000	29,652,000	$935,400,000	$99,167,000
Acquired	8,158,000	39,746,000	958,000	831,000	99,965,000	6,971,000
Indian	30,165,000	118,936,000	49,674,000	18,900,000	175,753,000	21,497,000
Military	499,000	28,973,000	25,017,000	--------	8,381,000	1,317,000
Outer Continental Shelf	405,492,000	3,027,000,000	1,726,315,000	1,568,000	2,211,800,000	360,000,000
Naval Petroleum Reserve No. 2	2,291,000	3,815,000	14,558,000	--------	10,033,000	1,282,000
Total	615,009,000	4,156,834,000	2,352,397,000	50,951,000	$3,441,332,000	$490,234,000

[1] Estimated in part

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

GEOLOGIC AND HYDROLOGIC PRINCIPLES, PROCESSES, AND TECHNIQUES

EXPERIMENTAL GEOPHYSICS

HEAT FLOW

Heat flow in eastern Panama and northwestern Colombia

Heat-flow determinations were made by J. H. Sass, R. J. Munroe, and T. H. Moses, Jr., along four proposed sea-level canal routes. In northwestern Colombia heat flows are very low, perhaps reflecting a thermal transient due to underthrusting of the Americas plate by the Nasca plate. In the central part of eastern Panama, heat flows are normal as they also are in adjoining regions of the Caribbean plate. West of the present Canal Zone, heat flows increase, as the region of the Panama fracture zone and Quaternary volcanoes are approached.

Geothermal gradients on Oahu

The shape of the island of Oahu can be described as a right circular cone resting on the ocean floor. The base has a radius of about 100 km and a height of about 6 km. Three-fourths of the cone is submerged by ocean water. The temperature of the ocean decreases rapidly from 25°C at the surface to nearly 1°C at a depth of about 800 m. Thus, the lower half of the surface of the cone is a major heat sink.

R. H. Dale measured water temperatures in about 300 wells to determine to what extent the heat affects the geothermal gradient of the island as indicated by ground-water temperatures. He found that in northern Oahu, ground-water temperatures decrease with depth at the rate of about 30°C/km. This is approximately the same gradient as for the ocean. In southern Oahu, however, where there is a thick sedimentary aquiclude that isolates the ocean from the aquifer, the geothermal gradient is only about —15°C/km.

The mechanics of oceanic spreading centers

It has been pointed out by A. H. Lachenbruch (1973) that if material rises gravitationally between diverging plates at an oceanic ridge, it must be lighter on the average than the solid rock that it creates. Unless the conduit for rising material widens drastically with depth, the increase in density of the material as it passes into the solid lithosphere cannot be accomplished by cooling or crystallization, as there is no way to dissipate the heat. This has encouraged the view that oceanic ridges are underlain by broad upwelling convection. It has been shown, however, that if the differentiation that causes crust and mantle results from accretion of refractory crystals on the conduit walls, a large gravitational driving force is generated with no heat loss from the rising material. In this case, simple models involving intrusion of steep-walled conduits are mechanically plausible. Gravitational and viscous forces acting on such steep-walled conduits can account for the observation that axial depression occurs in slow spreading, and axial uplift occurs in rapid spreading. Such models are also mechanically consistent with the observed pattern of near-right angle intersections between oceanic ridges and transform faults and the lack of earthquakes at depth on oceanic transform faults (A. H. Lachenbruch and G. A. Thompson, 1972).

ROCK MAGNETISM

Magnetism of sea-floor basalt in the western equatorial Pacific

The magnetic properties and petrology of submarine basalt from four JOIDES sites in the western, equatorial Pacific were studied by C. M. Marshall. The basalts range in age from Miocene to Cretaceous, as judged by the age of the overyling sediments. At two of the sites the silicate minerals, particularly the olivine and pyroxene, are largely altered to montmorillonite. The degree of weathering seems more dependent on factors such as fracture spacing than apparent age of the basalt.

Estimation of the paleolatitude of each site from the inclination of the remanent magnetism is handicapped by the limited number of samples, but the paleolatitudes calculated for the sites east of the

Mariana Trench are consistent with the hypothesis that the Pacific plate has moved in the directions and at the rates proposed by earlier workers.

The opaque mineral titanomagnetite, which carries the remanent magnetism, is oxidized during the sea-floor weathering to titanomaghemite. The degree of oxidation was observed in one hole to decrease with depth below the basalt-sediment contact. Significantly, the remanence direction is the only magnetic property unaffected by the increase in oxidation. This observation provides the most conclusive proof that the magnetic remanence direction of sea-floor basalt is unaffected by submarine weathering and can therefore be used to calculate the latitude of the basalt at the time it was erupted.

In a related study in 1971, the magnetic properties of a fragment of fresh pillow basalt dredged in the Philippine Sea were found to be quite similar to those previously observed by Marshall and A. V. Cox (Stanford Univ.) (1971) in basalt fragments dredged from the Indian Ocean and Juan de Fuca Ridges. Thus, any chemical differences between interarc basin basalts and ocean ridge basalts are apparently not reflected in their magnetic properties (C. M. Marshall and S. K. Banerjee, 1972).

Use of basaltic lavas in determining the ancient intensity of the geomagnetic field

Basaltic lavas which erupted during historic time on the island of Hawaii have been used by R. S. Coe and C. S. Grommé (1972) to compare the three principal methods of determining the ancient intensity of the geomagnetic field from heated materials that contain a natural thermoremanent magnetism. The original double heating procedure, devised by Thellier and Thellier for archeological materials, although the most laborious of the three methods, also gives the most reliable results for basaltic lavas. Use of moderate vacuum during heating experiments significantly improved the paleointensity values obtained from lavas with low Curie temperatures by inhibiting oxidation of titanomagnetite (Abdul Khodair and R. S. Coe, 1972). Magnetic interactions between different ferromagnetic oxides in single lavas do not appear to degrade the paleointensity data obtained by this method. Hence, many basaltic rocks may be expected to yield relatively precise values of the ancient geomagnetic field.

Paleomagnetic correlations of rocks in Arizona and on the Colorado Plateau

Study of the upper Precambrian rocks of the Grand Canyon and of central Arizona has enabled D. P. Elston and G. R. Scott to make a provisional correlation of the upper parts of the Unkar Group and Apache Group in these respective areas. The Troy Quartzite that occurs stratigraphically above the Apache Group appears to have no correlative in the Grand Canyon area but apparently predates rocks of the Nankoweap Group of Van Grundy (1934) of the Grand Canyon Supergroup.

A geomagnetic reversal chronology obtained by E. M. Shoemaker and D. P. Elston from near the type section of the Moenkopi Formation (Triassic and Triassic?) near Gray Mountain, Ariz., has demonstrated that these rocks are entirely younger than sections of the Moenkopi Formation occurring to the northeast in the Navajo Reservation and in eastern Utah and western Colorado.

APPLIED GEOPHYSICAL TECHNIQUES

Application of electrical techniques in geothermal studies

Two electrical field techniques, one old and one new, have been tested in Long Valley, Calif., in a continuing study of geophysical methods applied to geothermal energy search and evaluation. L. A. Anderson measured natural electrical potentials by surface methods in an area north and west of Casa Diablo Hot Springs. The contoured data display an anomaly of positive polarity centered approximately 1 mi northwest of the hot spring area. This anomaly is interrupted to the east by a known fault, and a similar effect can be observed on the southwest flank of the anomaly. The anomaly is attributed to the movement of ground-water in the vicinity of a source of heat energy. Migrating waters produce a small potential known as a "streaming potential," whose magnitude is dependent on pressure. This is the first evidence in the USGS geophysical research program of the positive expression of a convecting hydrothermal cell.

A. A. R. Zohdy, W. D. Stanley, and D. B. Jackson, following theoretical calculations derived by Zohdy, have prepared total field apparent electrical resistivity maps and percent lateral effect (residual bipole-dipole apparent resistivity) maps of a large area in Long Valley. The maps were derived from field measurements of the total electric field and display areas of low resistivity closely associated with areas of intense hydrothermal alteration. They thus provide a means of locating areas of present or past circulation of hot geothermal fluids.

Analytical programs

A new group has been formed in the Branch of Regional Geophysics for the purpose of digital processing and automatic interpretation of applied geophysical data. The group consists of geophysicists, mathematicians, and computer specialists, represented by M. F. Kane, R. L. Brace, and L. G. Cordell respectively, who work together on different aspects of various geophysical problems. In the past year this group has developed specific programs for the following: (1) Computation of theoretical electromagnetic sounding curves and transient response curves for multilayered earth models, (2) computation of magnetic profiles (and various derivatives thereof) over multiple prismatic bodies, (3) automatic interpretation of magnetic profiles, (4) computation of apparent resistivity sounding curves for multilayered earth models, (5) numerical integration of electromagnetic live source complex integrals for layered earth models, and (6) information storage and retrieval system for gravity station data.

Experiments with the truck-mounted magnetometer

A newly constructed truck-mounted magnetometer was tested over about 5,000 km of roads in New England and the southern Appalachian Mountains. The work followed the encouraging results of testing of a similar design in New England 2 yr ago by M. F. Kane. The method can discern clearly certain types of bedrock and map contacts, reveal features in the bedrock not clearly observable because of limited exposures, and, in some places, provide structural information. In general, it appears to be an excellent aid to mapping in terrain made up of moderately magnetic rock units that are largely obscured by overburden. Because magnetism is an ambiguous property of rocks, proper use of the equipment requires knowledge of rock magnetism.

Spectral and space domain interpretation of potential field data

The development of quantitative methods of interpretation of magnetic and gravity anomalies by R. G. Henderson and M. H. Goodman has been facilitated by mathematical transformation of the problem into the frequency domain. By this means both magnetics and gravity may be interpreted through use of the same basic formulas and the depth parameters of causative bodies may be rendered independent of uniform density or magnetization. The volume of data required in the frequency domain is somewhat of a problem. Recent results indicate that development in the space domain avoids excessive data volume and that solutions for depth and depth extent may be obtained without special considerations of the magnetization in the magnetic case. The solutions may be strengthened by the use of more data and the introduction of least squares. The possibilities of similar treatment for gravity data are currently under consideration.

GEOCHEMISTRY, MINERALOGY, AND PETROLOGY

EXPERIMENTAL AND THEORETICAL GEOCHEMISTRY

Effects of hydrothermal alteration on the uranium, thorium, and lead contents of metasediments

One hundred and twenty-three samples of igneous rocks and metasediments cut by the 23-mile long Roberts Tunnel, Colo., collected underground by E. E. Wahlstrom have been studied under the microscope and classified by George Phair. L. B. Jenkins and coworkers have analyzed all samples for uranium, thorium, and lead. Included are 47 samples of aluminous metasedimentary rocks, fresh to variably altered. The following table summarizes the analytical results in parts per million:

	Number of samples	Sericitization of plagioclase								
		Weak			Moderate			Strong		
		U	Th	Pb	U	Th	Pb	U	Th	Pb
Idaho Springs Formation	34	6.6	20.5	35.0	4.3	15.1	27.2	3.8	11.2	19.5
Biotite schist ± hornblende	13	6.8	21.6	23.3	6.9	18.0	22.1	6.5	26.1	12.6

Published information on the lead content of metamorphic rocks is sparse. This study shows that (1) the level of lead in the fresh metasediments is considerably higher along this line of section than Phair and coworkers have found elsewhere in Colorado, (2) lead concentration in both schists and gneisses increases with an increase in modal feldspar, and (3) strong hydrothermal alteration (Laramide) produces a heavy sericitization of plagioclase; both metasedimentary rock types lose as much as 50 percent of their original lead.

These data support abundant evidence obtained by Phair and Jenkins from Precambrian igneous rocks indicating that during the early and intermediate stages of wallrock alteration, old age lead tends to move outward from the country rocks into the veins.

Hydrothermal secretion of lead may be an important mechanism in the formation of vein deposits.

Role of nitrogen in hydrothermal ore formation

P. B. Barton, Jr., and J. L. Haas, Jr., have discovered from considerations of thermodynamic data and natural occurrences of nitrogen-bearing compounds that atmospheric nitrogen could have an oxidizing influence under some conditions of sulfide ore formation. The nitrogen is reduced to ammonia or ammonium ion, giving an oxidizing effect about three times as great as that of dissolved atmospheric oxygen. This effect is favored by low pH and fixation of ammonium in solid phases. It is suggested that these processes would lead to significant isotopic fractionation of nitrogen and that such fractionation could prove useful in the interpretation of conditions of ore formation.

Effect of ion-pairs on solubility of calcite in aqueous solution

P. B. Hostetler, R. M. Siebert (both at the University of Missouri), and C. L. Christ (USGS) have developed a new titration technique for determining concentrations of ion-pairs (such as $CaHCO_3^{1+}$) in aqueous solutions of carbonates. For solutions of calcium carbonate, conditions can be controlled so that $CaHCO_3^{1+}$ is the only important ion-pair present. The method depends on measurements of changes in pH and constancy of pressure of CO_2 being bubbled through the solution, rather than on measurements of absolute values of these parameters; the latter can be subject to significant error. This method has resulted in a revision of the activity-product constant for calcite: $K_c=[Ca^{2+}][CO_3^{2-}]$; $pK_c= -\log K_c$. The previously accepted value of pK_c was 8.40 ± 0.02; the revised value is $pK_c=8.52\pm 0.04$.

Oygen fugacities for oxide assemblages in the presence of metallic iron

Motoaki Sato has experimentally determined oxygen fugacities as functions of temperature for several oxide assemblages in the presence of metallic iron. This was done because metallic iron commonly occurs with the oxide assemblages of lunar rocks, and the data may be useful in the interpretations of thermal histories for these assemblages. Using a least squares method, the experimental data points were fitted by linear equations relating the logarithm of oxygen fugacity ($\log fo_2$) to the reciprocal of temperature in degrees Kelvin. The results are given in the following table.

Assemblage	$\log fo_2$	Temperature range (°C)
Iron-wustite	6.824–27470/T	800–1200
Iron-ulvospinel-ilmenite	6.496–27985/T	800–1200
Iron-ilmenite-ferropseudobrookite	8.108–30780/T	1000–1200
Iron-ferropseudobrookite-rutile	5.651–27650/T	1000–1200
Iron-ilmenite-rutile	7.120–29600/T	800–1000
Iron-chromite-chromic oxide	6.862–29174/T	900–1200
Iron-hercynite-corundum	7.245–29549/T	900–1200

Experimental melting of lunar pyroxenes

J. S. Huebner has found that during partial melting of lunar pyroxenes, Al_2O_3 and TiO_2 are strongly fractionated into the melt. This phenomenon causes the natural solidus for such bulk compositions to be greatly depressed relative to that for synthetic pyroxenes in the system $CaO\text{-}MgO\text{-}FeO\text{-}SiO_2$. The effect is to limit the magnesium content of the coexisting clinopyroxene, pigeonite. Another implication is that it is compositionally possible to derive a lunar mare basalt (containing roughly 10 percent by weight Al_2O_3 and 20 percent FeO) by partially melting pyroxenes (with or without olivine) in the lunar mantle.

Status of thermodynamic data on the system copper-iron-sulfur

P. B. Barton, Jr., and M. H. Appleman have resolved the general character of phase relationships in the central part of the Cu-Fe-S phase diagram based on interpretations of many experimental runs accumulated during the last several years. Values of the standard free energies of formation are now available for chalcopyrite, bornite, chalcocite, digenite, covellite, pyrrhotite, and pyrite. Thermochemical data are still unavailable for cubanite, talnakhite, mooihoekite, haycockite, the two forms of idaite, and variable solid solutions of intermediate ternary compositions. New data have also been obtained on the stability relations of the unquenchable solid solution of intermediate compositions that dominate the central part of the phase diagram at high temperatures.

Thermochemical parameters of minerals from oxygen-buffered experimental data

E-an Zen (1973) has shown that thermochemical information on minerals can be extracted from reversed univariant reactions in hydrothermal systems in which the redox states are controlled by oxygen buffers (H. D. Eugster and D. R. Wones, 1962). The dominant gaseous species present are H_2O and H_2; consequently the main problem is to calculate their chemical potentials in a binary mixture. Eugster and Wones based their results on the assumption that the mixture is ideal, but H. R. Shaw (1963) showed experimentally that this is not strictly valid. Zen has combined the simple-mixture model of nonideal mixing, proposed initially by Shaw and later graphically displayed (H. R. Shaw, 1967), with the equations of state for oxygen buffers to give the chemical potentials of the two components. The two different mixing models give closely comparable results for the more oxidizing buffers, but the correction for nonideal mixing can be significant for reducing buffers such as the assemblage quartz-fayalite-iron metal.

MINERALOGIC STUDIES AND CRYSTAL CHEMISTRY

CRYSTAL CHEMISTRY OF THE SILICATES

Distribution of silicon and aluminum in feldspar structures as determined by optical methods

In a study by D. B. Stewart (1973), the optic axial angle ($2V$) of alkali feldspars and the optical extinction angles on (010) and (001) were correlated with Al:Si distribution estimated from the unit-cell parameters of the same specimens, using the method of Stewart and P. H. Ribbe (1969). The $2V$ value increases greatly with increase in aluminum content of the tetrahedral T_1 sites. The $2V$ increases to a lesser extent with increasing sodium content in a feldspar series having identical aluminum content in T_1 sites and identical distribution of aluminum among the T_1 sites. The effects of twinning, exsolution, and domain structures on $2V$ are smaller than that of composition. Using presently available data, the $2V$ does not give as precise an estimate of aluminum content in the T_1 sites as do the unit-cell parameters. The $2V$ value depends on long range Al:Si order (total aluminum in T_1-type sites). There is little effect on $2V$, if any, due to the difference between two-site and four-site ordering schemes.

The extinction angle on (001) of potassic feldspars is linearly dependent on the difference in occupancy of the T_1o and T_1m sites, so that measurements of the $2V$ and this extinction angle suffice to characterize the aluminum distribution completely in the absence of twinning. This method requires less material than any other method except electron diffraction.

The extinction angle on (010) of potassic feldspars, regardless of structural state, is 5°. In the presence of an exsolved albite phase, even if submicroscopic in size, the angle ranges up to 12°. This extinction angle is the best predictor of anomalous or strained cell parameters yet discovered.

Calorimetric studies of alkali feldspars and lunar materials

The heat capacities of low and high albite ($NaAlSi_3O_8$) and of microcline and high sanidine ($KAlSi_3O_8$) were measured by R. A. Robie and B. S. Hemingway over the temperature range 15 to 375 K in order to obtain their standard entropies, $S_T°$.

The specific heats of lunar basalt 12152 and of lunar soils 15301 and 60601 were also measured in the temperature range 90 to 350 K in a continuing study of the thermal properties of lunar surface rocks and soils.

NEW MINERAL DATA

A new study of cuprobismutite

Cuprobismutite from Tunnel Extension New Two Mine, Ohio mining district, Utah, has been examined by C. M. Taylor (Stanford Univ.) and A. S. Radtke and C. L. Christ (USGS) (1973). The empirical formula, as determined from electron microprobe analysis, is

$$Cu_{20.8}Al_{0.97}Pb_{0.35}Mn_{0.22}Bi_{26.7}Sb_{0.06}Te_{0.05}Se_{0.55}S_{50.4}$$

The tentative conclusion was reached that unsubstituted cuprobismutite has the chemical formula $5Cu_2S\cdot6Bi_2S^3$ rather than the previously ascribed formula $6C_2S\cdot6Bi_2S_3$ and that cuprobismutite is therefore not dimorphous with emplectite. X-ray powder data obtained in the present study agree reasonably well with those obtained by E. W. Nuffield (1912) although his finding of a C-centered monocline cell for type cuprobismutite is not in agreement with a cell content of 23 S atoms. Thus, it is suggested that either cuprobismutite is a defect structure or that the cell found by Nuffield is a submultiple of the true cell, or that his reported symmetry is incorrect.

New mercury minerals

A presumably new mineral, "B", has been found by R. C. Erd, D. E. Appleman, and E. D. Ghent in association with cinnabar, euhedral crystals of the rare mercury mineral eglestonite, and another unidentified mercury mineral, mineral "A." Mineral "B" occurs as dark, reddish-brown, euhedral crystals with indices of refraction exceeding 2.00. The mineral is monoclinic, space group $C2/c$ or Cc, $a=11.24$, $b=11.60$, $c=6.53$ A (all ± 0.02 A), $\beta=98°\ 15'$. Only a few crystals have so far been found. Preliminary electron-microprobe analyses of these indicate that the mineral is a mercury oxychromate, near $4HgO \cdot HgCrO_4$ in composition. Microprobe analyses of microgram quantities of mineral "A" show that it is a mercury chromate sulfate. New crystallographic data for this mineral show that it has orthorhombic symmetry, space group $B22_12$, $a=12.82$, $b=14.75$, $c=7.62$ A (all ± 0.02 A). Single-crystal and powder X-ray data have been obtained for eglestonite; the mineral is cubic, space group $I4_132$, $a=16.043 \pm 0.005$ A.

Crystallography and crystal structure of ramsdellite

The mineral ramsdellite, a dimorph of pyrolusite, MnO_2, has been studied by H. T. Evans, Jr., using material from Lake Valley, N. Mex. (Michael Fleischer, W. E. Richmond, and H. T. Evans, Jr., 1962); it has also been studied in geodes from Chihuahua, Mexico, collected by R. B. Finkelman, J. J. Matzko, and H. T. Evans, Jr. Mineralogic evidence suggests that the ramsdellite from both localities is metastable and is pseudomorphous after groutite, $MnO(OH)$. However, a sample of groutite from Cayuna district, Minnesota, heated in air in the Guinier-Lenne camera did not show any reversion to ramsdellite but only to pyrolusite at 285°C (manganite also reverts to pyrolusite at the same temperature.

The crystal structure of ramsdellite was studied by A. M. Bystrom (1949), but was not accurately determined. A new refinement has been carried out by H. T. Evans, Jr., Douglas Rykhaus (summer student trainee), and D. E. Appleman, using crystals from Chihuahua. The unit cell is orthorhombic with $a=4.54(1)$ A, $b=9.27(2)$ A and $c=2.864(4)$ A, space group $Pbnm$. Atomic coordinates found by least squares analysis of 168 three-dimensional data, measured with the Picker automatic diffractometer using $MoK\alpha$ radiation, gave the following atomic coordinates: Mn, $x=0.0321(7)$, $y=0.1161(3)$, $z=\frac{1}{4}$; O_I, $x=0.1707(33)$, $y=-0.2229(16)$, $z=\frac{1}{4}$; O_{II}, $x=0.2205(35)$, $y=-0.0315(16)$, $z=\frac{1}{4}$ (no absorption corrections, reliability index $R=0.119$).

The six Mn-O bond lengths within the distorted MnO_6 octahedra are: 1.883(2), 1.930(2), 1.878, and 1.931 A (all ± 0.015 A).

Crystal chemistry of three calcium iodates

The crystal structures of the three known phases in the $Ca(IO_3)_2$—H_2O system have been determined by D. E. Appleman and M. E. Mrose. Two of these occur as minerals in the Chilean nitrate deposits: lautarite, $Ca(IO_3)_2$, and brüggenite, $Ca(IO_3)_2 \cdot H_2O$. All three contain virtually identical IO_3 groups, in the form of flattened trigonal pyramids with iodine at the apex. In these groups all three I-O distances are about 1.82 A, and the next nearest oxygen atoms are greater than 2.8 A away from the iodine atom. In the IO_3 pyramid the O-I-O angles are 97° to 100° and the O-O-O angles are 58° to 61°. The base of the pyramid is thus almost a perfect equilateral triangle. Hydrogen bonding is complex in the 6-hydrate where calcium is bonded to six H_2O molecules and two iodate oxygens. In brüggenite, with only one H_2O per formula unit, calcium is bonded to only one H_2O molecule and seven iodate oxygens, and hydrogen bonding plays a very minor role. Lautarite, of course, has no H-bonds, and calcium is coordinated completely by iodate oxygens. These studies are part of a cooperative investigation with G. E. Erickson into the mineralogy and mineral paragenesis of the Chilean nitrate beds. (See "International Cooperation in Earth Sciences," section on Chile.)

Lansfordite identified in the system $MgO\text{-}CO_2\text{-}H_2O$

On the basis of X-ray and goniometric studies one of four phases synthesized in the system $MgO\text{-}CO_2\text{-}H_2O$ has been characterized by M. E. Mrose as $MgCO_3 \cdot 5H_2O$, the synthetic equivalent of lansfordite. Single crystal X-ray photographs give the following crystallographic data: monoclinic, space group $P2_1/a$, $a=12.48$, $b=7.63$, $c=7.35$ A, and $\beta=101°43'$; $a:b:c=1.636:1:0.963$. The short prismatic crystals of synthetic lansfordite are colorless to milky white. The crystal habit resembles those of natural lansfordite studied by others from Nesquehoning, Pa., and Cogne, Italy, although the synthetic material shows fewer forms with only $c\{001\}$, $b\{010\}$, $a\{100\}$, and $m\{110\}$ appearing.

A new borate mineral from Argentina

A new borate mineral has been found by R. C. Erd, and J. A. Konnert (USGS) and C. S. Hurlbut, Jr. (Harvard Univ.), in a specimen of kernite and borax from Tincalayu, Salta Province, Argentina. The mineral occurs as euhedral, prismatic (along b) to tabular (on a), colorless crystals that are insoluble in hot water. The mineral is monoclinic, space group $P2_1/a$, $a=18.869(2)$, $b=7.531(1)$, $c=7.810(1)$ A, $\beta=97°\ 43.8(5)'$. The mineral is optically biaxial positive, $\alpha=1.485(2)$, $\beta=1.497(2)$, $\gamma=1.522(2)$,

$X=b$, Y to $c=38°$, Z to $a=47°$. It shows a cream-white fluorescence and very slight phosphorescence with short-wave ultraviolet radiation. Microchemical tests indicate that this is a hydrous borate of sodium and magnesium.

VOLCANIC ROCKS AND PROCESSES

SILICIC VOLCANIC ROCKS

Early Precambrian tholeiite-dacite magmatism

Closely interlayered plagioclase-quartz gneiss and amphibolite form much of the basement that underlies the Precambrian greenstone belts of the world. These rocks range in age from 2.7 to more than 3.6 b.y. They are especially well preserved in southern Africa but also are found in Greenland, Canada, north-central United States, and elsewhere. Fred Barker and Z. E. Peterman postulate that these ancient rocks represent metamorphosed volcanic rocks that were originally deposited as flows and tuffs of tholeiitic and dacitic compositions. They further speculate that magmatism in the early Precambrian involved higher heat flow and more hydrous conditions than in the Phanerozoic. Blocks of hydrous basaltic crust were tectonically depressed, perhaps by plate movements; in part the blocks were fractionally melted to dacitic liquid and an amphibole-rich residuum and in part wholly melted to tholeiitic liquid.

Age of volcanism, Clear Lake, California

In the Clear Lake volcanic field, Lake County, Calif., local age relations suggest to B. C. Hearn, Jr., that rhyolitic obsidian flows south of Mount Konocti are the oldest exposed volcanics and that olivine basalt and andesite cinder cones and the Borax Lake and Camelback Ridge rhyolitic obsidian flows are the youngest volcanics. Field magnetic polarity determinations indicate that in the main volcanic field all but one of the petrologic units have normal polarity, in contrast to the equal number of reversed and normal units expected if volcanic activity were constant over a reported span of K:Ar ages from 3 million to 50,000 years. Polarity data and sparse age data indicate that part of the Clear Lake volcanism was contemporaneous with late units of the Sonoma Volcanics and could be considered a continuation of Sonoma volcanism.

Metavolcanic section extends to northern end of Ritter Range pendant

Field mapping by R. S. Fiske and O. T. Tobisch in the Ritter Range pendant, Sierra Nevada, Calif., has been extended intermittently from the Shadow Creek-Thousand Island Lake area northward toward Mount Dana. The area between the Thousand Island Lake drainage and Gem Lake was mapped at a scale of 1:10,000. It was established that the thick sequence of ash flow toward the base of the metavolcanic section, east of the Middle Fork of the San Joaquin River, thins to the north but does extend at least as far north as Gem Lake. Overlying units also extend into the Gem Lake–Waugh Lake area, establishing the general continuity of stratigraphic units from south to north. Reconnaissance in the Alger Lakes and Mount Dana areas revealed that similar lithologic units in the metavolcanic rocks which have been studied contain the same general assemblage of folds, cleavages, and lineations, and efforts are being made to establish the absolute chronology of the various episodes of penetrative deformation.

Long Valley resurgent caldera

Geologic mapping of Long Valley caldera, Mono County, Calif., by R. A. Bailey (1973) has confirmed the suggestion of R. L. Smith and Bailey (1968, p. 629) that the Long Valley depression is a resurgent caldera. After eruption of the Bishop Tuff 0.68 m.y. ago and consequent subsidence of the 19 by 29 km elliptical Long Valley depression, the following events are postulated: (1) aphyric rhyolite tuffs and flows buried intracaldera Bishop Tuff and older rocks to a depth of at least 300 m, (2) the west-central part of the caldera floor was subsequently arched to form a broad structural dome 600 m high and 13 to 16 km in diameter, and simultaneously, sparsely porphyritic biotite and pyroxene rhyolite domes and flows erupted from faults mainly within a northwest-trending graben transecting the dome, (3) finally, coarsely porphyritic biotite-and hornblende-biotite rhyolite domes erupted from a probable ring-fracture zone peripheral to the resurgent dome. Potassium-argon dating and preliminary petrographic and chemical studies indicate that the extrusions represent the successive tapping of a subjacent rhyolitic magma chamber, which slowly congealed over a span of about 600,000 yr. The studies also indicate that the rocks will provide an unusual opportunity to investigate rates of magmatic differentiation.

Chemistry and age of volcanism, Bodie Hills

M. L. Silberman, B. P. Fabbi, and D. C. Noble (USGS) in cooperation with C. W. Chesterman (California Div. Mines and Geology) are studying trace element and strontium isotopic compositions of the Miocene and Pliocene volcanic field of the southern part of the Bodie Hills, Mono County, Calif., which is made up of about 35 km^3 of tuff breccias, lava flows, and intrusive rocks ranging in composition from subalkaline-olivine basalt to rhyolite. Dacite and high-potassium andesite are the most voluminous rock types. The volcanic rocks erupted from several centers that were active, at least in part, simultaneously.

The following geochronology has been established on the basis of 30 K-Ar age determinations:

I.	Younger rhyolites (Pliocene)	5.3 to 5.7 m.y.
II.	Dacites (Miocene)	9.4 to 8.0 m.y.
III.	Andesites, basalts, older rhyolites	13.4 to 9.1 m.y.

The volcanic rocks are characteristically high in potassium, rubidium, and strontium and have high K:Rb ratios, particularly the basalts and andesites. Strontium contents of the basalts are 750 to 1,100 p/m, andesites 700 to 1,500 p/m, dacites 500 to 1,300 p/m, older rhyolites 200 to 250 p/m, and younger rhyolites 300 to 350 p/m. K:Rb ratios are 375 to 430 for basalts, 300 to 560 for andesites, 200 to 440 for dacites, 200 for older rhyolites and 350 for younger rhyolites, $Sr^{87}Sr^{86}$ measurements of 0.7047 to 0.7057 were obtained on samples of different composition. The high strontium contents, high K:Rb, and high $Sr^{87}Sr^{86}$ are typical of young Cenozoic volcanic rocks of the eastern Sierra Nevada subprovince of the Basin and Range province. The data are in accord with the theory that the rocks originated by fractional crystallization from a magma of subalkaline olivine basalt derived in the lower crust. It is unlikely that the magma could have originated by simple melting of an oceanic lithospheric plate that was subducted beneath the crust of western North America.

A deeply eroded caldera, Sawatch Range, Colorado

Priestley Toulmin III reports that field studies showed that the volcanic center in the Mount Aetna-Billings basin area of the southern Sawatch Range, Colo., despite its unusual geometrical configuration as exposed today, seems to have undergone many of the stages of development typical of caldera-type centers. Multiphase early intrusion followed by ash-flow and lava eruption, resurgent doming, and finally violent explosive activity characterized the history of the center. Although the areal extent of the volcanic rocks immediately associated with the center is small (because of extensive erosion), it apparently was a major volcanic structure; it has been suggested (C. E. Chapin and others, 1970) that the Thirtynine Mile Volcanic series has a source in the Sawatch Range, and the Mount Aetna-Billings basin center seems a very likely candidate. There are also indications that some of the volcanic rocks in the northern part of the Bonanza volcanic field had a source to the north, quite possibly in the Mount Aetna-Billings basin area.

Mid-Tertiary volcanism, Sangre de Cristo Range

Volcanic rocks collected by C. L. Pillmore from the upper and lower parts of a complex volcanic sequence in the Underwood Lakes area in the Sangre de Cristo Range near the Colorado-New Mexico State line have been dated by the K-Ar method by J. D. Obradovich. The sequence consists largely of a lower unit of andesitic breccias, flows, and volcaniclastic rocks and an upper unit of rhyolitic ash-flow tuffs, volcanic gravels, and associated basalt and andesite flows. Hornblende from the lower unit has been dated as 35.6±1.4 m.y. old, an age that fits well with reported ages of early volcanism in the southern Rocky Mountains in Colorado. Sanidine from a distinctive quartz-bearing rhyolite welded tuff in the upper unit at Underwood Lakes was dated as 23.4±0.5 m.y. old. This age is analogous to reported ages of subvolcanic intrusive rocks and molybdenite mineralization at the Questa mine near Red River, N. Mex., about 32 km southwest of Underwood Lakes and suggests that the Red River area may have been the source for at least part of the Underwood Lakes sequence. (C. L. Pillmore and others, 1973)

BASALTIC ROCKS

Potassium, thorium, and uranium in Cenozoic basalts, Rio Grande rift

Late Cenozoic basaltic volcanism in southern Colorado and northern New Mexico was most intense near the Rio Grande rift depression but extends onto stable platforms to the west (Colorado Plateau) and to the east (High Plains). L. P. Lipman, C. M. Bunker, and C. A. Bush (1973) find that tholeiitic rocks are largely confined to the Rio Grande depression, and the basalts become increasingly alkalic with distance from the depression. The potassium, thorium, and uranium contents and the Th/K and U/K ratios consistently increase away from the Rio Grande depression and Th/U ratios also tend to increase slightly. Geographically, distinct suites of petrographically related basalts that are very similar in major-oxide compositions are readily distinguishable by potassium, thorium, and uranium contents. Sialic crustal contamination did not contribute significantly to development of these compositional variations, and the lateral change from tholeiitic to alkalic basaltic volcanism may be related to different depths of or degrees of partial melting in the mantle. The compositions and compositional ranges of basalts in the southern Rocky Mountain region are similar to those of many Pacific islands, despite the contrasting geologic settings.

Age and petrology, Emperor Seamount chain

New K-Ar age and petrologic data obtained by G. B. Dalrymple, E. D. Jackson, and M. A. Lanphere on Nihoa, Necker, French Frigate, Gardner, and Midway shows that these volcanoes are tholeiitic shields similar to those that form the principal Hawaiian Islands and that their ages increase northwestward away from the active volcano of Kilauea on the Island of Hawaii (Jackson and others, 1972). A cooperative study with D. A. Clague (Scripps Institution of Oceanography) of Koko Seamount, located in the southern Emperor chain about 300 km north of the Hawaiian-Emperor bend, indicates that Koko is also a tholeiitic shield that formed 46.4 ± 1.1 m.y. ago (D. A. Clague and G. B. Dalrymple, 1973). The results are consistent with the hypothesis that the Hawaiian-Emperor chain of volcanoes formed as the Pacific lithospheric plate moved west-northwestward over a fixed melting spot in the mantle, now centered beneath the Island of Hawaii. The new data, however, confirm the previous observation that the rate of propagation of volcanism is nonlinear along short segments of the chain and that the data presently cannot be extrapolated to determine either a rate of Pacific plate motion or an age for the Hawaiian-Emperor bend. The proximity of Koko Seamount to the bend, which is presumed to record a major change in Pacific plate motion during Tertiary time, suggests that the bend may be only about 42 to 44 m.y. old.

First underwater study of flowing lava

J. G. Moore and R. L. Phillips (USGS), R. W. Grigg (Univ. of Hawaii), and Lee Tapley (Lockheed Aircraft Corp.), using scuba-diving equipment, made underwater observations of two active lava flows from Kilauea Volcano, Hawaii as the flows poured into the sea; D. W. Peterson and D. A. Swanson made observations and mapped the flows on land. The reports of these observations (Moore and Tepley, 1972; Moore and others, 1973) shows that the March to May 1971 flow produced a distinct lava delta composed of subaerial pahoehoe lava resting on a submarine sequence of steeply dipping foreset-bedded volcanic sand and rubble that includes conformably dipping cylindrical lava tongues. Most of the pahoehoe streams pouring over the sea cliff were quenched and shattered to glassy sand and rubble that in turn were further fragmented by vigorous ever, larger pahoehoe flows maintained coherence across the cliff and through the surf one to feed submarine lava tongues. Underwater, these active lava tongues emitted a roaring noise as lava flowed inside their outer black glassy walls. Periodically, cracks in the walls exposed the brightly incandescent lava, and pillowlike buds and toes grew from the top and sides of the lava tongue. Only a small amount of steam was generated underwater. Water temperature close to the active tongues was elevated only 2.5°C.

The 1972 flow was more voluminous where it entered the sea and again produced foreset-bedded volcanic rubble including conformably dipping cylindrical lava tongues. Propagation of these tongues downslope occurred by cracking and budding as well as by stretching and expanding along distal fractures. The following additional observations were made:

1. Directly above the incandescent lava, the maximum water temperature ranged between 35° and 45°C.
2. Hot water accumulated in a layer 1 to 2 m thick on the ocean surface. Maximum temperature in this layer was 45°C.
3. Loud noises and sharp concussions accompanied the growth of flow lobes. In several instances, concussions appeared to be caused by collapse or implosion of an active flow lobe.

Convection in Makaopuhi lava lake

T. L. Wright has compiled evidence that pertains to convection transfer of liquid in Makaopuhi lava lake, that began about 2 yr after the lake formed, when the upper crust was about 10 m thick.

1. Isothermal surfaces in the melt (1,070°–1,120°C) are perturbed, first in a heating sense, then in a cooling sense, from the simple straight-line variation (depth against time) characterizing the first 2 yr history of the lava lake.
2. Samples of melt collected in the first year after eruption are highly vesicular and less dense than the crust collected at the same time. Melt samples collected nearly 4 yr after the eruption are nearly free of vesicles and are dense rela-

tive to samples of crust collected at the same time. Absence of a gas phase in the melt is considered necessary in order to have thermal convection.

3. Core samples collected at depths less than 9 m show a progressive loss of olivine as compared to samples collected during the eruption but are otherwise undifferentiated. Samples collected below 10 m have progressively differentiated compositions indicating removal of augite and plagioclase in addition to olivine. The crystal size and density of these phases preclude static gravitational setting. It is proposed that this differentation could be effected during convective flow. Differention during flow can be demonstrated in samples that flowed into open drill-hole casings and also can be inferred for the more crystal-rich samples erupted from the Kilauea east rift zone.

O_2 and S_2 fugacities measured in active vents

Motoaki Sato and J. G. Moore (1973) measured oxygen and sulfur fugacities of magmatic gases in active vents at 3,170 m elevation on the flank of the northeast crater of Mount Etna, Italy, in July 1970. Gas temperature ranged from 773° to 1,057°C. A least-squares fit of 13 measured log fo_2 values yielded the relation

$$\log fo_2\,(\text{atm}) = 2.175 - 15{,}110/\text{K}$$

which gives values of 2.2 to 0.9 log fo_2 units higher (difference decreasing with increasing temperature) than those based on previous measurements obtained at Makaopuhi Lava Lake, Hawaii. Laboratory study of a water-quenched sample of the Etna lava and gas equilibria calculations indicate that the difference is due partly to the intrinsically higher fo_2 of the Etna lava and party to mixing of air in the Etna gases. A sulfur fugacity of —2.4 log fs_2 at 860°C was measured at Mount Etna.

Gold in oceanic basalts

Contents of gold have been determined by neutron activation analyses by David L. Gottfried and J. Schwarz in 29 dredged basalt samples from the Reykjanes Ridge axis immediately south of Iceland (62° N. to 63°30′ N.) and 10 basalt samples from the Reykjanes Peninsula and southern Iceland. Petrochemically, the dredged basalts are quite similar to other tholeiitic basalts dredged from widely different geographic parts of the ocean-ridge system; they have low K_2O contents (0.06–0.22 percent) and high Na_2O/K_2O ratios. Basalts dredged from the Reykjanes Ridge, however, have distinctly higher gold contents; they average 1.8 p/b gold as compared to 0.5 to 1.0 p/b for samples from the Juan de Fuca Ridge, the East Pacific Rise, and other segments of the Mid-Atlantic Ridge. Subaerial Icelandic basalts average 2.5 p/b gold. Thus, oceanic basalts of similar major element chemistry are progressively enriched in gold in the sequence from (1) normal oceanic ridge crest, (2) submerged shelf, (3) oceanic island. The variations in gold content appear to be related to differences in geologic setting, which in turn may be related to differences in crustal thickness or to proximity to a mantle hotspot.

Magma fractionation by crystal floating

Electron microprobe analyses of minerals from rocks of the Reunion Island differentiated series and bulk analyses of the same rocks have been used by R. A. Zielinski in a computer program devised by T. L. Wright that relates rock compositions to addition or subtraction of minerals from a cooling magma. Progressive changes of rock composition from basalt through trachyte were modeled, and the computer-based predictions are in good agreement with observed phenocryst modes for some porphyritic rocks of the series. Magma densities calculated from a theoretical model (Y. Bottinga and D. F. Weill, 1970) indicate that the feldspars may have floated in some of the more mafic magmas, giving rise to the feldsparphyric basalts that are abundant on Reunion Island.

Weathering of olivine basalt

R. W. White studied the weathering of olivine basalt from the humid climate of the western Cascades of Oregon and Washington. The breakdown of clinopyroxene occurs over a distance of a few centimeters in the weathering profile by the complete dissolution of the crystals, leaving fragile skeletal pseudomorphs of limonite around small open cavities. These cavities are later filled with halloysite, the genesis of which is apparently unrelated to dissolution of the pyroxene. This mode of weathering is readily evident by study of samples prepared for thin section by impregnation with fluorescent plexiglas and by mercury porosimetry of unprocessed chips of the same samples. In contrast, weathering of plagioclase in the same rocks takes place by breakdown directly to halloysite, slightly in advance of pyroxene dissolution.

PLUTONIC ROCKS AND MAGMATIC PROCESSES

Ophiolite assemblage in the Tuolumne River area, western Sierra Nevada, California

Ultramafic and gabbroic rocks overlain by pillow lavas are being investigated by B. A. Morgan in an area of about 100 km^2 in the Tuolumne River area of the western metamorphic belt of the Sierra Nevada near Sonora, Calif. These rocks, interpreted as an ophiolite assemblage, are believed to be a fragment of oceanic crust and mantle thrust onto the continental margin during the Nevadan orogeny. They are bounded on the west by faults and on the east are in contact with the Mariposa Formation, but the relations are uncertain. The principal rock units are dunite, wehrlite, gabbro dikes, gabbrodiorite plutons, pillow lava, and pillow breccia. Dunite, composed of olivine (Fo 92) and spinel (FeChrom 53, MgChrom 21), makes up 80 percent of the exposed ultramafic rock. Wehrlite, composed of olivine (Fo 86), clinopyroxene (Ca:Mg:Fe= 45:39:16), plagioclase, ilmenite, and amphibole, overlies(?) the dunite. Olivine in the ultramafic rocks has been extensively serpentinized to lizardite and magnetite, but generally the original olivine fabric has been preserved. Near the base of the ultramafic sequence, however, antigorite schists containing regenerated olivine (Fo 98) are predominant.

Diffusion of H_2O in magma chambers

H. R. Shaw has investigated chemical exchange between magma chambers and country rock (wallrock) for values of chemical diffusivity typical of H_2O and many other components in silicate liquids at magmatic temperatures. He found that diffusion coupled with boundary layer convection within the magma chamber could significantly change the hydration state of the magma if there are strong contrasts in the chemical potential of H_2O across the contact. Absorption of H_2O from the contact zone could lead to a vertical zonation of H_2O content, and presumably of isotopic composition, with the most hydrated magma at the top. Loss of H_2O from magma to dry country rock would mainly enhance the rate of solidification at the crystal-liquid interface. The effects of diffusive exchanges of other constituents with country rock may lead to chemical zoning of magma chambers, but major changes in the bulk composition of the magma are not likely from such an assimilation mechanism.

Geochemistry of Precambrian trondhjemites in Colorado and New Mexico

Trondhjemitic rocks of 1.7 to 1.8 b.y. age are found in the Precambrian of southern Colorado and northern New Mexico. These include the plutonic quartz-eye granite near Brazos Peak, N. Mex., the Pitts Meadow Granodiorite of the Black Canyon of the Gunnison, the Kroenke Granodiorite of the Sawatch Range, and the volcanic Twilight Gneiss of the West Needle Mountains. A study of major elements and Rb-Sr by Fred Barker, Z. E. Peterman, and W. R. Hansen (1973) has shown remarkably regular increases in rubidium and strontium contents from south to north of 20 p/m Rb/100 km and 190 p/m Sr/100 km; K:Rb ratios exhibit an overall decrease to the north. Initial $Sr^{87}:Sr^{86}$ ratios are low—0.7015 to 0.7027—and show no regional variation but imply an ultimate mantle source. These magmas probably were generated at increasing depths northward in a complex island arc environment.

Origin of ultramafic rocks and ophiolites in the Alps

Adolphe Nicolas (Nantes Univ., Nantes, France) and E. D. Jackson (USGS) (1972) have proposed that ultramafic rocks along the Mediterranean parts of the Alpine chain belong to two different associations:

1. Dunite-harzburgite tectonite massifs that commonly contain chromite deposits. These massifs form an integral part of the ophiolite assemblage and are found in close association with much less deformed magmatic rocks of that assemblage.
2. Lherzolite tectonite massifs that are commonly associated with granulites and less commonly associated with magmatic group rocks of the ophiolite assemblage.

The dunite-harzburgite massifs and their associated rocks are found in the area from Austria to Anatolia, a province characterized by subduction or obduction of oceanic plates. The lherzolite massifs and their associated rocks occur from Austria to north Africa and appear to have been emplaced as a result of the direct collision of continental plates.

The dunite-harzburgite massifs of the eastern province are relicts of the Mediterranean oceanic mantle, and their associated magmatic rocks (cumulates of various kinds, diabases, and pillow basalts) are representative of oceanic crust. A review of the kinds of mafic and ultramafic rocks dredged from oceanic areas tends to support this idea.

On the other hand, the lherzolite massifs of the western province represent relatively undifferentiated mantle from beneath the continents, and the granulites associated with them are derived from the lower continental crust. This idea is supported by the abundance of lherzolite tectonite and granulite xenoliths in the belt of Tertiary basalts that parallels the Alps from Spain to Czechoslovakia. Nicolas and Jackson, however, do not imply that lherzolite is confined to undifferentiated continental mantle. Metamorphic lherzolites are found as xenoliths in the middle of the Pacific Ocean, and they also occur in minor abundances with predominantly harzburgitic massifs on both continental margins of North America. In each of these areas, there are suggestions that the metamorphic lherzolites may represent deeper, more primitive oceanic mantle. The presence of harzburgite alpine perioditites is more definitive and immediately suggests an oceanic source.

SEDIMENTARY ROCKS AND DIAGENETIC PROCESSES

Diagenetic zeolites in a Miocene marine sandstone in California

Several kinds of diagenetic zeolites have been found by K. J. Murata and K. R. Whiteley (1973) in the Briones Sandstone of the Diablo Range in central California. The pattern of their distribution indicates variation in intensity of diagenesis on a regional scale. The low-temperature zeolite clinoptilolite occurs characteristically in the northern 30-mi stretch of the Briones, whereas high-temperature laumontite is restricted to the southern 30-mi stretch. The five zeolites found to date define three diagenetic stages—clinoptilolite-mordenite, heulandite-stilbite, and laumontite—of increasing pressure and temperature.

Zeolitic alteration of Tertiary sedimentary rocks, West Spanish Peak, Colorado

J. D. Vine in a study of the Spanish Peaks area in southern Colorado noted the dissimilarity in the geology of the two peaks. East Spanish Peak has long been known to be a stock with a multiple intrusion of granite porphyry surrounding a granodiorite porphyry core (R. B. Johnson, 1968, p. G 8). West Spanish Peak is composed of relatively flat lying, altered sedimentary rocks of early Tertiary age. A volcanic pipe or vent comprises the crest of West Spanish Peak and also appears to be the focus of a number of radiating dikes, some of which extend for many miles beyond the mountains. The central pipe, approximately 500 ft by about 2,000 ft, consists chiefly of syenodiorite porphyry, but is somewhat variable in composition. It includes blocks of partly assimilated Tertiary sandstone and mudstone and is cut by several zones of hydrothermal alteration. On the south flank of West Spanish Peak, a zone of epidote-bearing sandstone is recognized at altitudes of about 11,000 to 11,500 ft. Mudstones that are typically red at lower altitudes weather black with a vertical fracture so that from a distance they could be mistaken for vertically jointed basalt. Zeolitic alteration is prevalent within the Tertiary sandstones and conglomerates at lower altitudes. Laumontite is the predominant alteration mineral in sandstones extending for as much as 6 mi to the south and 20 mi to the north of West Spanish Peak. Locally, analcime is recognized near the epidote zone, and heulandite is present in some more distant areas north of the peak.

Occurrence of ammonium feldspar in Phosphoria Formation in Idaho

R. A. Gulbrandsen found the occurrence of the ammonium feldspar, buddingtonite, to be widespread in the Meade Park Phosphatic Shale Member of the Phosphoria Formation of Permian age in southeastern Idaho. It occurs principally in the middle one-third of the member and generally is accompanied by albite in a wide range of proportions. Buddingtonite composes about 50 percent of a 1-ft bed at Gravel Creek Divide; the remainder is nearly all dolomite. A 0.25-in. bed at Trail Canyon is composed of nearly pure buddingtonite.

The full distribution of buddingtonite in the Phosphoria Formation is not yet known, but the mineral has also been found in the Meade Peak in western Wyoming and in the Retort Phosphatic Shale Member in Montana.

Apparently buddingtonite was formed by the reaction of ammonium in bottom and interstitial sea water with volcanic ash. The source of ammonium was the abundant organic matter that was deposited in the Phosphoria sea, and the source of the ash was probably Permian volcanism to the west.

Investigation of geochemical variation in Paleozoic rocks in the midcontinent region

The regional geochemical variability of Paleozoic rocks in two areas of the Midwest is currently being investigated by J. J. Connor and R. J. Ebens (1972); one area is in Kentucky and the other is in Missouri, northern Arkansas, northeastern Oklahoma, and eastern Kansas. In each area, lithologically coherent rock types within major stratigraphic units were collected from outcrop areas in a geographically nested sample design established for estimating the relation between sampling interval and percentage of mappable geochemical variation. For many elements in a given geologic unit, the variation is primarily local in scale and regional variation across an area the size of an average State in the Midwest is minor. This suggests that the chemical character of such a geologic unit covering a broad region may be estimated from data obtained on samples from only a few widely separated areas. The estimates then may be correctly extrapolated on the basis of geologic maps.

Rapid sedimentation as cause of gravity sliding and anomalous mineral occurrences

E-an Zen examined the Gibsonian model proposed by J. D. Bredehoeft and B. B. Hanshaw in which rapid sedimentation of minerals of low hydraulic conductivity lead to anomalous pore pressures, as has been observed in many oil fields. One problem with the model is that it predicts greater (and negative) deviation from lithostatic pressure with increasing depth, but in reality most of the high anomalous pressures are observed in deeper parts of wells, whereas shallower parts show general conformity with the hydrostatic pressure curve. This problem could be artificial, resulting from the imposed boundary conditions and from the use of constant physical parameters for solution of the differential equation where, in reality, the hydraulic conductivity should be a function of compaction and depth. Thus the model could still be a useful one. If different areas of the depositional basin (delta, eugeosyncline) have different sedimentation rates, different depth-anomalous pressure curves will be obtained for each sedimentary column. If these columns are connected by permeable aquifers, the pressures can be short circuited, and the thinner columns will tend to be floated by the high excess pressures of the thicker columns, possibly leading to gravity sliding. Some highly crumpled rock piles detected in the Gulf of Mexico, in front of the Sigsbee Scarp, could be the result of such hydraulic jacks, as the scarp area seems to coincide with a noted thinning of sedimentation at the front of the Mississippi delta. Sudden displacement of bodies of sediments, which retain their internal integrity and, therefore, slowly relax initial distribution of temperature and chemical activities of components, could lead to strange diagenetic paths and so to unexpected mineral distributions with depth.

GEOCHEMISTRY OF WATER

The primary objectives of geochemical studies in hydrology are to increase the understanding of (1) the hydrochemical processes that control the chemical character of water, (2) the physics of the flow system by application of geochemical principles, and (3) the rates of chemical reactions and rates of transport of physical and chemical masses within the hydrologic system.

Solubility calculations for natural waters

Further checking of the basic thermodynamic data employed, extensive testing, and a descriptive text were completed for the computer program, named WATEQ, which has been developed by A. H. Truesdell and B. F. Jones for calculating chemical equilibria from water analyses. The program has been used to estimate the concentrations of aluminum and iron to be expected from mineral solubility in streamflow. The computations are being used in connection with field and laboratory studies of filter needs in water sampling and subsequent analyses.

Calculations by D. W. Brown and R. A. Gulbrandsen (1973) showed that a brine of ionic strength 6.4 from a lake on Enderbury Island in the Pacific Ocean was at or above saturation with respect to calcite, aragonite, gypsum, hydroxyapatite, and fluorapatite. These minerals are known to occur on the island. The results indicate that chemical thermodynamic calculations are useful for brines, even though many approximations are required.

In a study of occurrence of manganese in ground water in Rhode Island, William Back and others concluded that the recent increase in manganese concentration is related to infiltration of stream water containing organic pollutants, thereby changing the pH and Eh environment which permits the previously stable manganese minerals to dissolve and release manganese ions to the water.

C. E. Roberson and Robert Schoen (1973) noted that water from many thermal springs in the Snake River Basin, Idaho, was near saturation with respect to fluorite. Addition of sodium fluoride in small amounts to some of these waters produced a fluorite precipitate, identified by X-ray diffraction patterns. The presence of mineral surfaces for nucleation sites in the ground-water systems would help fluorite precipitation to occur even if only a small degree of supersaturation had been attained.

Effect of clays on water chemistry

In the presence of 10 to 100 mg/l of fine-grained synthetic halloysite, prepared in aqueous systems of 25°C, a substantial decrease in apparent solubility of lead was observed by J. D. Hem. The equilibrium concentration of lead reached under these conditions may be less than 0.01 of the calculated hydroxide solubility. Lead is strongly adsorbed by the clay particles, especially from pH 6.0 to 8.0. Similar effects may help to explain the tendency for lead and many other trace metals in river water to be carried as part of the suspended load rather than in solution.

B. F. Jones and D. L. Parkhurst established that a poorly defined 7–A (0.7-nm) component of the medium to fine clay from alkaline saline Lake Abert, Oreg., is kaolinite, and they successfully separated it with size fractions $>0.05\mu m$. In the ultrafine fraction, careful removal of organics did not alter expanded mixed-layer clay, but alkali- and heat-treatment results were consistent with separate irregular interlayering of silica and other metal oxide components. Subsequent differential-dissolution experiments aimed at selective extraction of these components demonstrated that reactions were not structurally specific.

Source, movement, and discharge of ground water

Bulk precipitation, concentrated on the land surface and in the soil zone, is the principal source of minerals in the ground water of St. Thomas, V. I. D. G. Jordan and D. W. Fisher found that chloride levels of 5 to 10 mg/l in incident precipitation are increased by evapotranspiration to 70 or more mg/l in the initial recharge. Mineralization of the ground water is further increased by evapotranspiration directly from the aquifers.

Ratios of chloride concentration in precipitation, surface water, and subsurface water can be used to estimate initial recharge and also downslope evapotranspiration from aquifers on the island. The estimates made by this means agree favorably with calculations of recharge and ground-water loss made by standard physical techniques.

Stable isotopic analyses by J. R. O'Neil have shown that the mineral waters of the Bohemian massif are locally derived meteoric water. The results require chemical reactions to yield high (thousands of milligrams per liter) concentrations of sulfate, chloride, and bicarbonate; the reactions apparently take place in the area between the Kushne Hory mountains and the granites of the Bohemian massif.

Fieldwork on the initial phase of the Florida soil-gas study, with a vegetation survey at each sample site, has been completed. C. T. Rightmire and B. B. Hanshaw (1973) reported that vegetation type is the major influence on the carbon isotope composition of soil CO_2 at the study sites. Vegetation of the Hatch-Slack cycle yields carbon more enriched in carbon-13 than vegetation of the Calvin cycle and differences in isotope composition may facilitate identification of recharge areas.

In a study of the De Chelly Sandstone in northeastern Arizona, William Back, Meyer Rubin, C. T. Rightmire, B. B. Hanshaw, and E. H. McGavock have concluded on the basis of geochemical interpretation and isotopic analyses (primarily carbon-14) that significant recharge is occurring on the flanks of the fractured monocline rather than in the area of highest potentiometric surface as was believed previously. In addition, interpretation of carbon-14 analyses provided hydraulic-conductivity values that were consistent with values obtained from conventional hydrologic techniques.

Soil-gas samples have been collected by C. T. Rightmire in the proposed recharge areas of the De Chelly and Navajo Sandstones in conjunction with a study of the isotopic and chemical characteristics of ground waters in sandstone aquifers in arid regions. Preliminary results of the C^{13}/C^{12} ratio of the CO_2 separated from the soil gas and of the carbonate species dissolved in the ground water indicate that the major source of carbon is the soil CO_2 with a δC^{13} of approximately –12 per mil.

M. S. Hellmann developed a computer program, using the field and laboratory data of Back and Hanshaw, to determine regional permeability distribution from carbon-14 analyses of ground water from Florida. By use of the expression $V=\frac{Ki}{n}$, where V is velocity of ground-water movement determined by carbon-14 ages, K is hydraulic conductivity (permeability), n is porosity, and i is hydraulic gradient obtained from the potentiometric map, a regional $\frac{K}{n}$ distribution map was prepared. A ground-water velocity map and a gradient map were constructed, using arrows to show direction of movement and the size of the arrows to indicate magnitude of velocity and gradient.

During the continuation of their work in the Yucutan Peninsula of Mexico, A. E. Weidie (Louisiana State Univ.), Hanshaw, and Back have located, primarily on the basis of geochemical data, an area of major ground-water discharge along joint-controlled solution channels. In the area previously investigated along the northern coast of the Yucutan, discharge is by diffuse upward movement without structural control.

In a study by Back, Rightmire, P. R. Seaber, and R. N. Cherry, using environmental isotope techniques in conjunction with geochemical principles to substantiate and refine a solution-evaporation hypothesis for the origin of saline waters in the Punjab-Upper Indus Plain, Pakistan, analyses indicate that the ground water is influenced by waters from two adjacent rivers and that mixing and evaporation occur within interfluvial areas.

According to Ivan Barnes (USGS) and E. Mazor (Weizmann Inst., Israel), analyses of inert gases of oil-field and metamorphic waters have shown that both were exposed to the earth's atmosphere earlier in their histories. The result is not surprising for the oil-field waters, but it is surprising that the metamorphic waters should retain the imprint of exposure to the earth's atmosphere, considering the profound changes in chemical and isotopic compositions that the metamorphic waters have undergone.

NATURAL AND ARTIFICIAL ALTERATION OF CARBONATE AQUIFERS

Ground-water alteration of principal artesian aquifer of Florida

As part of their continuing work to prepare predictive chemical models, Anthony Randazzo (Florida Univ.), R. G. Deike, C. T. Rightmire, and William Back (USGS) have undertaken a joint study to evaluate the role of ground water in the alteration processes of a carbonate aquifer. A detailed petrologic and isotopic examination is made of three cores from a formation of the principal artesian aquifer of Florida (Avon Park Limestone, Eocene) and the results are compared with those obtained by a similar investigation of selected sites in Florida Bay, which is a sedimentary analog of the Avon Park.

X-ray diffraction and chemical analysis of a central Florida core shows extensive dolomitization of biocalcarenite accompanied by an increase in intergranular porosity and decrease in strontium. In the lower part of the formation, gypsum appears as crystal masses in dolomite below a horizon of secondary calcite in dolomite matrix. A core of the Avon Park from southern Florida is predominantly biocalcarenite and recrystallized calcite. The lower parts of the core (upper Lake City Limestone) are dolomite accompanied by gypsum and celestite. The mineralogy of a well core in west-central Florida was characteristic of the transgression-regression zone between the lower Inglis (of former usage) and Avon Park Limestones.

In Florida Bay, X-ray diffraction and chemical analysis of the >62 μm, 15 to 62 μm, 2 to 15 μm, and <2 μm fractions for the distribution of high-magnesian and low-magnesian calcites, aragonite, quartz, and clay minerals showed that coarser fractions are enriched in aragonite and finer fractions trend toward low-magnesian calcite (<2 mol percent $MgCO_3$). Fractions <2 μm (≈ 3 percent by weight) are enriched in high-magnesian calcite (>16 mol percent) and both 10–A(1.0nm) and 14–A(1.4 nm) clays. Fractions 2 to 15μm(≈ 50 percent by weight) were enriched in low-magnesian calcite. Aragonite and strontium, in proportion, increase to the south in all size fractions.

Ground-water alterations of the Edwards aquifer, Texas

In a study of cores of two wells near San Antonio, Tex., R. G. Deike found differences in mineralogy of the Edwards aquifer coexistent with "good water" (bicarbonate, low sulfate) in one well, and "bad water" (high sulfate, sulfide, low bicarbonate) in the second well. In the "bad-water" core, the Edwards is divided about equally between calcite-dominant, dolomite-dominant and mixed calcite/dolomite lithologies. Calcite occurs as lutite and micrite; dolomite as sucrose and micrite; and mixed calcite-dolomite fabrics are lutite, micrite, secondary spar, and sucrose. Kaolinite, gypsum, quartz, and pyrite occur in organic layers, particularly in the upper and lower parts of the formation. Celestite appears in the central part, and quartz, both disseminated and as secondary spar, occurs throughout.

The "good-water" core, by contrast, is predominantly calcite occurring in recrystallized and biocalcarenite fabrics. Red iron oxide staining is common and goethite was identified occasionally on X-ray patterns. Sulfides and gypsum are absent in calcite parts, but occur with organics in occasional thin dolomite beds, and toward the bottom of the core in the predominantly dolomitic Glen Rose Formation.

Acidic-waste injection in limestone

M. I. Kaufman, D. A. Goolsby, and G. L. Faulkner conducted geochemical investigations of an industrial-waste injection system at the south end of Lake

Okeechobee near Belle Glade, Fla. The waste is hot (71°–103°C), acidic (pH 2.6–4.5), and highly organic (COD 6,000–26,000 mg/l), and is injected under pressures of 30 to 60 psi into a highly transmissive cavernous aquifer of nearly pure limestone at a depth of about 2,000 ft. Observed geochemical effects associated with the movement of waste include increased concentrations of calcium, magnesium, organic carbon, COD, and alkalinity; reduction in pH and sulfate concentrations; and generation of considerable amounts of hydrogen sulfide (83–98 mg/l). Dissolution of the carbonate aquifer, anaerobic decomposition, and sulfate reduction within the subsurface environment have occurred.

STATISTICAL GEOCHEMISTRY AND PETROLOGY

Variance components in geochemical sampling

Studies by J. A. Erdman and G. L. Feder indicate that estimates of geochemical variance components are more reproducible than previously thought. Erdman's studies (U.S. Geological Survey, 1972a) include a geochemical survey of the uncultivated soils of Missouri, based on a four-level hierarchial sampling model similar to that used by Krumbein and Slack (1956). The sampling was performed twice, in two complete independent experiments, once with $N=60$ and again with $N=300$. The estimated variance components for log element concentrations agreed, for the most part, within a factor of two, and both experiments showed substantially the same distribution of total log variance among the four levels of the sampling design. Statistical theory for the reproducibility of variance components appears to be lacking. Feder's studies were directed at the chemistry of surface waters of Missouri and, like Erdman's, show that the geochemical variance components are more reproducible than previously believed.

Estimates of variance components are important because they can be used to design efficient sampling plans that will lead to results of any desired reproducibility, thus avoiding waste of field and laboratory resources. Variance component estimates from hierarchial sampling designs may also be used in much the same way as variograms are used by the French school of geostatisticians. Work by A. T. Miesch has shown that variograms can be constructed directly, and exactly, from variance component estimates.

Q-mode factor analysis

A. T. Miesch has extended the method of *Q*-mode factor analysis (Imbrie, 1963) to computation of the composition loading matrix (Imbrie and van Andel, 1964) in terms of the varimax axes. This is useful when many of the loadings on the oblique factor axes are negative and difficult to interpret in terms of geochemical processes. J. A. Erdman and Miesch have used the method to develop a *Q*-mode model which explains 90 percent of the compositional variation in the uncultivated soils of Missouri. The factors in the model represent three types of soil parent material (quartz sand, carbonate, and arkosic sand) and B-horizon development. The effects of B-horizon development are a decrease in the silica, carbonate, and organic carbon contents of the soil and corresponding increases in the contents of nearly all other of the 32 chemical constituents that were examined, especially those other than silica which are contained in clay minerals.

R. R. Tidball has developed a varimax *Q*-mode model for the geochemistry of the agricultural soils of Missouri. The model is similar to that for the uncultivated soils but contains only three factors: carbonate residuum and two contrasting types of alluvium parent materials (clay rich and silica rich). Map patterns displayed by the loadings conform to the distributions of these materials over the State and somewhat to the distributions of the three principal soil types (Alfisols, Mollisols, and Ultisols). The factor model was derived from data on 32 chemical constituents in 1,140 soil samples.

A-mode factor analysis has also been used by Miesch and D. E. Lee to show that essentially all of the chemical variation in the hybrid granitoid rocks of the Southern Snake Range, Nev. (Lee and Van Loenen, 1971) can be described in terms of mixing Pioche Shale (Cambrian) and aplite, suggesting the incorporation of Pioche Shale into an aplitic magma. This model was developed solely from the chemical data on 9 major oxide constituents in 81 samples from one area. Evidence for the possible validity of the model exists in the presence of numerous xenoliths of Pioche Shale in the pluton's mafic part. It was found that the "compositions" of the varimax axes correspond almost exactly with the observed average compositions of the aplite dikes and the Pioche xenoliths.

R-mode factor analysis

J. J. Connor and H. T. Shacklette have used *R*-mode factor analysis methods to examine compositional variations in Spanish moss (*Tillandsia usneoides*), sampled throughout its extent in the southeastern United States as an indicator of atmospheric metal burdens. (See section on "Environmental Geochemistry.") A total of 123 specimens were analyzed for 25 chemical constituents in the ash. Eigenvalue analysis of the correlation matrix derived for the log data demonstrated that about 70 percent of the total chemical variability may be described in terms of five arbitrary but uncorrelated reference components. Three of these components are defined by the varimax criterion whereas the remaining two are defined by a 30° orthogonal rotation of two other varimax components. Interpretation of the reference components follows from their proximities to vectors representing individual chemical constituents and from regional patterns in the variation of component scores. The reference components presently appear to represent (1) distance from the ocean, (2) automotive exhaust emissions, (3) metabolic processes within the plant, (4) an unknown process affecting boron, lithium, and vanadium concentrations, and (5) broad-scale variation in the composition of soil-derived dust.

Simulation studies of the constant-sum problem

A FORTRAN IV computer program has been designed to investigate the effects of closure on open arrays. Open arrays are those having variable row sums; closure, which consists of adjustment so that the row sums are constant, is analagous to the adjustment of chemical data on rocks to sum to 100 percent. It is well known that closure places severe restraints on intercolumn covariances and that this greatly hampers geochemical and petrologic interpretation (Chayes, 1960). The new computer program developed by A. T. Miesch allows the user to specify the size of the array, W, and either a normal or lognormal parent distribution for the open array columns. The user may also specify the column mean and variance parameters in terms of w or log w, where w is an element of the array W. Intercolumn correlations for either w or log w are specified by factor loadings on up to 30 common or unique factors. The open array is then drawn from a population having the specified parameters through use of a pseudorandom-number generator. The statistical properties of both the open and the derived closed arrays are then determined, and either array may be written on a magnetic tape or disk for further processing in the USGS STATPAC system. One finding of this work has been that in the open array, the partial correlations which effectively hold the row sum constant are approximately equal to the corresponding correlations in the derived closed array. Other experiments confirm the previously reported conclusion (Miesch, 1969) that the test of Felix Chayes and William Kruskal (1966) is ineffective in identifying correlation that is not a result of closure and, therefore, of possible petrographic significance.

ISOTOPE AND NUCLEAR GEOCHEMISTRY

ISOTOPE TRACER STUDIES

Strontium isotope study of Alaskan basalt

A strontium isotope study of basalts from Nunivak Island, Alaska, has recently been completed by R. K. Mark and J. M. Hoare. The initial strontium isotopic composition ($^{87}Sr/^{86}Sr$) of 21 Nunivak basalts averages 0.7030 and ranges from 0.7026 to 0.7033. This is within the range reported for oceanic basalts ($\approx$0.701 to 0.706, mean $\approx$0.7035) and at the low end of the range reported for continental basalts ($\approx$0.703 to 0.712). No evidence of crustal contamination was found in the basalts although they overlie a sedimentary basement consisting of interbedded sandstones and siltstones of Cretaceous age and obviously erupted in a continental environment.

Various models may be developed to explain the isotopic composition of the Nunivak basalts and their apparent lack of contamination. The model suggested here, however, is that the sialic crust beneath Nunivak Island is thin (probably no more than 8–10 km) and that it consists mostly or entirely of Cretaceous sediments. The average of two isotopic determinations made on the sediments yielded a ratio of 0.7039, a value sufficiently low to suggest derivation of the sediments from parental material that was also derived from the mantle but not low enough to account for the observed values of $^{87}Sr/^{86}Sr$ in the basalts. The model further assumes that the Cretaceous sialic rocks rest directly on mafic and ultramafic rocks which constitute an oceanic-type crust. Fragments of lherzolite, pyroxenite, and gabbroic rocks, as well as less abundant dunite and harzburgite are widespread in the highly alkalic basalts (mostly basanites) on Nunivak Island. These inclusions apparently are derived from the crust and subcrust as most of them are deformed and recrystallized to metamorphic rocks of the granulite facies. Some of the gabbroic inclusions are recrystallized to spinel-pyroxene symplectite or to garnet symplectite due to the reaction between forsteritic olivine and calcic plagioclase. Experimental data obtained on the Fo + An reaction by H. S. Yoder and

C. E. Tilley (Carnegie Inst. Washington) suggest that these inclusions probably are derived from depths between 25 and 75 km, that is, from the lower crust or upper mantle. The $^{87}Sr/^{86}Sr$ of a gabbroic inclusion and a lherzolite inclusion was found to be 0.7026 and 0.703 to 0.704, respectively. These values are very close to the basalt values and support the hypothesis reached from the experimental data.

Initial Sr^{87}/Sr^{86} ratios of granitic rocks of the Salinian block

A study by Z. E. Peterman, D. C. Ross, and R. W. Kistler of initial strontium isotopic compositions of granitic rocks in the Salinian block west of the San Andreas fault supports the concept of right lateral offset of large magnitude along the San Andreas fault. Comparison of the pattern of isotopic ratios to that in the Sierra Nevada batholith eliminates the suggestion proposed by several workers that the Salinian block is a continental fragment rifted from the western Sierra Nevada batholith. In addition, the pattern of isotopic ratios suggests at least 300 mi of movement along the fault since late Early Cretaceous time.

Origin of the Sierra Nevada batholith

Lead isotopic compositions were measured by B. R. Doe and M. H. Delevaux (1973) for granitic rocks of the Mesozoic Sierra Nevada batholith and Klamath Mountains of California. The samples represented each of three strontium isotope ($^{87}Sr/^{86}Sr$) groupings—<0.704, 0.704 to 0.706, and >0.706—for granitic rocks north of the Garlock fault in California. The isotopic compositions of lead in the samples from the Sierra Nevada batholith range from 18.73 to 19.37 for $^{206}Pb/^{204}Pb$, 15.61 to 15.71 for $^{207}Pb/^{204}Pb$, and 38.44 to 39.10 for $^{208}Pb/^{204}Pb$. A crude parallel correspondence was found between lead and strontium isotopes because the specimens with the most radiogenic strontium also tend to have the most radiogenic lead, similar to the Boulder batholith of Montana. A parallel correspondence is thought to imply similar characteristics of the source rocks for the plutons rather than consequences of partial melting or natural contamination. Lead isotopic compositions for the Sierra Nevada batholith and the Boulder batholith differ, average values of $^{206}Pb/^{204}Pb$ being at least 18.8 for the Sierra Nevada batholith and about 18.0 for the Boulder batholith.

In the Upper Cretaceous part of the Sierra Nevada batholith the secondary isochron age for the source materials from which the plutons were derived is about 2,900 m.y., far older than known Precambrian in California. To account for this age, sources are proposed for these plutons from the lower continental crust and upper continental mantle or dominantly recycled continental materials, possibly by subduction, and probably of intermediate composition. This source material may have been formed in Precambrian time but did not undergo a Precambrian metamorphism greater than upper amphibolite facies which would have reduced the values of $^{238}U/^{204}Pb$ in the source rocks and resulted in Mesozoic leads like those found in the Boulder batholith and elsewhere in the Rocky Mountain region.

A trondhjemite from the Klamath Mountains has a lead isotope composition ($^{206}Pb/^{204}Pb$, 18.57; $^{207}Pb/^{204}Pb$, 15.50; $^{208}Pb/^{204}Pb$, 38.08) similar to oceanic volcanic rocks, particularly like those of island volcanics on oceanic ridges. Derivation of this trondhjemite from an oceanic mantle or recycled mantle material is indicated by this observation and supports the conclusion of R. W. Kistler and Z. E. Peterman (1973) based on its alkali abundance and $^{87}Sr/^{86}Sr$ value.

Lead isotopic provinces in Western United States

R. E. Zartman has identified regional patterns of lead isotopic behavior in Mesozoic and Cenozoic igneous rocks and ore deposits which permit the delineation of distinct isotopic provinces that can be recognized in the Western United States. These patterns reflect the geologic history of the source materials from which the lead was acquired. Three areas having characteristic types of lead have been identified and related to specific source environments. They are area 1 (Montana, Idaho—except for the southwestern part—Wyoming, Colorado, Utah, New Mexico, Arizona, southern Nevada, and southeastern California) containing cratonic-type lead derived from Precambrian crystalline basement rocks; area 2 (eastern Washington, eastern Oregon, southwestern Idaho, and northern Nevada) containing geosynclinal-type lead derived from a homogenous sedimentary pile eroded from adjacent Precambrian sialic upper crust; and area 3 (western Washington, western Oregon, and California—except for the southeastern part) containing magmatic-ore-type lead in young plutonic and volcanic rocks, possibly originating in a subduction zone.

Time differences in meteorite formation determined by $^{207}Pb/^{206}Pb$

In order to obtain a more precise age for meteorites, the uranium-thorium-lead system of meteorites was studied by Mitsunobu Tatsumoto and R. J. Knight of the USGS in cooperation with C. J. Allegre (1973), University of Paris, France. Recent precise redeterminations of the decay constants of uranium-238 and uranium-235 and thorium-232 and of the abundance ratio of $^{238}U/^{235}U$, as well as development of improved analytical techniques, encouraged the present radiometric study of meteorites by the uranium-thorium-lead system.

The $^{207}Pb/^{206}Pb$ ages of the meteorites obtained in this study range from 4.56 b.y. to 4.64 b.y. (4.50–4.57 b.y. by the newly reported uranium decay constants) which are 10 m.y. to 90 m.y. older than the 4.55 b.y. age which was originally reported by C. C. Patterson (1956) and which commonly has been accepted as the age of formation of meteorites and the earth.

Clear evidence was observed for a difference in the times of meteorite formation, or more likely a later metamorphic event, that redistributed uranium and lead in the meteorites. Ages are 4.5 b.y. for meteorites from Sioux County, Kans., and Nuevo Laredo, Mexico, and 4.63 b.y. for Angra dos Reis, Brazil. The maximum age difference of 27 m.y. between Angra dos Reis and the others is analytically significant and is compatible with the difference between the initial ratios of ($^{87}Sr/^{86}Sr$) ADOR and ($^{87}Sr/^{86}Sr$) BABI (basaltic achondrite best initial) reported previously by others for these meteorites. The time difference is also comparable to the results obtained by others using $^{129}I/^{129}Xe$ chronology. Ages of ordinary chondrites (H5) and a hypersthene chondrite (L6) are between 4.64 to 4.55 b.y. and also exhibit time differences in the formation of the parent bodies or more likely later metamorphic events that might have altered the ages of formation. Carbonaceous chondrites (C2 and C3) appeared to contain a younger lead component than was obtained for other meteorites.

The older ages of 4.63 b.y. for Angra dos Reis and 4.64 b.y. for the Beardsley meteorite which fell in Rawlin County, Kans., (4.56 b.y. and 4.57 b.y. by the newly reported U-decay constants) coincide well with the estimated age of the Moon. The Moon's model age originally reported from the Apollo 11 study and further documented for subsequent missions as 4.63 to 4.61 b.y. is recalculated to be 4.56 to 4.58 b.y. using new uranium-decay constants. This mutual consistency in the age for meteorites, the Earth, and the Moon allows a determination of the age of the solar system at about 4.57 b.y.

Deuterium in snow cores characterizes climate?

K. J. Hardcastle has completed the analyses of about 110 snow core samples collected on April 1, 1972, from locations in New Mexico, Colorado, and Montana. The deuterium analyses of these snows, when compared with deuterium analyses of similar samples collected the previous year, give some interesting insights into the variations in storm trajectories of this region. For example, all the stations in Colorado are significantly enriched in deuterium for 1972 as compared with 1971, probably due to greater influences of Gulf of Mexico airmasses during 1972 as compared with the previous year. Other more local climatic influences can also be seen from this data.

Determination of nanogram amounts of bismuth in rocks

L. P. Greenland and E. Y. Campbell (1972) described a radiometric method for determining bismuth in rocks. Samples are dissolved in acids in the presence of ^{207}Bi tracer, and bismuth is separated from other constituents by extraction of the iodide. Bismuth is then reacted with a known substoichiometric amount of EDTA, and the excess bismuth is removed by iodide extraction. The original concentration of bismuth is determined from the specific activity of the EDTA complex found by counting ^{207}Bi.

STABLE ISOTOPES

Ore deposits research

J. R. O'Neil, M. L. Silberman, and B. P. Fabbi have examined the stable isotope and chemical relations in the Bodie mining district of California, a typical epithermal Au-Ag deposit. Analyses were made of altered host rocks, vein minerals, alteration clays, fluid inclusions, modern spring waters, and unaltered rocks of the area.

The results indicate that a hydrothermal convective system was set up by the interaction of a cooling shallow intrusion and local meteoric water. The water traveled to depth where it picked up ore constituents and SiO_2, K, Rb, and Sr without significant shifts in the stable isotope ratios of the water. The altered rocks have equilibrated to various degrees with an ore fluid of constant K:Rb, O^{18}/O^{16} and D:H ratios. Deposition of ore took place over the approximate temperature range 215° to 245°C. From C^{13}/C^{12} ratios of minor calcite a volcanic source of CO_2 is postulated. There is a pronounced similarity in chemical and isotope compositions between the ore fluid and modern spring waters in the area.

Bodie is the first deposit examined in which the entire ore deposition took place from virtually isotopically unaltered ground water. Other epithermal deposits from the Western United States are currently under investigation and are showing patterns similar to those observed at Bodie.

From stable isotope evidence, D. E. White and J. R. O'Neil have demonstrated that the Steamboat Springs geothermal system of Nevada is the present-day active equivalent of the fossil geothermal systems of epithermal Au-Ag deposits, as White has been contending for nearly 30 yr, based on similarities in ore-metal concentrations, gangue minerals, and hydrothermal alteration. New isotope data on the vein minerals of drill cores from Steamboat Springs, combined with results by others on epithermal deposits, such as Bodie, Calif., and Tonopah, Goldfield, and the Comstock Lode of Nevada, provide striking new evidence for great dominance of meteoric water in the ore fluids and for other similarities.

W. E. Hall and Irving Friedman have completed an isotopic and chemical study of the Climax mine in Colorado. Oxygen isotope compositions of quartz, potassium feldspar, and plagioclase were determined, as well as deuterium and chemical compositions of fluid inclusions from ore and host rock. The data indicate that the ore fluid was formed by the mixing of two deeply circulating waters: an isotopically heavy (magmatic) water and an isotopically light water similar to present-day meteoric water.

C. G. Warren, C. L. Webster, and H. C. Granger, in cooperation with Colorado State Univ., have measured Se^{74}/Se^{80} ratios in the selenium-rich zone associated with roll-type uranium deposits from Shirley basin, Wyoming. The selenium zone is roughly divided into a ferroselite-bearing subzone, on the oxidized side of the redox interface, and a native selenium subzone on the reduced side. In the ferroselite subzone, about 30 in. behind the redox interface, the selenium is isotopically light and has a δSe^{74} value of about 33 per mil relative to a laboratory standard. Twelve in. behind the redox interface the δSe^{74} value was only about 9.5 per mil.

At the redox interface, where the selenium is largely in the form of native selenium and perhaps seleniferous pyrite, the δSe^{74} value had jumped to 106. Twelve in. in advance of the redox interface, in the reduced zone, it had dropped to about 16. Intervening samples were consistent with the two trends. There was no variation of δSe^{82} in the samples analyzed.

Additional study by C. G. Warren showed a δSe^{74} value of about 100 per mil for pure native selenium specimens adjacent to the oxidized zone at Ambrosia Lake. N. Mex.; again there was no variation in δSe^{82}. Experimental reduction of $HSeO_3^-$ at pH <2 resulted in Se^{82}/Se^{80} fractionation about a third as large as Se^{74}/Se^{80} fractionation. At pH 3 this reduction yielded a product in which the Se^{82}/Se^{80} fractionation was only about one-twelfth that of the Se^{74}/Se^{80} fractionation. These preliminary results suggest that the degree of fractionation between certain isotope pairs is dependent on pH. The probability that roll-type deposits are formed at more nearly neutral pH's seems to agree with the trend suggested by the experimental findings.

Hydrogen isotope study of a regional metamorphic complex

R. O. Rye (USGS) and R. D. Schuiling (Vening Meinesz Laboratory, Utrecht, Holland) have completed a hydrogen isotope study of the metamorphic complex at Naxos, Greece. The complex consists of a central migmatite surrounded by schists and marbles of decreasing metamorphic grade.

The δD values of muscovite increase from an average of —75 per mil in the migmatite to about —40 per mil in the lowest metamorphic grade (glaucophane). Coexisting biotite, glaucophane, and chlorite also show an increase in δD values with decrease in metamorphic grade and indicate approximate hydrogen isotopic equilibrium with muscovite.

Calculations based on the δD data and oxygen isotope temperatures indicate that the δD of the metamorphic fluid averaged about -70 ± 5 per mil in the migmatite and decreased to —5 per mil in the glaucophane zone. The δD values of water in fluid inclusions in quartz segregations are consistent with the trend indicated by the δD data on OH-bearing minerals. The δD data are tentatively interpreted to indicate that water from deep-seated sources was mixed with water derived locally from the rocks during metamorphism and that the percentage of deep-seated water in the metamorphic fluids increased from almost nothing in the glaucophane zone to nearly 100 percent in the migmatite.

Hydrogen isotope composition of wood

Irving Friedman, A. E. Wilson, and J. D. Gleason have demonstrated that the D:H ratio in wood is approximately 60 per mil less than the D:H ratio of the water utilized by the growing tree. Therefore, the D:H ratio in tree rings can be used as paleoclimatic indicators. The authors are now analyzing samples of carbon-14-dated bristle-cone pines from the Nevada-California border area.

ADVANCES IN GEOCHRONOMETRY

Behavior of uranium, thorium, and lead in reduced age aureole

Pb^{206}/Pb^{204} and lead-alpha ages of zircons from the Precambrian Boulder Creek batholith, Colorado, are lower in relation to a Laramide age stock just northeast of the batholith (G. W. Phair, T. W. Stern, and David Gottfried, 1971). Within this aureole of reduced ages the partly recrystallized radioactive accessory minerals, zircon and allanite, have lost uranium, thorium, and lead relative to their counterparts in the less disturbed area in the southern half of the batholith. G. W. Phair and L. B. Jenkins are now studying whole-rock samples of the Boulder Creek batholith to determine if their uranium, thorium, and lead contents have been affected by the processes which lowered the apparent radiometric ages and altered the accessory minerals.

When uranium is plotted against SiO_2 and lead is plotted against K_2O, rocks lying within the reduced age aureole show much weaker systematic relationships and distinctly lower uranium and lead contents than do the rocks from the higher age undisturbed zone lying to the south. The latter rocks show the customary rising trends for uranium and lead with increasing SiO_2 and K_2O. When uranium (rock) and lead (rock) are plotted on a map of the batholith, the uranium and lead contours in the reduced age area are found to trend northwesterly subparallel to the through-going breccia reefs and at a wide angle to major rock boundaries represented by changing SiO_2. In the undisturbed zone lying to the south, uranium and lead contours tend to cut the breccia reefs at a wide angle and to conform more closely to major rock boundaries. The inference is that uranium and lead have been lost from the rocks lying in the disturbed zone during the occult hydrothermal metamorphism that produced the low zircon ages and that the breccia reefs along with their subsidiary fractures provided the main channelways for movement of solutions.

$^{40}Ar/^{39}Ar$ age spectra of some undisturbed terrestrial samples

$^{40}Ar/^{39}Ar$ age spectra and $^{40}Ar/^{36}Ar$ versus $^{39}Ar/^{36}Ar$ isochrons were determined by G. B. Dalrymple and M. A. Lanphere for 11 terrestrial rocks and minerals using the incremental heating technique. The samples, which included muscovite, biotite, hornblende, sanidine, plagioclase, dacite, diabase, and basalt range in age from 40 to 1,700 m.y. and were selected because their geology indicates that they represent essentially undisturbed systems. The age spectra are consistent with models previously proposed for undisturbed samples as the $^{40}Ar/^{39}Ar$ ratios, corrected for atmospheric and neutron-generated argon isotopes, are the same for most of the gas fractions released. Plateau ages and isochron ages calculated using plateau gas fractions are concordant and appear to be meaningful estimates of emplacement and cooling ages. Seemingly anomalous age spectrum points can be attributed entirely to small amounts of argon loss, previously unrecognized, from the samples and to gas fractions that contain too small a proportion of the total argon released to be geologically meaningful. It is worthwhile to use both the age spectrum and the isochron methods of data reduction for incremental heating experiments because each gives slightly different but complementary information about the sample from the same basic data. Use of a least squares fit that allows for correlated errors is recommended for $^{40}Ar/^{36}Ar$ versus $^{39}Ar/^{36}Ar$ isochrons. The results indicate that the $^{40}Ar/^{39}Ar$ incremental heating technique can be used to distinguish disturbed from undisturbed rock and mineral systems and will be a valuable geochronological tool in geologically complex terranes.

Lead-uranium ages in some Wyoming uranium deposits

Uraninite ages, determined by J. R. Dooely, Jr., I. T. Nkomo, J. N. Rosholt, and B. J. Szabo, from uranium deposits of the Gas Hills area and the Shirley basin in Wyoming both indicate a Pb^{206}/U^{238} age of 22 m.y. (±10 percent). The Pb^{207}/U^{235} ages are reasonably concordant for this type of uranium mineral each at about 10 percent greater than the Pb^{206}/U^{238} ages. Additional lead-uranium ages had been determined previously in three ore-grade samples representing a cross section of a roll-type deposit from an ore horizon separated from and 75 feet above the ore horizon in the Shirley basin from which one of the uraninite specimens was obtained. The uranium ore samples indicate an average of 24 m.y. (±20 percent) including a Pb^{206}/U^{238} to Pb^{207}/U^{235} discordancy similar to the uraninite samples. The uraninite samples were analyzed for equilibrium conditions. The activity ratio of U^{234} to U^{238} was found to be 99.8 and 99.5 percent for the uraninites. Equilibrium between Th^{230} and U^{238} also was established by mass spectrometric analyses for both uraninites.

The Shirley basin and Gas Hills uranium deposits are about 85 mi apart and in the Wind River Formation. Uraninite ages are probably more reliable than lower grade ore samples and represent uraninite formation in the early Miocene at 22±3 m.y. ago.

A test of thermoluminescence dating on some Hawaiian lavas

A. L. Berry, a Stanford University graduate student working with G. B. Dalrymple, completed preliminary studies of the potential applicability of thermoluminescence (*TL*) dating to young basalts. Eight Hawaiian flows whose ages, from carbon-14 dating and historic observations, range from 12 yr to 17,360±650 yr were selected for investigation. The results, when normalized for their individual sensitivity and for their annual radiation dose from uranium, thorium, and potassium, show a remarkably good correlation between *TL* and known age. Two alkalic flows gave anomalous results, but this probably can be overcome by changes in technique. The study indicates that the *TL* method is a potential new tool for dating young lavas. The age range over which the technique will be applicable is uncertain, but 50,000 to 100,000 yr is a reasonable estimate.

Minnesota geochronology

Uranium-thorium-lead isotopic analyses of zircons from the Rainy Lake region of Minnesota and Ontario by T. W. Stern date the Algoman Granite of Lawson (1941) at 2,700 m.y. This date places a minimum time limit on the major early Precambrian orogeny in the southern part of the Canadian Shield. Problems have arisen in attempts to date the Algoman Granite by the rubidium-strontium method, and these have been discussed by Z. E. Peterman, S. S. Goldich, C. E. Hedge, and D. H. Yardley (1972). The whole-rock rubidium-strontium data define an isochron indicating an age of 2,540±90 m.y. This age is significantly younger than the uranium-lead concordia age of 2,700±30 m.y., and it suggests that the rubidium-strontium isotopic system has been open but behaved in such a regular fashion as not to disturb appreciably the linearity of the points defining the isochron.

Work is in progress in the Penokean granites of east-central Minnesota. The McGrath Gneiss of Woyski (1949) is Precambrian W (lower) approximately 2,700 m.y., and not Penokean or Precambrian X (middle). Zircons from granites in the St. Cloud area are discordant with an approximate age of 1,800 m.y.

Fission-track dating of hydrothermally altered rocks

C. W. Naeser has determined that fission-track dating of zircons can yield ages for hydrothermally altered rocks that cannot be dated by other methods. Zircons from six badly altered rocks at the Henderson mine, Empire, Colo., were dated by fission tracks. Earlier attempts to date these rocks by potassium-argon have been unsuccessful. The zircon fission-track ages ranged only from 27.8±2.9 m.y. to 23.1±2.3 m.y., indicating that intrusion and mineralization at the Henderson mine took place about 25 m.y. ago.

Earliest time of rifting apart of North America and Africa

C. S. Grommé and G. B. Dalrymple (1972) have investigated the diabase dikes and sills that are abundant in northwestern Liberia. Potassium-argon ages on minerals and whole-rock samples from dikes intrusive into Precambrian crystalline rocks are discordant and range from 193 to 1,213 m.y. Data from Ar^{40}/Ar^{39} incremental heating experiments on neutron-irradiated samples of three of these rocks give argon-release curves that reach minima around 200 m.y. only at intermediate temperatures and do not fit an Ar^{40}/Ar^{36} versus Ar^{39}/Ar^{36} isochron. In contrast to these anomalous results, potassium-argon ages on dikes and sills intrusive into Paleozoic sedimentary rocks are all between 173 and 192 m.y., and Ar^{40}/Ar^{39} incremental heating data from one of these latter rocks give both a plateau age on argon-release curve and an isochron age that are within this range. These experiments indicate that the dikes intrusive into the Precambrian basement have absorbed and retained extraneous radiogenic Ar^{40} from the country rock and hence give ages older than the true crystallization ages. The dikes intrusive into Paleozoic sandstone are not so affected, and their age range appears to represent all the time of dike intrusion. The mean paleomagnetic directions in the two groups of dikes do not differ significantly, further indicating their contemporaneity. These paleomagnetic data, when combined with similar published data from Morocco and Sierra Leone, result in a Late Triassic–Early Jurassic paleomagnetic pole for west Africa that lies 44° great-circle distance from the corresponding pole for eastern North America. When these two continents are juxtaposed according to the mutual fit of continental shelf margins proposed by Bullard, Everett, and Smith (1964), the angular difference between the two poles is reduced to only 3°, which is a striking confirmation of the correctness of this continental reconstruction. The initial opening of the central Atlantic Ocean by rifting apart of North America and Africa has generally been considered to be about 180 m.y. ago, and these results confirm that separation of the two continents could not have commenced at a much earlier time.

Chronology of southern hemisphere glaciation

Potassium-argon and paleomagnetic studies of Cenozoic basalts in southern Argentina confirm the existence and age of the three major normal-polarity events in the Matuyama reversed geomagnetic polarity epoch and provide definition of the chronology of climatic variation in the southern hemisphere. R. J. Fleck and E. A. Mankinen (USGS), collaborating with A. E. M. Nairn and D. N. Peterson (Case-Western Reserve Univ.) and J. H. Mercer (Ohio State Univ.) (Fleck and others, 1972; Mercer and others, 1972) have shown that basalt flows, interbedded with glacial deposits at a number of localities in southern Argentina, range in age from 3.68 to 1.03 m.y. At Cerro del Fraile the three normal-polarity events in the Matuyama reversed epoch are recorded in a continuous cliff exposure, separated by tills and basalt flows of reversed polarity. The earliest glacial tills occurring at this latitude (about 50° south), are greater than 3.68 m.y. in age and are located at 1,400 m elevation, 75 km east of the crest of the Andes. Glacial outwash greater than 2.95 m.y. old occurs at 450 m elevation 100 km farther east, where the capping, normally polarized basalt is overlain by till from the most extensive southern hemisphere glaciation. The age of this most extensive glaciation is found to be less than 1.25 m.y. and probably greater than 1.03 m.y. At least four periods of glacial advance predated this glaciation, which may be correlative with the Nebraskan stage of the North American glacial sequence.

Volcanic ash marker bed associated with Blancan fauna

The finer grained downwind equivalent of the Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff, in the Jemez Mountains of northern New Mexico, is found as an ash bed at various localities eastward across New Mexico and into Texas. One of the most important localities where the Guaje ash has been identified by G. A. Izett, R. E. Wilcox, and G. A. Borchardt (1972) is near Mount Blanco, Crosby County, Tex., where it occurs as a 0.3-m-thick bed above the lake beds containing the Blancan fauna. Glass shards in the Guaje ash have been dated at about 1.4 m.y., using the fission-track method. A thinner gray ash bed lying within the Blancan faunal beds has not yet been dated or identified as to its age or source.

Dating of glaciations in the Rocky Mountains

K. L. Pierce, Irving Friedman, and J. D. Obradovich have detailed the dates of the Pinedale and Bull Lake Glaciations in the Yellowstone National Park vicinity. Their dates place the Pinedale maximum at approximately 40,000 yr B.P. and Bull Lake as being pre-Wisconsinan, that is, having occurred at approximately 150,000±20,000 yr B.P. These dates agree well with glaciation chronologies as deduced from deep sea cores although the dates are contrary to previous concepts of the age of Bull Lake Glaciation, which had been thought to be Wisconsinan (80,000–100,000 yr B.P.).

Obsidian hydration dates glacial loading?

Measurements by Irving Friedman, K. L. Pierce, J. D. Obradovich and W. D. Long (1973) of obsidian hydration on samples from Obsidian Cliff, Yellowstone National Park, show three thicknesses of cracks and edges. The thickest hydration (oldest) is related to the event that emplaced the flow 176,000 yr ago (K-Ar). The other two groups of hydration thickness measurements (7–8 μm and 14.5–15 μm) are the same as Pierce has found on obsidian pebbles in Pinedale and Bull Lake glacial moraines. It is postulated that these cracks in the Obsidian Cliff samples were caused by the loading of approximately 2,000 ft of Pinedale and Bull Lake ice on the obsidian flow.

Electron microprobe evaluation of terrestrial basalts for whole-rock potassium-argon dating

Four basalt samples for whole-rock potassium-argon dating were analyzed by E. A. Mankinen and G. B. Dalrymple (1972) with an electron microprobe to locate potassium concentrations. Highest concentrations of potassium were found in those mineral phases that were the last to crystallize. The two reliable samples had potassium concentrated in fine-grained interstitial feldspar and along grain boundaries of earlier formed plagioclase crystals. The two unreliable samples had potassium concentrated in the glassy matrix, demonstrating the ineffectiveness of basaltic glass as a retainer of radiogenic argon. The results clearly indicate that particular emphasis should be placed on determining the nature and condition of the fine-grained interstitial phases when selecting basalt samples for whole-rock potassium-argon dating.

A time-scale for the Late Cretaceous of the western interior of North America

Establishing a reliable radiometric time scale for the Cretaceous Period has proved to be an elusive task. In Europe, where the type sections of the stages of the Cretaceous are found, geochronologists are faced with a virtual absence of datable interlayered volcanic rocks and must make use of glauconite, a material of questionable reliability for dating.

The western interior of North America provides a more favorable situation for dating Cretaceous rocks and faunas. Numerous bentonites are interspersed throughout a nearly complete sequence of marine sediments ranging in age from late Albian through early Maestrichtian. Within this interval more than 60 range zones based on ammonites and inoceramids have been delineated. Unfortunately, only a few of these range zones can be correlated precisely with the European type sections.

Utilizing the published radiometric data and their own new potassium-argon data, P. D. Obradovich and W. A. Cobban assign the following ages to certain specific faunal zones and their inferred correlatives.

Zone	*Stage*	*Age (m.y.)*
Triceratops	Late Maestrichtian	64–66
Baculites grandis	Early Maestrichtian	Ca. 68
compressus	Late Campanian	Ca. 72
Didymoceras nebrascense	do	Ca. 73
Baculites mclearni and *B. obtusus.*	Early Campanian	Ca. 78
Desmoscaphites bassleri	Late Santonian	Ca. 83
Inoceramus deformis	Late Turonian	Ca. 86
labiatus	Early Turonian	Ca. 89
Dunveganoceras pondi	Late Cenomanian	Ca. 93
Neogastroplites	Late Albian	94–98

GEOTHERMAL SYSTEMS

First discovery of lepidolite in a geothermal system

In the course of a systematic petrological study of hydrothermal alteration of glacial sediments and rhyolite in core from USGS drill hole Y–3, Yellowstone National Park, lepidolite was discovered by K. E. Bargar. Mineralogical and chemical studies by Bargar, M. H. Beeson, R. O. Fournier, and L. J. P. Muffler (unpub. data, 1973) indicate that this lepidolite is a polylithionite and was precipitated at 130° to 140°C from water of the presently active geothermal system. This water has a very high fluorine content and an extraordinarily high ratio of lithium to potassium. This appears to be the first report of lepidolite from either a low-temperature hydrothermal system or a modern geothermal system.

Inventory of major thermal features of Yellowstone Park geyser basins

An inventory and histories of the principal thermal features of Upper and Lower Geyser Basins of Yellowstone Park has been completed by G. D. Marler (1973). The recorded history of some named features now extends slightly over 100 yr. Records are relatively good for the period $\approx$ 1870–90 immediately following discovery of the Park; records are then scanty until Marler's personal association with the geyser basins, first as a staff member of the National Park Service (1931–72) and then for a short time with the USGS. More than 280 of the principal features are now described, with emphasis on recorded changes in each, particularly those changes due to the Hebgen Earthquake of 1959.

Production characteristics of fluids from hot-water systems

A computer program has been written by Manuel Nathenson to solve the equations needed to obtain the well head characteristics of fluids from a well tapping a hot water geothermal system. The flow up the well includes flashing of water to steam as pressure declines. The hydrodynamics of the flowing mixture are treated in an approximate manner while the thermodynamics utilize data from steam tables. The program is being used to study the effects of various reservoir properties on the temperatures, pressures, and fluid proportions delivered at the well head. For example, the local water table can be located anywhere from ground surface to any specified depth below ground surface, with differences in required steam lift of residual water affecting the quantity and quality of the fluids delivered at the well head.

Resistivity, self-potential, and induced polarization surveys of a vapor-dominated geothermal system

The Mud Volcano area in Yellowstone National Park provides an example of a vapor-dominated geothermal system as evidenced by a test well drilled to a depth of about 106 m. The interpretation of 16 VES (vertical electrical sounding) curves of the Schlumberger type using graphical, computer modeling, and computer automatic interpretation techniques indicates that the vapor dominated layer has a high resistivity value of 75 to 130 ohm-m and that it is characteristically overlain by a low resistivity layer of about 2 to 6.5 ohm-m (A. A. R. Zohdy and others, 1972). Horizontal resistivity profiling corroborated the sounding interpretation and delineated the southeastern boundary of the geothermal field by a distinct transition from low to high apparent resistivities. A broad positive SP (selfpotential) anomaly was observed over the geothermal field. IP (induced polarization) anomalies probably were caused by concentrations of pyrite.

Seismic noise studies—cultural versus residual

H. M. Iyer reports that preliminary analyses of data collected in the Imperial Valley, Calif., in the vicinity of the Mesa thermal anomaly showed that the seismic noise picture is confused by the existence of a busy freeway and agricultural activities. The USGS experiment, however, provided sufficient data to permit correction for the cultural noise and calculation of the residual noise levels in the region of the Mesa anomaly.

A similar noise survey conducted in Yellowstone Park showed a good correlation between areas of high noise and areas of hot-spring activity.

SEDIMENTOLOGY

Sedimentology, the study of sediments and sedimentary rock, encompasses investigations of principles and processes of sedimentation and includes development of new techniques and methods of study. USGS sedimentology studies are directed toward two ends: (1) Solution of water-resources problems, and (2) determination of the genesis of sediments and application of this knowledge to sedimentary rocks for more precise interpretation of their depositional environment. Many USGS sedimentology studies are directly applied to other topics such as marine, economic, and engineering geology and to regional stratigraphic and structural studies; these are presented elsewhere in this volume under their appropriate headings.

Studies of fluvial sedimentation are directed toward the solution of water-resource problems involving water-sediment mixtures. Sediment is being considered more and more in the role of a pollutant. Inorganic and organic sediments transported by streams to sites where deposition takes place carry 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.

CHANNEL SCOUR PROCESSES

Scour at bridges in Alaska

A study of the response of streambeds to floodflows at selected bridge sites in Alaska has been conducted over the past 7 yr by V. W. Norman and others. Results of these studies indicate that local equilibrium depth of scour at piers is inversely related to the particle size of bed material, an observation which has not been possible in most laboratory studies because of the limited range in particle sizes used in the experiments. Local equilibrium scour depth on gravel-cobble-bed streams was on the order of five times less than that predicted by available pier-scour formulae. General scour at bridge openings varied directly with the amount of channel contraction at the openings. The process of general scour in a straight reach with some contraction appears to be one of removing the material from the high points of the bed rather than the scouring of the deep parts. Minimum bed elevations at most cross sections tended to remain stable, but their locations within each cross section often shifted laterally.

TRANSPORT PROCESSES

Stochastic models of sediment transport

Stochastic models to predict sediment-transport rates and dispersion of sediment particles in an alluvial channel are based on the idea that the movement of sand particles consists of a series of steps separated by rest periods. Therefore, the use of these models requires a knowledge of the probability distributions of the step lengths, the rest periods, and the elevation of particle deposition. According to B. K. Lee and H. E. Jobson (1973), with suitable assumptions for the dune-bed configuration characterized by a series of alternating deposition and erosion reaches, the distribution functions for the rest periods and the elevation of particle deposition can be obtained from a record of the bed elevation at a particular point as a continuous function of time. Similarly, the distribution function for the particle step length and the correlation coefficient between the step length and the elevation of particle deposition can be obtained from a series of instantaneous longitudinal bed profiles.

Water-discharge sediment-transport relations

G. V. Sabol reported that relations between daily water discharge and daily sediment discharge were developed from published long-term records for six perennial streams with large drainage basins (more than 1,800 mi^2). These relations were defined by logarithmic regression and by group average techniques for a 5-yr period of record for each stream using measured sediment discharges determined at 1-, 3-, 7-, 14-, 30-, 50-, and 100-d intervals. These relations then were used to estimate the daily sediment loads from the water discharge for the remaining period of record. Appraisals of the regressions were based on the criteria of accuracy of total annual suspended-load estimation and variance of daily sediment-discharge estimation. Five years of record were found to be sufficient to define the daily water-sediment discharge relation. There was no loss in accuracy of estimation using models generated from data up to a 14-d sampling interval. The procedure is applicable to perennial streams with fairly uniform sources of sediment influx.

Sediment transport and hydraulic geometry of the Trinity River basin, California

J. M. Knott reported that the extraordinary flood of December 1964 drastically changed water-sediment discharge relations in the Trinity River basin of northern California. Several times as much sediment was transported at a given flow after the flood than was transported before the flood. Within 2 yr after the flood, sediment-transport rates began to decrease and at present are approaching preflood levels.

Significant changes in the hydraulic geometry of many streams also were observed after the December 1964 flood. The largest changes in hydraulic geometry were observed at a gaging station on the South Fork Trinity River where, for median flows, average velocity increased 200 percent, average depth decreased 75 percent, and width increased 20 percent.

Sediment transport and channel armoring in the Owens River, near Bishop, California

After studying a 16-mi reach of the Owens River below Pleasant Valley Dam, Inyo County, Calif., R. P. Williams reported that, because of increased annual flow resulting from diversions from other drainages into the Owens River, armoring of the channel has occurred. Preliminary investigations indicate that the channel bed is approaching equilibrium, and there will be little change unless foreign material is introduced to the river system or a regime change occurs. Accelerated sloughing of the streambanks is occurring, and fine-grained bank material is being deposited on point bars at a minimal rate. Most of this material is transported out of the study reaches. The river apparently has adjusted its load to armored conditions, and consequently, future changes in meander length and amplitude will predominate over previously pronounced changes in slope.

Turbidity and sediment transport in the Russian River basin, Sonoma and Mendocino Counties, California

According to J. R. Ritter and W. M. Brown III (1972b), the most persistently turbid water in the Russian River basin was the water diverted from the Eel River into the East Fork Russian River. As long as that water was flowing into Lake Mendocino, the water in the lake remained turbid, and consequently the releases from the lake were turbid. During periods of little or no rain when the lake water was turbid, the river downstream from the lake was turbid when the releases were high and clearer when the releases were low. Turbidity currents flowing through the lake also influenced the turbidity of the releases. Sand and gravel mining, road construction, flushing of irrigation ditches, and algal blooms also produced turbid water in the Russian River basin.

Turbidity and concentration of suspended sediment, expressed in milligrams per liter, were highly correlative ($r>0.90$) at most sampling stations. The correlation differed for each station and varied slightly each year. At stations where flow was regulated, the turbidity was usually higher than the corresponding concentration. At stations where flow was unregulated, concentration was usually higher than turbidity. The difference in correlation between the stations where flow was regulated and those where flow was unregulated appeared to be related to the quantity of sand in the suspended load.

The average annual suspended-sediment yield for the basin upstream from Guerneville for the water years 1965–68 was 4,370 tons per mi^2. The area of lowest annual yield (1,350 tons per mi^2) and lowest runoff was in the East Fork Russian River basin, where the water was the most persistently turbid because of the diverted Eel River water. The area having the highest annual yield (5,770 tons per mi^2) was the Dry Creek basin, where the water was the least persistently turbid.

VARIABILITY OF SEDIMENT LOADS

Suspended-sediment discharges associated with Tropical Storm Agnes, June, 1972, Montgomery and Frederick Counties, Maryland

T. H. Yorke, Jr., reported that suspended-sediment discharges associated with Tropical Storm Agnes in June 1972 were 0.9 to 1.6 times the mean annual sediment discharges measured at gaging stations in Maryland. The load of the Northwest Branch Anacostia River near Colesville (21.1 mi^2) on June 21, 22, was 12,800 tons compared with the 8-yr annual mean of 13,900 tons. The storm load of the Monocacy River near Frederick (817 mi^2) was 218,000 tons compared with the 10-yr mean of 138,000 tons; and the load of the Potomac River at Point of Rocks (9,651 mi^2) was 1.3 million tons compared with the 10-yr mean of 878,000 tons. These sediment loads resulted from record peak discharges on the Anacostia and Monocacy Rivers and the fourth highest peak of record on the Potomac River.

Effects of Eel River sediments on beaches in California

The annual sand load of the Eel River averages about 4,600,000 tons which is equivalent to a deposition of about 2,100 acre-ft. According to J. R. Ritter (1972), some of this sand is deposited in the river estuary, and some is furnished to the nearby beaches. Ritter found that most of the sand, however, is carried into the ocean and scattered over the continental margin. Nevertheless, mineralogical and particle-size analyses suggest that the Eel River supplies most of the sand deposited on beaches from the Humboldt Bay entrance south to Centerville Beach, a stretch of about 13 mi. The sand on the beaches from the Humboldt Bay entrance north to Trinidad Head probably is supplied by the Mad and Little Rivers.

VARIABILITY OF SEDIMENT YIELDS

Sediment yields of Minnesota streams

Data obtained from a statewide network of 19 partial-record and 2 daily sediment-yield stations were used by C. R. Collier to estimate the long-term average sediment yields of streams in Minnesota. Streams in southeastern Minnesota have the highest annual sediment yields—520 tons per mi^2 at two stations on the Root River and 80 to 120 tons per mi^2 at stations on three other streams in that area. Suspended-sediment concentrations range from 2,000 to 10,000 mg/l in these streams during periods of storm runoff.

In the upper Minnesota River basin in southwestern Minnesota the annual sediment yields range from 20 to 80 tons per mi^2 and the suspended-sediment concentrations seldom exceed 2,000 mg/l during storm runoff. In the northern two-thirds of Minnesota, soils are less erosive, and numerous lakes and swamps retain much of the sediment eroded. Estimated annual yields of these rivers range generally from 2 to 20 tons per mi^2 and suspended-sediment concentrations seldom exceed 500 mg/l during storm runoff.

Sediment-yield trends in Stony Brook basin, New Jersey

According to L. J. Mansue and P. W. Anderson, a trend analysis of sediment yield from the Stony Brook basin (48 mi^2) in west-central New Jersey indicated that in the period 1956–61 yields were higher than they are today. Residential, highway, pipeline, and reservoir construction in and near the stream channel temporarily increased sediment yields. Lower yields during recent years (1962–70) reflect the influence of the 1962–66 drought, stabilization of residential growth, and completion of seven sediment-retention reservoirs in the watershed.

Sediment yields to Delaware estuary

L. J. Mansue and A. B. Commings reported that the quantity of sediment transported by streams draining into the Delaware estuary from Pennsylvania, New Jersey, and Delaware is estimated to average 1.6 million tons per yr. Of this amount, 49 percent is contributed by the Delaware River main stem at Trenton, 35 percent by Pennsylvania tributaries, 9 percent by Delaware tributaries, and 7 percent by New Jersey tributaries. Highest yields are found in basins draining the Piedmont province in Pennsylvania and northern Delaware; they range from 100 to 1,000 tons per mi^2 annually. Basins transporting the least sediment per square mile are located in the Outer Coastal Plain of New Jersey and Delaware. Yields in these stream basins vary from 5 to 10 tons per mi^2 annually.

Many of the lower Delaware River basin streams flow through areas which are already urbanized or are undergoing extensive urbanization. Comparison of sediment yields indicates that basins draining stabilized urban areas are similar in yield to those found in nonurban areas. However, streams draining areas in the developmental phases of urbanization (where exposure of soils by earth moving equipment has produced a readily erodible source) have yields two to four times higher than the adjacent nonurban or the stable urban areas.

Sediment resulting from highway construction, Durham County, North Carolina

A research study was made in cooperation with the North Carolina Highway Commission to explore methods of reducing sediment movement during highway construction. From the study, H. E. Reeder found that a settling basin was effective in trapping sediment. The 13-mo study of a 20-acre construction area near Durham, N.C., began after the area was cleared and terminated when final grass cover was established. During the period of study, 50.12 in. of rain was recorded in the basin. Sediment deposition was computed from periodic sedimentation surveys. The relation of rainfall to sediment deposition was variable. The variations were affected by rate of runoff, area of exposed surfaces, physical condition of exposed surfaces, intensity of rainfall, and type of construction activity.

Determinations were made of particle size of deposited sediment and watershed material. These data were used with deposited-volume data to estimate trap efficiency. As the settling basin filled, deposited sediment became coarser and trap efficiency decreased. Initially, the median diameter of deposited sediment was about 0.02 mm, and the trap efficiency was about 88 percent. When the basin was 98-percent full, the median diameter was about 0.08 mm, and the trap efficiency was about 42 percent.

About 1,110 yd^3 (1,440 tons) of sediment entered the basin. The erosion rate was 56 yd^3 (72 tons) per acre of exposed area. The basin trapped 722 yd^3 (962 tons) of the incoming sediment.

The results show that sediment can be efficiently trapped in relatively small basins adjacent to highway-construction sites, thereby reducing sedimentation downstream. They also show that prompt, interim treatment measures, if merely grass planting, appreciably reduce erosion from construction areas.

Sediment deposition in Williams Reservoir, California

J. R. Ritter and W. M. Brown III (1972a) determined that 52 acre-ft of sediment was deposited in Williams Reservoir between 1913 and 1971. From calculations of the sediment yields in other nearby drainage basins in Santa Clara County, Calif., it was determined that 24 to 38 acre-ft of sediment would have been transported to Williams Reservoir between 1961 and 1971 under natural conditions. Little or negligible sedimentation is reported for 1913–61, and the difference (14–28 acre-ft) probably is a consequence of increased sediment yield due to a fire that destroyed much of the vegetation in the drainage basin in 1961.

Sediment resulting from clearing prior to highway construction, Cumberland County, Pennsylvania

Analyses by L. A. Reed of suspended-sediment concentration and turbidity data collected during the clearing phase of highway construction revealed that each time a clearing operation was conducted affecting one of the streams, the resulting sediment and turbidities approximated those occurring with a rather intense 1-in. rainfall in the basin. However, on completion of clearing in the basin, and performance of no additional work, the sediment and turbidity levels returned to normal after 2 to 4 weeks.

Sediment yields from a small glaciated basin in central Pennsylvania

Analysis by J. F. Truhlar, Jr., of the 1972 water-year sediment data collected above the highway construction in the Applemans Run basin revealed that this small glaciated basin yielded sediment loads nearly five times those expected from the surrounding general Valley and Ridge area. These data do not include the abnormally high sediment discharge during the June 1972 flood.

Sediment yield from a construction site, Fairfax County, Virginia

A 24.1-acre construction area within a 49.1-acre drainage basin near Reston, Va., was found to be responsible for nearly all of a 600-ton sediment yield during Tropical Storm Agnes on June 21, 1972, according to H. P. Guy and T. L. Clayton (1973). The peak half hour of rainfall amounted to 1.30 in., caused an average runoff rate of 105 ft^3/s, and yielded 159 tons of sediment. The average particle size of sediment yielded from the basin during the storm was 6-percent sand, 49-percent silt, and 45-percent clay. Based on the relationship between particle size of the soils exposed to erosion in the basin and particle size of the sediment yielded, total estimated erosion in the basin during the storm was 1,170 tons, 570 tons of which must have been deposited at various locations in the basin.

GLACIOLOGY

Research by glaciologists of the USGS is directed toward the better understanding of snow, ice, and glaciers as water resources, as elements in the meteorologic and hydrologic environment of the high mountains, and as indicators of climatic change. Studies undertaken include the dynamics of ice flow, the relation of heat and mass exchanges at snow and ice surfaces, and the development and testing of new mass-balance measuring procedures.

Glacier hydrology

Liquid-water-storage investigations on South Cascade Glacier in the North Cascades, Wash., by M. F. Meier (1973), W. V. Tangborn, and R. M. Krimmel show that the transit time for a sizable percentage of melt water and rain from the glacier surface to the terminus is on the order of months rather than hours or days. Measurements of input and output of water show that a relatively large amount of water (as much as 1 m averaged over the glacier area) can be in temporary storage during the early part of the melt season. The mechanism controlling this variation in melt-water storage is hypothesized to be due to changes in size of conduits within the glacier depending on the viscous flow of ice and the rate of ice melt on conduit walls due to movement of water. Thus glacier runoff is not a direct consequence of ablation during the same interval, and glacier flow and water storage within a glacier are closely related. Occurrences of outburst floods from many glaciers prove that large amounts of water are stored in glaciers.

Donald Richardson (1973) compared mean monthly streamflow with monthly "net precipitation" (mean basin precipitation minus evapotranspiration) and determined that melt-water runoff is 41 to 53 percent of the total runoff in five basins of the Mount Rainier area. The mean water equivalent of the spring snowpack in each basin was estimated on the basis of mean annual precipitation and altitude using a general relationship defined by snow-survey data. Estimated melt-water runoff in August and September is greatest in those basins that have the largest glacier-covered areas. In 1963 a kinematic ice wave on the lower Nisqually Glacier had a volume of about 27×10^6 m^3, equivalent to the low-flow runoff of the Nisqually River near National, Wash., for 71 d.

Glacier mass balance

Results of IHD studies by W. V. Tangborn, L. R. Mayo, D. R. Scully, and R. M. Krimmel of four glaciers and basins ranging in latitude from 37°45′ to 63°15′ N. show that on some glaciers a significant proportion of glacier snow accumulation is derived from the slopes surrounding the glacier. For example, in 1967 on Maclure Glacier in the Sierra Nevada, Calif., 43 percent of the spring snow avalanched and drifted from adjacent areas. In the same year, accumulation by redeposition was 35 percent on the South Cascade Glacier in the North Cascades, Wash.; 22 percent on the Wolverine Glacier in the Kenai Peninsula, Alaska; and 15 percent on the Gulkana Glacier in the Alaska Range. The difference in the proportions of redeposited snow for these four glaciers is chiefly a function of size and the ratio of glacier to basin area.

A survey of Grinnell Glacier, Mont., by W. A. Blenkarn showed that the thickness of ice and snow had increased 1.5 to 3 m between August 30, 1970, and August 30, 1972. The increase reversed the trend of generally decreasing thicknesses that were measured during the period 1935–70. The reversal probably is temporary and reflects the heaviest snowfall of record during the winter of 1971–72. Although streamflow from the basin that includes the glacier was about 120 percent of average during the 1972 water year, the heavy winter accumulation of snow and ice had not completely melted by August.

Glacier dynamics

Three contemporary flow laws were compared in a three-dimensional, time-dependent glacier model by W. J. Campbell and L. A. Rasmussen. An earlier model for three-dimensional, time-dependent glacier flow by Campbell and Rasmussen (1970) had treated the ice as a Newtonian viscous fluid and related its dynamics to two large-scale bulk parameters: the ice viscosity v and a basal friction parameter A relating basal shear stress to volume transport. Recent research suggests that a more realistic basal flow law is one in which the basal shear stress raised to some lower power (1–3) is proportional to the vertically averaged velocity or to the ratio of the vertically averaged velocity to glacier thickness. These alternate basal flow laws were incorporated with the Campbell-Rasmussen momentum equation to form a generalized two-dimensional transport equation which, when combined with the continuity equation, yields a numerically tractable set of equations for three-dimensional, time-dependent glacier flow. Solutions of the model were found for steady-state flow and surge advance and recovery for a typical valley glacier bed using powers of 1, 2, and 3 for each of the basal flow laws and a given ice viscosity.

A relatively large number of glaciers in Alaska periodically surge at velocities from 10 to more than 100 times faster than their normal rate of movement. In 1969, Austin Post mapped 41 surging glaciers in the Alaska Range. This aerial inventory was continued by L. R. Mayo in 1971 and 1972. Of the 38 glaciers displaying definite evidence of surging in 1969, only one was active in 1972. However, two of three glaciers that showed possible evidence of surging in 1969 were very active in 1972. In addition, two other glaciers previously unrecognized as surging glaciers were active during the 1972 reconnaissance.

Chester Zenone and Mayo collected altitude data on Black Rapids Glacier in August 1972 which verified 1970 and 1971 measurements of a thickening of the glacier's ice-storage reservoir by as much as 50 m since 1950. The presence and buildup of such a reservoir is a characteristic of all glaciers that surge.

Changes in tidal glaciers

The Neoglacial advance and historic retreat (up to 100 km) of the tidal glaciers of Glacier Bay, Alaska, are greater than those of any other glaciers. Although two glaciers, Muir and Plateau, are still retreating catastrophically, tidal glaciers in the western part of the bay are now advancing. In July 1972, in cooperation with the National Park Service, studies of channel depth, former ice levels, and interstadial deposits were made by Austin Post, L. R. Mayo, and R. M. Krimmel. The large-scale asynchronous changes probably are not directly related to climatic change, but are due to changes in water depth at each glacier terminus; the glaciers build terminal moraine dams during advance then become unstable and retreat catastrophically when they melt back from the terminal shoal.

PALEONTOLOGY

Research by paleontologists of the USGS 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 attained during the past year, many of them as yet unpublished, are summarized in this section by major geologic age and area. Many additional paleontologic studies are carried out by paleontologists of the USGS in cooperation with USGS colleagues. The results of these investigations are reported under the section "Geological, Geophysical, and Mineral-Resource Investigation."

PALEOZOIC OF THE EASTERN STATES

Palynological assemblages from the Lee Formation, Kentucky

Assemblages from 17 Pennsylvanian samples including 6 coals have been determined by R. M. Kosanke from a 319 ft interval in the lower part of the Lee Formation. These samples are from Sawyer quadrangle in eastern Kentucky. The assemblages are distinct and contribute significantly in establishing range zones of important spore and pollen taxa in the Eastern United States. *Trinidulus diamphidios* is present in samples 145 ft above the Pennington-Lee contact. Previously this taxon was restricted in geographic occurrence to the midcontinent region of Oklahoma and Texas and from Morrowan rocks. *Lycospora nitida* is reported for the first time from eastern Kentucky from samples 200 ft above the Pennington-Lee contact. The base of the range zone of *Laevigatosporites* has been established in samples about 310 ft above the Pennington-Lee contact with the occurrence of both *L. ovalis* and *L. desmoinesis.* These samples are above a prominent sandstone that may be the Rockcastle Sandstone Member of the Lee Formation.

Analysis of coloniality in corals

The nature, development, and history of coloniality within zoantharian corals is the subject of a study by W. A. Oliver, Jr., (USGS) and A. G. Coates (George Washington Univ.). Genera of colonial corals have been more numerous than solitary genera through most of Phanerozoic time even though colonial genera were a minority of the Rugosa. Various forms of coralla represent widely different levels of development, in terms of both integration within colonies and adaptive success, but the two are not necessarily correlated. Phaceloid rugosans represent a low level of integration with no connection between individuals other than skeletal; in contrast, coenosteoid scleractinians represent a high level of integration with confluent gastrovascular cavities and coordinated skelton building. Both of these forms were successful in terms of generic diversity and longevity.

The evolution of coloniality in zoantharian corals was paralleled by the evolution of the coral-reef building habit. Paleozoic corals built only small reefs, apparently because of slow growth, relative instability, and failure to solve the problem of metabolic waste disposal. Mesozoic to Holocene corals developed porous skeltons that are strong, stable, and rapidly built. In addition they have developed an algal symbiosis that has solved the waste problem and increased the rate of $CaCO_3$ deposition. These factors together have made possible the surf-resistant oceanic reefs of late Mesozoic to Holocene time.

Paleogeographic distribution of Ordovician bryozoan families Ptilodictyidae and Stictoporellidae

In connection with O. L. Karklins' investigations of bryozoans from the Middle and Upper Ordovician rocks in Kentucky, the cryptostome bifoliate genera were selected for a detailed study of their skeletal structures and their geographic and stratigraphic distribution in the Ordovician. In the preliminary revision of classification, *Chazydictya, Escharopora, Championodictya, Graptodictya,* and *Stictoporella* are included among others in the family Stictoporellidae. The revised family Ptilodictyidae comprise among others the following: *Ptilodictya, Phaenopora, Phaenoporella, Insignia,* and *probably Clathropora.* On the basis of reported first occurrences, the Stictoporellidae appear first in the lower Middle Ordovician rocks of North America; Ptilodictyidae are first reported from the lower Middle Ordovician of the USSR. During the late Middle Ordovician and the early Late Ordovician, the genera of both families, or their descendants, began to intermingle: stictoporellids are reported from the USSR and ptilodictyids from North America. One possible explanation for this stratigraphic and geographic pattern of distribution is that both families were provincial at first; each family being limited to a separate basin. This restricted early history was followed by dispersal with both families becoming cosmopolitan during Late Ordovician and Silurian time and then disappearing from the record. The characteristic stictoporellid and ptilodictyid skeletal structures of the Ordovician stock ranged through the lower part of the Silurian; they disappear, with the possible exception of *Ptilodictya,* at the end of the Silurian.

Silicified Early Devonian ostracodes from eastern New York

Silicified ostracodes have been obtained by J. M. Berdan from the Lower Devonian Glenerie Limestone of Chadwick (1908) at Fourth Lake, southwest of Kingston, N.Y. Although poorly preserved, more than 20 species can be recognized, including 6, *Bollia zygocornis* Swartz, 1936, *Bollia* sp. cf. *B. cristata* Swartz, 1936, *Ulrichia* sp. cf. *U. pluripuncta* Swartz, 1936, *Neothlipsura confluens* Swartz, 1932, *Thlipsurella* sp. cf. *T. secoclefta* Swartz, 1932, and *Paraschmidtella dorsopunctata* Swartz, 1936 which were originally described from the middle and upper parts of the Shriver Chert in Pennsylvania. The underlying Port Ewen Limestone at the same locality contains many of the same ostracode genera, but the species are decidedly different.

Late Ordovician (Ashgillian) age of volcanic rocks, north-central Maine

The Ashgillian (Late Ordovician) Age of flinty rhyolitic tuff and tuffaceous conglomerate included in the Lobster Mountain Volcanics at Lobster Lake, Piscataquis County, Maine, has been determined by R. B. Neuman from an assemblage of brachiopods collected by him with R. G. Doyle (Maine Geological Survey), William Forbes (Maine Univ., Presque Isle) and Ralph Männil (Estonian Academy of Sciences). The assemblage includes the genera *Catazyga,* aff. *Doleroides, Glyptorthis, Leangella,* and *Sowerbyella.* This is the first paleontologic confirmation of Ashgillian-Age volcanic rocks in this region, showing that volcanism was active here throughout the Ordovician.

Fordilla, earliest known pelecypod

Working with Bruce Runnegar, University of New England, Armidale, Australia, and Jiri Kriz, Central Geological Survey, Czechoslovakia, John Pojeta, Jr. (USGS), has discovered the earliest fossils assignable to the Class Pelecypoda. This fossil species *Fordilla troyensis* occurs in the Lower

Cambrian rocks of New York, Newfoundland, and Greenland. It has long been misidentified as a bivalve relative of several arthropod groups, but the discovery of specimens retaining clear pelecypod type muscle scar impressions demonstrates its true affinities. Acceptance of *Fordilla* as a clam extends the range of the Pelecypoda backwards in time from Early Ordovician to Early Cambrian, or about 70 m.y.

PALEOZOIC OF THE WESTERN STATES

Lisburne Group carbonate stratigraphy and diagenesis

Four complete sections of the Mississippian-Pennsylvanian age limestones of the Lisburne Group in or adjacent to the Sadlerochit Mountains were sampled at 5- to 10-ft intervals for petrographic study. Study of these samples by G. V. Wood of British Petroleum Co. and A. K. Armstrong (USGS) have shown that the Sadlerochit Mountains acted as a landmass during Meramecian time, being subsequently submerged during the Chesterian transgression. Regional transgressions occurred during Meramecian time and at the beginning of the Pennsylvanian time.

The Alapah Limestone (Mississippian) dominantly has a lime-mud matrix often dolomitized towards the top, whereas the Wahoo Limestone (Pennsylvanian) is dominantly a grainstone facies with intergranular sparry calcite. The grains of the limestones are dominantly crinoids, bryozoa, and pelecypods together with pellets and oolites; the rocks range from supratidal to subtidal in depositional environment. It is concluded from recent work on the amino-acid content that biochemical elements had a large influence on the origin of the oolite grains.

Two phases of sparry calcite cementation occur in the grainstone facies; the first phase is a fringe around the clasts and is iron free, whereas the second phase fills the remaining intergranular spaces and is often iron rich. The dolomites are considered to be early diagenetic in origin. The coarse dolomites which occur as an accessory mineral in the grainstones are rich and tend to be zoned. These rhombs appear to be prone to dedolomitization during Chesterian time which could represent a period of emergence. The dedolomitization process is not of recent origin, as proved by post-dedolomitization overgrowths of iron-free dolomite.

Two types of chert: (1) "matrix" chert and (2) intragranular chert are distinguished. The "matrix" chert is considered to be of direct biogenic origin. The intragranular chert, usually restricted to the grainstone facies, is formed within pelecypod shells or crinoid plates by the reaction of silica in the sea water with the organic tissue in the bioclast to form a short-lived organo-silicic acid. This acid then in turn reacts with the calcite of the bioclast precipitating silica on a piecemeal basis.

Anhydrite, celestite, and barite have been located in the Lisburne limestones of the subsurface, and their association with algal mats suggests that sebkha-type sedimentation of the present-day Arabian Gulf is a depositional model for these beds. Marble fabrics are found interbedded with unaltered sedimentary limestone in the West Sadlerochit Mountains. They are considered to be a product of dynamic metamophism restricted to the sole of a major thrust plane.

The fabrics common in the limestones of the Old Man Creek section are attributed to thermal alteration which in turn suggests that the Romanof Granite of Sable (1967) is post-Pennsylvanian in age.

Prior to the formation of these marbles and stylolites and calcite-filled fractures, the diagenetic modification of the Lisburne limestones was essentially complete, and the rock fabrics remain essentially the same at the present.

Cambrian-Ordovician boundary in northeastern Utah

Preliminary evaluation of trilobites collected by M. E. Taylor from the basal few feet of the Garden City Formation in East Canyon, Bear River Range, northeastern Utah, suggests that the lower part of the *Symphysurina* zones of Ross (1951) extends down to the contact of the Garden City and St. Charles Formations. Conodonts from the upper part of the St. Charles Formation, identified by J. F. Miller, University of Utah, are assigned by Miller to the lowermost Ordovician *Missisquoia* Zone. These occurrences of fossils suggest that the Cambrian-Ordovician boundary, as traditionally recognized in North America, occurs within the St. Charles, and therefore the regional change in sedimentary regime from dolostone to limestone should not be used as the systemic boundary marker in the Bear River Range area.

Conodont zonation of type Devils Gate Limestone, Nevada

Detailed sampling of the Upper Devonian part of the type Devils Gate Limestone by C. A. Sandberg and F. G. Poole has yielded prolific, diversified conodont faunas that are as amenable to zonation as those from the West Range Limestone and lower part of the Pilot Shale previously reported by Sandberg and Poole (1970) and Sandberg and Ziegler (1973). The upper 130 m of the Devils Gate has yielded a complete succession of conodont zones from the *Ancyrognathus triangularis* Zone at least through the upper *Palmatolepis triangularis* Zone. The only physical break in sedimentation is evidenced by an angular unconformity which intervenes between rocks containing the *A. triangularis* Zone below and the *P. gigas* Zone above. A conodont lag bed, which directly overlies this unconformity, may also be present at other sections in Nevada and Utah—within the Pilot Shale or between the Pilot Shale and Guilmette Formation.

Age of the type Milligen Formation is Devonian

Conodont collections made by C. A. Sandberg, W. E. Hall, and J. N. Batchelder from the highest beds of the Milligen Formation at its type locality in the Wood River area, between Hailey and Ketchum, Idaho, are assignable to the lower Upper Devonian (Frasnian) Middle *Polygnathus asymmetricus* Zone. Collections from the upper part of the Milligen at a locality near Bellevue, 21 km to the south, are assigned to the slightly older but still lower Upper Devonian Lower *P. asymmetricus* Zone. Thus the age of the type Milligen can be no younger than early Late Devonian. A fragmentary conodont collection, made by C. M. Tschanz and and identified by J. W. Huddle, from an unknown position within the Milligen at a locality 12 km north of the type locality, cannot be zonally assigned but indicates a similar age.

The base of the type Milligen is not exposed in the Wood River area, but presumably the formation rests on the Phi Kappa Formation (Ordovician), which is exposed just to the east in the Pioneer Mountains. Hence, the age of the type Milligen should be considered wholly Devonian.

Ordovician age of pre-Kinnikinic quartzites of Nevada

A collection made by W. H. Hays in 1971 from quartzitic units in the area of the Wilbert Mine, near the mouth of North Creek, Southern Lemhi Range, yielded conodonts which were identified as Ordovician in age by L. A. Wilson. The unit in question has been considered to be Precambrian or Cambrian in the past. In 1972, E. T. Ruppel, R. J. Ross, Jr., and Wilson recollected from the section north of the creek and corroborated Hays discovery. The highest thick quartzite is probably the equivalent of the widespread Middle Ordovician Kinnikinic. The conodont-bearing beds are a thin brown weathering calcareous quartzite immediately below the Kinnikinic.

Occurrence of red beds with armored fish in the Nevada Formation

The Woodpecker Limestone Member of the Nevada Formation contains red shaly beds in its type area, the Eureka mining district, Nevada. At Red Hill, which forms the northeast tip of the Simpson Park Range 40 mi northwest of Eureka, these red beds are much thicker and, according to C. W. Merriam, lie between established coral horizons which fix the age of the red beds as that of Great Basin Devonian coral zone F or late Middle Devonian. Antiarch armored fishes resembling *Bothriolepis* and identified by D. H. Dunkle (Cleveland Museum) occur in the lower part of the red bed sequence. These antiarchs remain to be compared with fish from the Beartooth Butte Devonian Formation of Wyoming and with those from the Temple Butte Limestone of Arizona.

The Amsden Formation of Wyoming

Integrated paleontologic, petrographic, and stratigraphic analysis of the controversial Amsden Formation of Wyoming by W. J. Sando, Mackenzie Gordon, Jr., and J. T. Dutro, Jr., provides the basis for a regional synthesis of Mississippian-Pennsylvanian events in the northern Cordilleran region of the United States. The Amsden sea transgressed eastward from the miogeosyncline of Idaho onto the cratonic Wyoming shelf during Late Mississippian into Middle Pennsylvanian time. A northern arm of this sea formed the depositional locus of the Big Snowy Group of Montana that was separated from contemporaneous Chesterian deposits of the lower part of the Amsden Formation by an emergent barrier which was not breached until maximum inundation in Morrowan and Atokan time.

A study of the pelecypods of the Amsden Formation was completed by Mackenzie Gordon, Jr., and John Pojeta, Jr. As with the gastropods which are represented by about the same number of individuals, the pelecypods exhibit considerable faunal diversity; 16 families, 22 genera, and 40 species are present. These include all the common late Paleozoic marine families except the Parallelodontidae. Well-preserved Late Mississippian specimens from the Wind River Mountains permitted determination of the musculature of *Paleyoldia* for the first time. The muscle scar pattern differs from that of modern *Yoldia,* the muscle scars being smaller and more like those of primitive nuculanids such as *Phestia.* For this reason, *Paleyoldia* was probably not as active a burrower as the modern *Yoldia,* even though the shells of the two genera are very similar externally.

Permian entomophily

S. H. Mamay has deduced that insect pollination of seed plants probably was well established by Early Permian time. A new genus of Permian plants described by Mamay produced a cycadlike ovuliferous stalk characterized by glandlike spherical bodies regularly alternating with the seeds; identical glandlike objects occur abundantly on associated leaves presumed to be parts of the same plant. The known abundance of Carboniferous and Permian insects with well-developed piercing and sucking mouth parts suggests that plant material served as food for some Paleozoic insects. The idea is advanced that the cycadlike plants attracted herbivorous insects with the glandlike objects, which may be suspected to have been primitive nectaries; their regular disposition among the seeds would have made all seeds equally attractive to the visiting insects. Although entomophily among modern cycads is debatable, regular associations between certain beetles and cycads suggest the reflection of an unsuccessful Paleozoic experiment in entomophily.

MESOZOIC OF THE UNITED STATES

Stratigraphic distribution and zonation of Jurassic (Callovian) ammonites in southern Alaska

Ammonites from the Chinitna and Shelikof Formations in southern Alaska provide correlations with the early and middle Callovian of Europe and according to R. W. Imlay are divisible into two zones. The upper zone, named after *Cadoceras* (*Stenocadoceras*) *stenoloboide* (Pompeckj), is characterized by an abundance of *Stenocadoceras.* The lower zone, named after *Cadoceras* Pompeckj, is characterized also by *C.* (*Paracadoceras*) and *Lilloettia.* The Callovian ammonites in southern Alaska include some genera characteristic of the Boreal realm and other genera characteristic of the Pacific realm. All relationships on the specific level, however, are with Callovian ammonites along the Pacific coast as far south as northern California.

Occurrence of European Cretaceous ammonite in New Jersey

Trachyscaphites pulcherrimus (Roemer), an ornate ammonite originally described in 1841 from Upper Cretaceous rocks of Germany and subsequently found in Austria, France, Poland, and Russia, has been recently discovered in New Jersey. Several specimens found by amateur collectors at the top of the Wenonah Formation in New Jersey have been made available to W. A. Cobban for study. In Europe the species is confined to strata of late Campanian Age and consequently provides an important tie point for correlation of the Atlantic coast Cretaceous sequence.

Pollen of Normapolles group in the Mississippi embayment region

Pollen genera pertaining to the Normapolles group are virtually confined to Europe and eastern North America. Eighteen European Normapolles genera have been found by R. H. Tschudy in Upper Cretaceous and lower Tertiary rocks of the Mississippi embayment. In addition, seven new Normapolles genera are confined to the eastern North America province and have never been recorded from Europe. A total of 59 species assignable to Normapolles genera have been found in Mississippi embayment rocks.

European workers have postulated central Europe as the center of evolution and dispersion of the Normapolles group. Contiguity of Europe and North America during the Cretaceous has been postulated as providing a migration route from east to west. Alternatively, some Normapolles genera are indigenous to North America, and an earlier stratigraphic appearance in North America for other genera suggests that some may have originated in North America and migrated to Europe during the time that the continents were closer together than at present.

Structure and evolution of Antillean rudist frameworks

Rudists are an aberrant group of dominantly cemented, massively shelled, rapidly growing gregarious Bivalvia which were an important component of global Tethyan (tropical, subtropical) faunal assemblages during the Cretaceous. An analysis of their occurrences on the Antilles Islands by E. G. Kauffman of the Smithsonian Institution and N. F. Sohl (USGS) demonstrates that they were primarily distributed over the shallow, inner shelf carbonate environments during times of relative tectonic stability and low input of detritus from volcanic sources. Rudist-dominated frameworks occur widely, especially during Albian and Santonian to Maestrichtian time, over the shelves except in the shallowest subtidal conditions. Frameworks seldom were of great lateral or vertical extent, however, and most were only slightly elevated above the sea floor. Thus, no true climax barrier reef complexes developed in the Antillean area during Cretaceous time.

Two basic patterns of framework evolution can be defined in the Cretaceous rocks from the Antilles. The first begins with a calcarenite-rubble surface, containing abundant corals and diverse molluscs, which became progressively overgrown by loose to dense associations of erect radiolitid or hippuritid rudists. Clusters of rudists developed and merged to form thickets. Subsequent sediment infilling and then overgrowth and expansion by additional thicket surfaces gave rise to coppice structures.

The second pattern of development involves colonization of raised calcarenite-rubble surfaces (bars primarily) by associations of large recumbent rudists. Clustering of these forms provided a protected substrate for establishment of clusters of erect rudists (radiolitids). The combination of infilling by sediment and coalescence of erect rudist clusters led eventually to coppice development.

The small size and short duration of these rudist-dominated frameworks may have been due to tectonic, eustatic, and sedimentologic instability which characterized island arc systems during active periods of plate movements in Cretaceous time. Primarily, the limited development of biotic frameworks in the Caribbean was, however, caused by the lack of effective binding of the dominant rudists into wave resistant structure by corals, algae, stromatoporoids, or other organisms.

The Gasbuggy core—a palynological appraisal

Pollen and spore assemblages obtained from core material from the Gasbuggy 1 well by R. H. Tschudy indicated that the palynological Cretaceous-Tertiary boundary should occur in the interval between 3,655 and 3,714 ft.

The pollen and spore assemblages from the Cretaceous part of the well (Fruitland Formation and Pictured Cliffs Sandstone) are distinctly older than Hell Creek and Lance [Creek] assemblages. It was concluded that a marked hiatus exists between the top of the Fruitland Formation and the Ojo Alamo Sandstone at this locality. Furthermore, the Fruitland Formation is postulated to be within the *Baculites reesidei-Baculites cuneatus* zones of the Western Interior reference sequence, and the Pictured Cliffs Sandstone to be within the *Baculites compressus-Didymoceras cheyennense* zones.

CENOZOIC OF THE UNITED STATES

Correlation of the Paleogene-Neogene boundary with Europe

Giant pectinids—those species that regularly attain more than 90 mm in diameter—appear, according to W. O. Addicott (1973), at or near the base of the "Vaqueros Stage" and coeval units of the Pacific coast megainvertebrate sequence. A similar event occurred during the early part of the type lower Miocene in Europe (Aquitanian Stage). Recognition of this event in these widely separated provincial sequences, together with diversity trends in the Pectinidae as a whole and foraminiferal correlations, argues for placement of the Paleogene-Neogene boundary at the base of the "Vaqueros Stage" of the Pacific coast sequence.

"Precambrian" humbug

Peculiar white circular markings composed of ovate cells arranged in a crude spiral were found about 10 yr ago by David Hawley of Hamilton College in the Altyn and Siyeh Limestones of Glacier National Park, Mont. These markings were interpreted by some geologists as Precambrian algae. Similar markings were found later by R. C. Gutschick (Univ. of Notre Dame) in the Allan Mountain Limestone at a locality in the Sawtooth Mountains, Mont. In 1970, more specimens were discovered by W. J. Sando (USGS) (1972) in the Madison Limestone of the Beartooth Mountains, Mont., and the Wind River Mountains, Wyo. The Wyoming specimen includes an attached bees' nest with the same morphology as the original "algal" markings, clearly demonstrating the recent origin of these puzzling objects. Pupae found in the nest were identified by P. D. Hurd, Jr., of the Smithsonian Institution as the genus *Osmia*, a Holarctic bee that is now widespread in the Rocky Mountain region.

Role of sucking lice in seals' evolutionary history

Three papers presented in August 1972, at the International Symposium on the Biology of the Seal, held at the University of Guelph, were clearly mutually supporting. One, presented by C. A. Repenning (unpub. data, 1973) dealt with the fossil record, which indicated that modern sea lions diverged from the ancestral fur seallike lineage and had evolved into extinct species recognizable as belonging to living genera more than 2 m.y. ago. The ancestry of the northern fur seal, genus *Callorhinus*, has not been found (or recognized) in the fossil record, and the living southern fur seal, genus *Arctocephalus*, appears to be the modern representative of these ancestral fur seallike animals.

The second paper, presented by G. V. Morejohn (unpub. data, 1973) of Moss Landing Marine Laboratories in California, analyzed the bacular morphology of the living sea lions and fur seals and one fossil baculum from a 6 to 8 m.y. old representative of the ancestral fur seallike lineage. It was concluded that an evolutionary gradient existed, progressing from the ancestral lineage through the southern fur seal to the five living genera of sea lions—from most primitive to most specialized. This gradient was clearly reflected in the ontogenetic development of the bacula of the southern fur seal and the several sea lion genera. The single exception was the baculum of the northern fur seal which was most like the ancestral baculum but which had evolved along a separate pattern. It was suggested that the northern fur seal may have diverged first from the ancestral lineage, sometime prior to the divergence of the sea lions.

The third paper, presented by K. C. Kim of the University of Pennsylvania, described the sucking louse fauna endemic on the living fur seal and sea lions. It was emphasized that the lice are highly host specific. The two northern and three southern genera of living sea lions were shown to have the same endemic species of sucking louse and the living southern fur seal to have a different genus and endemic species of sucking louse. The northern fur seal was unique in being host to two genera of lice, one being that found on living sea lions and the other being that on the southern fur seal; in both genera, however, the species were different and endemic to the northern fur seal.

In a synthesis of the three studies, the authors concluded that the sucking lice endemic on the living sea lions had not evolved noticeably at the specific level since generic diversification of the sea lions, more than 2 m.y. ago according to the fossil record. It was also concluded that the northern fur seal was host to the same two genera of sucking lice which must have been endemic on the ancestral lineage, but, because of evidence of specific differentiation between the generic representatives on the sea lions and on the southern fur seals, the divergence of the northern fur seal lineage from the ancestral fur seallike lineage must be of considerably greater antiquity than that of the sea lions, a conclusion in accord with the interpretation of the baculum.

Oldest sea lion less than 1,000 yr old

Published records indicate that a fossil sea lion assignable to a living species was found in Pliocene rocks (Opoitian State) of New Zealand. Living species are not recognized in the North Pacific area before the late Pleistocene and so early a record of a living species from New Zealand suggested the possibility that the South Pacific area might have been the center of their evolution, despite a rather convincing fossil record indicating that all closely related seals evolved in the North Pacific and dispersed elsewhere at a late date.

Reexamination of the New Zealand specimen by C. A. Repenning confirmed that it should indeed be considered the living species, *Phocarctos hookeri*, but also showed that the specimen had a very recent appearance. Evaluation of the New Zealand locality by C. A. Fleming (New Zealand Geological Survey) and thin layer chromatography of the protein in the specimen by R. J. Weston (Chemistry Division of the New Zealand Department of Scientific and Industrial Research) indicates that the specimen is, in fact, not from the Pliocene deposits and is less than 1,000 yr old.

Mastodons from Martha's Vineyard

Two important mastodont tooth specimens were collected by R. L. Burt, an amateur collector, at Gay Head, Martha's Vineyard. One of these, probably from the Miocene greensand, has been identified by F. C. Whitmore, Jr., as a premolar of *Gomphotherium* sp., a member of the primitive subfamily Serridentinae. The serridentines originated in the Old World, first appearing in the Miocene of Europe and thence spreading through Asia into North America where they were rare in the Miocene but abundant in the Pliocene. Members of the subfamily are known from the Miocene of the High Plains of North America; only a few specimens have been found on the Atlantic coast. Of these, three came from the Calvert Formation on the west shore of Chesapeake Bay; the most recently found of these was a partial jaw with several teeth. It was recovered from the base of the excavation for the nuclear powerplant. One specimen has been found on the Delmarva Peninsula and one near Tarboro, N.C. This record, although sparse, establishes an extensive range for the first population of North American mastodons.

The second specimen collected by Burt is a cusp from a molar of the Pleistocene mastodon *Mammut americanum* (Kerr). This is the first record of the species from Martha's Vineyard, probably dating from a time when the island was connected to the mainland.

Raphidodiscus, a marine Miocene guide fossil

Raphidodiscus marylandicus Christian is a highly distinctive marine diatom with a near-circular outline but having a biraphid central structure characteristic of elongate diatoms. Examination under the scanning electron microscope shows that the valves are highly sculptured and are distinct enough from other genera to justify placing this diatom in a separate subfamily. *R. marylandicus* has a worldwide distribution, but it is restricted to rocks of Miocene age. According to G. W. Andrews it appears to have a relatively short range within the Miocene and is restricted to an interval from the uppermost part of the Burdigalian Stage (uppermost lower Miocene) to the lower part of the Helvetian or Langhian Stage (lower middle Miocene). The distinctive morphology, widespread geographic distribution, and restricted stratigraphic range should make this diatom a useful marker for this part of the marine Miocene section.

OTHER PALEONTOLOGIC STUDIES

Interpretation of paleoclimate

Extraterrestrial influences upon climate have operated in the past much as they do now. If the earth has always had its present solar climate, a more nearly uniformitarian approach to many problems of paleoclimatology is possible. A solar climate implies that polar regions have generally been cold, arid, and inhospitable. If solar control of climate is granted, continent displacement is required to account for distribution of at least the late Paleozoic of the Southern Hemisphere and India. According to J. M. Schopf (1973), these fossil climate indicators have been progressively displaced by modification of the relative positions of continents and oceans. Woody plants show a striking decrease in the increments of growth when located on the margin of frigid regions. Much larger growth increments of Permian woody plants collected near lat 85° S., and elsewhere in Antarctica, show that Antarctica was not polar when these plants were growing. There is no evidence that higher plants ever grew naturally at a location near the poles. On the other hand, the equatorial zone outlined by Köppen and Wegener (1924), traversing European and American coal fields during late Carboniferous and Permian time, corresponds best to the requirements of an actualistic interpretation of climate.

Foraminifera from Liberian continental shelf

M. R. Todd found the extinct foraminiferal genus *Daucina* in two lower Miocene rock fragments dredged from the continental slope of Liberia. In one fragment, the specimens are very abundant and dominate the fauna. *Daucina,* an elongate egg-shaped genus having a trilobate aperture, was originally described from Brazil in 1855 and since then has been reported only in the Eocene and Miocene of Gabon. This finding not only extends the geographic range of the genus but provides additional evidence of the close similarity between the faunas of Brazil and West Africa.

GEOMORPHOLOGY

Computer analysis of terrain

Stereo compilation, of a sample area from small-scale photography, by personnel of the Topographic Division was used as the basis for an experimental study of topographic parameters by M. J. Terman. The compilation consisted of (1) the x-y-z coordinates of a 961-point matrix in a 6-km square on the western slope of the Santa Cruz Mountains, Calif., and (2) three 50-km profiles from the Pacific Ocean across the mountains and across San Francisco Bay to the vicinity of Fremont. Geomorphic data were derived by application of a USGS computer program developed by R. J. Pike (USGS) and a vector computer program developed by R. D. Hobson (Northwestern Univ.). The descriptive products included statistical measures of elevation, gradient, curvature, and orientation as well as regression equations and appropriate graphs such as histograms and frequency curves. One potential application is the identification, using local positive gradient residuals, of slopes subject to instability.

In another experiment, basic terrain units were defined by the elevations of nine consecutive points along a profile or matrix line. Sixty-two variables based on these units were evaluated by use of statistical techniques. The final factor analysis dropped all but 12 of these variables. The 12 variables were distributed within 5 factors which together accounted for more than 95 percent of the variability in the terrain data. These factors were characterized as flatness, concavity, dissection, steepness, and general inclination. The experiments indicate the feasibility of using computer analysis in automating the evaluation and mapping of terrain types.

Geologic bench marks

The use of terrestrial photographs for establishing geologic bench marks is described by H. E. Malde (1973). Such photographs are made with a level camera placed at a measured height above a permanent mark on the ground. These photographs can be repeated later (with exactness) for exact measurement of changes in terrain, especially the subtle qualities of a landscape that are otherwise hard to map and describe. The geometry of such a photograph provides the same angular measurements between objects as can be determined with a transit, but the measurement of distances on a single photograph requires control points. Distances can also be determined by simple stereophotography from a baseline of suitable length.

Geomorphology of the upper Salmon River, Idaho

W. W. Emmett (1973) evaluated some baseline hydrologic characteristics in the upper 1,800 mi^2 of the Salmon River drainage in south-central Idaho. Stream runoff (R) at bankfull (B) stage varies with size of drainage area (DA) according to the approximate relation, R_B (in ft^3/s per mi^2) $=28.3\ DA^{-0.31}$ (in mi^2), but this relationship is locally variable as precipitation is locally greater or less than the mean for the area, whereas the size of stream channel is everywhere related to the magnitude of bankfull discharge (Q_B) by the approximate relations, W_B (width in ft at bankfull stage) $=1.37\ Q_B^{0.54}$ (in ft^3/s) and D_B (depth in ft at bankfull stage) $=0.25\ Q_B^{0.34}$. Bankfull discharge has a recurrence interval of about 1.5 yr, and flows proportional to bankfull discharge tend to have a common frequency of occurrence among streams. Mean annual discharge is about equal to 25 percent of bankfull discharge, and flows equal to or greater than bankfull discharge occur approximately 25 percent of the time. Magnitudes of high- and low-flow stream characteristics have been described in terms of the ratio of discharge to bankfull discharge, Q/Q_B, and the frequency and duration characteristics of these flows are about the same for all streams in the area.

Water resources of the Taunton River basin, southeastern Massachusetts

J. R. Williams and R. E. Willey (1973) along with D. F. Farrell mapped bedrock topography and the unconsolidated deposits of the Taunton River basin, southeastern Massachusetts. The map shows the discordance between preglacial and modern river valleys. The largest modern stream, the Taunton River, which originated during drainage of glacial lakes, cuts through deltas and meanders across lake-bottom sediments. Locally it follows its preglacial valley, which is about 150 ft below sea level near the Fall River. The drainage divide along the northern edge of the basin has been shifted southward by deposition of large glacial deltas. Other large preglacial valleys in the Lakeville Ponds region and in the eastern part of the basin are not now occupied by important streams. Description of the dominant texture of the unconsolidated deposits between land surface and bedrock provides information that can be used for regional evaluations of the basin for foundation conditions, solid-waste disposal, and ground-water supplies.

Hydraulic geometry and minimum variance

G. P. Williams analyzed the hydraulic exponents at 170 selected stations on movable-bed streams. The stations were grouped into four types to test the minimum-variance theory which W. B. Langbein (1964) proposed for predicting the most probable hydraulic exponents. Langbein's theory is based on the principle of distributing a change in discharge as equally as possible among dependent variables (velocity, depth, width, shear stress, and friction factor). Minimum-variance calculations for the four types of stations tested resulted in hydraulic exponents reasonably close to the average exponents for natural streams and for flumes. The minimum-variance theory is a reasonable and tenable theory to explain and predict the most common hydraulic exponents.

GROUND-WATER HYDROLOGY

Research on ground-water hydrology in the USGS continues to cover a broad range of subjects with the common objectives of better understanding ground-water systems and the development and application of new technical methods of study toward achieving improved management of ground water as an important national resource.

Problems relating to artificial recharge received emphasis during the year, ranging from studies of the geologic and geochemical aspects of artificial recharge to quantitative tests of percolation basins, injection-well systems, and connector-well systems.

Research on the hydrology of carbonate-rock terranes included the effects of karst features on ground-water circulation, field and laboratory tests of porosity in limestone, water-bearing potential of solution openings, and the application of photographic methods and infrared imagery in studies of the development of sinkholes.

Model simulation of aquifer systems, oriented toward both hydrologic and water-quality studies, received attention during the year; one such model made possible computation of water levels that closely matched historic water-level records over a period of more than 80 yr.

Advantages were demonstrated in the use of horizontal wells or collector galleries to lessen the likelihood of salt-water encroachment in offshore barrier islands.

Mathematical methods were successfully applied to problems involving horizontal flow and horizontal absorption and for the design of well networks spaced for optimum capture.

Applications of ground-water tracing methods were helpful in determining regional ground-water movement in one of the projects, and are a valuable tool for water-resources management. Another study showed that dye-tracer tests could be useful to determine hydraulic properties of an aquifer more accurately than conventional aquifer-test methods.

Studies of ground-water movement in basalt aquifers revealed differences in hydraulic continuity between shallow and deep aquifers under an anticlinal ridge separating two valleys.

Artificial recharge

California.—The percolation basin method seems to be the most feasible way to recharge the proposed 61,000 acre-ft/yr of imported Colorado River water in the Whitewater River area north of Palm Springs, Calif., according to S. J. Tyley. The Windy Point area provides the most logical artificial-recharge sites. No significant clay or silt layers exist in the alluvial fill in the area to impede the downward movement of artificially recharged water to the water table. Infiltration rates for three tests at a small pit in the Windy Point area ranged from 4 to 24 ft/d. A realistic long-term average infiltration rate would be about 5 ft/d.

Mixing the Colorado River water with native surface and ground waters in the aquifer system should have no detrimental effects on infiltration rates. The quality of the ground water as affected by artificial recharge with the imported water will depend on the ratios of quality and quantity of imported to local recharge water and on the degree to which the artificially recharged water mixes with the native water.

Florida.—During the year, two field tests were made in Florida to determine the feasibility of recharging the Floridan aquifer by connector wells screened in the surficial aquifer, cased through the confining layer, and open to the underlying limestone.

In the Hillsborough-Pasco-Pinellas tricounty area, W. C. Sinclair conducted tests with two connector wells installed in a poorly drained 7-acre field completely surrounded by a cypress swamp. Owing to the low permeability and thin saturated section of the surficial aquifer in this area, tests made thus far indicate that the volume of water that can be recharged by this method may not exceed 15,000 gal/d per well.

In the southwestern part of Orange County, a pilot installation of a connector well has been in operation for more than 2 yr. Here, an average transfer rate of about 18,700 gal/d has been maintained, according to F. A. Watkins, Jr. Additional connector wells to recharge the Floridan aquifer in central Florida are regarded as generally feasible.

A group of connector wells in the phosphate-mining area of Polk County is transferring about 2,000 gal/min of water from the water-table aquifer to the Floridan aquifer. R. W. Coble reported recharge rates ranging from 60 to 350 gal/min in 20 connector wells constructed by International Minerals and Chemical Corp. at their Kingsford mine area. Recharge rates can be increased with the use of commercial well screens and coarse-sand packs in the medium-sand water-table aquifer.

Kansas.—Infiltration of water through the Richfield silt loam in Scott County, in western Kansas, ranges from 1 to 3 ft/d after 1 d of submergence and from 3.5 to 5.5 ft/d after 15 d of submergence. J. B. Gillespie determined infiltration rates by a series of tests conducted in a fallow, 160-acre tract of land. Water used in the tests was from a well in the Ogallala Formation; it is a calcium bicarbonate type of water containing 287 mg/l of dissolved solids.

Infiltrometers 10 and 24 in. in diameter were used in tests at each corner and in the center of the quarter-section of land. Double-ring infiltrometers that combined the 10- and 24-in. sizes also were used at one of the sites. Infiltration rates from all of the different types of infiltrometers were similar. However, a 10-in. infiltrometer, set in undisturbed loess below the soil, showed infiltration rates of 6.1 and 13 ft/d after 1 and 7 d of submergence, respectively.

Minnesota.—In continuing studies of artificial recharge of fissured carbonate rocks in Dakota County, recent tests in the Prairie du Chien Group indicated that anisotropic and nonhomogeneous conditions prevail in the Prairie du Chien part of the aquifer system and possibly also in the Jordan Sandstone, according to H. O. Reeder. The tests demonstrated that it is hydrologically feasible to recharge artificially the Prairie du Chien Group and the Jordan Sandstone through wells completed in the Prairie du Chien. The fissures in the Praire du Chien act as conduits through which water spreads, passing into the Jordan Sandstone over a larger area than if injected directly into the Jordan.

New York.—Injection testing involving variations in organic content, chlorine residual, and pH of reclaimed water (tertiary treated sewage) was continued through 1972 at Bay Park, Nassau County, Long Island, according to John Vecchioli, H. F. H. Ku, and S. E. Ragone. Recharge is through a 480-ft-deep well screened in the Magothy aquifer.

In one test, the total chlorine residual of about 2.5 mg/l in the reclaimed water was reduced to zero before injection by dosing with a sodium thiosulfate solution. This dechlorinated water then was injected for 10 d to determine if bacterial growth would develop, as had occurred during an earlier test made with unchlorinated reclaimed water. No evidence of bacterial growth was found; however, such growth may have been inhibited by the relatively low temperature of the water (15°C) during this test.

Only minor differences in hydraulic, geochemical, and microbiological aspects of recharge were noted between tests using (1) reclaimed water that contained twice the normal dissolved organic load (measured by COD) and had been filtered through activated carbon, and (2) reclaimed water that had not been filtered.

In a third 10-d injection test, the pH of the injectant (reclaimed water) was raised from the normal 6.1 to 6.3 range to the 7.5 to 8.0 range by dosing the injectant with a sodium hydroxide solution. The dissolved-iron content of the mixed water for both ranges of pH exceeded the dissolved-iron contents of the native and the reclaimed water, but the iron content of the mixed water at the higher range of pH was less than that at the lower range. These data suggest that pH is a major controlling variable in the iron-dissolution phenomena in the aquifer.

Texas and New Mexico.—Geologic studies of recharge sites on the southern High Plains of Texas and New Mexico have resulted in identification of secondary solution openings in the alluvial sands of the Ogallala Formation, according to R. F. Brown, D. C. Signor, and W. W. Wood. Where present, these openings can serve as conduits for artificial recharge. Field tests show that these openings conduct water at an average rate of more than 15 ft/h during injection-recharge tests. Where such openings are present, the use of local surface water for injection recharge may be economically feasible.

Geochemical investigations of artificial recharge by spreading have resulted in the development of a new technique to collect water samples in the unsaturated zone. This technique consists of an installation of buried porous ceramic cups fitted with a check-valve assembly and two polypropylene collection tubes leading to the surface. A vacuum applied to the cup assembly through the tubes causes water from the unsaturated zone to flow into the cups; gas pressure is then applied at the surface to force the water into a collection bottle.

This technique has been used to collect water samples from depths of more than 100 ft. The check valve permits collection of samples at any depth and prevents pressurization of the porous cup. The new technique has application in areas where water-quality information on the unsaturated zone is important, such as sanitary landfills, feedlots, sewage lagoons, and artificial-recharge installations.

A new laboratory facility permits porous-media column studies to determine the clogging effects of suspended sediment, bacterial growth, and chemical incompatibility. Four porous-media columns can be tested simultaneously, and each can be packed with different materials to determine their effects or with identical material to replicate a given test.

A major component of the overall test system is a data-collection and computation system which acquires flow, differential pressure, temperature, and time data along with column designation and piezometer number. The data are stored in the memory of the calculator, punched on paper tape, and printed out; transducer calibration is applied, intrinsic permeability is computed, and a machine plot is made of intrinsic permeability against depth in the column at the time of acquisition. A complete sequence of acquisition, computation, and plot can be made at intervals of 10, 12, 15, 20, 30, or 60 min. The facility provides a capability of obtaining and partially analyzing large quantities of data in real time.

Virginia.—D. L. Brown and W. D. Silvey reported that during late 1971 and early 1972 three injection and withdrawal tests were carried out at Norfolk. In the first test, fresh water was injected at a rate of 400 gal/min. The specific capacity of the well decreased from an initial value of 15.4 gal $min^{-1}ft^{-1}$ of drawdown to a value of 9.3 gal $min^{-1}ft^{-1}$ at the end of 260 min of injection. In the second test, the initial injection rate of 400 gal/min decreased to 215 after 7,900 min of injection, and the specific capacity dropped from 14.2 to 3.7 gal $min^{-1}ft^{-1}$ during the same time interval. The third test began with the aquifer accepting water at a maximum rate of 290 gal/min. The injection rate fell to 100 gal/min in 150 min and continued to decline to a low of 70 after 1,300 min. The specific capacity decreased from an initial value of 3.7 gal $min^{-1}ft^{-1}$ to 0.93 at the end of the test. Volumes of fresh water injected in the first, second, and third tests were 198,320 gal, 2,445,530 gal, and 146,000 gal, respectively.

Specific capacities during the withdrawal phases dropped from 19.7 gal $min^{-1}ft^{-1}$ at the beginning of the first test to 6.7 at the end of the third test. All attempts at redevelopment of the injection well failed to improve the specific capacity. Current-meter surveys made during injection and withdrawal indicated that the reduction in the flow rate and the specific capacity were due to a uniform reduction in hydraulic conductivity of all contributing zones in the aquifer rather than to complete shutoff of flow from selected parts of the aquifer.

Clogging of the aquifer, when fresh water is injected, is probably caused by dispersion and migration of interstitial clay particles within the aquifer. By the introduction of fresh water into the brackish-water aquifer, the stability of the clay particles is affected when the electrolyte concentration of the interstitial water is changed. As the electrolyte concentration is lessened, the effective radius of the double layer of the clay particle is increased and the clay becomes dispersed and migrates until it lodges in a waterway and decreases the hydraulic conductivity.

Dispersion can be prevented temporarily by treatment of the clays with a preflush of calcium chloride or prevented permanently by the clay being flushed with hydroxy aluminum before fresh water is injected.

Wisconsin.—As part of a study in Waushara County of the effects of fish-hatchery water management on the hydrologic system, R. P. Novitzki studied the feasibility of recycling ground water through an infiltration pond at the pumping site. Initially, a discharge of 300 gal/min required an infiltration area of about 20,000 ft^2. However, hydraulic conductivity increased as wetting of the soil grains progressed and entrapped gases escaped. As a result, the infiltration area decreased to about 10,000 ft^2. The effective vertical hydraulic conductivity (incorporating some component of horizontal conductivity) is about 6 ft/d—a ratio of about 20 to 1, horizontal to vertical. Recharging has been continuous since December 1972. Infiltration has not been hampered by subzero winter weather, although the temperature in the pump discharge has been lowered as much as 1.5°C (range, 7.5–9°C) in response to cold-water recharge. Water temperatures in the infiltration pond have ranged from 0.2°C to 9.4°C.

Hydrology of carbonate-rock terranes

Test drilling and resulting cores from deep Silurian dolomite in Linn County, Iowa, indicate that an extensive system of solution openings exists in those rocks, according to K. D. Wahl. Although the Silurian was known to be permeable updip in the outcrop area, the downdip extent of openings was in doubt. The water-bearing potential of the openings is still to be investigated and may be less than indicated by the cores because some or all of the openings may be clay- or shale-filled in some areas.

In a statewide study of the geology and hydrology of sinkholes and subsidence along public roads in Alabama, J. G. Newton and W. J. Powell of the USGS and C. W. Copeland (Alabama Geol. Survey) estimated that more than 1,500 sinkholes, areas of subsidence, or internal-drainage features have formed in four study areas in the State since about 1950. Collapses occur where cavities in unconsolidated sediments have formed as a result of the migration of the sediments into underlying openings in carbonate rocks. The largest recent collapse is about 425-ft long, 350-ft wide, and 150-ft deep. Limited black-and-white, color, and infrared photography shows that vegetative stress prior to a collapse is due to ponding of water in subsiding areas and to subsurface evaporation of soil moisture in walls of internal drainage features and in uncollapsed cavities with roofs that have penetrated root zones. Unusual photography has been obtained that shows the progressive enlargement of a cavity in unconsolidated clay and the relationship of the roof to the overlying root zone. Thermal infrared imagery shows water loss that is associated with the development of sinkholes, and images obtained from special processing (contouring) show lineaments developed on faults and joints along which sinkholes are occurring.

In a related study, J. G. Newton (USGS), C. W. Copeland (Alabama Geol. Survey), and L. W. Scarbrough (Alabama Geol. Survey) (1973) evaluated active sinkhole development in and adjacent to a proposed interstate-highway right-of-way near

Greenwood in Jefferson County, Ala. More than 150 sinkholes, depressions, and related features have formed in and near the right-of-way. They began to appear in about 1950 and continued through March 1972. Complex geologic and hydrologic conditions related to their development were defined by geologic mapping, an extensive test-drilling program, a shallow refraction seismic survey, and use of multispectral photography and thermal infrared imagery.

A general lowering of the water table during the early 1950's or the latter part of the preceding decade resulting from large withdrawals of ground water from wells and mines, compounded with a prolonged drought during the 1950's, make the area prone to the development of sinkholes. Openings along faults and a fold provide hydraulic connection between aquifers at the surface and mines at depths exceeding 1,000 ft. Cessation of pumping from wells and mines has resulted in conditions favorable to the recovery of the water table. Available information indicates that the water table could recover to its pre-1950 level as early as the summer of 1973, but the recovery may extend over a much longer time. Previous studies indicate that a recovery of the water table will result in a cessation of sinkhole development, or in a drastic decrease in their occurrence.

Sinkholes occur where cavities develop in residual or alluvial deposits overlying openings in limestone. The downward migration of the deposits into openings in the underlying limestone and the formation and collapse of the cavities are caused or accelerated by a decline in the water table that results in (1) an increase in the amplitude of water-table fluctuations, (2) the increased movement of surface water through unconsolidated deposits into openings in bedrock in areas where recharge had previously been rejected, (3) an increase in the velocity of movement of ground water, and (4) loss of support to unconsolidated deposits overlying openings in bedrock.

Evaluation of multispectral photography and thermal infrared imagery to study active subsidence indicates that they are of considerable value in locating signatures related to the development of sinkholes. Color infrared and color Ektachrome photography defined existing and prior vegetative stress that resulted from subsidence and interior drainage through openings in unconsolidated sediments at the land surface. Lineaments associated with a fault and adjacent highly inclined beds were discernible in one area on all photography. All photography defined vegetative stress over tile drains and subsidence over couplings joining the drains buried beneath the land surface more than 40 yr ago. Thermal infrared imagery showed water loss where tributaries discharge into streambeds and sinkholes. Special processing (contouring) of the imagery to enhance thermal interfaces resulted in the recognition of lineaments associated with faults not apparent on photography.

Information obtained from the seismic survey was used in locating "pinnacle" weathering on limestone that is related to the development of sinkholes. Subsurface irregularities recorded during the survey corresponded closely with geologic structures defined by test drilling.

Hydrologic and geologic studies of the Edwards Limestone in the Balcones fault zone of the San Antonio, Tex., area, by R. W. Maclay, P. L. Rettman, and T. A. Small, have provided information for estimating the amount and distribution of water in storage in the aquifer. Cores from four test holes, which penetrated the entire thickness of the aquifer, show that large vuggy openings occur at scattered depths. Nonvuggy rock has interparticle porosity that ranges from less than 5 to about 35 percent. Total porosity in the upper part of the aquifer is apparently about the same as in the lower part. Radiation and electrical logs of the four test holes indicate an average porosity of about 20 percent. Laboratory determinations of the porosity of rock samples compare closely to porosity determined by geophysical methods.

Coordinated research on the hydrology of carbonate-rock terranes by V. T. Stringfield (Herak and Stringfield, 1972) and H. E. LeGrand (Davies and LeGrand, 1972) is currently centered on studying the effects of karst features on the circulation of water in carbonate rocks. Some karst topographic features give evidence of certain aspects of hydrology, such as the degree of permeability and depth to the water table. A comparison of the karst hydrology of many regions of the world with some regions of the United States is revealing data on the factors and stages of karst development. The uneven distribution of permeability caused by karst processes results in streamflow characteristics that are different from those in noncarbonate terranes.

Aquifer model studies

Model studies were used by O. J. Taylor to analyze the hydrologic system in the San Luis Valley, Colo. (P. A. Emery, 1970; Emery and others, 1971), and to design alternate methods of salvaging nonbeneficial evapotranspiration from the unconfined aquifer. Mathematical models indicated that hydraulic conductivity of the confining layer between the unconfined aquifer and underlying confined aquifer ranges from 6×10^{1} to 5×10^{-4} ft/d. The location of wells in the most transmissive zones of the unconfined aquifer would induce a widespread cone of depression and large amounts of water salvage. Electric-analog-model analyses indicate that the present withdrawals from wells in the confined aquifer are inducing salvage from the unconfined aquifer through the confining layer. The present rate of withdrawal could be doubled to induce additional salvage. Sensitivity tests show that salvage is inversely related to the degree of hydraulic connection between the rivers and the unconfined aquifer. The system response was less sensitive to changes in the vertical hydraulic conductivity of sediments beneath the rivers.

The principal artesian aquifer in the Brunswick and Savannah areas, in Georgia, is being modeled in an attempt to answer questions needed to solve contamination problems. Leakage through confining beds, heretofore essentially neglected in hydraulic computations, is an important factor in the modeling. Leakage of brackish water upward and its dispersion downgradient in the aquifer have been successfully modeled for the Brunswick area by H. B. Counts and R. E. Krause, using a mass transport model developed by J. D. Bredehoeft and others. Computed distribution of chloride concentration in the aquifer closely matches that measured in field studies.

Transient ground-water flow in the Savannah area from the time of earliest development also has been modeled successfully. Model simulation time was 87 yr, 1885–1972, and the computed water levels very closely match those measured during the same period. Output from this model is being used to model salt-water movement from a leakage area in the northeastern part of the Savannah area.

R. G. Wolff reported that the hydraulic diffusivity of a confining bed exhibiting vertical heterogeneity (R. G. Wolff and S. S. Papadopulos, 1972) was determined by field and laboratory tests. A thin sand aquifer was pumped, and head changes were observed in the aquifer and at three vertically separated piezometers in the overlying confining bed. A four-layer digital model was used to analyze the field data. The hydraulic diffusivity for each layer was adjusted in the model until calculated head changes in all piezometers closely matched those observed in the field. Laboratory-determined hydraulic diffusivities were several orders of magnitude smaller than the field-determined values. Interfingering of layers within the confining bed is believed to have caused this difference. Additional studies are needed before a general conclusion can be reached on the value of laboratory determinations of hydraulic parameters for heterogeneous confining beds.

Historic water-level trends in the artesian aquifer in a 300-mi^2 area in west-central Florida can be duplicated with reasonable accuracy with a digital model. A. F. Robertson found that a leakance value of 2.7×10^{-4} d^{-1} and a transmissivity value of 2.0×10^{4} ft^2/d allow a reasonable approximation of water-level changes in the aquifer.

Three digital-computer models designed to simulate the hydraulic-head response to natural and manmade stresses in a two-aquifer system were completed by H. H. Tanaka, A. J. Hansen, Jr., and J. A. Skrivan. The two-aquifer system underlying a Columbia River basin irrigation project area in central Washington comprises an unconfined upper aquifer in unconsolidated materials and an underlying confined aquifer in basalt. The two aquifers are separated by a leaky confining basalt layer.

The models were verified by matching the computed ground-water levels to historic ground-water levels measured before and after 6, 11, and 16 yr of project irrigation. Irrigation with imported water distributed by a network of canals and laterals, and applied at an average rate of 4 acre-ft/yr on about 450,000 acres, was simulated in the three models. Mainly as a result of deep percolation from irrigation and leakage from canals and laterals, more than 8 million acre-ft of water was added to ground-water storage in the upper aquifer and nearly 70,000 acre-ft to the lower aquifer, after 16 yr (1952–67) of irrigation.

Water-quality modeling

A digital water-quality model of the aquifer near Barstow, Calif., was evaluated by S. G. Robson to determine the applicability of the model computer program to varied hydrologic problems. The evaluation was made on the basis of the data requirements of the model, the characteristics and limitations of the model computer program, the relevance of the model results, and computer costs associated with the model.

Two-well tracer-dilution tests are a workable means of determining the aquifer dispersion constant and porosity, but such tests may not be necessary if a water-quality model with a large grid interval is under consideration, because of the relative insensitivity of such a model to these parameters. The water-quality model is not readily applicable to hydrologic conditions such as abrupt changes in aquifer-saturated thickness or transmissivity, and model head declines that are large in relation to the saturated thickness of the aquifer can cause disruptions in the water-quality calculations of the model. The model results were relevant to the real-life head and water-quality conditions in the aquifer and provided an excellent means of evaluating the cause-and-effect relations associated with ground-water pollution. The cost of operating a water-quality model may be nominal if a small number of model nodes and a short simulation period can be used.

Several one- and two-dimensional transient digital models that incorporate nonideal flow have been formulated by D. D. Grove to predict the spatial and temporal distribution of chemical species in the saturated ground-water system. Models currently in use and under continual development include: (1) A one-dimensional, rate-controlled reaction model that predicts concentrations for any order of reaction of up to two, (2) a two-dimensional, explicit, finite-difference model for conservative species that includes the dispersion tensor, (3) a one-dimensional transport model that utilizes an equilibrium-controlled chemical-reaction subprogram to predict complicated chemical reactions. All of these models compare well with known analytical solutions and are in the process of being applied to appropriate field situations.

Mathematical methods in ground-water hydrology

An approximate analytical solution to the one-dimensional nonlinear diffusion equation has been obtained by A. F. Moench (1973) and applied to two hypothetical cases: (1) horizontal flow in an aquifer when transmissivity and storage coefficients are functions of hydraulic head, and (2) horizontal absorption in an unsaturated soil where the diffusivity is a function of moisture content. The method of solution requires that the region under consideration be divided into a number of zones each with known constant diffusivities. The boundaries between zones move at rates that are initially unknown. The mathematical technique may be applicable to other simple boundary-value problems such as that of a well pumping at a constant rate from an infinite water-table aquifer.

Unconfined aquifers having a high water table often lose a considerable amount of water through evapotranspiration and (or) rejected recharge. The lowering of the water table through pumpage by wells decreases evapotranspiration losses and may also provide for additional recharge by increased induced infiltration. S. S. Papadopulos reported that the relation between rate of capture and depth to water table can be closely approximated by assuming a linear increase in the rate of capture until a maximum rate is reached at a certain depth, and continuation at this maximum rate at greater depths.

The steady flow to wells deriving their discharge from capture was analyzed, and equations were developed for estimating the discharge and drawdown distribution around such wells, and for designing well networks spaced for optimum capture.

Salt-water and fresh-water relations

The use of horizontal wells or collector galleries can be a highly effective method of increasing the potential yield of fresh water from shallow, sandy aquifers of offshore barrier islands without significantly increasing the risk of salt-water encroachment into the well system where the fresh-water–salt-water interface is commonly only 10 to 15 ft below the land surface. Results of a recently completed study of Cape Hatteras National Seashore in North Carolina, by M. D. Winner, Jr., show that maximum drawdowns in a horizontal well are only about one-third of those produced in vertical wells pumped at the same rate. In effect, the drawdown around a horizontal well is spread over a large area instead of being concentrated about a point as it is in a vertical well. The upcoming response of the salt-water interface is likewise spread over a large area. The relationship between a head change in the aquifer and the corresponding inverse change in the depth of the salt-water interface is also shown to be different for different head changes. For example, a head change of 1 ft produced a 15-ft change in the depth of the interface, whereas a head change of 0.1 ft produced only 0.6 ft change in the interface. A pumping horizontal well produces smaller incremental head changes over a larger area and thus gains advantage over a vertical well from the standpoint of less induced salt-water encroachment.

Salt-water encroachment in the "600-ft" sand of the Baton Rouge, La., area is being fed by salty water moving across the Baton Rouge fault from the downthrown "400-ft" sand. The salty water is moving northward from the fault toward major well fields in the industrial district, according to C. D. Whiteman, Jr. The average rate of encroachment in the "600-ft" sand has slowed from more than 300 ft/yr before 1956 to less than 200 ft/yr since 1956. The leading edge of the dense salty water advances along the base of the aquifer and was initially moving along a narrow channel. The salty water has reached an area where the channel widens; thus, the salty water is apparently now advancing across a broader front but at a slower rate. Test drilling during 1972 confirmed that the base of the "600-ft" sand rises more than 50 ft between the present position of the salty water and the major pumping center in the industrial district to the north. This rise will inhibit the northward movement of the salty water until fresh water below the rise is displaced. This new information indicates that a much longer period of time than was previously estimated will elapse before salty water reaches the wells of the industrial district.

Geohydrology of the Claiborne Group

J. N. Payne completed the following maps of the geohydrology of the Claiborne Group: (1) Thickness and sand isoliths of the Cook Mountain Formation and Weches Greensand, (2) thickness of the Claiborne Group exclusive of the Carrizo Sand, (3) total thickness of sand in the Claiborne Group, (4) cumulative thickness of massive sand units (sand units 50 ft or more in thickness) in the Claiborne Group, and (5) estimated transmissivity of the total sand thickness of the Claiborne Group.

Payne reported that two centers of thicker sand accumulation and of higher transmissivity occur in the Claiborne Group, one in west-central Mississippi, where the total thickness of sand is 1,300 to 1,400 ft and the transmissivity may be as much as 60,000 ft^2/d, the other in southern Texas where the total thickness of sand is 1,900 to 2,000 ft and transmissivity is about 30,000 ft^2/d. These areas of thick sand accumulation are potential sources of significant amounts of fresh and slightly saline water.

Sewage-effluent disposal by spray irrigation

The Tallahassee Southwest Water Pollution Control Facility has been experimentally disposing of sewage effluent by spray irrigation since 1966. As much as 250,000 gal $acre^{-1}d^{-1}$ has been applied for 7 continuous days without serious flooding. L. J. Slack reported that water-level data indicate: (1) Some mounding occurs in the "Single Gun" area but is negligible in the area most heavily sprayed, and (2) there is a southerly movement of ground water from the spray area. Chloride and nutrient data collected since the project began corroborate the water-level evidence. Chemical analyses of effluent samples and of water from observation wells indicate that some denitrification occurs before dilution by aquifer water.

Underground waste disposal

C. A. Pascale and M. I. Kaufman reported that injection of acidic industrial waste into a confined saline limestone aquifer (D. A. Goolsby, 1972) in Pensacola, Fla., now averages about 2,500 gal/min. Wellhead pressure at each of two injection wells averages 195 lb/in^2. The pressure at two monitor wells open to the injection zone at points 1.9 mi north and 1.5 mi south of the injection site averages 115 $lb/in.^2$ At the injection site, pressure in a monitor well tapping the aquifer immediately above the 200-ft-thick confining layer remained the same (about 14 $lb/in.^2$). Chemical analyses indicate that water in all monitor wells is native to the respective aquifers. Since 1965, injection rates have nearly doubled whereas injection pressures have decreased from 235 $lb/in.^2$, suggesting that permeability of the injection zone is increasing.

In June 1972, one injection well was logged (it was physically impossible to log the other) to evaluate the extent of possible solution cavities in the injection zone. The logged well (J. B. Foster and D. A. Goolsby, 1972) was initially constructed with 250 ft of 8-in.-diameter open hole in the limestone injection zone. Analyses of mechanical-caliper and sonar-caliper logs suggest that waste injection presently occurs entirely in the uppermost 35 ft of open hole which, in places, was enlarged to a diameter of at least 40 in. The lower part of the hole could not be penetrated by logging probes, which suggests that it had filled or collapsed. Analysis of gamma-ray and neutron logs suggests that the upper clay confining layer is fully supported and intact.

According to R. M. Waller a "first-run" mathematical model of the injection-well system at Lackawanna, N.Y., for injection of spent pickling liquor from steel-processing operations has been designed. Calculations for injection at rates as much as 75 gal/min and at a pressure of 500 $lb/in.^2$ into a Cambrian dolostone at a depth of 3,800 ft indicate that pressure at land surface would increase to 1,200 $lb/in.^2$ within a few days and would increase as far away as 10 mi. Newly installed seismographs in the area indicate very active, low-level regional seismicity. Hydrofracturing of the disposal formation probably occurred during the preliminary injection tests.

Ground-water movement in southern Missouri

Application of ground-water tracing techniques are helping to define the rate and direction of ground-water movement in the Ozarks of southern Missouri. E. E. Gann and E. J. Harvey (USGS) along with D. E. Miller and D. L. Fuller (Missouri Geol. Survey) reported that successful tracing experiments by the U.S. Forest Service, the Missouri Geological Survey, and the USGS have established direct hydraulic connections between losing streams, sinkholes or caves, and at least 17 springs. Fluorescein dye, rhodamine dye, and *Lycopodium* spores have been used to trace the subsurface movement of water for distances as great as 40 mi at indicated velocities ranging from 0.1 to 7.0 mi/d. Interbasin movement of water to several springs has been established. Continuing tracing experiments in the area are expected to contribute further to the understanding of ground-water movement in the Ozarks and to yield valuable information for the management and preservation of the water resources of the area.

Hydraulic continuity in deep basalt aquifers

Data on the potentiometric head and lithology from a test well tapping deep basalt aquifers in Medicine Valley correlate with similar data in the Toppenish Creek basin of the lower Yakima Valley in Washington. According to D. O. Gregg and R. J. Burt, the flat potentiometric gradients and the water-level response in Medicine Valley to pumping stress in Yakima Valley indicate probable hydraulic continuity in the deep basalt aquifer under an anticlinal ridge separating the two valleys. In the shallow basalt aquifers, however, the anticline does form a barrier preventing appreciable lateral movement of water. This results in water levels being near land surface in wells penetrating shallow basalt aquifers in Medicine Valley, compared with water levels between 200 ft and 250 ft below land surface in wells penetrating the same section of basalt in Yakama Valley, east of the ridge.

An analysis by S. L. Robbins of a gravity survey of the Yakima Valley showed that the top of the Yakima Basalt is relatively flat and is overlain by about 1,000 ft of the Ellensburg Formation and younger sediments.

Drilling affects ground-water heads in a deep well in basalt at Richland, Washington

A. M. La Sala, Jr., G. C. Doty, and F. J. Pearson, Jr., reported that a 5,661-ft-deep test well, drilled in 1969 in the Columbia River Group, was reentered in 1972 and piezometers were installed at five intervals between depths of 1,219 and 4,849 ft. Temperature logs indicated that ground water had been circulating downward prior to reentry and that cool water, used as a circulating medium during reentry, had entered the water-bearing zones. A radioactive tracer log made just prior to installing the piezometers showed that heads throughout the well were equalized. In contrast, when the well was drilled, the heads decreased with depth and had a maximum difference of about 40 ft. At this time the heads in deeper zones probably were depressed because water was produced during drilling. Measurements of water levels in the piezometers showed an increase in head with depth of about 8 ft during a 9-mo test period. Such an increase is to be expected considering the regional flow system. Experience with hydraulic testing at this well indicates that heads in deep water-bearing zones may be considerably affected by drilling operations.

Hydraulic properties of an aquifer determined from dye releases

Rhodamine WT dye was used as a tracer in a test to determine the hydraulic properties of the Ogallala Formation near Dighton, west-central Kansas. The dye was injected into the saturated, unconfined part of the formation at a distance of 100 ft from an irrigation well while the well was discharging 1.4 ft^3/s. Traces of the dye first appeared in the pumped water 12 h after injection, and peak dye concentration occurred 30 h after injection. Using a technique described by Halevy and Nir (1962), E. D. Gutentag and L. E. Stullken determined that transmissivity and specific yield of the Ogallala are 4,500 ft^2/d and 0.18, respectively. Conventional methods of aquifer-test analysis, based on water-level declines at various times and distances caused by the pumping, indicate that values of transmissivity and specific yield are 5,000 ft^2/d and 0.02, respectively. The specific yield of 0.18, determined by the dye-tracking techniques, is considered to be closer to the actual value than the much smaller value obtained from the conventional tests.

Automated procedures in aquifer tests near Appleton, Minnesota

Two pumping tests using a new remotely controlled observation system were conducted as part of the Appleton, Minn., sand-plain irrigation study according to S. P. Larson. Stevens type-F recorders and Keck units were used at each observation well. However, the solenoid clocks on the type-F recorders were replaced by small electric motors. The motors were connected in a common circuit enabling activation from a single source. Activation of the system thus produced discrete timing marks on all recorder charts simultaneously.

Both tests involved existing irrigation wells tapping the surficial outwash sand and gravel aquifer. Pumping rates were 475 and 1,150 gal/min in saturated thicknesses of 28 and 45 ft, respectively. Analyses have shown that the hydraulic conductivity was about 334 ft/d at both sites. Specific yields ranged from 0.10 to 0.18. The use of the remotely controlled observation system resulted in near-optimum data collection with the use of minimum manpower.

Desert pupfish endangered by irrigation pumping

The Ash Meadows area, at the southern tip of the Amargosa Desert in southern Nevada, discharges ground water collected over several thousand square miles of a regional flow system developed in Paleozoic carbonate rocks. A small pool in Devils Hole, which is a collapsed depression in Cambrian limestone, and numerous springs in the adjacent desert valley contain rare fish species of the genus *Cyprinodon*, faunal remnants of the biota of Pleistocene lakes. The Devils Hole pupfish, *C. diabolis*, is the most endangered of the several surviving species that have evolved since the post-pluvial isolation of their ancestors, according to W. W. Dudley, Jr., and G. F. Worts, Jr. This population feeds and reproduces on a slightly submerged rock ledge. Recent pumping for irrigation has nearly exposed this ledge and caused the flow of certain springs to decrease. In terms of water-level change in Devils Hole, the natural level originally was about 1.4 ft below a copper-washer bench mark. In October 1972 the level had declined to nearly 4 ft below the washer—a net decline of about 2.6 ft. The fish may perish if the water levels continue to decline.

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.

Hydrologic modeling

R. W. Lichty and A. L. Putnam used a modification of the rainfall-runoff model developed by D. R. Dawdy, R. W. Lichty, and J. M. Bergmann (1972) to synthesize a long series of annual flood peaks for each of 10 small urban streams in North Carolina. The median annual floods based on results of synthesis averaged about 35 percent higher than the comparable floods based on a partial-duration analysis of the short observed records. The slope of the synthetic frequency curve was always flatter than the slope of the curve based on observed data, with the two curves tending to be alike above the 25-yr recurrence interval. The apparent bias in the synthetic frequency curves is attributed to overestimation of the volume of runoff from small rainfall events, a result that may be due to point rainfall not being representative of basin rainfall.

L. D. Hauth used the Dawdy-Lichty-Bergmann rainfall-runoff model to calibrate many drainage areas of less than 10 mi^2 in Missouri. The average model error was about 35 percent. Precipitation records, averaging 67 yr in length, at Kansas City, St. Louis, Columbia, and Springfield, were used to synthesize four peak-discharge records at each calibrated site. Floods of 50-yr recurrence interval, based on synthesis using records from the more northerly precipitation stations, are generally of less magnitude than those derived by using records from precipitation stations to the south. Average annual precipitation in Missouri increases from 32 in. in the northwest to 48 in. in the southeast. Magnitudes of floods of 50- to 100-yr recurrence interval, based on observed records of less than 25 yr, are generally higher than those obtained by synthesis.

H. H. Jeffcoat developed a model for estimating daily mean discharges into a reservoir from an upstream gaged point. When applied to a 50-mi reach of Santee River, S. C., there was good agreement between actual and computed flows. Input to the streamflow routing program consists of values of discharge from the upstream gaging station. Current calculations for operational flow estimates using the calibrated model are made on a desk-size programable computer.

F. E. Arteaga and S. E. Rantz (1973) have demonstrated the source-area concept of storm runoff by analysis of the rainfall-runoff relation for Queen Creek tributary, a small ephemeral stream in south-central Arizona. The concept, in effect, is that even during intense basinwide storms, only certain source areas in a watershed contribute runoff. The remaining areas are noncontributing because they can support infiltration and subsequent percolation at rates that usually exceed the rainfall intensities that are experienced. The observed runoff of Queen Creek tributary could not be explained by conventional rainfall-runoff analysis. In accordance with the source-area concept, the percentage of the study watershed contributing runoff from a storm was related to total rainfall received—that is, antecedent and storm rainfall—on the assumption that the availability of rainfall excess from any subarea was dependent on the saturation of a permeable upper layer of soil.

B. L. Neely, Jr., developed a procedure for releasing flood volumes from Toledo Bend Reservoir (Louisiana and Texas) prior to flood inflows so that the water level in the reservoir as well as the peak outflow generally can be kept within prescribed limits. The analysis was based on a mathematical model of flood routing by unit hydrographs. It was thought that by placing rain gages upstream, the inflow to the reservoir could be predicted far enough in advance that early release could be made, but it was found that the time between rainfall and inflow was so short that early releases governed by rainfall alone are not feasible. However, early releases can be based on flows at the Tatum gage.

Turbulence and diffusion in open channels

In the past few years, short-term dye-dispersion tests have been conducted in several estuaries to evaluate the effects of waste releases on long-term water pollution. Nobuhiro Yotsukura and C. R. Faust have established a theoretical basis for such prototype tracer simulation by use of the linear superposition principle applied to a convective diffusion equation. A problem in numerically solving the convective diffusion equation is to upgrade the accuracy of the convective terms relative to that of the diffusive terms. Fromm's third-order approximation of convective terms is vastly superior to the Bella-Dobbins second-order approximation for many field situations where diffusion coefficients are extremely small and (or) initial solute concentrations are not evenly distributed.

According to C. F. Nordin, Jr., and R. S. McQuivey (USGS) and J. M. Mejia (Colorado State Univ.) (1972), records of turbulent velocity fluctuations from both laboratory flumes and rivers exhibit the Hurst phenomenon, a form of long-term persistence peculiar to most geophysical time series. The implication is that the integral time scales do not exist in turbulent flows, but rather, that the turbulent velocity fluctuations have the properties of fractional Gaussian noise. Some indirect evidence from dispersion studies supports these implications.

A method of predicting water temperatures in nonstratified open channels which integrates the surface- and hydraulic-transfer mechanisms was developed by H. E. Jobson and Nobuhiro Yotsukura (unpub. data, 1973). Tests using excess-temperature data obtained from several streams show that the method is capable of predicting temperatures with an overall error of about 1° Celsius.

Relation of streamflow characteristics to channel geometry

A detailed study in Kansas by E. R. Hedman and W. M. Kastner has shown that peak discharges at recurrence intervals of 5, 10, 25, and 50 yr are related to the width and average depth of the channel cross sections between active flood plains. The relationships, defined for perennial streams, have standard errors of estimate of about 40 percent.

In a reconnaissance study of the southern Uinta basin, Utah, Donald Price and L. L. Miller estimated the mean annual runoff at 29 sites by the channel-geometry method (E. R. Hedman, D. O. Moore, and R. K. Livingston, 1972). The runoff values were then related to the extent and mean altitude of their drainage areas. The resulting relation produced computed values of annual runoff within 25 percent of the field-estimated values at 17 of the 29 sites. Total estimated mean annual runoff at all 29 sites was about 106,000 acre-ft, approximately 75 percent of the total from the 4,600-mi^2 project area.

Open-channel hydraulics

Preliminary investigations by F. N. Lee of floodflows through bridges in Louisiana indicate that the Manning roughness coefficient n for wide, heavily wooded flood plains should be much higher than that previously used. Most of the roughness coefficients, obtained by step-backwater methods from known flood profiles and discharges, ranged from 0.15 to 0.20, but a value of 0.30 was computed at one site.

In a study of floodflows through bridges across rivers in Mississippi having wide flood plains, B. E. Colson found that the formula for computing discharge through bridge openings could be significantly improved by inclusion of a valley-width parameter. He postulated that the length of the bridge-approach reach used should be a function of the valley width B and the bridge length b, rather than only of the bridge length. The use of an approach length based on an average of B and b from 27 sets of data reduced the mean error in computed discharge from 50 to 8 percent.

Hydrology and sediment transport in Moanalua Valley, Oahu

For 2 years, B. L. Jones and C. J. Ewart III have collected extensive data on rainfall, runoff, and sediment movement in a 3.5-mi^2 basin in which areal variation of rainfall is extreme. Calibration of a rainfall-runoff model (Dawdy, Lichty, and Bergmann, 1972) using data from 10 storm events produced reasonable results. In a 22-month period, about 48,000 ft^3 of coarse material has accumulated in the debris basin at the downstream boundary of the project area. Observations and calculations indicate that the stream often moves rocks larger than 2 ft in diameter. Preliminary calculations show that a 50-yr flood would transport a sediment load of about 12,000 tons.

Water-delivery study on Arkansas River in Colorado

R. K. Livingston reported results of a study of releases from Twin Lakes Reservoir to Colorado Canal headgate, a distance of 175 mi. The time required for a release to reach the headgate ranged from 29 to 69 h, depending on the antecedent flow in the Arkansas River. Between the reservoir and the canal headgate the hydrographs of these releases are modified by channel and bank storage, inadvertent diversions, and evaporation. During an average reservoir release of about 450 ft^3/s for 12 days, the volume of released water arriving at Colorado Canal was reduced by about 7 percent due to bank storage, by about 8 percent due to inadvertent diversions, and by about 1 percent due to evaporation. Some of the released water is held in channel storage, but only briefly, so that channel storage does not constitute a transit loss.

Time-of-travel measurements

E. A. Pustay reported that time-of-travel measurements have been conducted on reaches of many New Jersey streams to provide data for use in various environmental programs. The measurements, using fluorescent tracers, were made during at least two different flow conditions on about 300 mi of streams in the State. These include 118 mi in the Delaware River basin (Delaware and Musconetcong Rivers and Assunpink and Rancocas Creeks); 90 mi in the Passaic River basin (Passaic, Pompton, Rockaway, Whippany and Saddle Rivers and Hohokus Brook); 56 mi in the Raritan River basin (North Branch Raritan, South Branch Raritan, Raritan, and Millstone Rivers); and 29 mi in the Manasquan River basin. Major uses of the data will be to determine reaeration coefficients in oxygen-resource models and to predict traveltimes of accidental pollutant spills.

Data transmission by satellite

A specially designed gaging station was installed on Verde River near Camp Verde, Ariz., to evaluate the feasibility of transmitting near-real-time streamflow data by the ERTS–1 DCS. On November 3, 1972, the station was equipped with a Stevens digital water-level recorder modified for telemetry and an ERTS–1 data-collection platform operating in the digital-parallel mode. According to H. H. Schumann, the DCS relayed 552 transmissions during 193 data passes in the 43-d period, November 3 to December 15, 1972. The DCS transmitted stream-stage information on the average of 4.5 times per day, greatly exceeding the expected single high-quality transmission rate of once per 12-h period.

Low-flow characteristics at ungaged sites

W. A. Gebert and B. K. Holstrom developed generalized relations for estimating low-flow characteristics in Wisconsin. Using these relations, they have estimated the low-flow characteristics at 640 sewage-treatment-plant outfall sites where the information is needed by the Wisconsin Department of Natural Resources to meet established water-quality deadlines. These initial estimates will be verified or modified when discharge measurements are obtained at the sites.

Simulation of unsteady flows by digital computer

Chintu Lai and C. A. Onions have added two new versions to Lai's computer model for simulating one-dimensional unsteady flows in rivers and estuaries. The original model, which uses the multiple-reach method of characteristics and the assumption that each short subreach is of prismatic form, was found to be inefficient under certain conditions, but it is suitable for channels having abrupt changes in cross section and for manmade channels. One new version is adapted to tidal estuaries or relatively flat channels with irregular bottom slopes. The second new version was developed for upland streams having relatively steep but uniform bottom slopes.

CHEMICAL, PHYSICAL, AND BIOLOGICAL CHARACTERISTICS OF WATER

Characterization of humic acid fractions by ultraviolet and visible spectrophotometry

R. L. Wershaw (USGS) and A. R. Monahan and A. F. DeLuca (Xerox Rochester Research Center) investigated the ultraviolet and visible absorption spectra of solutions of sodium humate fractions. Results revealed that (1) some of the fractions disaggregate into monomers at low concentrations, and (2) the absorption spectra of the monomers of each of the fractions are distinct and different. The ultraviolet and visible absorption spectra of a molecule is a function of the electronic state of the molecule; for the first time, the molecular structures of humic fractions from different sources can be compared.

Leaching of salts from inundated soils at Flaming Gorge Reservoir, Utah

E. L. Bolke and K. M. Waddell reported that the leaching rate of soluble salts from the reservoir area at Flaming Gorge increased from 120,000 tons per yr for 1969–70 to 150,000 tons per yr for 1971–72. The increased rate was due to the rise in reservoir water levels which covered soils not previously inundated. After periods of sustained rise in reservoir level, the leaching rate decreased. Because the reservoir level during 1972 was near maximum pool elevation, future levels will envelop soils previously inundated, and the leaching rate should decrease.

Quality of water in South Fork Ninnescah River, Kansas

A. M. Diaz reported that the inflow of highly saline ground water to the South Fork Ninnescah River from the underlying bedrock of Permian age has been confirmed by chemical analysis of water from a test well drilled to bedrock in the problem area near Cairo, Kans. Historical and current chemical analyses of water from the bedrock, from the overlying formations of Pleistocene age, and from the stream have been statistically analyzed to calculate the percent ion distribution in assumed mixed waters. Results indicate that immediately downstream from the problem area, 4 percent of the streamflow consists of water from the bedrock. The characteristically high sodium and chloride solutes constitute the major source of dissolved solids for the stream.

Chloride in rainfall in Mattole River basin, California

The variation of chloride in rainfall was studied in detail by V. C. Kennedy, R. J. Avanzino, and G. W. Zellweger for a single large storm which occurred during the period January 19–23, 1972, in the Mattole River basin of northern California. Sequential samples representing successive 0.1 in. of rainfall were analyzed and commonly found to contain 0.5 to 3.0 mg/l chloride when the rate of precipitation was less than about 0.1 in. per h. When the rate of precipitation exceeded 0.1 in. per h, the chloride concentration decreased to less than 0.02 mg/l. A short-duration hailstorm occurred at the end of the major storm period, and precipitation then had a chloride concentration of approximately 38 mg/l; as the position of the collection station is about 4 mi east of the Pacific coastline, varying wind direction and great turbulence associated with the hailstorm are thought to account for the 38 mg/l chloride value. Nevertheless, the difficulty of getting representative samples of average rainfall in the area is evident when a single constituent, such as chloride, can vary by more than two orders of magnitude during one storm period.

Ground-water quality of Hawaiian Island sources

L. A. Swain prepared ground-water quality maps for the five major islands of Hawaii. The maps indicate that most basal water is of the sodium chloride type except in certain areas where an extensive caprock of alluvium or calcareous deposits exists. In the latter places, the water is a sodium magnesium chloride, a magnesium sodium chloride, or a sodium chloride type, as a result of cation exchange or of dissolution of calcareous deposits. In the Pearl Harbor–Honolulu area of Oahu, the chloride content increased with depth, but the percentage of sodium decreased with depth, resulting in percentage increases in calcium and magnesium content. This supports the cation-exchange explanation of the water-quality variation for this area mentioned above.

The high-level water in volcanic bedrock is generally a sodium magnesium bicarbonate type or a sodium magnesium calcium bicarbonate type.

The Hawaiian ground waters generally contain low percentages of sulfate except for two sources in the Waianae Range on Oahu.

Selenium in Nebraska's ground water and streams

R. A. Engberg reported that, since 1969, selenium content has been determined in water from 139 wells and 39 stream sites in Nebraska. Forty percent of all ground-water samples contained selenium concentrations greater than 10 μg/l (the USPHS drinking-water standard for selenium). Because many of the ground-water samples were collected from known seleniferous areas, they cannot be considered representative for the entire State. Nevertheless, measurable selenium concentrations, some greater than 10 μg/l, were detected in ground water not previously suspected to be seleniferous. The highest concentration detected in water from an area where selenium was not expected was 103 μg/l in south-central Nebraska, whereas the highest concentration observed in water from a known seleniferous area was 480 μg/l in northern Nebraska. Concentrations of selenium exceeded 10 μg/l at least once in samples from 26 percent of all surface-water locations, but the highest observed concentration was only 20 μg/l at two locations more than 200 mi apart.

Aquatic biota as a water-quality index

B. W. Lium developed a numerical rating system, based on aquatic biota information, collected in Chester County, Pa., that indicates environmental conditions of a stream. The rating scheme is on a scale of 1 to 10; a value of 10 indicates a balanced biological condition, whereas lower values indicate an adverse change in the balance as a result of enrichment or of nature-induced phenomena such as channel scouring or winter conditions. The lowest values indicate conditions toxic to aquatic biota. Uniformity of sampling procedures and analytical techniques is of primary concern.

Biology of an arctic stream

J. W. Nauman, L. J. Tilley, and K. V. Slack found that the aquatic life of an arctic stream exhibits some unique characteristics. A reconnaissance study of the remote unpolluted Dietrich River basin in Alaska's Brooks Range during August 1971 disclosed fewer kinds of water-living insects than would occur in a similar unpolluted stream in the temperate zone. Larvae of the family Chironomidae, aquatic midges or gnats, comprised an average of 71 percent of the taxa of aquatic insects in drift-net samples from five sampling sites along the river. At the headwaters, Chironomids made up 80 percent of the aquatic insect taxa, decreasing to 58 percent at the lowest site sampled. Of the six subfamilies of Chironomidae, three were represented in the Dietrich River samples, the Diamesinae, Orthocladinae, and a single species of Podonominae. Distribution of these subfamilies changed dramatically from the upper station, where Diamesinae made up 98 percent of the Chironomid individuals in the samples, to the lower four sites where Orthocladinae comprised 69 percent of the Chironomid individuals. Only two Podonominae individuals were seen.

Because of their abundance in the population, the Chironomids are of unusual ecological importance in arctic streams. Moreover, the diversity of this group of insects (30 or more taxa were found in the Dietrich River alone) may provide a sensitive index of the environmental quality.

Aquatic environmental changes along the trans-Alaskan pipeline corridor

A water-quality monitoring program was initiated to determine preconstruction characteristics and associated aquatic invertebrate populations in selected streams along the trans-Alaskan pipeline corridor. The monitoring program involved the use of artificial substrates for benthic-invertebrate sampling, traditional water-quality measurements, and observations of weather conditions. According to J. W. Nauman and D. R. Kernodle, preliminary results show that streams with the higher specific conductance, dissolved silica, and suspended chlorophyll *a* concentrations also had the highest number of total benthic invertebrates and were located in the Arctic Coastal Plain and in the lowland and low-mountain regions of the Alaska Range. Other observations, below a fuel-oil-spill area, indicated that the total number of benthic invertebrates found in a small stream were reduced by one-half, although there were no other measurable changes in water quality.

Water quality improves with distance from developed areas

B. F. McPherson reported that selected chemical indicators of water quality in and near the water conservation areas in south-central Florida from 1970 to 1972 varied with location and season. Dissolved-solids concentrations were generally highest in the north and northeast (from 471 to 604 mg/l) and lowest in the south and west (from 172 to 387 mg/l). Pesticide concentrations showed a similar distribution trend. DDT, the most commonly detected pesticide, averaged 192 μg/kg in bottom sediments in the north compared with 13.8 μg/kg in the south. DDT averaged 723 μg/kg in centrarchid fish (bass and sunfish) at the north end of Water Conservation Area 1; 264 μg/kg at the south end of Area 1; 230 μg/kg in Area 2; and 56 μg/kg in Area 3.

RELATION BETWEEN SURFACE WATER AND GROUND WATER

Stream-aquifer interaction included in channel routing

Flow of the North Canadian River has been simulated in the 86-mi reach between Canton Reservoir and El Reno, Okla. Using the techniques of convolution, A. F. Moench, D. B. Sapik, and V. B. Sauer combined the unit-response procedure for open-channel routing with a simplified aquifer model using a unit-step-response function to account for the interaction between the river and the aquifer. Simulated streamflow hydrographs for two test periods were in good agreement with observed flow at the El Reno gaging station. The model shows that, during a release of 1,000 ft^3/s, river water goes into bank storage at a rate of about 400 ft^3/s initially and declines to 150 ft^3/s a week later. When the release is stopped, flow at the stream-aquifer interface reverses. Return flow in excess of 200 ft^3/s declines gradually.

Digital model of flow and water quality of a stream-aquifer system

L. F. Konikow and J. D. Bredehoeft (1973) reported that salinity increases in ground water and surface water in the Arkansas River valley of southeastern Colorado are primarily related to irrigation practices. A digital-computer model was developed to predict changes in dissolved-solids concentration in response to spatially and temporally varying hydrologic stresses. The equations which describe the transient flow of ground water and the transport and dispersion of dissolved chemical constituents were solved numerically. The model was used to simulate the flow as well as the changes in water quality for both the stream and the aquifer.

A 1-yr period during which detailed field measurements had been made in an 11-mi reach of the valley between La Junta and the Bent-Otero County line was used to verify and calibrate the model. Calculated water-table elevations in the aquifer were within 1 ft of the observed values approximately 90 percent of the time, and calculated dissolved-solids concentrations were within 10 percent of the observed values for both the aquifer and the stream approximately 80 percent of the time. The calibrated model was then used to predict and evaluate the effects of possible changes in water-management practices on the hydrology and water quality of both the aquifer and the stream.

Ground-water gradients near Malheur Lake

Malheur Lake, an intermittent lake in southeastern Oregon, has a complex relationship to local ground-water bodies, according to L. L. Hubbard and A. R. Leonard. The lake is at the south end of the 20-mi-long Harney Valley and was expected to be a "sump" with inward gradients from all ground-water bodies. Water levels in the deeper confined zones have potentiometric heads higher than lake level and seem to be unaffected by the size and stage of the lake. In contrast, water levels in the shallowest ground-water zones apparently are intimately related to the stage of the lake and to inflowing rivers. In the alluvial Donner und Blitzen Valley, on the southwest side of the lake, the ground-water gradient in the shallow zone is toward the lake, and on the northeast and southeast sides the gradient is away from the lake.

Use of ground water to maintain lake levels

Lake levels were lower than usual during the past few years at several homesite lakes about 12 mi north of Tampa, Fla. Rainfall was less than normal, changes in natural drainage diverted storm runoff away from some lakes, and ground-water levels were lowered locally by pumping from the Floridan aquifer at a nearby municipal well field. Residents at some lakes forestalled extreme declines in level by drilling additional wells into the Floridan aquifer and pumping water into the lakes. During 1971, pumpage into three of the homesite lakes (combined area, 55 acres) averaged 1.1 Mgal/d (1,230 acre-ft/yr) and equaled about 6 percent of the total pumpage from the municipal well field. Yearly rainfall in 1971 was about equal to yearly lake evaporation; the lakes did not overflow. Hence, the water that was pumped into the lakes replaced water that leaked from the lakes into the shallow aquifer or into the deeper Floridan aquifer. J. W. Stewart and G. H. Hughes estimated that 86 percent of the water pumped into the lakes returned to the Floridan aquifer where the water was retrievable for beneficial use. The increase in lake evaporation caused by maintaining the relatively high lake levels accounted for less than 3 percent of the 1971 pumpage.

Relation of ground water to lakes

R. J. Wolf, S. P. Larson, and M. S. McBride reported that preliminary appraisal of aquifer test data collected for digital modeling of the surficial outwash in the Pearl-Sallie Lakes area, Minn., indicated a transmissivity of 6,000 ft^2/d, storage coefficient of 0.2, and hydraulic conductivity of 335 ft/d. Ground-water inflow to Lake Sallie from the surficial outwash occurs through sections of saturated material ranging in thickness from less than 1 ft to 90 ft. The width of the outwash sections is restricted between several hills which rise from the underlying till surface and outcrop near the edge of Lake Sallie.

An anomalous local recharge area centered around Dart Lake affects the potentiometric surface. The level of the lake is from 3 to 7 ft above the water level in the surrounding aquifer. Under natural conditions the lake level should correspond to the surrounding ground-water levels because no surface-water inflow or outflow occurs, except for inflow from the immediate drainage area, and lake evaporation normally exceeds precipitation. Since 1951, 538 acre-ft/yr of water from Dart Lake has been used to wash gravel from a nearby pit. Wash water is returned to the lake via an overland channel. An additional 160 acre-ft of water is withdrawn from a deep aquifer to supplement lake water in the washing operation. The ground water added to Dart Lake evidently has caused a rise in lake level, making the lake a local recharge area.

Hydrology of spring ponds

In a research study of natural springs discharging from glacial drift in Langlade County, Wis., W. J. Rose found a wide variation in the specific conductance of ground water discharging at different points into one of the spring ponds. The observed values ranged from 275 to 390 μmho/cm. The water in the area is a calcium magnesium bicarbonate type. Water with the higher values of specific conductance probably followed longer flow paths toward the discharge points than water with lower specific conductance. There was no logical pattern to the spatial distribution of the areas discharging water of high or low specific conductance that could be explained by surface topography or water-table gradients in the surrounding area. Apparently, the ground-water-flow paths near some spring ponds are controlled and distorted by the heterogeneity of the aquifer material.

Effect of ground-water withdrawals on streamflow

Ground-water withdrawals for irrigation from the alluvial aquifer in the South Platte River valley in northeastern Colorado have increased from 102,000 acre-ft/yr in 1947 to 591,000 acre-ft/yr in 1970. According to R. T. Hurr and D. R. Minges, these withdrawals have reduced the return flow of ground water to the river from about 800,000 acre-ft/yr to about 550,000 acre-ft/yr during the same period. The effect of the decrease in return flow on the flow of the river, however, has been compensated for by two other changes: (1) An increase in tributary flow resulting from increased importations of transmountain diversion water and (2) a decrease in surface-water diversions directly from the South Platte River. Presumably, the decrease in direct surface-water diversions from the South Platte River and the increase in use of ground water has been a matter of choice rather than of necessity.

Effects of ground-water development on supply to proposed reservoir

Test drilling in Texas along the Navidad and Lavaca Rivers, which will be sources of water for the proposed Palmetto Bend Reservoir, has shown that the streams receive ground-water discharge even during the irrigation season when large ground-water withdrawals normally lower the water table at many places. Low-flow investigations support the findings. The study by E. T. Baker, Jr., and C. R. Follett also indicates the remoteness of future loss of the low flow of the streams by infiltration to a lowered water table.

A study of land-surface subsidence, resulting from loading when the reservoir is filled, shows that average annual subsidence on a long-term basis will range from 0.013 to 0.015 ft at the upper ends of the reservoir to 0.019 ft near the dam site. The fairly uniform distribution of the subsidence over a large area minimizes undesirable effects such as structural failures of man-made features.

Effects of canal on ground-water levels

In west-central Florida, the 7-mi reach of a canal, which intersects the lower Withlacoochee River 9 mi above its mouth, was completed in 1969. The river channel and the canal penetrate the cavernous limestone of the Floridan aquifer below the water table. According to G. L. Faulkner (1973), ground-water levels in a 15-mi^2 area centered at the canal about 4.5 mi from the Gulf of Mexico are 0.5 to 15 ft lower than expected values, had the canal not been built. In another 0.7-mi^2 area surrounding the Inglis Lock bypass channel, the ground-water level has been raised 0.5 to 20 ft above the precanal level. The average ground-water contribution to the flow of the lower river is 20 percent (7 ft^3/s) less than before the canal was built. This is about 0.5 percent of the average fresh-water flow that would have passed down the river from October 1, 1970, through September 30, 1971, had the canal not been built.

Degree of canal and aquifer interconnection studied in southeastern Florida

A program to interface the surface-water and ground-water regimes in an electrical analog model is being implemented by E. H. Cordes. The model has been used on a representative ground-water basin in southeastern Florida to determine the necessity of simulating the degree of hydraulic connection between canals and the ground-water system. Comparison of results obtained using no connection and 100 percent hydraulic connection showed that the ground-water-storage duration curves differed initially by only 6 percent, and by only 11 percent after 30 d. Because, under most circumstances, other hydrologic events override variations of this magnitude in periods of 30 d, future modeling techniques need not be concerned with degrees of hydraulic interfacing between canals and the ground-water system.

SOIL MOISTURE

Soil-moisture retention and movement are vital links in the chain of hydrologic principles under study in efforts to understand and control our environment. The mechanisms involved in infiltration, evaporation, transpiration, and movement of water to the water table are being investigated in the natural environment as well as in the laboratory.

Portable probe for measuring soil-water suction

A portable tensiometer probe has been devised by C. D. Ripple in connection with development of field equipment for determination of water properties in unsaturated soils. The intrument, which is small and light, consists of a rapid-response, differential-pressure transducer coupled to a porous ceramic-tipped probe. In operation, the probe tip is brought into uniform contact with moist soil. The suction (subatmospheric pressure) of the soil water is indicated within a few seconds by the transducer-conditioning equipment.

Waterflow in unsaturated soils

The uniqueness of the relation between hydraulic conductivity and water content of unsaturated, wetting sand was studied in the laboratory by C. D. Ripple and Jacob Rubin. In these vertical-infiltration experiments, infiltration rates were controlled by an infusion pump and were either constant or stepwise increasing. Quasi-steady water contents were measured in the upper parts of the infiltration columns with the same final infusion rate but with different infusion histories. The water contents observed imply that the relation in question is slightly, but significantly, nonunique. If confirmed by long-duration infiltration experiments, this conclusion will call for changes in the current unsaturated-flow theory.

Infiltration index for drainage basin from soil-association indexes

S. J. Stankowski reported the development of an inexpensive and rapid technique for determining a hydrologically significant soils index for application in regional water-resources analyses. Infiltration capacity influences the amount of direct runoff from a storm and the amount of delayed subsurface runoff. Generally, infiltration has a high initial rate that diminishes during continued rainfall to a minimum rate that is reasonably constant and reproducible. Ranges of minimum infiltration rates have been determined by the SCS for four hydrologic soil groups, each with minimum cover and thorough prior wetting and after prolonged rainfall in excess of the infiltration rate. The influences of both the surface and the horizons of a soil are thereby included. Using minimum infiltration rates as weighting factors, Stankowski determines a mean-minimum-infiltration index for each soil association by summing the weighted proportions of land area in each hydrologic soil group. The infiltration index for a drainage basin is then determined by superimposing an outline of the basin divide over corresponding soil association maps. Using the percentages of the soil association areas contained within the basin as weighting factors, the basin infiltration index can be determined as the weighted sum of the soil association indexes. This method is being used in the development of flood-magnitude and flood-frequency estimating relations for New Jersey.

EVAPOTRANSPIRATION

Evapotranspiration consists of the conversion of water to vapor and mixing of water vapor at the earth-atmosphere boundary. It accounts for approximately 70 percent of the 30-in. average annual precipitation in the conterminous United States, for nearly all of the precipitation in the arid regions, and for one-third of the precipitation in the humid regions.

Quantitative measurements of evapotranspiration are important for water-resource planning activities, such as prediction of available water supplies for various uses, estimation of drought incidence, and location of storage reservoirs and conveyance systems. The USGS makes these measurements using techniques which are being studied continuously to improve their accuracy and to reduce their cost.

Evaporation from Lake Michie

G. L. Giese reported that evaporation from Lake Michie, in North Carolina, was measured for the period 1961–71 utilizing the mass-transfer technique described by Harbeck (1962). Average annual evaporation for the period was 38.3 in., ranging from 30.9 in. in 1967 to 45.4 in. in 1966. Within-year variation of evaporation from the lake is cyclic, with an average January low of 1.54 in., gradually increasing to a July average of 4.71 in. and then decreasing through the remainder of the year. The minimum monthly evaporation during the 10-yr period was 0.66 in. in January 1962, and the maximum monthly evaporation was 7.41 in. in July 1966. In a given year, there are 9 chances in 10 that the evaporation will be within 1 or 2 in. of the 10-yr average for that month.

Pan coefficients derived for Lake Michie, using nearby pan-evaporation data, are similar to those obtained for other lakes in the southeast. The average annual pan coefficient for Lake Michie is 0.78; average monthly pan coefficients ranged from 0.57 for April to 1.09 for December.

Regional evaporation loss from reservoirs

A regionalized relation for determining the evaporative loss from reservoirs for the Piedmont area of North Carolina was developed by E. F. Hubbard, Jr., using Goddard's (1963) draft-storage relations. Evaporation data required for the relation were taken from the 10 yr of record at Lake Michie, N.C. The evaporation draft from reservoirs is expressed as a function of reservoir-surface area and drainage area of streams tributary to the reservoir. The surface area is an index to reservoir capacity and hence to the critical period. (The critical period, or the time which a drought of certain magnitude most severely depletes the water stored in a reservoir, is primarily a function of reservoir capacity.) The drainage area is an index of the inflow to the reservoir during the critical period.

The regional relation shows that a 1,000-acre lake impounding streams draining 100 mi² would have an evaporation loss during the most critical period in 50 yr of about 1.4 Mgal/d. During an equivalent drought, a 10-acre reservoir on a stream with a 10-mi² watershed would lose an average of about 0.023 Mgal/d.

An analysis of the technique indicates that, for 20-yr draft-storage relations, the regional curves will provide estimates of evaporation losses within 10 percent, assuming that the Lake Michie evaporation records are representative of long-term regional evaporation.

Denver water-supply reservoirs

Evaporation data were collected for six reservoirs at altitudes ranging from 6,000 to 9,000 ft in the water-supply system for Denver, Colo. J. F. Ficke and T. W. Danielson developed computer techniques that reduced the time required for evaporation computation. Preliminary analyses show that the pan coefficient for converting class A pan evaporation to lake evaporation remains constant with altitude.

Changing consumptive use on the Gila River flood plain, southeastern Arizona

R. L. Hanson, F. P. Kipple, and R. C. Culler (1972) used the water-budget method to evaluate the reduction in evapotranspiration caused by removal of phreatophytes, primarily saltcedar, from 5,000 acres of the Gila River flood plain in southeastern Arizona. Results of the study gave evapotranspiration rates ranging from 20 in. per yr for bare ground to 60 in. per yr for 100-percent phreatophyte cover. The average annual evapotranspiration from a 1,720-acre segment having a canopy of 39 percent was reduced from 50 in. per yr to 20 in. per yr. In addition, using preclearing and postclearing evapotranspiration data obtained during the 9-yr study, monthly consumptive-use coefficients for bare ground and varying amounts of phreatophyte cover were defined by the Blaney-Criddle formula.

The use of homoclimates in hydrologic studies

Data for the planning of water-resource projects in arid or semiarid climates are generally inadequate, according to T. E. A. van Hylckama. An example of inadequate data is the estimation of evapotranspiration by various empirical formulae which use only measured or estimated air temperatures and length of growing season. These estimates often lead to erroneous results. Because evapotranspiration is also a function of other variables besides air temperature, it is better to use parameters such as net radiation, humidity, wind speed, and rainfall characteristics, obtained from regions with climates similar to that of the region under study. Such homoclimatic regions have comparable soils and vegetation because both are largely a result of the climate itself. Results of transfer of parameters to determine evapotranspiration by use of homoclimates show that such monthly and yearly values are, at most, 10 percent larger or smaller than the measured values, a significant improvement over empirically determined values which often have a margin of error of more than 30 percent.

LIMNOLOGY

Limnology, the study of the ecology and biology of inland surface waters, deals with the relations between aquatic environments and the organisms that inhabit them. Limnology uses geological, physical, chemical, and biological data to evaluate the functional interactions between natural waters and their living communities. The information derived from limnological studies is useful to water-resource planners and managers and is especially applicable to problems of water quality.

Physical and chemical limnology of a small glacial lake

The physical and chemical characteristics of Pretty Lake, Lagrange County, Ind., have been evaluated by R. G. Lipscomb through nearly two annual cycles. During the summer, Pretty Lake is divided into three well-defined temperature layers. The maximum temperature of the uppermost layer of water, the epilimnion, is about 26°C by late July and early August. The temperature in the middle layer, the metalimnion, ranges from 23°C at the top (6 m deep) to 10°C at the bottom (about 11 m deep). In the hypolimnion, the lowermost layer, the temperature ranges from 9.8°C at the top to 8.1°C at the bottom of the lake (25 m deep). At the time of complete mixing in late November and early December, the water temperature is 8.5°C. Winter temperature ranges from 0.0 to 1.0°C immediately beneath the ice cover and from 2.0 to about 4.0°C in the bottom water. Some warming of the entire volume of water, except that immediately beneath the ice cover, occurs by the end of the ice period. Water temperature at the time of complete mixing after ice breakup in late March and early April is about 3.8°C.

Most of the chemical characteristics of Pretty Lake follow a pattern set by thermal stratification and circulation. The specific conductance (micromhos at 25°C) of the epilimnion ranges from 250 to 280 and increases with depth to between 300 and 320 in the hypolimnion. During complete mixing, the water has a specific conductance of 300. Specific conductance also increases with depth beneath ice cover, reaching a maximum of 380 at the bottom.

The pH in the epilimnion is between 8.2 and 8.8, and DO concentration ranges between 8.0 and 12 mg/l (100- to 140-percent saturation). In the upper metalimnion the pH is 8.2 to 8.4 with DO concentration that remains high at 10 to 12 mg/l (110- to 120-percent saturation). The minimum pH of 7.4 in the hypolimnion corresponds to the depletion of DO which occurs there by late season. With complete mixing in the fall and spring, the pH is 8.0. DO concentration, however, is not equal for those periods, being 10 mg/l (about 82-percent saturation) in the fall and 12 mg/l (about 95-percent saturation) in the spring. Under ice cover, the water has a pH range of 8.8 immediately beneath the ice to 7.6 near the bottom of the lake. Corresponding values for DO concentration are 16 mg/l (120-percent saturation) and zero, respectively.

Calcium and total alkalinity increase in concentration with increasing depth both during summer stratification and during periods of ice cover. In the bottom water, near the end of the ice-cover period, calcium is concentrated at 50 mg/l and total alkalinity at 180 mg/l, which are annual maximum concentrations for those parameters. During periods of complete mixing of the lake, calcium concentrations are 35 to 37 mg/l and total alkalinity is 150 mg/l.

Less than 0.5 mg/l silica is present in the upper levels of Pretty Lake during most of April, all of May, and the first half of June. At most other times of the year, silica content ranges from 1.0 to 3.0 mg/l. Concentrations of silica increase with increasing depths and, in the bottom water, vary with the seasons. The maximum concentrations, up to 10 mg/l, occur in the deepest water when the lake is ice covered.

The concentration of nitrate nitrogen in Pretty Lake is generally uniform during the summer. Nitrate nitrogen concentrations of 0.3 to 0.4 mg/l in the upper layers of water increase to 1.2 mg/l in the hypolimnion during late July and early August. When the lake is ice covered, concentrations of nitrate nitrogen are from 0.1 to 1.2 mg/l to a depth of about 18 m where the concentration gradient increases abruptly. At 25 m the concentration of nitrate nitrogen is 5.6 mg/l. During complete mixing in the fall the amount of nitrate nitrogen is 0.3 mg/l, and in the spring it is about double the fall value.

Orthophosphate phosphorus is not abundant in Pretty Lake. There is little relative change in the upper levels of the lake where concentrations range from 0.01 to 0.03 mg/l during summer stratification and during the ice period. The largest change occurs at greater depths as DO is depleted. By late summer the concentration of orthophosphate phosphorus in the deepest water increases to a maximum of 0.20 mg/l, and during the ice-cover period it increases to a maximum of 0.10 mg/l.

Primary productivity of Lake Koocanusa

Monthly determinations of primary productivity were made in Lake Koocanusa near Libby, Mont., from July to November 1972. Lake Koocanusa formed during the summer of 1972 after the Kootenai River was dammed. Determination of primary-productivity variations with time are part of a continuing study of water quality in this newly formed lake.

A number of modifications of existing methods and techniques were developed and used by V. J. Janzer, L. J. Schroder II, and J. R. Knapton (1973), during the study. Radioactive carbon-14 was used to determine the in situ rate of photosynthetic fixation of dissolved carbon by phytoplankton. After separation of the radioactive plankton by filtration, the associated radioactivity was determined by liquid-scintillation counting techniques. Graphical methods were used to calculate primary productivity in terms of the weight of carbon fixed per square meter of lake surface area per day (mg C m^{-2} d^{-1}). The method is particularly applicable to slow-moving or standing low-productivity waters and has a range of about 0.05 to 100 mg C m^{-3} h^{-1} of photoperiod.

Initial results disclosed that two types of productivity curves may be obtained at the same location in Lake Koocanusa. Sunlight intensity at the lake surface appears to be the dominant factor which determines the type of curve obtained under similar conditions of temperature and other water properties. In sunny weather a productivity maximum occurred at about 2 or 3 m near the depth of penetration of 30 percent of the surface light. Although the productivity values ranged considerably, typical values for radiocarbon-measured primary productivity under sunny conditions were 120 to 200 mg C m^{-2} d^{-1}. If overcast conditions existed during most of the incubation period, light inhibition appeared to be negligible and productivity reached a maximum near or at the surface. Typical values for primary productivity under overcast conditions were 50 to 80 mg C m^{-2} d^{-1}.

Algal blooms in Lopez Reservoir, California

Lopez Reservoir, a relatively new but enriched body of water in San Luis Obispo County, Calif., was initially filled by torrential rains shortly after its construction in early 1969. According to R. H. Fuller, W. G. Hines, and R. C. Averett, more than 575,000 t of sediment, enriched with over 900 t of nitrate nitrogen and 400 t of phosphorus, entered the reservoir at that time. The reservoir is thermally stratified during the summer months, and low DO levels occur in the hypolimnion. Algal-cell counts in the surface water commonly exceed 100,000 cells per liter and may exceed 850,000 cells per liter during bloom conditions. Species of *Stephanodiscus*, *Fragilaria*, and *Aphanizomenon* are commonly associated with bloom conditions. Copper sulfate has been used, but with little success, in an attempt to control algal growth in Lopez Reservoir.

Florida impoundment limnology

The limnological characteristics of Taylor Creek impoundment, located about 15 mi west of Cocoa, Fla., were studied from July 1971 to October 1972 by D. A. Goolsby and B. F. McPherson. The impoundment was shown to be chemically and thermally stratified from early spring until midautumn. By late spring, oxygen is depleted at depths greater than about 3 m (8–10 ft) and concentrations of inorganic carbon, nitrogen and phosphorus, free carbon dioxide, iron, and dissolved solids increase with depth. Primary productivity in the 4-yr old impoundment is higher than in a nearby natural lake.

When releases are made from the bottom of the impoundment at low discharge rates, the released water is anaerobic and contains higher nitrogen and phosphorus concentrations than are found in unpolluted tributaries of the basin. However, when releases are made at moderate- to high-discharge rates, water is drawn from other levels, and the released water contains nitrogen and phosphorus concentrations that are similar to those in nearby tributaries. At the higher rates of water discharge, therefore, there is no significant difference in water quality whether release is made from the bottom or top of the impoundment.

Characteristics of Pennsylvania recreational lakes

In the summers of 1971 and 1972, limnological reconnaissance surveys were completed at 29 Pennsylvania lakes and reservoirs to provide a base of information on those lakes of high recreational importance. According to J. L. Barker, the surveys have shown that Pennsylvania waters vary considerably in physical, chemical, and biological characteristics important to lake-management schemes. Seventeen of the 29 lakes surveyed were thermally stratified, and all lakes having a depth greater than 3 m disclosed at least some thermal stratification during periods of minimal streamflow. Depths to the thermocline ranged from 2 to 7 m, and the majority of lakes were stratified at a depth of 3 m.

Chemical quality of the impounded waters correlates with the geology and soil characteristics of the basins. Natural waters in geologic units of low solubility (that is, shales and sandstones) are generally low in dissolved nutrients, alkalinity, and biological productivity. On the other hand, waters in more soluble material such as limestones and dolomites are generally high in dissolved nutrients, high in alkalinity, and are moderate to excessive in productivity. The aquatic biota also may be related to geologic units and the resultant water quality. It was observed, for example, that the species distribution of aquatic weeds varies according to alkalinity of the water in which they grow. Chlorophyll *a* of phytoplankton also appears to correlate well with alkalinity. Thus the phytoplankton and other aquatic organisms are distributed according to water-quality characteristics attributable to drainage-basin lithology.

Limnological characteristics of Shastina Lake, California

A. E. Dong observed that Shastina Lake in Siskiyou County, Calif., exhibited strong thermal and DO stratification during the summer. Free circulation started after autumn overturn and lasted until late spring. In summer months, DO saturation was as high as 200 percent near the lake surface, indicating a high rate of algal production. During the same period, DO was virtually absent below about 5 m, indicating extensive decomposition of organic matter and microbial respiration. Anaerobic conditions near the lake bottom persisted throughout the summer stagnation period, and during this time large quantities of nitrogen and phosphorus nutrients were regenerated within the lake itself. Core samples indicated that anaerobic conditions during thermal stratification have probably existed for some time. The lake inlets contributed nitrogen and phosphorus, mainly during winter and spring. The net annual input of nitrogen and phosphorus to the lake from inflow probably was lower than the input by regeneration within the lake. Most of the essential elements were present in sufficient concentrations to support algal growth, indicating that the lake was enriched.

Limnology of the Sacramento River, California

The Sacramento River is a controlled flow system that drains the northern Central Valley of California. R. C. Averett, E. A. Jenne, R. F. Ferreira, and L. J. Britton began a limnological study in April 1972 to evaluate selected physical, chemical, and biological features of the river. Five stations along a 168-mi reach were sampled.

Suspended-sediment concentrations ranged from 3 to 6 mg/l at the upstream stations and from 41 to 74 mg/l at the downstream stations. Benthic invertebrate numbers and species decreased in the downstream direction as the river substrate changed from a rubble-gravel mixture to a sand-clay mixture. In contrast, phytoplankton numbers and species increased at the downstream stations. Periphyton growing on plexiglass substrates exposed in the river varied widely in species and abundance at the various stations with biomass ranging from 0.8 to 38 g/m^2. There was a strong inverse relation between periphyton biomass and the amount of inorganic sediment on the plexiglass substrates.

Nitrogen and phosphorus concentrations generally increased at the downstream stations. Preliminary analyses indicate a wide variation in pesticides of the DDT family and PCB extracted from riverbed material. This variation ocurred within and between stations and is probably a function of the type of bed material.

Algal-bacterial symbiosis

T. A. Ehlke reported that bacteria-free (axenic) blue-green algal cultures were obtained by mechanical manipulation and by ultraviolet radiation. The growth rate of algae in axenic culture was determined to be much slower than in the presence of the bacteria. In diffusion-chamber studies with axenic algae separated from the bacteria by membrane filter, the data suggest that a near-normal growth rate of the axenic algae occurs. The growth rate of axenic blue-green algae was not enhanced by the experimental addition of minute amounts of vitamins, amino acids, or inorganic salts.

PLANT ECOLOGY

Effects of drought on Mojave Desert vegetation

E. B. Leopold made a 9-yr study of the relationship of drought to productivity of desert vegetation in the western Mojave Desert. The most detailed part of the study involves changes through a 3-yr drought that began in 1970. During the first year of drought, the main impact was limited to low elevations along the margins of the playas below 2,000 ft; effects included a decrease in the numbers of annual herbs by a factor of 8 and a decrease in diversity and heights of annuals. Blooming of shrubs at this elevation was inhibited, but effects at higher elevations were not noticeable. The second year of drought brought severe impact up to 3,000-ft elevation, decimating the annual herb crop and causing a more severe inhibition of flowering of shrubs. Some deaths among the shrub layer on lower fans were recorded, but no clear effects were evident at higher elevations. During the third year of drought, impact was felt in the herb layer all the way to tree line at 6,000-ft elevation. Blooming of shrubs decreased over this range and most shrubs were not flowering below 3,000-ft elevation. Deaths were recorded in about 50 percent of the desert holly bushes along the playa margin at Searles Lake, Calif. These results indicate that the lower edges of the vegetation belt were retreating upslope and that the size of the playas was expanding by about 50 to 100 yd at some transect sites, depending on slope.

Vegetation reflects water-impoundment practices in southeastern Florida

Comparisons of 1940 with 1972 vegetative models of conservation areas by B. F. McPherson indicate recession of tree islands in the southern and southeastern parts of Water Conservation Area 3, where water levels are deep, and expansion in the northern part, where water levels are shallow. Recession was coincidental with increased flooding in the southeast as a result of increased rainfall in the late 1960's and of water-impoundment practices.

Controlled streamflow resulted in new establishment of riparian vegetation

Changes in vegetation along the major water courses in Arizona are being studied through the use of historical records, old maps, and old photographs. R. M. Turner reported that marked changes have occurred recently along the Marble Canyon–Grand Canyon reach of the Colorado River. Old photographs (dating from 1871 to 1963) compared with photographs taken in 1972, show that the banks of the river are being actively invaded by riparian plants. The invasion is apparently related to the construction of Glen Canyon Dam. Prior to 1963, when the dam was completed, scouring floods occurred frequently enough to eliminate all riparian plants. Consequently the banks were bare. Now that flow is regulated within narrow limits, new vegetation, such as saltcedar, willow (*Salix* species), arrowweed (*Pluchea sericea*), camelsthorn (*Alhagi camelorum*), cattail (*Typha domingensis*), and cottonwood, is growing along this part of the river.

Results of erosion caused by off-road vehicle use

Preliminary results of studies by R. F. Miller and C. T. Snyder indicated that off-road or recreation vehicles have had a marked effect on frail lands in western Fresno County, Calif. In the Panoche Hills, an area on the west side of San Joaquin Valley that was subject to intensive motorcycle use before it was closed to public access, severe erosion is developing along the used trails. Miller reported that native plants have not been able to reestablish themselves on the trails because changes in soil density and soil characteristics have inhibited plant growth. The steeper hills were less damaged, and the integrity of the plant cover on them has been maintained. Incomplete runoff records show that there has been less overland flow from the unused part of the study basin than from the area of intensive use.

Most trees survived Tropical Storm Agnes flood along Potomac River

Flooding on June 21–24, 1972, along the Potomac River had little long-lasting effect upon the flood-plain vegetation in Virginia and Maryland near Washington, D.C. R. S. Sigafoos observed that the immediate effect was one of devastation of large areas of flood-plain forest where large stands of trees were felled. Later observations through the summer showed that trees, shrubs, and herbaceous perennial plants were not killed; felled trees produced sprouts, defoliated shrubs produced new leaves, and herbaceous plants sprouted anew. Just as vegetation recovered following the 1936, 1937, and 1942 floods and the 1948 ice jam, so will the vegetation recover after the 1972 flood (the fourth highest recorded at the gaging station near Washington, D.C.). Only the forms of the trees will record the devastation.

Drought reduced pollen rain from desert plants

A 9-yr study by E. B. Leopold of the productivity of vegetation in the western Mojave Desert showed marked changes in pollen rain during 4 drought years. Modern pollen rain dropped 50 percent during the first year of drought and was about the same during the second year of drought. Over the 9-yr study period, the 4 drought years (1964, 1967, 1970, 1971) brought a sparse modern pollen rain that was half that of the 2 wettest years (1966, 1969). Pollen deposition tends to be greater at high elevations and falls off sharply as distance from the edge of the coniferous forest increases—pollen deposition decreased 90 percent 12 mi from the forest front.

NEW HYDROLOGIC INSTRUMENTS AND TECHNIQUES

MISCELLANEOUS NEW AND COMPUTER-AIDED HYDROLOGIC INSTRUMENTS

G. F. Smoot reported the development of a constriction device which can be used in storm sewers to measure flow under both open-channel and full-flow pressurized conditions. The device, a modified venturi meter, was laboratory tested and rated by Jacob Davidian, using facilities of the Georgia Institute of Technology. To date, one device has been installed in a 42-in. storm sewer in Denver, Colo., and negotiations are in progress for additional installations at sites in Albuquerque, N. Mex.; Palo Alto, Calif.; Broward County, Fla.; and Philadelphia, Pa. Flow is determined by measuring the head, both in the throat of the constriction and upstream in the approach. A computer program has been developed to convert the head readings to discharge.

Smoot and H. O. Wires reported the development of a multiparameter, streamside, water-quality monitor which will accept data from as many as 10 standard water-quality sensors and will digitally record the values. Provision was made for interfacing with either analog or digital telemetry equipment as well as for regular onsite recording. The primary objectives for development of the monitor were improved reliability and accuracy, compatibility in procurement, and ease of maintenance and upkeep.

Wires reported development of a shaft digitizer for digitally encoding positions of mechanical devices such as gates of dams. This device provides a 16-bit, parallel BCD (binary coded decimal) output proportional to a shaft position.

Wires also reported the development of a digital, parallel-input, punch-paper-tape recorder, utilizing 16-channel tape. The recorder has several desirable features for recording multiple-parameter data, and it is intended that it will be used with water-quality monitors, urban-hydrology monitors, and the shaft encoders. Not only is the new recorder considerably faster than the standard ADR (analog to digital recorder), recording data at approximately 2-s intervals, but it also allows input of channel-identification data, eliminating previous dependence on maintaining punching sequence in order to provide parameter identification.

D. M. Preble reported that data-collection platforms for the ERTS relay network have been interfaced with hydrologic sensor devices and installed at widely separated points such as Lassen National Park, Calif., and Surtsey Island, near Iceland.

L. M. MacCary is field testing a prototype focused resistivity system based on the guarded electrode method. The system, when fully operational, will be used to measure the resistivities of thin beds in core holes drilled for the Edwards Limestone research project in Texas. The system should have wide applicability in boreholes where salty mud, thin beds, and other borehole and geologic factors make the spacing logs difficult to interpret. An acoustic televiewer and 4-track acoustic caliper, to be used in research in the Edwards project, deep waste storage, and hydrofacturing, are also being tested.

MacCary and T. A. Taylor are using the card-entry–STATPAC computer technique to analyze geophysical logs. Thirteen separate log curves from the Edwards project were digitized on 9-track magnetic tape for ease of data entry into the computer.

A. E. Hess has tested and calibrated a 1-in.-diameter impeller flowmeter for use in boreholes. He is also investigating the practicability of using thermal systems to measure borehole flow over a wide range of velocities and is designing a system for digitizing geophysical logs in the field.

J. V. Skinner and J. P. Beverage reported that newly designed plastic sample splitters and plastic sieves are being used for studying the movement of trace metals in natural streams. Also, two instruments have been developed to help operators raise and lower sampling equipment at a uniform rate when collecting sediment samples by depth integration. One instrument is an adjustable timer that emits an audible tone pulse; the operator first determines the optimum transit rate for the sampler, sets the timer, and then synchronizes each revolution of the cable drive with the tone pulse. The other instrument, by means of a special clip-on tachometer, continuously measures and displays the cable speed. Skinner and Beverage also modified parts of the PS–69 pumping sampler to improve reliability and to reduce production and maintenance costs.

D. W. Fisher reported than an improved sampling device has been used to determine vapor pressures of dissolved gases in natural waters. In use, one chamber of the sampler is filled and flushed with the sample water. This chamber is then isolated from the source and from the atmosphere and then opened to an evacuated inner chamber. The advantage of the sampler is that each of the gases evolved into the inner chamber will be in equilibrium with the known volume of water in the larger chamber. Composition of the gas phase is determined chromatographically after the sampler has been connected to an evacuated, calibrated loop of a gas-sampling valve. Finally, vapor pressures of the gases in the original water sample are calculated from the gas-composition data, sampling and analysis temperatures, liquid and vapor volumes, estimates of equilibrium distributions of the gases based on published solubility data, and the assumption of ideal gas behavior at the low pressures of the analytical steps. Nitrogen partial pressures of several natural waters, determined by this procedure, are higher than the pressures expected for recharge water in equilibrium with the atmosphere. The high nitrogen pressures may indicate a substantial contribution from subsurface sources to nitrogen concentrations in ground water.

COMPUTER PROGRAMS FOR MODELING AND SOLVING HYDROLOGIC PROBLEMS

J. O. Shearman has developed a generalized computer program based on a simplified continuity method for routing streamflows through a channel system. The program utilizes data from the USGS tape back-file library and has been tested on a field project in the upper Kentucky River basin. The program, by virtue of a number of options, allows the user considerable flexibility in calibrating and simulating streamflow conditions in large river networks.

M. E. Jennings and W. R. Slaughter developed a computer program, modified from an existing computer program obtained from the Hydrologic Engineering Center, Corps of Engineers, which is being used to determine long-term regulated streamflow characteristics below a recently constructed reservoir in Arkansas. The computer program is useful for modeling the hydrologic impact of Corps of Engineers–type reservoirs on streamflow.

D. P. Bauer developed and adapted computer programs for computing excess stream temperature below waste-heat discharge points. The package of programs includes two-dimensional heat models in the near and middle fields and a one-dimensional heat model in the far field. The near-field heat model may be used where the momentum of the heated surface jet is an important aspect of the heat-prediction problem; the two-dimensional middle-field heat model is a mixing model; and the far-field heat model is basically a heat-transfer model.

Bauer, M. A. Seijo, and Jennings developed three computer programs for prediction of DO concentrations in stream systems. The programs utilize existing techniques and are designed to handle field problems of varying complexity.

J. B. Peterson developed procedures for handling hydrologic data and related operational computer programs to increase their usefulness in solving field-level problems. Peterson and Jennings developed a computer program for analysis of a two-reservoir stream system in support of a field investigation on the Santee River in South Carolina.

The Hurst phenomenon is an important characteristic which is a measure of persistence in streamflow. The broken-line process was developed by J. M. Mejia (Colorado State Univ.), Ignacio Rodriguez-Iturbe (Massachusetts Inst. Technol.), and D. R. Dawdy (USGS) (1972) as an alternative stochastic streamflow-simulation model which is based on the Hurst phenomenon and an arbitrary correlogram. Streamflow studies were extended by Dawdy to demonstrate a technique for assessing the worth of regional relations when used for highway-culvert and bridge design. The marginal economic improvement in design, as a result of the change in accuracy of a regional regression relation, is used as the measure of the value of additional streamflow data necessary to obtain the better accuracy.

SEA-ICE STUDIES

Sea ice undergoes large spatial variations in structure and position in short time periods and is the most variable solid feature on the earth's surface. USGS investigations of sea-ice dynamics include remote sensing in polar regions, participating in international expeditions to the Arctic Ocean, and developing numerical models for ice-covered oceans.

Dynamics and morphology of Beaufort Sea ice

W. J. Campbell (USGS) and William Nordberg and Per Gloersen (both NASA) reported that ERTS–1 has provided extensive high-resolution, sequential, synoptic imagery of sea ice, particularly of leads and polynyas. ERTS–1 imagery of the Beaufort Sea in the summer of 1972 provides data on (1) ice-floe dynamics, (2) ice-edge dynamics, (3) lead and polynya dynamics, and (4) floe size and distribution. Some data show nonuniform distribution of ice-floe sizes in the Beaufort Sea; in the eastern part of the sea ice, floes have diameters as great as 40 km and are rounded, whereas in the western part of the sea ice, floes are only several kilometers in diameter and are angular. ERTS–1 imagery used in conjunction with NASA–AIDJEX passive microwave images strongly suggests that shearing forces fracture the large multiyear floes as they are transported westward through the Beaufort Sea.

NASA-AIDJEX sea-ice investigations

Each of seven flights of a NASA remote-sensing aircraft included (1) an outbound run 153° W. between 70° N. and 74° N. over the shoreline, shorefast ice, and boundary ice, (2) an inbound run 10 km east of and parallel to the outbound run, and (3) a high-altitude photomosaicing mission covering an area of approximately 10,000 km^2. AIDJEX ground-truth measurements of microwave emissivities, temperature, and morphology of selected ice types, mesoscale ice strain, exposed water temperature and salinity, and surface meteorological parameters were obtained simultaneously with overflights of the remote-sensing aircraft. According to W. J. Campbell (USGS) and Per Gloersen (NASA), it is possible to distinguish first-year sea ice from multiyear sea ice through clouds and at night by using microwave images. Photographic mosaics correlated with in situ strain measurements show that mesoscale strains can be measured by using high-resolution airborne photography. Photomosaics accurately show ice deformational features that undergo large variations in several days; the most pronounced are those of the boundary (transition-zone) ice.

Time-dependent model for sea-ice studies

W. J. Campbell and L. A. Rasmussen (USGS), and C. H. Ling (AIDJEX) developed a time-dependent model for sea ice. The model includes the simultaneous solution of a momentum and continuity equation. The ice rheology used in the momentum equation treats ice as a strain-hardened material. A means of numerically generating the surface air-stress vector field for the observed geostrophic wind field also was developed.

ANALYTICAL METHODS

ANALYTICAL CHEMISTRY

Rapid determination of sulfur in rocks

A rapid procedure to determine sulfur in rocks was developed and described by Leonard Shapiro (1973). Sulfur is determined turbidimetrically as barium sulphate after an aqua regia attack. The turbidity is formed in an ammoniacal solution from which R_2O_3 has been centrifuged. Reproducibility of turbidity is obtained by adding barium chloride as a solid rather than as a solution. Sulfur is determined in the range 0.01 to 4 percent within ± 0.02 absolute, or approximately 5 percent of the amount present, whichever is larger. A 100-mg sample is used for sulfur concentrations of up to 0.50 percent sulfur, a 20-mg sample for higher levels. A determination requires about 5 min.

Spectrophotometric determination of low levels of molybdenum in rocks

A sensitive and rapid procedure for determining submicrogram amounts of molybdenum in rocks was developed by E. G. Lillie and L. P. Greenland. After dissolution of a sample, molybdenum is separated from major amounts of iron and tungsten by extraction with tributyl phosphate. Molybdenum is stripped with water and extracted into chloroform as the α-benzoinoximate. The isolated molybdenum is then stripped with concentrated hydrochloric acid and determined spectrophotometrically as the thiocyanate at 465 nm. As little as 0.25 μg molybdenum can be determined. Although molybdenum-99 tracer solution is presently being used for final yield correction, results obtained on numerous analyses indicate that correction may be unnecessary.

Formaldehyde in meteorites

It had been reported previously that specimens of the Allende meteorite contain as much as 3 p/m of formaldehyde (I. A. Breger and others, 1972). This study has been extended to the Murchison meteorite. No formaldehyde was found in spite of the fact that this chondrite contains 10 times as much carbon as does the Allende. The Allende meteorite contains formaldehyde but no amino acids, whereas the Murchison meteorite contains amino acids but no formaldehyde. The occurrence or absence of formaldehyde in a meteorite may provide a clue as to its origin and history.

Microgravimetric determination of acid-insoluble impurities

A procedure for the determination of acid-insoluble impurities in small samples of acid-soluble minerals has been described by Robert Meyrowitz (1973). The basis of the procedure is the use of a Schwarz von Bergkampf glass filter stick which uses a filter paper medium to separate the insoluble material.

Mercury determination in submicrogram amounts by flameless atomic absorption

A procedure for the determination of submicrogram amounts of mercury has been described by J. W. Marinenko, Irving May, and J. I. Dinnin (1972). Powdered samples are heated with a calcium oxide-cupric oxide flux in a quartz combustion tube packed with lime and elemental copper. Evolved mercury vapor is swept through a packing of gilded silica where it is amalgamated. The amalgam is rapidly heated, and the released mercury vapor is swept through an absorption cell and determined by atomic absorption spectrometry. Two nanograms of mercury absorb 1 percent of the incident signal.

Spectrophotometric determination of titanium, total iron, niobium, phosphorus, vanadium, and zirconium in rutile

In a continuation of the development of methods of analysis of rutile, Robert Meyrowitz (1972) has reported the direct spectrophotometric determination of titanium, total iron, niobium, phosphorus, and vanadium. Titanium, total iron, niobium, phosphorus, vanadium, and zirconium are directly determined in rutile using hydrogen peroxide, 1,10-phenanthroline, 4-(2-(pyridylazo)-resorcinol[PAR], heteropoly blue, phosphotungstovanadate, and pyrocatechol procedures, respectively. One part of each sample is decomposed by potassium pyrosulfate fusion in a transparent quartz crucible, and a sulfuric acid solution of the melt is used for the determination of titanium, iron, niobium, phosphorus, and zirconium. A second part is decomposed by sodium carbonate fusion in a platinum crucible, and a sulfuric acid solution of the melt is used for the determination of vanadium. The elements commonly present in rutile do not interfere in the determination of titanium, iron, and phosphorus. Titanium and iron interference in the determination of niobium is eliminated by adding the titanium and iron contents of the sample to the standard niobium solutions used to prepare the niobium curve. Similarly, iron interference in the determination of vanadium is overcome by adding the iron content of the sample to the standard vanadium solutions used for standard vanadium curve. Titanium and niobium interference in the determination of zirconium are overcome by adding these to the standard zirconium solutions.

ACTIVATION ANALYSIS

Homogeneity of antimony, hafnium, tantalum, and gold in the USGS standard rocks

J. J. Rowe and L. J. Schwarz (1973) have applied instrumental neutron activation analysis to the determination of homogeneity of the new USGS standard rocks. Using 0.3-g samples, all were found to be homogeneous for antimony, hafnium, and tantalum when the calculated F ratio was tested against $F_{.95}$ except for MAG–1 which is homogeneous for antimony and hafnium at $F_{.975}$. As little as 0.1 p/m of antimony could be determined using the 1,690 keV peak of ^{124}Sb; hafnium was determined at the 1 p/m level using the 482 keV peak of ^{181}Hf; and tantalum was determined at the 0.5 p/m level using the 1,221 keV peak of ^{182}Ta. Gold was also determined in the new USGS standard rocks to study homogeneity (L. J. Schwarz and J. L. Barker, 1973). The neutron activation analysis method, using fire assay for radiochemistry, of Rowe and Simon (1968) was applied to two samples from each of three bottles of each standard. Except for SDC–1, all samples are homogeneous for gold for the 1 g samples used. The precision of individual analyses is about 10 percent at the 10 p/b level, 20 percent at 1 p/b, and decreases to 30 percent at concentrations of 0.4 p/b.

Determination of gold in phosphates

J. J. Rowe (1973) has described a simple method using activation analysis to determine gold in phosphatic materials. Samples in a cadmium container are irradiated with epithermal neutrons to minimize the formation of ^{32}P, while permitting the formation of adequate amounts of ^{198}Au. Fire assay–radiochemical methods are used to separate the ^{198}Au. Concentrations as low as 0.1 p/b can be determined readily while maintaining low radiation levels.

X-RAY FLUORESCENCE

Technique for bulk analysis of thin sections

A technique for the bulk analysis of thin sections of rocks was developed by J. R. Lindsay and G. W. Leo whereby the section is removed from the slide by soaking it in methylene chloride; between 5 and 30 mg is recovered. The sample is ground and mixed with two times its weight of lithium tetraborate and fused in graphite at 1,000°C. The cooled bead is mounted in epoxy and prepared for electron microprobe analysis. Standards are prepared similarly.

Determination of sodium in silicate rocks

B. P. Fabbi (1973) has developed two alternative preparation techniques for the determination of sodium in silicate rocks using X-ray fluorescence. The first technique, direct dilution of sample with an equal proportion of cellulose binder, yields higher X-ray intensities and higher analytical precision (±2 percent relative). The second technique, dilution-fusion of the sample with lithium metaborate flux, requires replicate preparations, is lengthier, and has lower precision (±3 percent), but has the advantage of minimizing matrix effects in the determination of silicon, aluminum, and iron. The lower limit of detection is 0.07 percent and 0.34 percent Na_2O for the direct dilution and dilution-fusion techniques, respectively. A rubidium acid phthalate analyzing crystal is used to reflect the sodium spectra.

Determination of yttrium in silicate rocks

A quantitative X-ray fluorescence technique has been used by L. F. Espos and B. P. Fabbi to determine yttrium in silicate rocks. The determination of yttrium is hampered both by iron absorption effects and spectral interference from Rb$K\beta1$ on the analytical line of Y$K\alpha4$. By correcting the net intensity of the yttrium signal for iron absorption and then subtracting the amount of signal which is due to rubidium in the sample, yttrium can be satisfactorily determined in silicate rocks. Precision of the determination averaged ±2 p/m yttrium in the range 6 to 450 p/m. The lower limit of detection for the method was 6 p/m at the 2σ confidence level.

ISOTOPE DILUTION

Homogeneity of bismuth, niobium, and molybdenum in USGS standard rocks

L. P. Greenland, E. Y. Campbell, E. G. Lillie, and F. J. Flanagan reported the results of an analysis of variance experiment to determine the homogeneity of the USGS standard rocks (Greenland and others, 1973; Campbell and Greenland, 1973; Lillie and Greenland, 1973). Analyses were performed using isotope dilution procedures. No evidence was found of differences of bismuth, niobium, or molybdenum contents among samples of a given standard rock.

Determination of tungsten in rocks

E. G. Lillie and L. P. Greenland (1973) have developed a procedure to determine microgram amounts of tungsten in rocks. Samples are decomposed with acids in the presence of ^{181}W tracer. Molybdenum and iron are removed by tributyl phosphate extraction from hydrochloric acid solution, and then tungsten is separated from most other elements by extraction of the α-benzoinoximate. Tungsten is determined spectrophotometrically after extraction as the thiocyanate complex into amyl alcohol. A correction for chemical losses is made by counting ^{181}W in the final solution.

EMISSION SPECTROSCOPY

Spectrographic analysis using a tape-recording system

The high-speed magnetic tape-recording system developed by A. W. Helz, F. G. Walthall, and Sol Berman (1969) is now being successfully applied on a routine basis for the semiquantitative spectrographic analysis of silicate rocks. Many refinements and options have been added to the original computer program for reading the spectral plates (Walthall, 1973) which improve its flexibility and line finding.

The original air atmosphere has been changed to argon-oxygen using the d-c arc (A. F. Dorrzapf, 1973). Instrumental improvements are discussed by Helz (1973). A new direct-drive motor allows a 20-in. spectrum to be scanned in 70 s while making nearly 100,000 transmittance measurements. From these the program selects and stores 500 analytical lines, an ample number for determining 68 elements.

ANALYSIS OF WATER

Arsenic

An atomic-absorption spectrophotometric method for determining arsenic has been investigated by O. J. Feist, Jr., and M. J. Fishman. The method involves evolution of arsine gas after reduction of trivalent arsenic in a zinc-acid solution. The arsine is swept by a stream of argon into a hydrogen flame, and absorption is measured at 1,937 A (193.7 nm). Chemical interferences in the flame are minimized, inasmuch as the arsine is separated from the sample matrix. As little as 1 μg/1 of arsenic can be measured. Incorporation of a preliminary digestion step in the procedure ensures conversion of arsenic in organic arsenic-containing compounds to an analytically determinable form.

Automated analyses

An automated determination of iodide, utilizing the Technicon AutoAnalyzer, was developed by D. E. Erdmann. The method is based on the well-known ceric-arsenious oxidation-reduction reaction, which is catalyzed by iodide. The extent of reduction of ceric ion, and, consequently, the loss of color of the solution, is directly proportional to the amount of iodide present. Iodide concentrations are thus determined colorimetrically. Twenty samples per hour can be determined in the concentration range of 0.005 to 0.06 mg/l.

Humic acid salts

EPR (electron paramagnetic resonance) studies of free radicals in aqueous humic acid–salt solutions are hampered because the high dielectric constant of water causes large intensity losses in the EPR signals obtained. R. L. Wershaw and D. J. Pinckney found that some fractions of sodium humate are soluble in ethylene glycol and glycerol. Each of these solvents has a dielectric constant about half that of water, and mixtures of these solvents with each other and with water may be used to good advantage. In addition to being used to adjust the dielectric constant of the solvent, they may also be used to adjust its viscosity. Increased viscosity slows certain reactions and permits a study of intermediate states.

Radioactive cesium

A rapid method for determining trace quantities of radioactive cesium isotopes was developed by V. J. Janzer (1973). Radioactive cesium is concentrated by ion exchange on finely divided ammonium hexacyanocobalt ferrate, and then determined by beta counting. It is unnecessary to add a carrier. Five samples can be prepared for counting in approximately 3 h. The method can be used to determine beta-emitting cesium isotopes at the 10-pCi/l level using a 100-ml sample, and the method is applicable to both fresh and saline waters.

Sulfate extraction method

A technique for extracting sulfate quantitatively from low sulfate waters using an ion-exchange column was developed and tested by M. D. Bodden, D. W. Fisher, and C. T. Rightmire. This method is particularly applicable for obtaining samples for sulfur isotope analyses of sulfate in low sulfate waters.

Neutron-activation analysis

L. L. Thatcher and J. O. Johnson (1973) extended a short (2-min) irradiation technique for determining Na, Cl, Br, Ca, Mg, Al, and V to include an additional element, strontium, which is determined by means of Sr-87m with a half-life of 2.8 h. They further developed the carrier-sulfide-hydroxide precipitation technique for determining Se, Au, Sc, Cu, Mo, Cd, Hg, Zn, As, Sb, Cr, Fe, Co, and several rare-earth elements to include two additional elements, tungsten and uranium. By these techniques, strontium and uranium have been detected in many natural waters, but tungsten has only rarely been detected.

Interaction between the container and the water sample under irradiation, resulting in possible contamination of the sample, has frequently been ignored by analysts. This phenomenon was investigated for arsenic and certain other toxic elements. Arsenic is sorbed from solutions to the surface of quartz containers, but the effect is greatly reduced by other salts commonly found in water. There is no measurable loss of arsenic from samples in polyethylene containers; mercury is strongly sorbed by polycarbonate containers.

Although progress is being made by instrument manufacturers, presently available commercial systems are not fully satisfactory for fast computation of neutron-activation-analysis data. Consequently, an analog computer and computation disks are being developed to handle immediate requirements. Disks for As, Cu, Hg, Sb, and Zn have been constructed and successfully used. This computation technique will be extended to cover approximately 20 elements.

Research reactor

The USGS TRIGA (Training, Research, Investigations, Gulf Atomic) reactor is used primarily as a source of neutrons for research investigations. G. P. Kraker reported that the major efforts have been: (1) Neutron activation analyses of earth materials, mineral samples, and surface- and groundwater samples, (2) uranium and thorium determinations using delayed neutrons, (3) fission-track studies, (4) age-dating studies (argon and potassium) by fast-neutron activation, and (5) tracer production to study various chemical processes. The reactor has also performed irradiations for other government agencies and for educational institutions. Over the year, the reactor generated 858 MWh of thermal energy in the irradiation of about 5,000 samples.

GEOLOGY AND HYDROLOGY APPLIED TO ENGINEERING AND THE PUBLIC WELFARE

EARTHQUAKE STUDIES

GEOPHYSICAL STUDIES

Seismicity

Since 1967 the USGS has built up a dense telemetered network of seismograph stations in central California to study local earthquakes in detail. At present this network includes 97 high-gain vertical seismograph stations which permit the accurate location of thousands of earthquakes each year. Analysis by R. L. Wesson reveals a marked increase in earthquake activity in 1972 along the San Andreas fault south of Hollister, Calif., including the moderate earthquakes of the February 1972 Bear Valley sequence (magnitudes 5.0 and 4.6) and the magnitude 4.7 Stone Canyon earthquake of September 4, 1972. Other significant California earthquakes include the magnitude 4.7 shock near San Juan Bautista on October 3, 1972, two small events beneath San Francisco Bay on a previously unrecognized active fault, and two sequences of small earthquakes along the Silver Creek fault near San Jose. As in previous years, most of the local events were concentrated along the San Andreas fault south of Corralitos, and along the Calaveras, Sargent, and Hayward faults.

Over 1,000 earthquakes of the 1972 Bear Valley earthquake sequence were analyzed by W. L. Ellsworth. Their hypocenters—which mark the point of initial fault movement—delineate three distinct zones of fault movement within the San Andreas rift near Pinnacles National Monument. Faulting occurred along the main San Andreas fault during the largest shock, a magnitude 5.0 event, and in two zones to the northeast of the main trace of the fault. The earthquake hypocenters in each zone lie in narrow vertical bands less than 0.5 km wide and may represent a shear zone concentrated on a single vertical plane. Small earthquakes which occurred in the 18 mo prior to the sequence were found to be distributed along the San Andreas fault and immediately northeast of it. Dense clusters of small earthquakes were observed to occur adjacent to the hypocenters of the two largest events of the February sequence.

S. W. Stewart, P. R. Stevenson, and T. C. Jackson are using small, specialized computer systems to develop techniques for rapid and efficient analysis of large amounts of earthquake data. In one experiment, a 30-station subset of the larger California seismic telemetry network was monitored continuously by a computer for 6 mo. Results from the computer detection system compare favorably with those obtained from the methods routinely used to process the data from the full network. Of approximately 180 local earthquakes which were analyzed in detail, 70 percent of the epicenters calculated from the computer-picked onset times are within 2 km of those calculated by routine analysis of data from the full network. Events as small as magnitude 0.7 were detected by the computer system. With the exception of a magnitude 1.7 event that occurred in the coda of a smaller event, the computer system detected all events of magnitude 1.3 or greater that were located by the standard processing methods. This experiment has proved the reliability and efficiency of specialized computer systems in the automated analysis of earthquakes occurring within localized regions.

J. R. Van Schaack has designed a low-powered seismograph telemetry station for the USGS seismic network. The equipment, complete with seismometer and a year's supply of batteries, will fit down a 3-in. drill hole in a package about 2 ft long, whereas existing equipment requires a vault of about 6 ft^3. The station is easily adaptable to downhole and ocean bottom use; one is presently operating in a field container on the Pacific Ocean floor about a mile off Point Mugu, Calif.

In reviewing strong-motion data recorded within 20 km of the causative fault during recent moderate-sized earthquakes (magnitude 5 or 6), R. A. Page and D. M. Boore conclude that the intensity of shaking within 10 to 20 km of the fault is greater than that previously assumed in the absence of instrumental data. The pattern of damage associated with moderate-sized earthquakes occurring in urbanized areas (for example Santa Rosa, 1959, magnitude

5.7 and San Fernando, 1971, magnitude 6.6) is consistent with this finding of a localized zone of intense shaking close to the causative fault. There are now sufficient data available to predict, with statistical estimates of confidence, the peak ground acceleration as a function of distance from the fault for magnitudes 5, 6, and 7 at distances greater than 10, 20, and 40 km respectively. For larger magnitudes and smaller distances, one must extrapolate from the existing data using seismic source theory or deterministic computer modeling of the faulting mechanism.

W. B. Joyner and R. E. Warrick have obtained good agreement between theoretical predictions of surface ground motion and the motion actually recorded at a downhole seismometer array on the west shore of San Francisco Bay. The array, which consists of three-axes instruments placed at four levels from the surface down to the top of the Franciscan bedrock, was installed in 1970 to study the propagation of seismic waves through soft, unconsolidated materials. A large number of earthquakes have been recorded including both small local events and larger distant ones. These records are being used to test theoretical methods for predicting surface ground motion. Theoretical surface motion has been computed by applying the motion observed at the bedrock interface (186 m depth) to a plane-layered viscoelastic model of the overburden. Dynamic properties for the model were obtained from an analysis of earthquake recordings at the array and were confirmed by measurements on artificially generated shear waves. The agreement obtained between theoretical and predicted motion is encouraging, but further work is necessary before the methods can be confidently applied to the prediction of strong ground motion as would occur in a major earthquake.

Preliminary results of R. A. Page and J. C. Lahr for the location of earthquakes recorded by a network of 23 seismograph stations in southern coastal Alaska indicate that the thickness of the seismic layer in the Benioff zone beneath Cook Inlet is locally less than 10 km. The zone, which is associated with the northwestward underthrusting of the Pacific lithosphere beneath the Alaska Peninsula and the Aleutian Islands, is less than 60 km deep under the western Kenai Peninsula, from 60 to 100 km deep beneath Cook Inlet, and >100 km deep west of the inlet. The active volcanoes Augustine, Iliamna, Redoubt, and Spurr are located above earthquakes occurring in the depth range from 100 to 120 km and define a trend that is parallel (to a resolution of 10°) with the strike of the Benioff zone. Reliable locations of shallow earthquakes beneath the eastern Kenai Peninsula and in Prince William Sound are relatively difficult to obtain with the existing network of seismographs.

Earthquake counters and tiltmeters that send their data twice daily via the ERTS–1 satellite and standard seismographs have been installed on the following volcanoes: Iliamna and Augustine in Alaska; Kilauea in Hawaii; Baker, Rainier, and St. Helens in Washington; and Lassen Peak in California by P. L. Ward, E. T. Endo, D. H. Harlow, D. J. Marquez, and R. V. Allen. Similar equipment has also been prepared for installation in Central America in 1973. These instruments are part of an effort to develop a prototype volcano surveillance system to monitor large numbers of apparently dormant volcanoes in order to give early warning of any reawakening.

D. P. Hill completed the installation of a 16-element array of short-period vertical seismometers in the Imperial Valley, Calif. The array is designed to monitor seismic activity associated with the geothermal fields in the Imperial Valley and to define seismicity associated with active faults of the southern San Andreas system.

J. C. Roller has found that no natural earthquakes have occurred in 1972 within 50 km of the site of the New Melones Reservoir, Calif., or within 50 km of the site of a proposed injection well near Tuscaloosa, Ala. He monitored the records from special seismic networks centered on the sites.

Theoretical and laboratory studies of earthquake mechanics

W. R. Thatcher has used a recently proposed seismic source model to derive a theoretical relation between earthquake magnitude and source parameters. Magnitude can be obtained accurately using this result. The relation also provides for a better understanding of the advantages and shortcomings inherent in commonly used magnitude–fault length, magnitude-energy, and magnitude-moment relations. With the physical constraint that decreases in average shear stress during faulting vary from a fraction of a bar to several hundred bars, the theoretical relation may be used to construct a range of magnitude-source parameter relations which bracket all available observations.

J. H. Dieterich has performed computations for the quasi-static and transient deformations of earthquakes on a pre-existing fault with plane strain and three-dimensional finite element models. Results of the computations offer a basis for prediction of the dependence of displacements and near-field transient motions on stress drop, rupture dimensions, and seismic energy. Scaling laws evaluated with the computational results are in good agreement with the observed earthquake data. The earthquake data show that ground motions and source parameters are functions of earthquake magnitude, but there is considerable scatter. The scaling indicates that more precise predictions for potential ground motions and source parameters may be obtained using stress drop and source dimensions.

J. B. Byerlee has found that the *b* value (the slope of the frequency of microshock occurrence versus magnitude curve) for dry samples of Weber Sandstone subjected to a confining pressure and a differential stress is about 0.8, but during fluid injection *b* increases to about 1.5. This indicates that during fluid injection the proportion of small shocks to large shocks is much greater than it is when the rock is dry. If this is also true in the earth, fluid injection may be used to relieve stress with many small earthquakes; the risk of generating a large earthquake may be smaller than originally feared.

Peridotite rocks in the Ivrea Zone in the Italian Alps are believed to be exposed upper mantle rocks. The results of Louis Peselnick's measurement of compressional (*P*) wave velocity to 6 kbar on a peridotite rock from the Ivrea Zone, along with fabric and structural studies in this region support the interpretation that upper mantle anisotropy near ocean ridges is a result of solid-state deformation. Correlation of the measured velocities and the olivine fabric (which is the principal mineral governing velocity anisotropy) with the structural setting of the Lanzo Massif in this region shows that the maximum velocity in the massif is in the flow direction while the minimum velocity can be represented by the pole of the plane of flow. The measured velocity anisotropy for the Ivrea rock is about 0.5 km/s, which is within the range observed seismically near ocean ridges (0.2–0.7 km/s). Finally, the mantlelike velocities and high densities obtained for these peridotites support the models, based on seismic data, that the Ivrea body has been derived from the upper mantle.

The elastic properties of rock glass have been measured by Robert Meister, Rudolph Raspet, R. W. Werre, and E. C. Robertson. Wave velocities and elastic moduli of quartz glass decrease (anomalously compared to crystalline solids) about 1 percent/kbar (measured to 8 kbar) and increase about 0.03 percent/100°C (measured to 150°C). Basalt glass moduli and velocities increase 0.06 percent/kbar (to 8 kbar) and probably decrease with heating. Obsidian and albite and andesite glasses range in between according to SiO_2 content; for example, the change of bulk modulus with pressure ranges from —5.8 kbar/kbar for quartz glass, through —1.5, +0.02, +0.8, to +2.1 for basalt glass. An explanation for this behavior is that filling between the silica tetrahedron by other cations develops small, ordered domains which stiffen the glass structure. The reduction in wave velocities in the low velocity zone in the earth's upper mantle may be ascribed to the anomalous negative pressure effect on velocities in a glass with quartz or feldspar structure.

Crustal stress and strain studies

M. D. Wood has continued analysis of tiltmeter data. He reports anomalous tilts for periods up to 1,000 h preceding the occurrence of several local earthquakes. The Danville (1970), Monterey (1971), and Bear Valley (1972) tilt anomalies are associated with the largest earthquakes within the USGS central California seismic network over the past 3 yr.

R. O. Burford reports that fault creep rates measured at several surface sites along a 40-km section of the San Andreas fault from San Juan Bautista to near the Pinnacles National Monument, Calif., increased dramatically after the February 1972 Bear Valley earthquake (magnitude 5.0) at the southeast end of the section. Records obtained from a measurement site near the epicenter of the quake (Melendy Ranch, Bear Valley) show that a 1969–71 average creep rate of about 17 mm/yr was composed of discrete events of 2 to 3 mm each lasting a few hours separated by periods of 110 d average duration during which background steady-state creep generally accumulated at rates close to 8 mm/yr. The average recurrence interval for events decreased to about 60 d after the February quake, resulting in an increase in the 1972 creep rate to 26 mm/yr without a noticeable change in the average size or character of the events. Fault creep records from other sites to the northwest also show an increase in creep rates of up to twice the pre-1972 values.

Fault creep records from the measurement site near San Juan Bautista indicate a long-term average slip rate of about 6 mm/yr for the main slip plane, and about 12 mm/yr for a 100-m width of the slip zone covered by an alinement array. The slip rate for the main trace was below average during most of 1972 (about 2 mm/yr) until the time of the October 3, 1972, San Juan Bautista earthquake (magnitude 4.7). During the quake, surface slip of 0.4 mm was recorded, and during the following 49 h, a pair of unusually large creep events occurred which totaled 5.7 mm. By the end of December, the postearthquake slip value for the main trace had increased to about 13 mm, for the most part by a process of increased frequency of 1 to 2 mm events. This period of accelerated activity brought the 1972 average creep rate up to about 14 mm/yr. The shape of a smoothed postearthquake slip accumulation curve indicated logarithmic decay in the creep rate following the sudden onset of activity, suggesting an afterslip phenomenon similar to that produced by the 1966 Parkfield and 1968 Borrego Mountain earthquakes.

R. V. Sharp recently found five power transmission lines to be offset by the Calaveras fault in central Alameda County, Calif. For the first time they permit estimates of the rate of creep over relatively long periods on this major strand of the San Andreas fault system in the San Francisco Bay region. Right-lateral offset of about 13 cm has been measured on four transmission lines constructed in the years 1924, 1930, and 1939, indicating virtually no creep during this interval of time. At some time between 1939 and 1944, perhaps beginning with the nearby magnitude 4.2 earthquake of March 29, 1942, the fault began to creep at a rate that has averaged slightly more than 0.4 cm/yr. This rate of creep is comparable to the average creep rate along the nearby Hayward fault during the past 50 yr.

Earthquake control

C. B. Raleigh, J. H. Healy, J. P. Bohn, L. G. Peake, and J. D. Bredehoeft continued the earthquake control experiment in the Rangely, Colo., oil field. A complete cycle of lowering the bottom-hole fluid pressure in the hypocentral region of the oil field from 4,000 lb/in^2 to 3,000 lb/in^2 and increasing the pressure back to 4,100 lb/in^2 has been accomplished. The earthquake frequency is well correlated with the bottom-hole pressure. With bottom-hole pressure at the experimental wells of 4,000 lb/in^2 or more, about 30 earthquakes occur per month; below that pressure, the rate is one earthquake per month or less.

GEOLOGIC STUDIES

Field evidence that the Green Valley fault is active

Field evidence indicating geologically young activity on the Green Valley fault west of Fairfield, Calif., was obtained by M. G. Bonilla and C. M. Wentworth, Jr., (USGS) and R. H. Rice (Dames and Moore, Consulting Engineers). This evidence confirms the photogeologic interpretations made earlier by R. D. Brown, Jr., (1970). A scarp, seeps, and differences in type of grass occur along the fault where it crosses a small alluviated valley. Soils of the Zamora series are developed on the deposits in this valley (E. J. Carpenter and S. W. Cosby, 1930). Samples obtained about 3 m below the surface of deposits on which Zamora soils are developed elsewhere in the San Francisco Bay area yield radiocarbon ages of 20,000 yr, and the surface soils must be younger than that (E. J. Helley, oral commun., 1973). An exploratory trench across the fault shows that the base of a black clay surface layer is clearly cut by the fault at a depth of 1.5 m. An angular flake of obsidian 5 cm long found in this layer at a depth of 1.3 m directly above the faulted contact is thought for several reasons to have been transported there by early man: the flake shows no evidence of abrasion by stream transport, no other large fragments were seen in the clay, and no natural source of obsidian is known in the drainage area uphill from the site. The flake is estimated by K. R. Lajoie to be about 12,000 yr old, based on hydration rind thickness, and the deposit therefore is probably less than 12,000 yr old.

Another exploratory trench across the fault exposed a series of curved and horizontally slickensided surfaces that had been developed within the upper 2 m or so of clayey alluvial soils, suggesting young strike-slip tectonic movements. A right-lateral bend of several centimeters in a fence crossing the fault at right angles probably has been caused by fault displacement, possibly by creep. The scarp, seeps, and vegetation anomaly in soils younger than 20,000 yr, the fault displacement of the base of a surface layer that is probably less than 12,000 yr old, the slickensided surfaces, and the apparent fault displacement of the fence all indicate that the Green Valley fault should be considered active for purposes of land-use planning. This conclusion is supported by the recent occurrence of four earthquakes in the magnitude range 2.5 to 3.5 whose epicenters were close to the Green Valley fault (U.S. Geological Survey, 1972g).

Recent elevation changes across Red Mountain fault near Ventura, California

J. M. Buchanan, J. I. Ziony, and R. O. Castle (1973) have found that comparative profiles derived from repeated first-order levelings along a north-south line across the east-trending Transverse Ranges province show a marked inflection about 5 mi (8 km) north of Ventura, Calif., coincident with the Red Mountain fault. This structure, a north-dipping reverse fault, locally has displaced a Holocene(?) soil zone and exhibits scarps and sag depressions suggestive of very young ground displacements. Between 1934 and 1968, the region north of the Red Mountain fault rose as a block 0.83 ft (0.26 m) relative to survey stations on the south. Differential elevation changes could not be detected across either the Arroyo Parida or Santa Ynez faults, structures farther north, that exhibit stratigraphic and topographic evidence of late Pleistocene movements but for which Holocene displacements are unknown.

Current displacement in the Garlock fault zone

M. M. Clark has found fresh displacement along nearly 10 km of faults of Pleistocene and Holocene age that form the south border of Fremont Valley, a structural depression created by movement of the Garlock fault. The new displacement is entirely vertical, valley side down, and ranges from 10 to 50 mm. No seismic activity appears to be connected with this movement, which may have been underway for several years. Although the new fractures clearly follow older fault scarps, a tectonic cause for the new movement is not definitely established. Pumping for irrigation is lowering ground-water levels by as much as 3 m/yr at locations 5 to 10 km west of the new fractures, but no obvious geometrical relation connects the pattern of fracturing and the center of the pumping depression.

San Andreas fault in its type area, San Mateo County, California

An opportunity to inspect a 2-mi segment of the 1906 trace of the San Andreas fault, normally under the waters of San Andreas Reservoir, was afforded in September 1972 when the lake was drawn down for construction purposes. Three sag ponds on the east slope of San Andreas Valley, shown on a U.S. Coast Survey map dated 1867, were visible for the first time in more than 25 yr. Positions of these ponds coincide with the 1906 trace as projected between known points where offsets of as much as 7 ft were measured.

The area exposed during low water was mapped by E. H. Pampeyan, who found it underlain by a tectonic melange consisting of blocks of hard rock in a matrix of strongly sheared siltstone and shale. There appeared to be two different types of bedrock in this area: the first, with shear planes nearly horizontal or dipping gently westward, extends a mile east into parts of the cities of Millbrae and Burlingame and consists wholly of Franciscan Formation rocks; the second, with shear planes vertical, lies on the west side of the first type and contains blocks of Pliocene rock in addition to the Franciscan rocks. The second type presumably defines the San Andreas fault zone here. Its total width is probably on the order of 500 ft, less than half of which was visible at low water. Colluvium and lake sediment obscure most of the bedrock although two areas near the San Andreas Dam were well exposed. Each was on line with and less than 200 ft away from a structure damaged in 1906, but even though the rocks were clean and reference points were nearby, there was no physical evidence to either confirm the existence of recent movement or pinpoint the 1906 break in the fault zone. A pipeline trench near the north end of the lake yielded similar information. In this general area, therefore, it seems that the best natural evidence for locating the trace of the most recent movement consists of relatively broad geomorphic features, and it is difficult—if not impossible—to locate the actual break at a given site closer than about 100 ft unless some prefault artificial reference points (fencelines, structures, and so forth) remain on the site.

Clark fault in northwestern Imperial Valley, California

The Clark fault, a major strand within the active San Jacinto fault zone, has been traced by R. V. Sharp 5 km farther into the Salton Trough than it was previously known to extend. East of the Borrego Badlands, the fault is marked by a zone of scarps in terrace gravels and shear zones in Pliocene-Pleistocene strata. Although traces of the individual breaks do not delineate a continuous and simple fault strand, complex zones of intense folding associated with well-defined scarps and shears suggest the likelihood of a throughgoing and possibly active deformational zone into areas where there is no obvious evidence of recent faulting.

Recent movement on the Concord fault, California

Evidence of very recent movement on the Concord fault has been discovered by R. V. Sharp (1973) near the downtown area of the city of Concord. The fault, previously identified chiefly on the basis of its groundwater effects, probably extends from the area north of Suisun Bay southeastward to the western slope of Mount Diablo. The alinement of this fault is parallel to the other major active fault strands within the San Andreas system in the San Francisco Bay area.

The evidence for recent movement consists of right-laterally offset manmade structures and physiographic features of active faulting, including scarps and sags. Offsets of several centimeters on curbs and sidewalks in the downtown Concord area occur along the base of a prominent scarp. Near Avon, 8 km farther northwest, right-lateral offsets have been found on railroad sidings and bridges near Pacheco Creek. Although no evidence of continuing movement has been found either in the segment between these two localities or southeast of Concord, creep probably has occurred but has not been recorded because of the absence of suitable linear manmade structures. However, a strong geomorphic argument can be made for all of the observed offsets belonging to a single zone of movement—namely that the linear southwestern margins of the Diablo Mountains and the ridge of hills immediately south of Avon are fault bounded.

Epicenters of earthquakes (in 1971) clearly delineate a major part of the Concord fault between Concord and Walnut Creek. Although the level of seismic activity may be slightly less than that occurring along other actively creeping faults in the San Francisco Bay area, the coincidence of epicenters with the trace of the Concord fault is as clear as it is along the other faults. Earthquakes at least up to intermediate size apparently can be generated by movement on the Concord fault. One of the large earthquakes in the last three decades in the bay area, a magnitude 5.4 event, occurred in 1955 near the point where the best evidence of active movement is visible in Concord.

Characteristics of the surface rupture associated with the Borrego Mountain earthquake of 1968

In an investigation of the effects of the magnitude 6.4 Borrego Mountain, Calif. earthquake of 1968, M. M. Clark (1972b) found that older scarps and vegetation boundaries extended along roughly one-third of the 31 km length of the 1968 surface rupture and were in all places coincident with new fractures. Where vertical displacements and vegetation boundaries were absent, however, there was little other surface evidence that would have betrayed the position of the fault. Few offset drainage channels survived from previous displacements because erosion in the poorly consolidated sediments proceeds more rapidly than tectonic displacement. Along about 50 percent of the length of the rupture, the position of the main fractures could have been predicted before the earthquake to within 100 m or closer.

The width of the band of fracturing along the three main breaks exceeded 50 m along about 35 percent of the length of the 1968 rupture and exceeded 100 m along 25 percent of the length of the rupture, but most of the ground displacement along the main breaks occurred within a band less than 20 m wide. Associated fractures with potentially damaging displacements extend more than 100 m from the main breaks in some locations, and as much as 500 m from the main breaks in a few locations.

Fault creep and rain-induced collapse maintained or enlarged some fractures as late as 1972, more than 4 yr after the earthquake. No significant post-earthquake creep took place on the north break, but simple measurements made at irregular intervals since April 1968 reveal that postearthquake movement along the central and south breaks has increased original displacements by as much as 100 percent. Some of this creep was apparently continuous, beginning immediately after the earthquake, but several parts of the central and south breaks did not start moving until at least several months after the earthquake.

Displaced stones suggest accelerations

M. M. Clark (1972a) found that characteristics of stones displaced during the Borrego Mountain earthquake of 1968 allow rough estimates of the accelerations responsible for displacement. Areas of displaced surface stones were generally restricted to certain high ridges in Ocotillo Badlands, indicating that topography magnified the intensity of shaking. Nearly every unrestrained stone on the surface of one such ridge was either tipped, slid, or flung as much as 0.5 m in one direction, whereas only cobbles and boulders taller than about 50 mm moved on an adjacent ridge, sliding a maximum of 0.1 m in the opposite direction. These directions of displacement indicate that the horizontal shaking responsible was oriented 70° to 80° from the general trend of surface breakage although the influence exerted on these directions by the position, shape, or material of the ridges is unknown.

Theoretical considerations indicate that, in the absence of adhesion, simple sliding of a rectangular block depends only on the values of coefficient of friction, slope, and acceleration and is independent of size and shape. Tipping depends only on slope, shape, and acceleration. Size of the block affects sliding or tipping only if adhesion or other surface forces are present or if rocking has begun.

Estimates of coefficients of friction, combined with characteristics of size, shape, and movement, suggest that horizontal accelerations on the first ridge were greater than 0.5 g and possibly as high as 1 g (acceleration of gravity), whereas vertical accelerations were definitely less than 1 *g*. Stones of the second ridge experienced smaller accelerations, with the horizontal component apparently in the range of 0.5 to 0.9 *g*. Adhesion between stones and the surface of the second ridge prevented stones shorter than 50 mm from moving.

ENGINEERING GEOLOGY

Geologic evaluation of the Van Norman reservoirs area, California

The geologic environment of the Van Norman reservoirs area, northern San Fernando Valley, Calif., was assessed by R. F. Yerkes and others on behalf of the U.S. Office of Emergency Preparedness in connection with a plan to replace two dams that were severely damaged by the 1971 San Fernando earthquake. The dams lie athwart a southeast-trending drainage system where it crosses a north-dipping fault zone that forms the southern tectonic boundary of the San Gabriel and Santa Susana Mountains. Fault segments that are prehistoric but considered active extend westerly through the existing and proposed damsites, and sections of one of the faults ruptured immediately east of the reservoirs during the 1971 earthquake. Differential vertical and horizontal displacements occurred at the lower dam, and horizontal accelerations greater than 0.6 *g* were recorded. Permanent deformations were most pronounced in the valley area east of the reservoirs but extended into the reservoir area. Tectonic rupturing apparently did not extend across the reservoirs, although small relative displacements of the abutment areas of each damsite are attributable to permanent surface deformation. Each type of deformation—fault displacement, arching, and horizontal translation—decreased progressively westward across the valley toward the reservoir area. Significantly, the 1971 deformations reproduced or renewed the growth of long-established features of considerable areal extent, thus demonstrating that the local structure is an integral part of the active regional tectonic system.

The 1971 San Fernando earthquake, which had a Richter magnitude of approximately 6.5, probably was not the largest to have occurred on this part of the mountain-front fault system during the last 200 yr. Evidence for this is ancient wood found in collapse rubble beneath a buried fault-scarp that is alined with 1971 ruptures and that has greater vertical separation than the 1971 ruptures (U.S. Geological Survey, 1972e, p. A158). On the basis of this evidence and on the tectonic setting and seismic history of the region, the investigators concluded that an earthquake of magnitude 7.7 should be expected in the Van Norman area. The expectable permanent and dynamic effects of such an earthquake have been derived from the measured effects of the 1971 earthquake and from correlations of the several parameters as based on the worldwide record.

Slope-stability investigations

Investigations by W. E. Davies, J. F. Bailey, and D. B. Kelly (1972) of the February 26, 1972, catastrophic failure of a coal-waste dam on Middle Fork, Buffalo Creek, W. Va., showed that weak foundations, insufficient compaction of materials in waste banks, and lack of adequate water-control structures can give rise to rapid, destructive failures of waste banks. Previous studies of coal-waste banks in the Eastern United States in 1966 and 1967, after the disaster at Aberfan, Wales, had indicated that many waste banks in the Appalachian region were unstable. After the Buffalo Creek calamity, interagency governmental teams evaluated the stability and safety of all waste banks in the Appalachian region. The Department of Interior Task Force to Study Coal Waste Hazards subsequently formulated interim regulations to guide the development of greater safety and stability in waste banks, based on the 1966, 1967, and 1972 studies.

A reconnaissance survey of the shorelines of a part of Lake Powell in Arizona and Utah, by A. L. Brokaw, has revealed numerous geologic features that are potentially dangerous to recreational users of the area. Shore erosion associated with the overall rise and short-term fluctuation of the lake level has undercut the lower slopes of large piles of windblown sand that have accumulated on the leeward sides of near-vertical cliffs. Subsequently, these unstabilized sandpiles commonly fail suddenly and slide with great speed and force into the water. In many areas, bentonitic shales that underlie near-vertical cliffs of massive, flat-lying sandstone have been eroded and lubricated by the rising waters. As a consequence of the weakening or removal of the supporting shales, large slabs of sandstone commonly separate along joint planes and slide or topple into the lake. Because the sandpiles and the shale outcrops have more gentle slopes than the cliff-forming sandstones, they are favored areas for campsites and the beaching of boats.

Engineering-geologic reports used by governmental agencies

A report of geologic investigations in the Juneau, Alaska, area by R. D. Miller (1972) has been used extensively in the mass-wasting and seismic phases of a geophysical hazards project of the City and Borough of Juneau. According to the senior planner for the city and borough, consulting firms engaged by contract to study the geophysical hazards of the area found that the basic data provided in Miller's report are of sufficient detail and usefulness that funds previously scheduled for accumulating such data could be used instead to enlarge their seismic investigation program.

Geologic evaluations of the sites of more than 20 existing Veterans Administration Hospitals were made for the VA by H. H. Waldron in 1972. The objective of this work is the delineation of potential geologic and earthquake hazards that might affect the future safety of hospital buildings and associated facilities. The site evaluation program was initiated by the Veterans Administration because of the collapse of part of the Sylmar VA Hospital during the San Fernando, Calif., earthquake of February 9, 1971.

Research in soil mechanics

Published procedures for estimating settlement in dry sand resulting from seismic compaction take into account the initial density of the sand, the initial stress conditions, and the duration and intensity of the earthquake motion. T. L. Youd and T. N. Craven (1972) have found that an additional factor, the number of cycles of previous strain, significantly influences the compaction of sands. Results from cyclically-loaded simple shear tests show that samples with no prestraining compacted 6 times as much during 10 loading cycles as those with 50 cycles of prestraining and 250 times as much as those with 5,000 cycles of prestraining. Thus, it appears that the history of loading due to earthquake-induced motions (representing previous cycles of strain) could significantly influence the amount of settlement attributable to seismic compaction of sands during future earthquakes.

The San Francisco Bay mud commonly is described as a normally consolidated deposit of highly to medium-plastic organic silty clay. In a recent study, H. W. Olsen has shown that the young bay mud consists of a number of discrete soil layers, or subunits, consisting of materials that range in size from clay (<0.002 mm) to gravel (>2 mm). The distribution of the granular subunits appears to correlate with the past location of streams that discharged into the bay. Olsen has found, moreover, that the clay subunits (excluding desiccated surface zones) are lightly overconsolidated by an amount that fluctuates vertically and horizontally from zero to approximately 0.5 kg/cm^2.

Research in rock mechanics

T. C. Nichols, Jr. (USGS), and D. W. Stearns (Texas A & M Univ.) found that daily atmospheric changes alter the in situ elastic strains at or near the surface of a rock mass in a manner previously unrecognized. Radiant energy seems to be especially effective in creating boundary strains that appear to be elastically transmitted and intensified at shallow depths. Long- and short-term permanent strain changes occur which apparently are related to the input of radiant and atmospheric thermal energy and to atmospheric moisture variations. Measurements of strain changes in a large block of Llano Granite led to the following conclusions:

1. When strain-relief methods are used to measure in situ strains, care must be exercised to eliminate deleterious strains caused by atmospheric changes. It is best to make measurements in the predawn hours when the rock mass is closest to thermal equilibrium; the worst time is in the later morning hours when thermal change is most rapid.
2. The common method of locating a temperature-compensating strain gage on a small, separate block of the same material upon which the active gages are installed does not give consistent results because certain diurnal strain variations depend on the volume of the rock being measured. Therefore, the compensating gage should be installed directly on the rock mass being measured, but far enough away from the active gages so as not to be affected by other work being done on the rock.
3. Measurements should not be made soon after rainstorms; a wait of several hours is necessary for the rock mass to return to equilibrium with the long-term external conditions. The results of this research have been summarized by John Handin (1971).

Research in engineering geophysics

A simple, shallow seismic-refraction technique for generating and recording horizontally-polarized shear waves (SH) at the ground surface is being investigated by H. D. Ackermann. The measurement of shear wave velocities in situ has important engineering applications because the velocities of shear waves as well as of compressional waves are used in calculating elastic constants of earth materials. Shear waves commonly are not detected by conventional seismic-recording techniques, however, because the usual energy sources produce insufficient shear motion, and any shear wave arrivals are masked by a precursory compressional wave train.

In the technique being studied, shear waves are generated by striking the end of a long plank resting on the ground surface. The plank is firmly coupled to the ground by loading it with a heavy weight, such as a truck. The ensuing ground motion is dominantly transverse (SH and Love waves) as measured along a line perpendicular to the length of the plank, with very little compressional motion. The direction of dominant motion can be reversed by striking the opposite end of the plank. Vibrations are detected with transverse seismometers and are recorded on magnetic tape. The resultant seismogram records SH as an easily timed first arrival in the wave train.

SH-refraction seismograms have been made at three locations near Denver, Colo. Clear SH arrivals were detected as far as 125 m from the source. Depth calculations compare favorably with those obtained by conventional methods, and the ratios of compressional to shear velocities are in the range anticipated.

ENVIRONMENTAL GEOLOGY

URBAN AREA STUDIES

The Urban Studies program began in January 1970 as a cooperative effort between the USGS and HUD in the San Francisco Bay region. In fiscal year 1972 the program was expanded to include investigations in the Connecticut Valley, Baltimore-Washington, Pittsburgh, Denver, Phoenix-Tucson, and Puget Sound areas. Individual project areas were selected on the basis of need, geographic and geologic diversity, amount of basic data already in hand, availability of knowledgeable USGS personnel in the particular area involved, and local interest and willingness to cooperate. The primary goal of the studies is to provide the kinds of earth science data that will be of material assistance in regional urban planning, particularly information regarding rock and soil conditions, slope stability, availability and quality of water, susceptibility to earthquake damage, waste disposal and storage, and location of construction materials and other resources. Coordinated investigations by State geological surveys are supported by grants from the USGS.

SAN FRANCISCO BAY REGION ENVIRONMENT AND RESOURCES PLANNING STUDY

During 1973, numerous reports in the basic data, technical, and interpretive series were published. In addition, a number of procedures were initiated in order to document and elicit user reaction and input to the products of the San Francisco Bay region study (SFBRS). These include: (1) Systematic maintenance and analysis of records and requests for products, (2) formal evaluation of selected products by multidisciplinary review teams, (3) a contractual "state of the art" analysis which includes user reaction to and evaluation of SFBRS products, and (4) formal project and product review by two planning review groups. The results of these procedures are being used to help design and modify the final products in order to make them as responsive as possible to user needs.

Geological and geophysical studies

Much of the basic data contributions including landslide inventory maps, active fault maps, bay mud maps, surficial geologic maps, bedrock geologic maps, earthquake epicenter data, and historic seismicity data are now available for the entire area, and work is underway on interpretive reports dealing with these elements. A valuable byproduct of this work is the book, "Environmental Planning and Geology" (D. R. Nichols and C. C. Campbell, 1972), which is the proceedings of the 1969 annual meeting of the Association of Engineering Geologists and was published jointly by HUD and the USGS in March 1972. Approximately 12,000 copies were printed, but the book, oriented for use by city planners and public policy decision makers, became so popular that a second printing was made in December. The editors received many requests for copies of photographs which appeared in the book, and numerous colleges and universities have been using it as a text book for courses in environmental planning and environmental geology.

Hydrologic studies

As part of a study of the ground-water resources of the San Francisco Bay region, D. A. Webster has prepared two reports for the use of regional planners and local government officials. One report

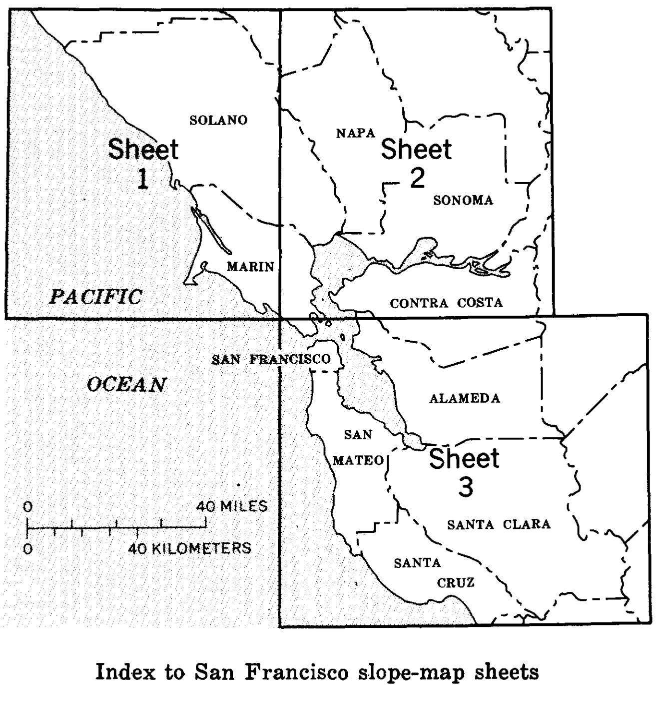
(Webster, 1972) presents general criteria for the development of an emergency water-supply plan and gives necessary data for the development of such a plan in the Napa Valley area. The other report, still in preparation, briefly lists problems associated with shallow ground water and identifies areas peripheral to the southern part of San Francisco Bay where the presence of shallow ground water may be troublesome to land owners, land users, and land managers. It also outlines an area where water confined in deeper deposits may be troublesome if pumping is significantly decreased.

T. J. Conomos and D. H. Peterson reported that releases of surface and seabed drifters and measurements of salinity and temperature in the bay water system and adjacent Pacific Ocean since March 1970 have shown that the bay system can be divided into two water-circulation regimes: (1) The north bay–Gulf of the Farallones, which has a permanent circulation cell typical of a partially mixed estuary, and (2) the south bay, which has seasonally reversing, partially stratified flow. The perennial estuarine-circulation pattern in north bay and the adjacent ocean is maintained by Sacramento–San Joaquin River runoff. Seaward surface drift of low-salinity water annually averages more than 5 km/d; landward near-bottom drift of ocean water annually averages 4 km/d. Factors causing density stratification in south bay include low-salinity water exchanges from north bay and fresh-water inflows from small streams tributary to south bay; this density stratification is nearly nonexistent during the summer low-discharge period. Imbalance between density- and wind-induced forces causes reversal of the net drift of surface waters and near-bottom waters; density-induced circulation dominates during winter whereas the prevailing wind, generally twice as strong in summer as in winter, dominates during summer. Near-bottom and surface drifts in the south bay annually average between 1 and 2 km/d.

W. L. Bradford reported that a project is underway to determine whether there are processes occurring in San Francisco Bay which remove heavy metals from the aqueous phase and, if so, to measure the overall rate of removal. Measurements of the zinc-influx rate due to sewage-water discharge were made over a 4-mo period. Concurrent measurements were made of the zinc concentrations in the aqueous phase and in the suspended-solid phase of bay water. Supporting measurement of zinc in the interstitial water and muds is planned. Preliminary data show that, during the period of measurement, a few metric tons of zinc were discharged into the bay and that this zinc did not accumulate in the aqueous phase. This result suggests that zinc-removal processes are occurring and that the removal rate is surprisingly fast. The data are not sufficient to indicate what the processes might be.

Topographic studies

Representing the final major topographic product of the extensive USGS-HUD San Francisco Bay region mapping project, a 3-sheet, multicolor set of maps delineating ranges in slope of the land surface over 10,867 mi^2, including the 10 bay region counties and parts of adjoining counties, was released during March 1973. Published at a scale of 1:125,000 (1 in. equals about 2 mi), the maps use separate colors to depict six slope zones (0–5 percent, 5–15 percent, 15–30 percent, 30–50 percent, 50–70 percent, and 70 percent vertical) that can be related to different ranges of soil stability and land development potential. The maps are expected to be of particular use to urban and regional planners, administrators, environmentalists, engineers, and others concerned with such problems as soil erosion and hillside development. Prepared as a companion edition to the recently published San Francisco Bay region topographic maps, the slope maps provide countywide coverage for Marin, Sonoma, Napa, Solano, Contra Costa, Alameda, Santa Clara, Santa Cruz, San Mateo, and San Francisco (see index maps). Topography is shown by contours at 200-ft



Index to San Francisco slope-map sheets

intervals, with 40-ft contours used in areas of low relief. Drainage, highways, geographic names, hydrographic soundings, and depth curves complete the maps.

Whereas earlier types of slope maps for such areas of the country as Anchorage, Alaska; Aspen, Colo.; and Hartford, Conn., were prepared by hand, a slow and time-consuming operation, the new San Francisco maps were produced by the recently developed semiautomatic photomechanical procedure for preparing maps directly from existing contour drawings.

CONNECTICUT VALLEY URBAN AREA PROJECT

Publication of 18 single-subject, natural-resource maps, the folio of the Hartford North quadrangle, Connecticut, (U.S. Geol. Survey, 1972b) signified completion of one of the objectives of the Connecticut Valley urban area project (CVUAP). As a consequence of the project's initial responsibility for developing new formats for the effective presentation of geologic and hydrologic information to aid in planning and resource management, CVUAP first inventoried existing maps, reports, and unpublished earth-resource data covering the greater Hartford area. Analysis of this information, combined with interviews and discussions with a variety of planners and nongeologically oriented citizens engaged in land and water management, led to the concept of a flexible natural-resource data base composed of a variety of simplified geologic and hydrologic maps each showing a single natural-resource characteristic in a given area. The Hartford North Folio provides an example of this method of presentation and offers an opportunity to evaluate the usefulness of the natural-resource maps as aids in the planning process. The maps are also available on transparent scale-stable material to facilitate their use as overlays in various combinations depending on the nature of the planning problem.

FRONT RANGE URBAN CORRIDOR, COLORADO

The configuration of part of the Denver basin between Greeley, Colo., and Colorado Springs has been defined by J. C. Romero, of the Colorado Division of Water Resources, and E. R. Hampton (USGS) using numerous data points at wells drilled to the Laramie–Fox Hills aquifer (J. C. Romero and E. R. Hampton, 1972). As shown by contours on the top of the aquifer, the deepest part of the basin is just east of the city of Denver, its axis trending roughly north to south through Aurora and Cherry Creek Reservoir. North of Aurora the basin axis trends northeast toward Deerfield, and the basin configuration is modified by subordinate northwest-trending cross wrinkles having amplitudes of about 100 ft, widths of 2 to 4 mi, and lengths of several miles. From Cherry Creek Reservoir south, the basin axis trends nearly due south toward Colorado Springs.

The Denver basin is very asymmetrical. The west flank is much steeper than the east and, close to the mountains, is locally overturned. The basin axis seems to shift westward with depth; at the top of the Dakota, which is several thousand feet below the Laramie–Fox Hills aquifer, E. A. Finley, C. E. Dobbin, and E. E. Richardson (1955) show the basin axis to be 5 to 6 mi farther west in the latitude of Denver and as much as 20 mi farther west in the latitude of Greeley.

Mapping by R. B. Colton in the area between Boulder, Fort Collins, and Greeley, Colo., shows that extensive gravel deposits follow all major drainageways leading out from the mountains to and along the South Platte River. The most suitable deposits for concrete aggregate are late Pleistocene outwash trains along the valley bottoms or on Piney Creek, Broadway, and Louviers terraces. Higher terraces or pediment remnants contain large volumes of lower grade gravels generally suitable for road or backfill use but not suitable for concrete without extensive preliminary treatment.

Five interpretive and derivative maps utilizing geologic data but directed to the needs of those interested in land-use planning have been prepared for the Golden quadrangle, Jefferson County, Colo. (H. E. Simpson, 1973). The maps express various engineering and lithologic characteristics of the bedrock and surficial materials in terms understandable to planners, civil engineers, land owners, and others who may not be geologically oriented. The text that accompanies each map explains the origin or cause and general behavior of the particular characteristic shown on the map, indicates the relation of the map subject to land-use planning, defines technical terms where needed, and in some places suggests possible methods of reducing, correcting, or avoiding problems associated with the map subject.

Fourteen interpretive maps were prepared for the folio of the Parker quadrangle, Colo., by J. O. Maberry (1972). Of particular interest were the maps showing areas inundated by past floods, areas of landslide deposits and unstable slopes, an interpretation of ground-water conditions, and the evaluation of the swelling-pressure potential of geologic materials. The Douglas County Planning Commission decided to use the "past flooding" map to delineate a zone of warning to real estate developers and as a guide to future restrictive zoning, such zoning to be based on outlines or projections of repetitive-flood areas which are to be furnished by another agency. J. O. Maberry and J. R. Keith mapped native vegetation in the Parker quadrangle and J. R. Keith evaluated the economic botany; they listed some 73 separate plant genera found in the quadrangle. Information shown on this map (I–770–L) is useful to planners and developers in environmental control and reclamation.

BALTIMORE-WASHINGTON URBAN AREA STUDY

Studies by A. J. Froelich based on field examinations, water well records, and construction data show that the thickness of overburden, mostly saprolite, is closely related to the character of the parent rock as well as to topographic position.

Quartz veins and dikes and indurated quartzites have little or no overburden. Massive ultramafic (serpentinite) bodies generally have less than 5 ft of overburden on either valley bottoms or ridgetops; and foliated mafic rocks (greenstones) commonly have 5 to 20 ft of cover. Gneisses and granitic rocks are mantled by as much as 60 ft of saprolite but may contain relatively fresh "core stones," and schist and phyllites commonly have a cover from 80 to as much as 120 ft thick. Saprolite is thickest beneath interstream ridges and thins towards valley bottoms. The larger streams are incised in and may flow directly on hard unaltered bedrock, except where fresh rock is blanketed by alluvium.

Although a weathered regolith locally overlies Triassic sedimentary rocks of the western Piedmont in Montgomery County, Md., it rarely exceeds 20 ft in thickness.

Where coastal plain sedimentary rocks of Cretaceous age lap over the eastern margin of the Piedmont, a thin layer of saprolite averaging 20 ft in thickness commonly separates fresh gneiss or schist bedrock from the overlapping strata. The saprolite-bedrock interface under the coastal plain dips southeasterly about 200 ft/mi, whereas on the piedmont, this interface slopes regionally less than 40 ft/mi.

LAND RESOURCE ANALYSIS

The Land Resource Analysis program was initiated in fiscal year 1973 in response to the need for earth science data to assist in the land-use planing and resource management primarily of nonurban areas that are not yet critically affected by growth and development but which, according to present trends, are in danger of being seriously impacted in the future. Innumerable areas in the United States fit this category, but present funding levels permit full-scale studies in only a very few areas. One of the areas selected was the Eastern Snake River Plain, which includes the bulk of Idaho's agricultural, urban, manufacturing, and transportation centers, and which faces imminent environmental problems related to projected growth trends. Several geologists, hydrologists, and geophysicists of the USGS have been involved in past studies in the region, and hence are uniquely qualified to conduct the multidisciplinary investigation.

Another area being studied is Knox County, Tenn., which includes the city of Knoxville. The county is situated in a geologically complex terrane in the Valley and Ridge province, and most early land use decisions were based on expediency which largely ignored physical limitations. In order to encourage better land resource use and to maintain a suitable environmental quality, a folio of 13 maps compiled by L. D. Harris (1972) concerning the physical environment and its limitation has been made available to the Knox County Metropolitan Planning Commission.

In addition to the above 2 projects, the objectives of 25 other projects have been expanded to include the preparation of special purpose and interpretive maps for land-use planning and development. The Land Resource Analysis program also includes the development of a land-use information system (see section on "Applications to Geographic Studies"), under the direction of the Chief Geographer, which utilizes remote sensing imagery to map and analyze current and future trends in land use practices. During fiscal year 1973, the following results were reported.

Jackson quadrangle, Wyoming

Six environmental maps were prepared by J. D. Love (1973) for the Jackson quadrangle, northwestern Wyoming. It is the only quadrangle studied in this way in Wyoming and was selected because (1) it contains abundant good, bad, and unusual environmental features, (2) more than 3 million people pass through it each year so human impact is considerable, (3) less than 3 percent of the land surface in the county (Teton) in which the quadrangle is located is privately owned, making it unique in the conterminous United States, (4) land values are increasing dramatically and most development has been random, without regard to geologic hazards or to natural resources such as water, (5) the area has a geologic record of seismic and landslide activity and more can be expected.

The six maps are as follows: A, geologic map; B, rock materials useful for construction; C, distribution, thickness, and environmental significance of loamy soil; D, snow avalanche possibilities; E, steepness of slope and summary of related environmental problems; F, differences in stability of ground. Additional maps on precipitation, ground water, land ownership, and geophysical studies, and annotated stereophotographic pairs and photomosaics in black and white and color were prepared as background data for more detailed types of land-use planning.

Point Dume quadrangle, California

An isopleth map of landslide distribution in the Point Dume quadrangle, California, has been constructed by R. H. Campbell as an experiment in the search for a way to generalize information from a landslide inventory map into a format for regional land-use planning or other purposes. It has the form of a contour map on which the lines are isopleths of equal percentages of areas covered by landslides, and it is prepared as a transparent overlay that can be easily compared with the slope map, the landslide map, the geologic map, and others that may be available on the same topographic base. It can be combined with other data from the same area that can be displayed in contoured form (such as isohyetal maps) to produce more specialized maps.

RESOURCE AND LAND INFORMATION PROGRAM

The Resource and Land Information (RALI) program was established as an Interior Department program on September 1, 1972, under the leadership of the USGS, to satisfy the need for improved multidisciplinary information systems which would provide essential data for those concerned with land-use planning, resource management, and assessment of environmental quality. This effort is an attempt to enhance the value of existing information programs including the urban studies, land resource analysis, and geographic applications programs of the USGS.

The ultimate goal is to improve the visibility and accessibility of resource and land information and to simplify integrating data from various sources for interpretive purposes. The fiscal year 1973 program is divided into two principal categories—program planning, and design studies and demonstration projects. The first includes separate efforts on the (1) assessment of user needs, (2) inventory of information systems, (3) cataloging of available information, (4) improvement of information systems, and (5) research on technology for data collection and display. Demonstration projects are directed from Washington but are carried out at numerous locations around the country. Work groups in both categories are composed of personnel from many Interior Bureaus.

Because the RALI program is concerned with subjects ranging from rapid collection of needed data to sophisticated analysis of land-use alternatives, few local situations lend themselves to demonstration of the full RALI concept. Conversely, many specific problem areas are suitable for demonstration of one or more of RALI's principal objectives.

Twenty-three RALI demonstration sheets were completed during fiscal year 1973. Among the 14 sheets of the Tucson-Phoenix area are those that delineate and describe the flood hazards, water resources, land status, alluvial deposits, slopes, and copper resource potential. The five sheets from the Puget Sound area describe the climate as related to land-use planning, slope stability, spawning areas of anadromous fish, percolation rates of earth materials, and volcanic hazards around Mount Rainier. Four sheets from the Powder River Basin area delineate the energy resources of that entire region and detail the land use, ownership, and coal deposits of the Gillette area.

A comprehensive report (U.S. Department of the Interior, 1973) on south Dade County, Fla., was also completed during fiscal year 1973. It describes the area's land and water resources and its man-related problems and offers some suggestions for the possible resolution of these problems.

INVESTIGATIONS RELATED TO NUCLEAR ENERGY

UNDERGROUND NUCLEAR EXPLOSIONS

Nevada Test Site

The Nevada Test Site in southern Nevada is the area within which the U.S. Atomic Energy Commission conducts most of its underground nuclear explosion tests. Since 1956 (before the first underground nuclear explosion), the USGS has made extensive and detailed studies, on behalf of the Commission and the Departmnt of Defense, of the geology and hydrology of the Nevada Test Site. These studies have provided the earth-science data necessary to insure proper environmental safeguards in the underground testing of nuclear explosives. The USGS participates in the appraisal of the safety, engineering feasibility, and postshot effects of all explosions conducted at the Nevada Test Site.

W. W. Dudley, Jr., has demonstrated a direct correlation between the water content and the amount of clay-sized material in unsaturated alluvium at the Nevada Test Site; the greater the amount of clay-sized material the greater the amount of water. This relationship has proved useful in predicting moisture contents based on knowledge of the character of the alluvial sediments in valley fill.

At the Nevada Test Site the only regional aquifer extending beyond the boundaries of the site is the Paleozoic carbonate aquifer. H. C. Claassen has conducted several two-well tracer tests in this aquifer and has demonstrated that the effective porosity of the aquifer is only about 1 percent. This measurement is required in order to predict the rate of water movement and possibly radionuclide transport beyond the boundaries of the Nevada Test Site.

Following most nuclear explosions, the ground above the explosion collapses into the explosion-produced cavity, thereby creating a collapse sink at the surface. R. P. Snyder has studied the plan-view shape of all collapse sinks at the Nevada Test Site, and he notes that nearly all of the collapse sinks have a tendency to be oval with the longer axis oriented in a northwest-southeast direction. It is postulated that faults buried beneath the alluvium and the natural tectonic stress field influence the orientation and shape of collapse sinks.

J. R. Ege and D. L. Hoover have shown that certain volcanic tuff units at the Nevada Test Site are crushed more than other units when subjected to pressures in the laboratory as great as 4 kilobars. The most permeable rocks, such as tuffaceous sandstone and reworked ash-fall tuff, are also the most compactible. Less permeable rocks, such as ash-fall tuffs and argillized tuff, are less compactible. With this knowledge and an understanding of the geology of an area, it is possible to predict in advance the location of the more compactible zones and to avoid those zones in selecting the location of sites for nuclear explosions.

J. R. Ege and C. H. Miller have developed a hydraulic stress probe that can be installed in NX drill holes. The advantage of these probes is that they can be positioned in the free stress field at a distance (usually greater than twice the width of a tunnel) away from a tunnel wall. This probe is durable enough to withstand nuclear detonations that are only a few hundred feet away. Eight of these probes have been installed in tunnels that are used for nuclear tests. Both static and dynamic stress fields have been measured. The static stress fields have an apparent long-term (secular) drift; the cause of this drift is unknown but is being investigated. The dynamic response to underground nuclear explosions has been measured in excess of 3,000 lb/in^2 on a microsecond time base. Knowledge of natural stress conditions is utilized in tunnel design and construction whereas knowledge of dynamic stress conditions following an explosion is used in the design of nuclear experiments.

Amchitka Island, Alaska

The Cannikin nuclear explosion, the largest underground explosion ever detonated by the United States, was successfully executed on November 6, 1971, on Amchitka Island, Alaska. Since then the USGS has been monitoring the Cannikin site to evaluate the hydrologic effects of the explosion (D. D. Gonzalez and L. E. Wollitz, 1972).

A drill hole was successfully drilled into the Cannikin cavity and collapsed zone, permitting the monitoring of water quality at various depths and the measurement of the ground-water rise as the explosion cavity was filling. According to W. C. Ballance and D. D. Gonzalez, the subsurface water level at the Cannikin site has risen to approximately preshot conditions (a rise of about 1,750 m) in 15 mo.

About 38 h after the Cannikin explosion, the cavity produced by the explosion collapsed, forming a chimney of rubble which propagated to the surface causing the land surface to subside. White Alice Creek, whose major tributaries are within the subsided area, had its flow intercepted by the subsided depression. The intercepted flow has been filling the cavity and chimney through faults and fractures created by the collapse. In November 1972, 1 yr after the explosion, the subsided depression had filled with water, forming the largest lake on Amchitka Island. Overflow from the lake has reestablished the discharge of White Alice Creek to pre-Cannikin conditions.

In November 1972, a drill hole (HTH–3), 31.2 m deep, was drilled inside and near the perimeter of the subsided depression. Water samples from the hole are being analyzed for radioactivity; no radioactive contamination had been detected as of January 1973. Intensive water sampling and analyses of surface waters in the vicinity of the Cannikin and Milrow (detonated October 1969) explosion sites reveal no radioactive elements above background level 1½ yr after the Cannikin event and 3½ yr after the Milrow event.

D. D. Dickey, F. A. McKeown, and R. C. Bucknam evaluated the displacement (both horizontal and vertical) of the ground surface around the Cannikin site. Their analysis of the displacement data indicates that the Cannikin explosion caused the release of tectonic strain. The strain release caused the ground to undergo extension in a northeast-southwest direction and to contract to a lesser amount in a northwest-southeast direction. The northeast-southwest direction is subparallel to the principal faults on Amchitka Island.

In 1972 a report was published interpreting an aeromagnetic survey of Amchitka Island and the adjacent insular shelf (G. D. Bath and others, 1972).

RELATION OF RADIOACTIVE WASTES TO THE HYDROLOGIC ENVIRONMENT

Radioactive materials in suspension or solution could be introduced into the hydrologic environment as a result of the operations of nuclear-energy facilities. Research, sponsored by the AEC, is related primarily to the transport of radioactive materials through the hydrologic cycle and to the prediction of the destiny of radioactive materials released accidentially into the hydrologic environment. The research is devoted to protecting the hydrologic environment from contaminating solutions and to developing new waste-disposal methods and techniques.

Movements of radionuclides in the Columbia River estuary

In a study of temporal variations in radiological and other characteristics of suspended-particulate material in the Columbia River estuary, J. L. Glenn, observed that concentrations of scandium-46 and zinc-65 had tidal and seasonal changes that generally correlated with changes in cation-exchange capacity, carbon content, and (or) mineralogy. Seasonal variations in sources and transport of particulate material, however, were responsible for poor correlations at certain times. Statistical analyses show that the texture and radionuclide content of multiple samples of bottom sediments from selected locations in the lower Columbia River estuary vary significantly with time. An inverse relation betwen temporal trends of river discharge and of mean particle size suggests that a textural change results from seasonal changes in the competence of river currents. Temporal changes in radionuclide content result from textural changes and radioactive decay.

G. A. Lutz, D. W. Hubbell, and H. H. Stevens, Jr., adapted a one-dimensional, constant-density, transient-flow model to compute water discharge in the Columbia River estuary at Astoria, Oreg. The adaptation included a time-variant roughness factor and a variable datum (slope) correction factor. Daily mean flows, determined by integrating computed discharges over 24-h periods, exhibited major cycle fluctuations having a period of approximately 14 d.

Hubbell, Stevens, Lutz, and Glenn computed rates of transport of radionuclides through cross sections of the Columbia River estuary at Astoria, Oreg., and Beaver Army Terminal near Quincy, Oreg., by combining data from models that continuously define water discharge, concentrations of suspended particulate material, and concentration of radionuclides in solution and in association with particulate material. The suspended-particulate materials (sediment) model adjusts for the influence of a turbidity maximum that develops in the vicinity of Astoria. The radionuclide-concentration models are constructed to reproduce observed temporal variations and to utilize concentrations from periodic samples, as does the sediment model, to greater absolute concentration curves. An accounting of the discharge of radionuclides and sediments through the two cross sections indicates that the amounts of radionuclides and sediments in the reach between the sections tend to build up during periods of low flow and to diminish during times of high flow.

Digital modeling of waste transport in ground water at National Reactor Testing Station, Idaho

In order to understand the observed behavior and to predict future waste migration in ground water of the Snake River plain aquifer, J. B. Robertson developed a digital model for the system. The model has two basic segments. The first is a hydrologic model of the aquifer using the iterative alternating-direction implicit finite-difference solution to the differential equations of ground-water flow. The second segment simulates the chemical-transport systems. The two modeling segments are coupled together so that ground-water flow-velocity vectors generated by the hydrologic model are used in the chemical-transport model. The chemical-transport model uses the method of characteristics to approximate the solution to the differential transport equations. Several controls on chemical transport, such as convective transport, flow divergence, two-dimensional hydraulic dispersion, radioactive decay, and reversible sorption are included in the model. The model has successfully duplicated the 20-yr transport and distribution history of waste chloride (a conservative solute) and tritium (conservative except for radioactive decay). Preliminary work has begun on modeling less conservative cationic solutes such as strontium-90 (subject to sorption reactions). The modeling results indicate that hydraulic dispersion (especially transverse) is a much more significant influence than previously suggested from laboratory and theoretical studies by other researchers, which agrees well with recent analyses of field studies by other USGS scientists. The model may be used to project future waste-migration patterns for varied hydrological and waste conditions.

Evaluation of geohydrologic environments for the storage of radioactive waste products

C. B. Yost, Jr., and J. T. Barraclough reported that a study to evaluate possible radioactive-waste migration from a solid-waste burial ground at the National Reactor Testing Station, Idaho, was nearly completed. Four test wells (640-ft deep) outside the burial ground and six wire-line core holes (250-ft deep) inside the burial grounds were drilled. The hydrogeologic framework below the burial ground was outlined, measurements were made to determine if waste radionuclides were present at depth, and wells to monitor ground-water quality and flow direction were prepared. Two principal sedimentary strata were located at depths of 110 ft and 240 ft within the basalt flows. These sediments would impede the downward migration of radionuclides. The fine-grained sediments have a capacity for removal of radionuclides from solution by cation exchange. Sediment coatings on fractures in the basalt provide additional cation-exchange capacity. The regional ground-water flow is to the south-southwast. However, the ground-water flow is to the northeast beneath the burial ground due to recharge from ponds southwest of the burial ground.

The USGS provided the AEC with geologic and hydrologic data required for evaluating the most promising site in bedded salt for a pilot-plant repository for solid high-level radioactive waste. The potential site is in secs. 10 and 11, T. 22 S., R. 31 E. According to A. L. Brokaw, the area meets most of the hydrogeologic criteria for waste emplacement in salt beds. Several exploratory boreholes will be drilled in the selected area to provide samples and geophysical data for more detailed investigations of the lithology, mineralogy, and hydrology of the evaporite sequence.

Thick (100–600 ft) unsaturated zones beneath mesas, plateaus, and selected valleys in the Southwest were evaluated by I. J. Winograd as possible target areas for storage of solidified high-level radioactive wastes from fuel reprocessing plants. Hydrogeological and logistical factors seemingly favorable to such storage area are as follows: (1) Absence of a viable mechanism to transport the wastes to deep water tables under present climatic conditions, (2) probable protection from exhumation by erosion in a time frame of several thousands of years, more than enough time for decay of strontium-90 and cesium-137 to safe levels, (3) availability of remote Federal lands with thick unsaturated zones, and (4) relative ease of placement and retrieval of the wastes. Potential major liabilities to unsaturated-zone storage include the following: (1) Difficulty of assessing protection from exhumation in a time frame of 10^4 to 10^5 yr, the time needed for decay of the transuranic elements in the wastes, (2) difficulty of assessing the magnitude of waste transportation to deep water tables under pluvial climatic conditions, (3) need for extensive field and laboratory studies to measure and to predict effects of a major heat source upon the porous medium and its contained moisture, the waste canisters, and surface vegetation, and (4) need for nominal monitoring of the burial site into perpetuity. It appears that chemical separation of the transuranic elements from the high-level wastes is mandatory if thick unsaturated zones are to be used as national waste repositories; the transuranics could be disposed of by recycling, transmutation, or placement in bedded salt.

SITES FOR NUCLEAR POWER REACTORS AND OTHER FACILITIES

The USGS has continued its reviews of geologic and hydrologic aspects of license applications to the

AEC for nuclear facilities such as power reactors, fuel processing plants, and solid waste burial grounds. These reviews evaluate geologic and hydrologic phenomena which are related to the safety of the facility, such as faulting due to seismic activity, flooding, availability of water for cooling, and foundation conditions, as well as the potential extent of contamination of water resources that could occur through the operational or accidental release of radionuclides. The reviews result in reports to the AEC which are included in the public record of the licensing proceedings before the AEC.

During the past year, F. N. Houser, E. H. Baltz, Jr., and F. A. Kilpatrick reviewed, examined in the field, or reported regional and local geologic and hydrologic conditions for 22 sites. The experience continues to indicate that regional and local geologic and hydrologic knowledge, applied to evaluations of specific sites, allows the engineering design criteria for nuclear facilities to be closely adapted to the environment, resulting in increases in safety and decreases in cost of design and construction.

FLOODS

The USGS studied three major categories of floods: (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

Disastrous flood on Rapid Creek in Rapid City, South Dakota

A flash flood occurred June 9–10, 1972, on Rapid Creek in Rapid City, S.D., as a result of rainfall ranging from 4 to 12 in. on a 60-mi^2 area between Canyon Lake and Pactola Dam, 9 mi west of Rapid City.

The flood is considered the greatest disaster in the history of South Dakota. At least 237 lives were lost. Flood damage in Rapid City was estimated by the U.S. Army Corps of Engineers to be more than $79 million. More than 1,300 homes and 5,000 automobiles were destroyed. Large quantities of debris and sediment were transported by the floodwaters. Overbank flow generally lasted less than 10 h. O. J. Larimer (1973) reported that peak discharges were several times those of a 50-yr flood.

At the gaging station upstream from Canyon Lake, the peak stage (15.77 ft) was 7.69 ft higher and the peak discharge (31,200 ft^3/s) was 12 times as much as that of the flood of May 23, 1952, previously the greatest flood in 26 yr of record. In Rapid City, at the gaging station located upstream from West Street, the peak stage (15.45 ft) was 7.08 ft higher and the peak discharge (50,000 ft^3/s) was 15 times as much as the previous peak of record on July 13, 1962. The failure of the dam creating Canyon Lake at the western edge of Rapid City was considered to have had only a minor effect on peak discharges.

Flood magnitudes were measured at seven sites. A profile of the water surface along 20 mi of Rapid Creek was obtained from high-water marks identified in the field, and boundaries of the inundated areas were delineated on a topographic map. Field surveys indicated that velocities as great as 25 ft/s occurred. The channel slope downstream from Canyon Lake exceeds 30 ft/mi.

Tropical Storm Agnes caused record-breaking floods in Eastern States

The most destructive flood, as well as one of the most widespread floods in the history of the United States was caused by Tropical Storm Agnes, June 21–24, 1972, in a 10-State area of Eastern United States. More than 130 lives were lost and thousands of people were made homeless. Damage estimates approached $2 billion. Pennsylvania suffered the greatest damages.

J. C. Kammerer and others (1972) reported that streams crested at their highest stages and discharges in more than 100 yr in parts of New York, Pennsylvania, Maryland, and Virginia. Cities that suffered especially great damages included Harrisburg, Wilkes-Barre, and Pittsburgh, Pa.; Corning, Elmira, and Wellsville, N.Y.; and Richmond and Roanoke, Va.

The combined effects of floodflows in the Susquehanna, Potomac, and James River basins and some smaller adjacent basins resulted in the highest monthly flows into Chesapeake Bay for any month in at least the past 21 yr. The combined monthly discharges in June totaled about 325,000 ft^3/s, of which 186,000 ft^3/s was contributed by the Susquehanna River basin. The inflow to the Bay from all the basins on June 24 was estimated to be 2,200,000 ft^3/s.

Delaware and Maryland.—On June 22, Tropical Storm Agnes caused extensive flooding throughout the northern half of the Delmarva Peninsula (northern and central Delaware and adjacent Maryland). R. H. Simmons (K. R. Taylor, 1972) reported that record-breaking peak stages and discharges occurred at half of the gaging stations. The heaviest rainfall, 11.2 in. in 18 h, was recorded near Kennedyville, Md., (about 30 mi east of Baltimore). By comparison, the National Weather Service estimates that the 24-h, 100-yr rainfall is about 8-in. in the Kennedyville area. The peak discharge on Morgan Creek near Kennedyville was nearly five times greater than the previously recorded maximum. Runoff in the Morgan Creek basin (10.5 mi^2) was 9.9 in. on June 22 (714 ft^3 s^{-1} mi^{-2}). In spite of the record high stream stages, flood damage was confined largely to farm crops in low-lying areas.

Taylor's report shows that 1-d rainfall ranging from 6 to 12 in. in central Maryland resulted in record peak stages and discharges at 53 continuous-record gaging stations in Maryland. Discharges on Western Run at Western Run, Md., and on North Branch Patapsco River at Cedarhurst, Md., were nearly seven times greater than those previously recorded in 25 yr of record. New record peaks were 4 times those of previous floods at 5 gaging stations and were double those of previous floods at 30 stations.

Nineteen lives were lost in Maryland, more than 1,000 homes were badly damaged or destroyed, and damage to public and industrial property was estimated in the tens of millions of dollars.

New York.—The greatest flood disaster in the history of New York State resulted from the intense rainfall associated with Tropical Storm Agnes. More than 6 in. of rain fell June 18–19, 1972, in parts of Westchester County, and greater amounts fell in adjoining areas in Connecticut. Total precipitation during June 20–25 was nearly 14 in. in the Wellsville-Alfred area of eastern Allegany and western Steuben Counties in the southern part of the State.

K. I. Darmer (1972) reported that the peak stage on Chemung River at Chemung, with 65 yr of record, was 31.62 ft (discharge, 189,000 ft^3/s) as compared with the previous peak stage of 23.97 ft in 1946. Long-term gaging stations on Allegheny River at Salamanca (67 yr of record) and Genesee River at Portageville (63 yr of record) also had peaks far above the previous maximums. In some smaller drainage basins, the stages and discharges of the flood of June 1972 were less than those of previous floods. The distinctive aspects of the June 1972 flood were the devastation of extremely large areas and the occurrence of the highest known flows on large streams.

Flooded areas in the Susquehanna River basin, Lake Ontario basin, and Allegheny River basin in New York were delineated on 18 topographic quadrangle open-file maps.

Pennsylvania.—The most severe flooding ever recorded in central Pennsylvania occurred June 22–25, 1972. Property damage was estimated at more than $1 billion. Precipitation ranging from 4 in. to more than 18 in. fell over the Commonwealth. The greatest amounts were centered near Harrisburg, in the Susquehanna River basin. Rainfall ranging from 8 to 16 in. was recorded upstream from Harrisburg.

L. V. Page determined that the flooding in the Susquehanna River basin was the greatest of record, exceeding the previous historical flood of 1936 by several feet. Recurrence intervals were well over 200 yr in some places and more than 100 yr in many places. Some levees designed to contain floods greater than the 1936 flood were overtopped. Flooded areas in the Susquehanna River basin were delineated on nine topographic quadrangle open-file maps.

At Harrisburg, the Susquehanna River peak on June 24 was the highest in at least 185 yr; the maximum stage at the Nagle Street gaging station was 32.57 ft (discharge, about 1,000,000 ft^3/s). At Wilkes-Barre, on June 23, the Susquehanna River reached a stage of 40.6 ft (discharge, about 370,000 ft^3/s), 7.5 ft higher than the flood of 1936.

In the Delaware River basin the greatest flooding occurred in the upstream reaches of the Schuylkill River and on some of its larger tributaries. Previous record flood crests on the Schuylkill River, set in 1955, were exceeded in all but the lower reaches (downstream from Pottstown).

Flooding in the Ohio River basin was severe but not as great as from earlier floods.

Virginia.—P. N. Walker reported that the James River at the City Locks gage at Richmond reached a stage of 36.5 ft (discharge, 319,000 ft^3/s), 6½ ft higher than the historic flood of 1771. It is believed to be the highest stage since the first colonization of the lower James River basin in 1607. The extent of the flooding along James River was delineated on photomosaic maps.

Flood discharges exceeding those having a 100-yr recurrence interval occurred at 25 long-term gaging stations. New maximum stages were observed at 40 gaging stations.

Damages in excess of $200 million and the deaths of 13 people were attributed to Tropical Storm Agnes flooding in Virginia.

According to P. L. Soule, peak stages and discharges on Bull Run near Manassas (stage, 37.8 ft; discharge, 76,000 ft^3/s), Difficult Run near Great Falls (stage, 21.40 ft; discharge, 32,000 ft^3/s), and

Goose Creek near Leesburg (stage, 30.56 ft; discharge, 78,000 ft^3/s) far exceeded any of record. Torrential downpours in northern Virginia during the evening June 21 and continuing through June 22 resulted in about 16 in. of rainfall near Chantilly. At nearby Dulles International Airport a total of 13.65 in. was recorded, with 11.88 in. falling within 24 h.

H. P. Guy and T. L. Clayton (1973) observed that the impact of rainfall caused unusual floods where streams had a time of concentration in excess of 3 h and generally no flooding where the time of concentration was less than 45 min. At Reston, the storm yielded a maximum 8-h rainfall of 9.14 in. which greatly exceeds the 6.08 in. normally expected for an 8-h, 100-yr return period.

Near Washington, D.C., the flow of the Potomac was fourth highest in at least 83 yr of record, exceeded by the floods of June 2, 1889, March 19, 1936, and October 17, 1942. Flash flooding occurred on most small streams in this vicinity, and the extent of flooded areas along the Occoquan River and the downstream 3 mi of Four Mile Run were recorded on photomosaic maps.

Flood of August 2, 1972, on Little Maquoketa River near Durango, Iowa

A. J. Heinitz reported that severe flooding in northern Dubuque County resulted from a storm system that dropped from 4 to 9 in. of rain over the Little Maquoketa River basin and the upper part of the North Fork Maquoketa River basin. Most of the rain fell during a 3-h period ending about 2:00 a.m. on August 2, 1972.

Nearly all the homes in the small towns of Durango, Sageville, and Daytonville along the Little Maquoketa River were inundated to some extent. Flood damages were estimated to be in excess of $1 million. Damages to farm crops were extensive, many streets and roads were washed out, and several bridges were destroyed. Peak elevation at the gaging station on the Little Maquoketa River near Durango (drainage area, 130 mi^2) exceeded that of the 1925 flood of record by 1.7 ft. The discharge, 40,000 ft^3/s, was about twice that of a 100-yr flood.

September floods in southwestern Iowa

Severe flooding in Audubon and Shelby Counties in southwestern Iowa resulted from rains totaling as much as 21 in. in a 50-h period during September 10–12, 1972, and averaging 10-in. or more over both counties. Hardest hit were the upper basins of the East and West Nishnabotna Rivers.

According to A. J. Heinitz, depth of floodwater from Crooked Creek exceeded 2 ft on part of Interstate Highway 80 near Adair. Two lives were lost. About 110,000 acres of croplands were inundated and crop damage was estimated at $10 million. Total damage to roads and bridges was estimated at $4.5 million.

At gaging stations on East Nishnabotna River at Red Oak and Nodaway River at Clarinda, each with 42 yr of record, the flood was greatest since 1947. The peak discharge of Crooked Creek at the Interstate Highway 80 crossing (drainage area, 22.2 mi^2) was 14,800 ft^3/s on September 11, 1972, or 2.2 times that of a 100-yr flood.

Floods of October 6–7, 1972, in south-central Virginia

Extensive flooding in south-central Virginia, centered in the Appomattox and Chowan River basins, resulted from heavy rains on October 6–7, 1972. As much as 11 in. of rainfall was reported in Amelia and Dinwiddie Counties. Estimated damages at Petersburg exceeded $1 million.

P. N. Walker and E. M. Miller reported that flood magnitudes at many places approached or exceeded those of August 1940. Near-record floods also occurred on the Nottoway and Meherrin Rivers, tributaries of the Chowan River.

The extent of flooding by the Appomattox River in the vicinity of Petersburg and Colonial Heights was delineated on topographic maps. Flood profiles were obtained for an 11-mi reach.

Floods along Lake Erie shore in Ohio in November 1972

E. E. Webber reported that strong onshore winds, associated with a major storm system, caused severe wave and flood damage November 14, 1972, along the Lake Erie shore in Ohio from the vicinity of Loraine westward to Toledo. Initial estimates of property damage amounted to about $22 million.

Lake Erie water-surface elevation at Toledo, reported by NOAA's U.S. Lake Survey, was about 577 ft above mean sea level (approximately 2 ft higher than the previously recorded maximum water-surface elevation). USGS investigators documented the flood by marking and determining the mean-sea-level elevations of more than 100 flood marks.

FLOOD-FREQUENCY STUDIES

Channel flood surveys in Alaska

Channel surveys at 24 sites in northern Alaska were used by J. M. Childers (1972) to compute bankfull discharge and maximum evident flood discharge. The results were compared with flood discharge characteristics estimated from multiple-regression equations. Bankfull discharge was found to be a good estimate of the 50-yr flood; the maximum evident flood discharge was found to be about twice that of the 50-yr flood.

Estimating mud- and debris-flow frequencies in California from botanical evidence

Investigations by L. E. Jackson, Jr., indicate that mud and debris flows similar to those in the Big Sur area in Monterey County during October and November 1972 have occurred there many times in the recent geologic past. Areas damaged by the 1972 flows were located either upon or adjacent to alluvial fans composed predominantly of older mud and debris flow deposits. Root horizons of coastal redwoods (*Sequoia sempervirens*) growing on these deposits provide a basis for rough estimates of the frequency of past mud- and debris-flow events. Up to five root horizons have been identified beneath trees with estimated ages of 300 yr, which suggests that five events similar to the mud and debris flows of 1972 may have occurred in the Big Sur area in the past 300 yr.

Preliminary flood-frequency relations for small streams in Georgia

New information from 102 small natural drainage basins (0.1–20 mi^2), not available for previous flood-frequency analyses, has been analyzed by H. G. Golden (1973) to provide planners and designers with preliminary relations for estimating the magnitude and frequency of flood peak discharges on small streams in Georgia. Multiple regression methods were used to define the relation between Q_2 (2-yr flood discharge) station data and selected basin characteristics. Only drainage area, soil-infiltration capacity, and precipitation intensity were found statistically significant. Equations for estimating Q_{50} (50-yr flood) discharges were developed from the Q_2 equations by ratio method using the station flood-frequency data computed for larger stations (20–1,000 mi^2). Equations were developed for three physiographic regions with the following approximate standard errors of estimate: Valley and Ridge and Blue Ridge provinces, 41 percent; Piedmont province, 48 percent; and Coastal Plain province, 37 percent.

Flood-frequency relations by multiple regression methods in Idaho

C. A. Thomas, W. A. Harenburg, and J. M. Anderson (1973) have developed regression equations for each of eight regions by multiple-regression methods which determine Q_{10}, the peak discharge which, on the average, will be exceeded once in 10 yr. Peak flows Q_{25} and Q_{50} can then be estimated from Q_{25}/Q_{10} and Q_{50}/Q_{10} ratios developed for each region. Equations were derived from relationships between peak-flow characteristics and physical and climatic basin characteristics for 303 gaged sites which were analyzed in the study.

Q_{10} can be determined from drainage area in two of the regions. In the other six regions, Q_{10} can be determined from drainage area and one or more of the following variables: percentage of forest cover in the basin, percentage of water area in the basin, latitude of the centroid of the basin, and longitude of the centroid of the basin. Standard errors of estimate using these equations range from 41 to 62 percent. Data for streams in certain areas which all together total about 20,000 mi^2, mostly in southern Idaho, were found to be too poor to develop regression equations.

A plot of the maximum discharges of record related to drainage area showed a wide range in the relative magnitude of floods in the State. Most of the maximum flows of record were between about 5 $ft^3\ s^{-1}\ mi^{-2}$ and 80 $ft^3\ s^{-1}\ mi^{-2}$. However, several streams having 50 yr or more of record had maximum flows of less than 1 $ft^3\ s^{-1}\ mi^{-2}$ and others had maximum flows of more than 4,000 $ft^3\ s^{-1}\ mi^{-2}$. The extremely low rates of streamflow occurred in valleys filled to great depths with alluvium. The extremely high flows were caused by thunderstorms, mostly on unforested, impermeable areas.

A large number of physical and climatic characteristics of the gaged basins were investigated including, but not limited to, the following: basin elevation and shape factors, soil-infiltration index, a geologic factor, factors defining exposure of basin to moisture sources, precipitation index, precipitation-intensity index, and mean runoff. The regression analyses showed that most of these characteristics were of less significance in determining Q_{10} than the variables used in the regression equations. For convenience of application, several of the more complex basin characteristics were deleted at the sacrifice of some increase in the standard error.

Flood magnitude and frequency on small streams in Ohio

E. E. Webber and R. I. Mayo investigated techniques for estimating magnitude and frequency of floods on drainage areas of less than 1 mi^2 in Ohio.

Analyses of limited data indicated that the techniques now in use are satisfactory. These techniques are based on the index flood method of analysis in which the individual gaging station mean annual (index) flood is computed from basin characteristics, including mean channel slope, and an empirical factor related to principal soil types. The average slopes of the individual gaging-station frequency curves are then used to estimate peak flood discharges at longer (10-, 25-, and 50-yr) recurrence intervals.

Flood-frequency relations defined for medium and large streams in Oklahoma

V. B. Sauer reported that multiple regression techniques were used to define a set of equations for computing 2-, 5-, 10-, 25-, 50-, and 100-yr flood magnitudes in Oklahoma. Most significant variables were drainage area, channel slope, and mean annual precipitaion. Estimates of the 50-yr flood discharge at ungaged sites having drainage areas greater than 100 mi^2, computed by regression equations, have about the same accuracy as those based on 6 yr of actual record.

Flood-frequency analyses on small watersheds in Oklahoma

Regression analyses of annual peak discharges from 60 drainage basins, of less than 100 mi^2 each, produced useful estimating equations, according to investigations by W. O. Thomas and R. K. Corley. Peak discharges were limited to those of 2-, 5-, and 10-yr recurrence intervals because of the short length of flood records on small watersheds in Oklahoma (average length of record is 10-yr). The three most important basin and climatic characteristics were contributing drainage area, main channel slope, and mean annual precipitation. Estimates of the 10-yr peak discharge based on these three variables have the accuracy equivalent of those computed from 6 yr of streamflow record.

The rainfall-runoff model developed by the USGS has been used to develop a rainfall-runoff relationship for one basin in Oklahoma; two-thirds of the simulated peaks were within 30 percent of the observed peaks. These results are encouraging and indicate that the rainfall-runoff model can be used to successfully extend annual peak data at gaging stations. A new regression analysis will be made to relate the extended peak data to basin and climatic characteristics on the basis of synthetic peak data generated at several sites.

Extending peak-discharge records in Wisconsin

Research to extend short-term peak-discharge records by using long-term precipitation records is be ing conducted by D. H. Conger. Six short-term rainfall-runoff stations have been calibrated by use of the Dawdy model. The calibrated parameters will be used with long-term precipitation records and evaporation records to generate the long-term peak series.

FLOOD MAPPING

Flood-prone areas on the Alafia River at Lithia, Florida

Flood discharges on the Alafia River at Lithia, with recurrence intervals of 10-, 100-, and 200-yr, are about 12,000, 51,000, and 75,000 ft^3/s, respectively. A. F. Robertson and J. F. Turner, using step-backwater techniques to define flood profiles, are delineating areas subject to flooding.

Effects of flooding on lower Hillsborough River in Florida

The lower Hillsborough River, which includes Tampa Reservoir, traverses large urban areas of northeast Tampa and Temple Terrace. Reservoir operation minimizes not only possible downstream flood hazards, but also water-level fluctuations in the reservoir.

The extent of backwater upstream from Tampa Dam associated with a 2-yr flood-peak discharge was evaluated by comparing step-backwater profiles computed for controlled- and uncontrolled-flow conditions through Tampa Dam. These comparisons, made by J. F. Turner (1972), indicated that backwater during controlled-flow conditions is more than 1 ft at Tampa Dam and diminishes to about 0.15 ft at Fowler Avenue, 9 mi upstream.

A backwater profile of the 100-yr-flood peak discharge indicates that many homes in the 10-mi reach between Tampa Dam and Fletcher Avenue would be flooded, as would the Fowler Avenue and Fletcher Avenue bridges.

Flood-flow study at Cedar Falls, Iowa

The city of Cedar Falls is evaluating several flood-plain improvement plans. O. G. Lara (1973) computed and tabulated: (1) Profiles for a regulatory flood and lesser floods on University Branch Dry Run Creek under present channel and valley conditions, (2) floodways and profiles for selected surcharges ranging from 0.2 to 1.00 ft, and (3) a profile for an assumed floodway width of 125 ft. University Branch Dry Run Creek, a small stream flowing from west to east through the campus of University of Northern Iowa and the city of Cedar Falls, drains 2.68 mi^2. Approximately 50 percent of the basin is used for agriculture.

Flood-insurance studies in Minnesota

Investigations are being conducted by L. C. Guetzkow to identify flood-hazard areas and to provide flood profiles and flood-elevation frequency data which are used to establish the actuarial-rate structure for flood insurance. The data are also used to evaluate required land-use control measures which local governmental units must adopt to maintain eligibility for Federal flood insurance.

Flood-plain studies in the lower Minnesota River basin

A hydrologic and hydraulic study of the flood plain of the Lower Minnesota River, extending from Carver Rapids to the mouth, is in progress. The flood plain of the Minnesota River in the 35-mi reach under study is broad and flat and has experienced considerable flood damage in the past. Availability of river-barge transportation in the valley, and the area's proximity to the Twin City metropolitan center, have created much pressure for industrial development on the flood plain.

L. C. Guetzkow used a digital-computer model to delineate flood hazard areas and to evaluate the effects of proposed encroachments on the flood plain. The results obtained are being used for basin planning and as a basis for flood-plain zoning ordinances being adopted by local governmental subdivisions. Data generated by the computer model indicate that recent developments in the basin have caused significant increases in the potential river stage associated with the 100-yr flood in the upper reach of the study area.

Hydrologic and hydraulic studies of flood-plain areas have been conducted by L. C. Guetzkow (1971a, b, c), G. H. Carlson (1971a, b, c), and K. T. Gunard (1971), in seven communities in Minnesota. These studies are used to provide the technical data required for the identification and zoning of flood-plain areas under requirements of Minnesota Statewide Standards for Management of Flood Plain Areas.

Floods in Yahara River basin, Wisconsin

C. L. Lawrence and B. K. Holmstrom defined the profiles and approximate outlines of areas subject to overflow by the regional (100-yr) flood along a 34-mi reach of the Yahara River, Dane County, Wis., at and downstream from Lake Mendota, and for major reaches of six principal tributaries of the Yahara River in the vicinity of Madison. Floods are not serious on this part of the Yahara River because of the great volume of lake storage, but there are several potential flood areas on the tributaries. Investigations of the effects of future urbanization on the regional flood were made for the tributary streams. Major factors considered were estimates of percent of impervious area and lag time of storm runoff.

Maps of flood-prone areas

Areas inundated by the 100-yr flood are outlined on topographic maps as part of the National Program for Managing Flood Losses. The objective of this activity is to quickly inform cities and towns of the general extent of their potential flood problems. A total of more than 8,000 such maps have been completed for all of the States, the District of Columbia, and Puerto Rico.

Inundation maps of urban areas

Maps showing areas inundated by major floods, flood profiles, discharge-frequency relations, and stage-frequency relations were published during the current year as Hydrologic Investigations Atlases for the following areas: Caguas, Gurabo, Juncos, and San Lorenzo, P.R. (F. K. Fields, 1972); and Rapid City, S. Dak. (O. J. Larimer, 1973).

WATER QUALITY AND CONTAMINATION

The development and use of water in many areas are restricted or complicated by the presence of undesirable waste products and natural constituents in surface and ground waters. To study these undesirable water contaminants, the USGS conducts basic research and areal investigations that define the causes and the extent of contamination in the environment.

Mine drainage in Colorado

D. A. Wentz used field observations of pH, specific conductance, aquatic biology, and condition of stream bottom and water to identify streams which are adversely affected by mine drainage or metal-mining and milling operations. Water samples for chemical analyses were collected from Colorado streams at 149 sites where field observations indicated a deterioration of water quality. Maximum observed concentrations of dissolved trace elements include As, 20 μg/l; Cd, 520 μg/l; Co, 280 μg/l; Cu, 10,000 $\mu g/l$; Fe, 45,000 $\mu g/l$; Pb, 220 $\mu g/l$; Mn, 82,000 $\mu g/l$; Hg, 4.5 $\mu g/l$; Mo, 26,000 $\mu g/l$; Ni, 900 $\mu g/l$; Se, 24 $\mu g/l$; Ag, 2 $\mu g/l$; V, 510 $\mu g/l$; and Zn, 99,000 $\mu g/l$. Samples also were analyzed for chromium, but it was not detected. Cadmium exceeded the USPHS drinking-water standards in more than 12 percent of the samples analyzed. Only manganese, iron, and selenium, at 58, 19, and 19 percent, respectively, of the samples analyzed, exceeded the specified limits more frequently than cadmium did. Zinc exceeded USPHS drinking-water standards in 9 percent of the samples, whereas silver and mercury have not been found in excess of acceptable limits. The remaining elements exceeded USPHS standards in approximately 2 percent of the samples.

Field observations and water-quality analyses at 30 stream sites in areas of known or potential coal-mine drainage showed neither adverse effect on the pH nor increased trace-element concentrations. Data collected at 13 stream sites in control areas were very similar to those collected to evaluate the effect of coal-mining operations on stream-water quality.

Contamination in a marine environment in Washington

Isolated high fecal-coliform counts detected in the marine waters surrounding the Lummi Indian Reservation in Washington appear to be caused by decreased bacteria die-away resulting from the preservative effect of freezing water temperatures. G. G. Parker, Jr., and D. R. Cline reported that the highest counts usually occur from November through April, following prolonged periods of subfreezing temperature.

Contamination of ground water in Jefferson County, Colorado

A large number of residents in the mountainous area of Jefferson County rely on individual ground-water supplies and domestic waste-treatment facilities. Chemical and bacteriological analyses of water from wells showed that many wells in the county are contaminated. W. E. Hofstra and D. C. Hall reported that results of 205 chemical analyses showed that 15 samples (7.3 percent) had nitrate concentrations above USPHS drinking-water standards. One sample also contained fluoride in excess of that recommended by USPHS for drinking water. Of 236 bacteriological analyses, 61 (25.8 percent) showed coliform bacteria in excess of Jefferson County Health Department standards. Fecal coliforms were also found in water from about 10 percent of the wells.

Simulation of contaminant migration through a shallow aquifer in Colorado

Salts have leaked from disposal ponds at the Rocky Mountain Arsenal east of Denver and have migrated through the shallow aquifer toward the South Platte River. Salt movement since 1943 has been simulated with a digital model. This model couples a finite-difference technique with the method of characteristics to solve the flow equation and the dispersion equation. L. F. Konikow states that the model shows the rate and direction of movement of contaminants through the aquifer and shows changes in concentration with respect to time and space. The calibrated model can be used to predict the effects of possible alternative management techniques.

Evaluation of spraying sewage effluent near Lakeland, Florida

Irrigation with sprinkler-applied, secondary-treated, chlorinated sewage effluent is being conducted on 30 acres of cattle pasture near Lakeland in central Florida. The water table in the shallow sand aquifer underlying the sprayed pasture ranges from 2 to 8 ft below the land surface. Each day's application averages 25,000 gal of effluent, which is characterized by a BOD of 40 mg/l; by average total nitrogen (principally NO_3-N and organic nitrogen) of 13 mg/l; by average total phosphorus of 7 mg/l; by average total organic carbon of 58 mg/l; and by average total inorganic carbon of 35 mg/l.

R. C. Reichenbaugh reported that, after 30 mo, there were only minor changes in the quality of ground water in the water-table aquifer. At one 4-ft-deep well in the sprayed pasture, NH_4-N is 1.9 mg/l and organic nitrogen is 3.2 mg/l. At an adjacent 8-ft-deep well, NH_4-N is 1.0 mg/l and organic nitrogen is 0.97 mg/l. Nitrogen-specie concentrations in water samples from all other wells downgradient from the pasture are similar to those in nearby wells in the shallow aquifer. Coliform counts of less than 300 colonies per 100 ml have been confirmed in four wells.

Effects of spraying effluent near St. Petersburg, Florida

R. N. Cherry monitored the effects of spraying waste-treatment effluent on a 6-acre practice area at a golf course in northwestern Pinellas County, Fla. A well-leached sand, about 15 ft thick, underlies the field and is separated by a 15-ft-thick clay from the bedrock, the Floridan limestone aquifer.

The nitrogen-species concentration of the sprayed effluent ranges from 15 to 20 mg/l as nitrogen. Nitrate concentrations equivalent to 80 mg/1 nitrogen have been observed in ground water in the sand underlying the spray field. Even higher concentrations of nitrate have been observed in ground water in areas upgradient from the spray field. The high concentrations are probably due to solution of a nitrogenous chemical fertilizer applied to the grassed areas.

Evaluation of ground-water degradation resulting from waste disposal near Barstow, California

The Mojave River alluvial aquifer near Barstow, Calif., has been subjected to contamination from percolation of industrial and municipal sewage for nearly 60 yr. According to J. L. Hughes, effluent discharges have been high in detergents, phenolic compounds, nitrogen, chromium, oil and grease, phosphates, and chemical substances typical of human wastes. The affected ground water has forced abandonment of several domestic wells because of taste, odor, and foaming, and threatens a well field serving a U.S. Marine Corps supply center. The degraded ground water is moving in very permeable river-channel deposits at an estimated rate of 1.0 to 1.5 ft/d and has been defined in extent both areally and vertically. Concentration gradients for dissolved solids, chloride, total nitrogen, dissolved organic carbon, and detergents also were defined.

The chemical stratification within the Mojave River alluvial aquifer indicates that an old plume of degraded water is moving near the base of this aquifer. Since 1910, this degraded plume has moved downgradient about 4 mi. A more recent overlying plume of degraded water occurs near the downstream edge of the deeper plume. This overlying plume is produced by percolation from sewage-treatment facilities installed in 1968. Detergent concentrations beneath the present waste-disposal facility reflect the current use of LAS (linear alkylate sulfonate) types in contrast to the ABS (alkylbenzene sulfonate) types that are found in the deeper zones of degradation.

Distribution of nitrogen and chloride indicates that the gradual increase in dissolved-solids concentrations in the Marine Corps wells is due to the use of treated-sewage effluent on a local golf course. Areal and vertical mapping of the degraded water indicates that the water supply at the base will also be affected by the poor-quality water in the Mojave River alluvial aquifer unless preventive measures are taken to avoid contamination.

The effects of dilution, adsorption, dispersion, and biochemistry were briefly investigated. Comparison of areas degraded by dissolved organic carbon and synthetic detergents indicates that adsorption by the river sediments combined with dispersion has resulted in differential rates of movement of chemical substances. The anaerobic bacteria, genus *Clostridium*, has been identified in the ground water adjacent to the city's present treatment facility.

Contamination of Snake River aquifer in Idaho

K. L. Dyer found that waste irrigation runoff usually contained higher levels of sediment and fecal bacteria than were present in the water applied for irrigation in the south-central part of Idaho's Snake River plain. Most of Idaho's approximately 5,000 waste-disposal wells discharge waste water to the Snake Plain aquifer. The waste water discharged through septic-tank drains contains relatively high levels of nutrients and bacteria. Street-drain water and storm-runoff water may be relatively high in both sediment and fecal bacteria.

R. L. Whitehead, in a similar study in the eastern part of the Snake River plain, reported similar results. Samples from city-street drains showed concentrations of oil and grease ranging from 13 to 4,000 mg/l. The dissolved lead concentration in waste water from three street drains serving subdivisions ranged from 19 to 520 μg/l.

Ground-water contamination near Toledo Bend Reservoir, Texas

The presence of high coliform densities in many samples and fecal coliforms and fecal streptococci in a few samples from test wells near the shoreline of Toledo Bend Reservoir was reported by E. T. Baker, Jr., and Jack Rawson (1972). Coliform density varies considerably in time and place, and the densities of fecal coliforms and fecal streptococci in samples from most wells are much lower than the densities of total coliforms.

The test wells were drilled into unconsolidated clastic sediments, ranging in size from coarse sand to clay, downslope of areas of commercial and residential developments using septic-tank systems. Because the water generally is moving toward the reservoir, the probable source of the pollution is effluent from septic tanks.

Deterioration of ground-water quality at Lake Charles, Louisiana

Industrial wells are pumping water having chloride concentrations of more than 100 mg/l in many areas and of 275 mg/l at one site from the "500-ft" sand of the Chicot aquifer in the Lake Charles area. Chloride concentration generally has been about 30 mg/l. D. J. Nyman reported that a test-drilling program is in progress to determine the source of the high-chloride water. Several possible chloride sources are under investigation—infiltration from salty surface sources, leaky oil and gas wells and test holes, coning of salty water at the base of the aquifer, and pore water from the confining clays.

Preliminary results of the test drilling indicate that surface sources and the oil and gas fields are not the major cause of the problem. The increase in chlorides correlates with heavy pumping in the areas of high water-level decline; therefore, one possible explanation is that salty water may be migrating from the clays into the aquifer. Clay cores have been collected and are being analyzed to determine the chloride content of the pore water, vertical permeability, and other physical properties.

Downstream deterioration of ground water in the Fountain Creek valley, Colorado

J. M. Klein and D. L. Bingham reported that an increase in hardness and dissolved solids in the alluvial aquifer of Fountain Creek valley contributes to deterioration of ground-water quality downstream between Colorado Springs and Pueblo, Colo. Soluble gypsum in the bedrock and alluvial material, and continual reuse of ground water and surface water for irrigation account for the approximate fourfold increase in hardness (from 230 mg/l to 880 mg/l) and dissolved solids (from 480 mg/l to 1,760 mg/l). Calculations indicate that most samples are saturated or supersaturated with calcite and kaolinite.

Microbial ecology of ground water near Barstow, California

G. C. Ehrlich and Ernest Lory isolated a number of obligately anaerobic bacteria from a contaminated ground-water body in the vicinity of Barstow, Calif. Special, glass-bead-filled, perforated metal cylinders were lowered into wells drilled into the degraded water body and were allowed to equilibrate with the ground water. Indigenous bacteria colonized the beads and were subsequently separated from them.

Both gram-negative and gram-positive organisms were found. One isolate, a gram-positive spore-forming organism was identified as *Clostridium beijerinckia*. Pure cultures of *C. beijerinckia* and other isolates did not undergo rapid multiplication when suspended in various samples of degraded and nondegraded ground water from the Barstow area.

Corrosion and encrustation studies in Alaska

A study of corrosion and encrustation of well casings and accessories in selected water supplies in Alaska continued. H. L. Heyward reported that, in general, well parts and accessories constructed of steel are in good condition after 10- to 20-yr exposure to naturally corrosive waters.

Contamination of canals in Florida

H. W. Bearden and C. B. Sherwood, Jr., reported that coliform-bacteria content in the highly controlled canal system of Broward County is considerably higher than State and Federal standards for body-contact water recreation. DO levels in canals receiving large quantities of treated effluent are often below standards set by pollution-control agencies. Nutrient content is generally within acceptable levels in the canals but is above the levels found in natural waters in the area. Contaminants from sewage effluent, road runoff, and other urban wastes are the chief threat to the surface-water resources.

Pesticides in sediment in California streams

L. M. Law and D. F. Goerlitz analyzed bottom muds from 26 streams flowing into San Francisco Bay for chlordane, DDD, DDE, DDT, and PCB residues. The compounds were present in nearly all of the samples. Chlordane was found at levels as high as 800 μg/kg, which was considerably higher than the other insecticide levels. PCB, an industrial compound not an insecticide, occurred more often and in greater amounts than the other compounds; PCB levels were as high as 1,400 μg/kg.

Biological index of organic pollution in Florida

A biological index comparing the diversity and populations of benthic-animal species in relatively clean canal systems and organically polluted canal systems was used by T. N. Russo. Waters relatively free of pollution have an index of about 1.5 in southern Florida, whereas water heavily polluted with organic wastes (nitrogen concentrations of 14 mg/l of NH_4 as N, phosphorus concentrations of 25 mg/l of PO_4 as P, and DO concentrations so low that anaerobic conditions probably occur at night) has indices of 0.1 to 0.2. Because pollution loads vary greatly in time and space, the biological index using the benthic animal populations may prove to be a better index to pollution than the analyses of periodic water samples.

Water quality in the Raritan River basin, New Jersey

P. W. Anderson and S. D. Faust, in studies of the Raritan River basin (1,105 mi^2), have grouped the basin's streams into three regions of isochemical quality. The predominant cations in all regions are calcium and magnesium. In the headwaters region, the predominant anion is bicarbonate; however, a combination of sulfate, chloride, and nitrate is predominant in the other two regions. Dissolved solids in areas little influenced by man's activities generally range from 40 to 200 mg/l and average annual sediment yield ranges from 50 to 500 tons/mi^2.

Results of trend analyses of stream quality in headwater areas indicate an increase in chloride, sulfate, and nitrate content over that observed in the 1920's. Trend analyses of dissolved solids and DO during the period 1957–72 at the confluence of the Millstone and Raritan Rivers at Manville (basin areas above this point, 287 and 497 mi^2, respectively) indicate a deterioration in quality of the Millstone River, particularly at low flows, and an improvement of the Raritan River. The latter change is attributed to low-flow augmentation by upstream-reservoir releases. Below Manville, the main stem flows through a rather large industrial and urban complex. Data collected from 1927–72 indicate a general stream-quality deterioration since the 1920's, particularly in the World War II period; an improvement in the late 1950's after the construction of a trunk sewer; and a decline during recent years owing to increased waste-water discharges and urban runoff.

Effect of a pollution slug on DO in a large river

A slug of heavily polluted water which entered the Yadkin River at the mouth of Muddy Creek, in North Carolina, allowed J. E. Shoffner and H. B. Wilder to observe the complex DO variations that can exist in a large stream. The polluted water created a local oxygen deficit, which caused fish to come to the surface, and was probably responsible for a fishkill at Yadkin College, approximately 10 mi downstream. The water discharge at Yadkin College was 2,520 ft^3/s and the average stream velocity was about 2.3 ft/s. A continuous DO recorder showed that, 10 mi downstream from its point of entry into the river, the polluted slug was still sharply defined, and hand samples indicated that it had not mixed laterally across the river. Within a period of about 40 min, DO decreased from the minimum allowable value of 4.0 mg/l to zero, remained zero for 85 min, quickly increased to 2.2 mg/l within a period of 10 min, then recovered to 4.0 mg/l over the next 125 min. Additional DO determinations showed that higher concentrations existed throughout much of the cross section during the periods of anoxicity on the left bank, and indicated the possibility that no serious deficiency occurred except near the left bank. It appears that fish trapped in the heavily polluted slug of water were unable to escape despite the fact that a tolerable environment was close at hand.

Source of nutrients in Lake Okeechobee, Florida

A. G. Lamonds stated that most of the major nutrients contributed to Lake Okeechobee by the Kissimmee River, its largest tributary, originate in the lower, agricultural part of the basin and not in the upper, urban part of the basin. Analyses of water samples collected in the lower Kissimmee River indicate that local inflow in the lower basin generally is more highly mineralized than the water in the river, and phosphorus concentration in the local inflow is several times greater than that in the river.

ENVIRONMENTAL GEOCHEMISTRY

Geochemical survey of Missouri

In the 4 yr since the geochemical survey of Missouri was initiated, about 7,000 samples of rocks, soils, plants, and waters were collected according to formal experimental designs and were analyzed for about 60 elements. This has resulted in a wealth of background geochemical data for most of the major natural units of the State's landscape. Tabulated summaries of nearly all the data are available in a series of progress reports issued at 6-mo intervals over the life of the program. (See particularly U.S. Geol. Survey, 1972c, d, e, and 1973.)

Much of the soil of the State is developed on two widespread unconsolidated geologic deposits—loess, which occurs over most of northern and eastern Missouri and particularly adjacent to the Missouri and Mississippi valleys, and carbonate residuum, a thick deposit similar to terra rossa occurring over much of southern Missouri. R. J. Ebens and J. J. Connor report that loess collected from thick, well-exposed deposits formed in the bluffs above the Mississippi and Missouri Rivers is in general a very homogeneous unit when compared to residuum. A study undertaken to assess the compositional variability of loess away from the bluffs near the Missouri River indicates that Ca, Mg, K, Na, C, Mn, and Sr generally decrease in concentration away from the bluffs; these elements are held largely in the carbonate or feldspar minerals. Conversely, another suite of elements, believed to be associated with clay or other fine-grained minerals, generally increases as a function of distance from the bluffs. The suite includes Al, Fe, Ga, Li, Se, and V. The relations appear to reflect underlying changes in mineralogy with distance, as might be expected in an eolian deposit. The coarser grained minerals including carbonate and feldspar minerals would tend to be preferentially deposited near the flood plain which was the source of the material. An additional effect which might give rise to variation with distance is that of weathering. Deposits of loess far from the bluffs are thin and are more subject to weathering throughout their vertical extent than are the thicker deposits in bluffs adjacent to the flood plains.

Geochemical investigations of carbonate residuum developed in areas underlain by rocks of Meramecian, Osagean, Jefferson City, Roubidoux, Gasconade, Potosi-Eminence, and Bonneterre age in southern Missouri, northern Arkansas, and northeastern Oklahoma indicate that Al, Cr, Cu, Fe, Ga, Sc, Y, Yb, and Zn in the residuum exhibit statistically significant variation among these different parent rocks. Seven of these elements (Al, Cr, Fe, Ga, Sc, Y, and Yb) are noticeably low in residuum from the area of the Roubidoux Formation. This probably reflects the fact that residuum formed on the Roubidoux tends to be sandy, thus containing lower concentrations of clay-related elements. Six of the elements (Al, Cr, Ga, Sc, Y, and Yb) are noticeably high in residuum from the Osagean or Meramecian parent areas. This probably reflects the fact that such residuum developed from relatively pure carbonate bedrock with little or no interbedded sands. This would give rise to a residuum high in clayey materials and hydrous iron oxides. Exceptionally high concentrations of Cu, Zn, Pb, and Ba in residuum developed on Potosi-Eminence rocks undoubtedly reflect the fact that many of these samples were collected in the southeast Missouri mineralized area.

G. L. Feder, in a preliminary study, noted a marked statewide variation in the chemistry of surface waters collected last year during low flow in Missouri. Differences in surface water collected in the morning and afternoon and differences between filtered (at 0.1 μm) and unfiltered water are slight compared to the effects of the geographic variation. This variation parallels a similarly strong variation among the ground waters of the State and may reflect, in part, dynamic interconnections of surface drainage with local underground water supplies.

H. T. Shacklette, J. A. Erdman, and J. R. Keith found considerable statewide variation in the chemistry of the B horizon of uncultivated soils in Missouri. They report that Q-mode factor analysis of the B horizon of uncultivated soils in Missouri suggests that such soils reflect development on three types of parent material. (See section on "Statistical Geochemistry and Petrology.") The same investigators note that specific plants do not exhibit strong regional geochemical patterns like those observed in the associated soils. For example, the elemental composition of stem ash of sumac (*Rhus glabra*), a shrub common throughout the State, is probably controlled more by soil pH than by soil composition. Correlation coefficients relating the chemical composition of the ash of several tree and shrub species to the composition of local soil are uniformly low. Preliminary analysis of chemical variation in corn and soybeans grown throughout the State indicates that regional geochemical variability in these food crops is even less than in native plants. Chemical variation in plant ash in Missouri appears to occur mostly between species. Within a species, there is little compositional variation associated with variations in the supporting soils.

A number of studies in recent years have attempted to establish a relation between human disease or mortality and the chemistry of soils in the locale of residence. R. R. Tidball (USGS) and H. I. Sauer (Missouri Univ.) (1972) recently reported on an attempt to identify such a relation in Missouri.

The frequencies of premature death (death before age 75) among white males and females, aged 35 to 74 yr, within all 114 Missouri counties for the period 1950–59 were compiled by H. I. Sauer, according to disease, as follows: coronary, other major cardiovascular, diabetes, and cancer. Multiple regression analysis was used to test each mortality rate against the concentrations of 32 soil elements simultaneously. The soil chemistry was that used in a study of 1,140 agricultural soils (U.S. Geological Survey, 1972b, 1972d).

The regression equations are rather poor predictors of the mortality rates. For example, if the concentrations of fluorine, total carbon, and calcium in the soils are known, the logarithm of the mortality rate due to coronary among males may be predicted as follows:

$$\text{Coronary (log, males)} = 2.60+6.28\ F^2-0.0084\ C^3+0.317\ Ca^3$$

This equation, however, accounts for only 19 percent of the variance in the log mortality rate. There are other unknown but obviously important factors that were not included in the test. This result does not completely exclude soil composition as an important factor; rather, some alternate measure of composition, such as the water-soluble component, might be a better predictor. The corresponding equation for females may be expressed as follows:

$$\text{Coronary (log, females)} = 2.18-0.165 \log C$$

This equation accounts for only 4 percent of the variance in the log mortality rate. Regression equations for other mortality rates generally explain less than 25 percent of the variance.

Cadmium and lead in plants

H. T. Shacklette (1972) reported that cadmium in low concentrations most likely is a normal constituent of all plant tissue. The concentrations of this element in plants are controlled by the inherent ability of the species to absorb cadmium and by the cadmium concentrations in the local environment. Differences in cadmium content among plants of different species in low-cadmium soils commonly are proportionately greater than differences in amounts of cadmium in the soils. The cadmium content of plant tissue tends to increase with increase in soil cadmium above certain background amounts. Airborne cadmium, originating in emissions from the combustion of hydrocarbons or from certain industrial processes, may enter the soil and be absorbed by plants or may be deposited on the surface of plants in particular matter until very high levels of cadmium have accumulated. Dry tissues of plants grown in environments with ordinary cadmium levels contain 0.02 to 0.1 p/m cadmium; if grown in environments having uncommonly high cadmium levels, the dried plants may contain 40 to 340 p/m. There seems to be no natural means by which cadmium is eliminated from plant tissue, and no cultural practice has been found to be effective in reducing or preventing the absorption of cadmium.

H. L. Cannon reports that whereas lead in plants in uncontaminated and unmineralized areas averages about 2 p/m in the dry weight, as much as 350 p/m lead has been measured in the dry weight of vegetation rooted in soils overlying rocks containing lead ores, and as much as 664 p/m have been reported in vegetation subjected to the effects of man. A large percentage of lead in ordinary soils is not available to plants, and only in areas of high-soil lead, such as mining districts, is the growth of plants ever seriously affected. Probably of greatest environmental significance is atmospheric lead derived from lead smelters or other industrial plants and automobile emissions. Although there is no clear evidence that lead from the atmosphere enters into plant tissue, and atmospheric lead in or on forage may constitute a hazard to livestock. Washing and preparation of vegetables commonly reduces their lead content prior to human consumption, with the possible exception of lettuce or other leafy vegetables that may be consumed in the raw state.

Lithium and cadmium in soils of the United States

The concentrations of lithium and cadmium in 912 samples of soils and other surficial materials from sites approximately 50 mi apart throughout the United States were reported by H. T. Shacklette, J. G. Boerngen, J. P. Cahill, and R. L. Rahill (1973). The geometric mean lithium concentration is 20.4 p/m for all samples, 17.3 p/m for samples from the Eastern United States (east of the 97th meridian), and 23.3 p/m for samples from the Western United States (west of the 97th meridian). Cadmium concentrations were found to be less than 1 p/m in all but 11 of the 912 samples. Ten of these 11 concentrations ranged from 1 to 1.5 p/m; one sample contained 10 p/m cadmium.

Mercury in the Four Corners region

H. L. Cannon and V. E. Swanson report that mercury analyses of 110 soil, stream sediment, vegetation, and water samples in the Four Corners region indicate that no discernable pattern of mercury exists in the region that can be attributed to the burning of large tonnages of coal at the Four Corners powerplant. Samples of soil from the top ½ in. and from 1 to 6 in. below the surface, which were collected on a 50-mi traverse between the powerplant and Navajo Lake, generally contain less than 0.07 p/m mercury and exhibit no significant vertical or lateral pattern of variation; all vegetation samples contained less than 0.025 p/m of mercury. Samples of sediments from streams tributary to Navajo Lake from the north range from less than 0.01 to 0.06 p/m mercury. Nine sediment samples from Navajo Lake itself all contained less than 0.07 p/m mercury. The mercury contents of 10 water samples from streams and lakes were all below the limit of detection or less than 0.5 μg/l. Thus, any mercury omitted by combustion of Four Corners powerplant is so disseminated areally as to be undetectable except possibly within a few miles of the plant.

Chemical elements in Spanish moss

Spanish moss (*Tillandsia usneoides*) is a widespread finely divided pendant plant on trees and other aerial supports throughout much of the Southern United States. Because it is an epiphyte, it must obtain all of its nutrients and other constituents directly from the air, either as gases, solutes in rainwater, or airborne particulate matter. Recent work by H. T. Shacklette and J. J. Connor (1973) on the chemistry of 123 samples of this plant collected throughout its range of occurrence suggests that it may act as a long-term integrator of local atmospheric element loads. Its usefulness for atmospheric evaluation seems confirmed by the discovery that four of six samples of Spanish moss containing detectable tin were located within 50 mi of the only tin smelter in the United States.

Multivariate analysis of the compositional variation observed in ash of this plant and suggestions as to general element sources are briefly described in the section on "Statistical Geochemistry and Petrology."

Geochemistry of the Front Range urban corridor

The regional distribution of about 35 elements in surficial materials of the Front Range urban corridor in central Colorado is being investigated by H. A. Tourtelot to reveal areas of possible geochemical concern as well as to determine backgrounds against which future effects of urbanization can be measured. A pilot study has been completed in an 1,800 km^2 strip centered on Longmont, Colo., to establish the geographic scales at which element variation is most important. Samples for the pilot study were taken at the surface independent of the particular earth materials involved. Preliminary work suggests that element patterns in the pilot study strip primarily reflect compositions of underlying geologic units and secondarily reflect element contributions from local technological activities.

LAND SUBSIDENCE

Land subsidence, caused by the extraction of fluids from the subsurface, probably affects 10,000 mi^2 in heavily developed basins of five States. Whereas rates have diminished greatly in most of the subsidence areas of California due to surface-water importation, problems continue to multiply in local areas of Texas, Arizona, Louisiana, and Nevada. Studies of sinkhole collapse, caused by water-table lowering, continue in part of Alabama and Florida and are discussed in the section "Ground-Water Hydrology."

Land subsidence continues in the Baytown, Texas, area

Extensive production of ground water, oil, and gas in Harris County, Tex., has caused fluid-pressure declines and widespread land subsidence in the area of Baytown, according to R. K. Gabrysch (1973). Production of oil and gas from the Goose Creek field at the southern edge of Baytown had caused as much as 3.25 ft of subsidence by 1925, largely restricted to the area of production. Withdrawals of water by large-capacity industrial wells began about 1918 and have caused widespread subsidence of the land surface. Between 1920 and 1971, as much as 250 ft of pressure decline and 7.5 ft of subsidence occurred. Homesites around Burnett, Scott, and Crystal Bays on the western edge of Baytown are now subject to inundation by high tides.

Gabrysch reported that undisturbed clay samples, water-level records, and pore pressures in clay beds were analyzed for computation of predicted subsidence. Ultimate subsidence, on the basis of present loads, was computed to be 9.3 ft and, on the basis of predicted loads, was computed to be 11.2 ft.

Canal deliveries reduce subsidence rates in the San Joaquin Valley, California

Subsidence rates have greatly diminished throughout most of the subsidence areas of the San Joaquin Valley, according to studies by J. F. Poland and B. E. Lofgren. This is due principally to large surface-water imports to areas of pumping overdraft, from the Friant-Kern Canal on the east side of the valley and the Federal-State California Aqueduct on the west side of the valley. At the center of maximum subsidence, 40 mi west of Fresno, where more than 28 ft of subsidence has been measured, the subsidence rate has decreased from a maximum 1.76 ft/yr during the period 1953–55 to 0.66 ft/yr during the period 1966–69.

The total area affected by subsidence is about 5,200 mi^2, or about half of the valley floor. About 15.5 million acre-ft of subsidence occurred from

1926 through 1970 of which roughly three-quarters occurred since 1950. In one area, about one-third of the 24 million acre-ft gross pumpage from wells for the 26-yr period 1943–69 was derived from the compaction of the sediments.

Radiocarbon dates suggest rapid tectonic subsidence in San Jacinto Valley, California

Recent carbon-14 age determination of wood samples collected from drill cuttings of a water well in the graben trough of San Jacinto Valley indicate continuing rapid tectonic subsidence in this major branch of the San Andreas fault system, according to B. E. Lofgren. The following age determinations were supplied by USGS scientists:

Sample depth, in feet	*Age, in years B.P.*
292	15,270± 450
322	21,260± 650
480	42,000±1,500

Assuming that graded San Jacinto River serves as a rough reference datum during this depositional sequence, these sample dates indicate a surprisingly rapid rate of downfaulting in the graben. From 42,000 to 15,000 yr ago, the depositional rate averaged about 7.6 ft per thousand years. Since 15,000 yr B.P., the rate has been much more rapid.

ASTROGEOLOGY

LUNAR EXPLORATION

APOLLO FIELD GEOLOGY INVESTIGATIONS

In 1972 the last two Apollo missions to the Moon were undertaken by NASA. The Apollo 16 space vehicle was launched from Kennedy Space Center on April 16, and on April 21 the LM (lunar module), carrying J. W. Young and C. M. Duke, landed at lat 8°59′29″ and long 15°30′52″ E. in the central highlands north of the old crater Descartes. Young and Duke spent more than 20 h outside the LM, traversed more than 20 km, and returned with 95 kg of lunar samples.

The final mission, Apollo 17, launched December 7, landed E. A. Cernan and H. H. Schmitt on December 11 at the Taurus-Littrow site in the highlands east of Mare Serenitatis (lat 20°10′ N., long 30°46′ E.). Cernan and Schmitt traversed about 30 km and collected about 120 kg of samples during 22 h of exploration outside the LM.

Summary reports of the geology of the Apollo 16 site have been published by W. R. Muehlberger, principal investigator, and members of the Field Geology Investigations Team (Muehlberger and others, 1972; Apollo Field Geology Investigations Team, 1973). Preliminary reports covering the Apollo 17 site are in preparation.

The prime objective of Apollo 16 was to sample materials directly from the central lunar highlands. The site is close to the Kant Plateau, the topographically highest part of the lunar near side. Two photogeologic units had been recognized throughout the highlands by their morphology: a relatively smooth but locally irregular plains-forming unit filling topographic lows, mapped as Cayley Formation, and topographically higher rugged, hilly, or mountainous constructional terrain, of which the Descartes Mountains at the landing site are an example (D. J. Milton and C. A. Hodges, 1972). Before the mission both kinds of terrain were interpreted to be formed of volcanic materials, in spite of the absence of distinct volcanic landforms. It was, however, also recognized that these units might be ejecta from large impact basins or deeply churned fragmental debris transported by mass wasting or impact from adjacent high areas.

The Apollo 16 crew explored and sampled both plains and rugged hilly and furrowed highlands. Their samples, photographs, and observations indicate that the Cayley plains at the Descartes site consist of a sequence of crudely stratified breccias at least 200 m thick, overlain by 10 to 15 m of regolith. The components of the breccias are derived from plutonic anorthosite, feldspathic gabbro, and metamorphic rock of similar composition. The textures and structures of the breccias and their clasts resemble those of impact breccias rather than those of volcanic rocks.

Materials of the Descartes highlands collected on the flanks of Stone Mountain are lithologically similar to the samples attributed to the Cayley Formation. In the absence of marked differences, it is difficult to be certain that Descartes materials were sampled. The regolith from both units is also compositionally similar, and both units appear to be composed of anorthositic rocks; the Descartes highlands differ from the Cayley plains more in physiographic expression than in lithologic character. Possibly, however, no Descartes materials were available for collection at the surface in the traverse area.

The crew of Apollo 17 explored more northerly lunar highlands and found them likewise to be composed of impact-generated breccias. The mission landed in a deep (> 2 km) narrow valley that embays the mountainous highlands at the southeastern rim of Mare Serenitatis, one of the major basins of the lunar near side and the site of a pronounced mascon. The valley is oriented radially to the mare, has a flat floor, and is interpreted to be a deep graben between steep-sided mountain blocks and to have formed as a result of the Serenitatis impact event. Pre-mission maps (D. H. Scott and others, 1972) showed five major rock units believed to represent some of the oldest and youngest materials on the Moon.

Results of the mission indicate that the valley is filled by a kilometer of basalt with small amounts of orange glass, black devitrified glass, and a regolith of fragmental material on the order of 15 m thick. Material from both highland massifs was obtained by sampling boulders that had rolled down the steep (25°) slopes and from avalanche debris on the south side of the valley. These boulders are composed of complex breccias generally similar to the breccias in the samples from Apollo 15 and 16. The avalanche was broken loose by impacts of secondary ejecta blocks near the crest of the massif. Two stratigraphic units were sampled from this debris. The boulders sampled from the north valley wall can be traced by their tracks to their source about one-third of the distance up the mountain side. These highland breccias are interpreted as ejecta from large impact basins.

LUNAR AND PLANETARY INVESTIGATIONS

Mariner 9

The highly successful Mariner 9 Mission provided photographic coverage of 100 percent of the surface of Mars. Team Leader Harold Masursky and members of the Mariner 9 television team prepared preliminary geologic maps of the entire planet (J. F. McCauley and others, 1972) and conducted studies on a wide variety of topics suggested by the pictures.

M. H. Carr reports that two classes of volcanic features occur on Mars. The first are sparsely cratered plains that resemble the lunar maria and the second are circular features generally of enormous size. In some respects the latter appear to be analogous to terrestrial intraplate volcanic features although no evidence for subduction zones has been recognized in any of the pictures. Carr speculates that the Martian shield volcanoes are larger than their terrestrial counterparts because the Martian crust is fixed. He also points out that the volcanic activity has occurred throughout all the decipherable history of the planet.

Photogeologic interpretation of the Mariner 9 pictures also leads to the discovery of numerous channel systems on Mars. The largest system is as much as 100 km in width and 3,000 km in length. Individual channels with braided patterns and structures resembling bars have been attributed by D. J. Milton to the action of running water. Numerous other generally smaller channels occur on steep slopes and may have been produced by runoff of precipitation. The configuration of the dendritic canyon systems suggests that sapping by ground water was an important agent in their development and may have contributed significantly to the retreat of large escarpments on a regional scale. The channels, and the plains that are associated with them, apparently are relict landforms from an earlier fluvial stage in Mars' history.

J. F. McCauley has suggested that wind erosion is a far more important surface-shaping process on Mars than it is on Earth. At least seven different types of probable erosion windforms are recognized in the Mariner 9 data. Detailed comparisons between these landforms and those of the coastal desert regions of Peru have shown remarkable similarities in form and scale. Observations of the north polar region of Mars, as reported by L. A. Soderblom, indicate that the polar cap displayed a peculiar polygonal outline during most of the period of retreat. Whereas densely cratered terrain dominates the southern hemisphere, moderately cratered plains occupy much of the northern hemisphere. These plains are mantled by layered deposits in concentric belts, and the erosional boundaries between these deposits and the cratered plains show no topographic relief. Some of the smooth plains and etch-pitted plains underlying the permanent ice caps of both Martian polar regions display locally coherent patterns of ripplelike wave forms similar to those identified in the equatorial regions as dune fields.

D. E. Wilhelms has identified a number of multiringed circular basins in the more primitive-appearing parts of Mars. Examples are Argyre, Hellas, Libya, Edom, and Iapygia, which resemble in varying degrees the basins that control the regional geology of the Moon. As in the case of the Moon, there is a relation between basin size and the number of rings; the larger the basin, the more rings present and the wider their spacing. In addition, radial structures are conspicuous around several of the Martian basins. The similarities between Martian and lunar basins are considered evidence for a similar origin, probably by impact.

Systematic mapping of Mars

Preliminary work by a group of university and USGS personnel involved in systematic geologic quadrangle mapping of Mars indicates that the geologic history of Mars has been more active than that of the Moon and probably involved the interaction of terrestriallike processes as well as some that may be unique to the planet itself, according to D. H. Scott. Ancient cratered terrains are more subdued than those on the Moon, and extensive areas of smooth plains are occupied by eolian deposits. Systems of deep, broad canyons may represent crustal subsidence along major fractures and sinuous channels eroded by transitory floodwaters. Some extremely large volcanoes appear to be relatively young, localized features; more extensive, perhaps older, volcanism is indicated by flowlike ridges and lobate scarps only partly buried by windblown material. Long linear systems of fractures, faults, and graben are common; swarms of these structures extend radially outward from the Nix Olympica–Tharsis ridge volcanic complex and indicate that volcanic doming and (or) isostatic uplift have affected an area of several million square kilometers. The polar regions of Mars exhibit a unique stratigraphy including a well-developed succession of layered materials—possibly ice and eolian dust.

Viking landing-site investigations

Data on Mars, both from spacecraft and Earth observations, were examined by a panel of planetary scientists to select sites for unmanned landings by two Viking spacecraft in 1976. Geological maps of 22 possible sites were prepared by the USGS and were used in the analysis of scientific objectives and landing safety. Harold Masursky directed the mapping efforts. The search for life on Mars influenced the eventual selection of two prime sites and two backup sites. The geologic studies indicated that a wide variety of eolian volcanic, and possibly fluvial materials are present at the four sites.

Lunar geological mapping

While compiling a synoptic map of the west limb and far side of the Moon (scale 1:5,000,000), D. H. Scott has shown that the smooth facies of the Orientale ejecta blanket is indistinguishable from material mapped elsewhere (beyond the Hevelius Formation) as smooth plains deposits. Prior to the Apollo 16 Mission to the Moon (Descartes landing site), the smooth plains were regarded as composed chiefly of volcanic material similar to the mare basalts. The Apollo 16 samples indicated that the smooth plains at the Descartes site consisted mostly of breccias. These data, coupled with the foregoing observations around the Orientale basin, suggest an alternate origin for much of the lunar plains materials.

A reconnaissance geologic map at the scale of 1:5,000,000 of the north polar region of the Moon is being prepared by B. K. Lucchitta. Geologic mapping and interpretation are based predominantly on images from Lunar Orbiters IV and V. The far-side region is dominated by ancient cratered terrain and hilly terra regions, probably composed of many ancient, overlapping ejecta deposits of craters and basins. The hilly morphology is thought to have developed from impact-generated seismic vibrations causing structural adjustments and mass wasting. Several basins can be recognized on the far side of the Moon: Birkhoff and Schwarzschild have walls resembling those of craters but have interrupted ringlike mountains rather than central peaks. The early Imbrian crater Compton has a well-defined mountainous ring instead of a central peak and may be regarded as straddling the borderline between craters and basins. A nameless ancient basin centered at lat 52° N., long 123° E. was identified. The Humboldtianum basin has a radially structured ejecta blanket and secondary craters. Several Imbrian and Eratosthenian craters occur in the vicinity of the lunar north pole. Conspicuous among them is the large (> 100 km diameter) crater Plaskett at lat 82° N., long 175° E. This crater contributed to the anomalously dense secondary crater population visible in the north polar area on the front side of the Moon.

Several areas of the Moon which are of special geologic interest are being mapped at a scale of 1:250,000 to permit the portrayal of more detail than was possible in the 1:1,000,000-scale series. The Censorinus map by Mareta West has been completed and covers an area in the east-central part of the near side of the Moon. The crater Censorinus is a relatively fresh feature, presumably formed by impact, in the lunar uplands between Mare Tranquillitatis and Mare Nectaris. Bright rays, extending 12 to 15 crater diameters beyond the rim crest, and blocks as large as 50 m were ejected during the event which formed the 4.5-km-diameter crater. Also of interest in the Censorinus areas are mantling materials, which appear to have obscured remnants of the Nectaris basin and therefore are younger than the basin.

The Rima Hyginus map, by R. J. Pike, Jr., includes the rille which is part of an extensive system of fractures and lineaments near the center of the lunar earthside hemisphere. Pike has recognized a subtle lineament which probably is a 400 km extension of Rima Ariadaeus. Mapped on the floor of the crater Hyginus are three rock units interpreted to be of volcanic origin.

Lunar data synthesis

Farouk El-Baz (Natl. Air and Space Mus., Smithsonian Inst.) and D. E. Wilhelms (USGS) have correlated laser and geochemical data obtained in lunar orbit by the Apollo 15 and 16 spacecraft with geologic provinces previously mapped on the basis of photographs. The laser altimeter shows that the rugged, densely cratered, light-colored highlands approximately between Tsiolkovsky and long. 180° are 2 km higher than the highlands west of Tsiolkovsky which are more extensively mantled by basin ejecta. The latter terrain in turn lies about 2 km higher than near-side terrain which is characterized by extensive mare flooding and which begins at about long. 95° E. of the east edge of Mare Smythii, the easternmost of the deeply flooded, circular basins. The X-ray fluorescence spectrometer shows that the elevated and highly cratered highlands on the far side have the highest Al:Si ratios and correspondingly the lowest Mg:Si ratios on the Moon. The maria, on both far and near sides, are low in Al:Si and correspondingly high in Mg:Si. The gamma-ray spectrometer has measured a very low level of radioactivity on the far side, apparently indicating less than 1 p/m of thorium. Only near the maria do counts increase up to a few parts per million. The highest radioactivity is in the western maria of the near side, where counts reach 10 p/m.

R. J. Pike, Jr., has quantitatively classified more than 20 different types of lunar and Martian craters as well as terrestrial analogs (400 craters in all). The classification yielded two groups of strongly contrasting crater shapes and modes or origin. "Main-sequence" lunar craters and one type of Martian crater are similar to terrestrial impact and experimental explosion craters. They differ markedly from lunar dome craters and another type of Martian crater, terrestrial calderas, cinder cones, and lava domes and cones. Terrestrial maar craters and tuff-rings are not entirely consistent in shape with either group.

The distribution of melted ejecta around lunar impact craters suggests to K. A. Howard and H. G. Wilshire that, for craters between 50 and 200 km diameter, shock melted material occurs as far as a crater radius from the present crater rim. Extrapolated to the Imbrium basin, this would indicate the presence of melted ejecta beyond the Apollo 14 site; the apparent absence of pooled melt this far from the basin may be the result of dispersal of melt in a much larger volume of unmelted debris.

Re-examination of the question of lunar highlands volcanoes was made by H. G. Wilshire, D. E. Wilhelms, and K. A. Howard in terms of terrain and sample analysis at the Luna 20 and Apollo 16 sites. These comparisons suggest that both areas are underlain by basin ejecta rather than by volcanic rocks and that similar terrain elsewhere on the Moon may also be underlain by ejecta.

L. A. Soderblom has developed a technique to obtain estimates of ages of lunar mare units from orbital photography by studying the distribution of shapes of small (<1 km) eroded craters. The technique is based on a quantitative model of small impact erosion. The results indicate that (1) the period of major mare vulcanism continued to about 2.8 b. y. ago, (2) Apollo 11 and 12 samples represent units of old and moderate age respectively, and (3) certain small localized volcanic episodes may be <2 b. y. old.

TERRESTRIAL ANALOG AND EXPERIMENTAL STUDIES

DRY VALLEYS OF ANTARCTICA

Mariner 9 pictures of Mars reveal that much of the surface of the planet is occupied by vast deserts with many eolian and depositional features. The USGS is participating in a NASA-sponsored program of investigating selected terrestrial deserts as analogs of Martian terrain. Cold desert regions, such as the dry valleys of Antarctica, are thought to be particularly advantageous for gaining an understanding of the surface conditions of Mars.

A field of active transverse dunes in Lower Victoria Valley, South Victoria Land, Antarctica was studied during the austral summer of 1971–72 (E. C. Morris and others, 1972). On a moderately windy day, some dunes in the field were advancing at a rate of about 1 cm/h, measured at their crests. The prevailing wind is nearly constant during the summer months and blows from the east up Victoria Valley. Aerial photographs taken of the field in 1962 and again in 1970, however, show that the individual dunes have not moved or changed shape appreciably over the 8-yr period.

A close examination of the dunes reveals beds of frozen snow and sand exposed beneath the mobile sand of the dunes. These frozen beds have attitudes inconsistent with the present dunes and were probably deposited during the austral winter by winds blowing from the west down the valley towards the Ross Sea. The conclusions are that these beds are part of a system of winter dunes that are eroded and buried by summer dunes and that the individual dunes oscillate about a more or less permanent position, reversing directions with the seasons.

PLANETARY CARTOGRAPHY

Mars

A 1:25,000,000 shaded relief map of Mars was published as USGS Miscellaneous Geologic Investigations Map I–810. This map was based on an early generation of uncontrolled mosaics prepared from scaled, unrectified pictures. A second generation of 1:5,000,000 "semicontrolled" mosaics is being made with specially enhanced pictures, geometrically transformed and scaled to standard map projections. Individual frames are custom processed, and the mosaic is retouched by airbrush for optimum effect without loss of map information. This series of mosaics is currently being used for Mariner 9 data reduction. Mosaics of proposed Viking landing sites have also been prepared at scales of 1:1,000,000 and 1:250,000.

Other missions

Methods for cataloging and accessing large amounts of cartographic data are being developed to support future planetary missions. These methods include (1) rapid compilations of photomosaics and (2) computer programs devised to search large sets of picture data, select picture categories desired for a given area, list the picture identification numbers, and plot picture footprints on specified map projections. These methods will be applicable to Mariner Venus-Mercury '73, ERTS, and Viking Mars '75 cartographic problems. Methods for digital cartographic picture processing are also being developed. These include programs for geometric transformation of television pictures, and tone and contrast matching for optimum mosaicking.

LUNAR SAMPLE INVESTIGATIONS

Petrology of lunar rocks

Based on petrographic studies of thin sections at the Lunar Receiving Laboratory, Houston, Tex., hand specimen photographs, and megascopic and chemical data provided by the Lunar Sample Preliminary Examination Team, a preliminary genetic classification of about 50 Apollo 16 samples of hand-specimen size has been formulated by E. C. T. Chao.

This genetic classification is based on criteria similar to those adopted for classifying other lunar rocks and breccias of earlier missions. It includes the following categories: (1) "Young" and "old" regolith breccias, (2) brecciated, granulated anorthosites and essentially monomict anorthositic breccias, (3) highly feldspathic polymict breccias, (4) hornfels of feldspathic or noritic composition with abundant xenocrysts but few xenoliths, (5) breccias of feldspathic or noritic composition, with moderate to abundant white feldspathic xenoliths, metamorphosed to hornfels, (6) fine-grained xenocryst-laden vesicular rocks with igneous textures, (7) glass-impregnated complex breccias of various types, and (8) feldspathic basalts and rocks with igneous textures. Each category is further classified into unshocked and shocked types.

The predominant rocks are breccias in category 3 which are highly feldspathic polymict breccias with a wide range of induration and history of shock; some were thermally metamorphosed, then shocked. Many of the light feldspathic clasts and dark noritic and troctolitic clasts within the feldspathic breccias of category 3 and many of the hand-specimen size, dark-colored hornfels and breccias metamorphosed to hornfels (categories 4 and 5) probably represent recrystallized or thermally reheated fragment-laden glasses. The hornfels, some of which contain well-developed poikiloblastic pyroxenes, grade into thermally metamorphosed breccias in which xenoliths are abundant. Distinction between categories 4 and 5 versus 6 is based on interpretation of textures.

As compared to the Apollo 14 breccias, the Apollo 16 breccias are distinctly richer in plagioclase—in xenocrysts, xenoliths, and in the matrix. Unlike the Apollo 14 Fra Mauro breccias which were interpreted to be Imbrium ejecta, the Apollo 16 breccias were derived from a distinctly plagioclase-predominant source area (Chao and others, 1973).

Principally on the basis of study of hand-specimen size samples using binocular microscopes, H. G. Wilshire, D. E. Stuart-Alexander, and E. D. Jackson made a preliminary classification of the Apollo 16 rocks into three groups: (1) Crystalline rocks which are subdivided into igneous and metamorphic subgroups, (2) glass, and (3) breccias which are divided into five subgroups on the basis of clast and matrix colors.

More than 75 percent of the samples returned are breccias, and of these the majority are either annealed fine-grained dark-gray breccias with light-gray crushed gabbroic clasts or unannealed light-gray breccias with clasts of fine-grained dark-gray material. Analogy with large terrestrial impact structures in crystalline rocks suggests that rocks like the annealed Apollo 16 breccias formed as a consequence of a major lunar impact event. Relict, uncrushed rocks indicate that the target material consisted of plutonic anorthositic, noritic, and troctolitic rocks. First generation breccias, consisting of anorthositic clasts in a matrix of annealed, partly melted anorthositic rocks, were subsequently reworked by smaller impact events to produce the varied lithologies of the samples.

H. G. Wilshire and E. D. Jackson (1972) published a report on monomineralic aggregates of olivine, pyroxenes, and plagioclase from Apollo 14 breccias. These aggregates are shown to represent recrystallization of single mineral grains; the average size of the aggregates is smaller than the grain size of their probable source rocks. Hence, application of igneous rock names to these aggregates and inferences regarding differentiation trends based on them are thought to be inappropriate.

The crystallization history of lunar feldspathic basalt 14310 has been investigated by O. B. James. It crystallized at or near the lunar surface from a melt of essentially the same bulk composition as the present rock. This melt contained no silicate xenoliths or xenocrysts and probably no phenocrysts, but meteorite-derived Fe-Ni-P-S melt globules (and possibly also solid particles) were present. Plagioclase was the first silicate to form, at about 1,310° to 1,320°C. After crystallization began there was no abrupt volatilization of alkalis from the melt. Orthopyroxene was the second major silicate to precipitate; some grains of this mineral show complex oscillatory and reverse zoning probably related to local variations in volatile content of the melt. As crystallization progressed in the silicate melt, the following events occurred: (1) Orthopyroxene reacted with liquid, and pigeonite precipitated; (2) augite precipitated; (3) ilmenite precipated; (4) augite crystallization ceased; and (5) mesostasis minerals crystallized, and glasses solidified. During crystallization of the silicate melt, the globules of Fe-Ni-P-S melt precipitated first Ni-Fe, then schreibersite, and then troilite. Characteristics of these particles indicate that the melt from sample 14310 was not quenched at any time during crystallization, that final solidification of the rock took place at about 950°C, and that subsolidus equilibration continued to below 550°C. Oxygen fugacity throughout crystallization was about comparable to that in Apollo 12 basaltic melts.

The 14310 melt could have been generated by (1) partial or bulk melting of a feldspathic rock in the lunar crust or (2) impact melting of feldspar-rich lunar surface materials. The latter alternative is favored.

A detailed chemical and petrographic investigation of Apollo 16 sample 68415 has been made by R. T. Helz and D. E. Appleman. This study was carried out principally on polished thin section 68415,37 and rock chip 68415,74 with additional data from polished thin section 68415,134 and bulk sample 68415,85. The rock consists chiefly (80 wt. percent) of randomly oriented plagioclase laths ranging from less than 0.1 mm to several milimeters in length. As in rock 14310 (O. B. James, 1973), the size of the plagioclase varies continuously, rather than having a bimodal distribution. The remaining 20 percent of the rock consists principally of subhedral to anhedral grains of olivine, pigeonite, and augite which are interstitial to the plagioclase laths.

Most of the plagioclase in 68415 occurs in laths with well-developed crystal faces, and the tabular habit characteristic of feldspar that has crystallized from a melt. Crystals of this type range in composition from An^{97} to An^{71}. The laths are strongly zoned near the margins; in 68415,37 the zoning is always normal although many of the larger laths in 68415,134 show a narrow band of reverse zoning, similar to that described by A. J. Gancarz and others (1972). The most sodic feldspar occurs as thin rims on the medium to large laths and as independent small laths in the groundmass.

In addition to the plagioclase laths described above, sample 68415 contains a few percent of plagioclase grains of highly irregular shape showing no developed crystal faces. These grains range from 0.5 mm to several milimeters in size, are usually subequant, and display curved fracture patterns and wavy extinction. Twinning is poorly developed in contrast to the heavily twinned lath-shaped crystals. The composition of such anhedral plagioclase crystals is restricted to the range An^{97} to An^{93}. These grains show no evidence of reaction with a melt, such as resorption, nor do they have overgrowths of more sodic feldspar. They are further distinguished compositionally by their extremely low FeO content, 0.04 to 0.12 weight percent. The lath-shaped plagioclase has a higher FeO content for the same An content.

Unlike rock 14310, rock 68415 contains about 5 weight percent olivine. The olivine ranges in composition from Fo_{70} to Fo_{67}; no zoning is evident. In section 68415,134 olivine is commonly mantled by pigeonite; in section 68415,37 this relationship is rare.

Rock 68415 contains two pyroxenes, augite and calcic pigeonite, with pigeonite predominant. The augite is strongly zoned and contains exsolved pigeonite. The coexisting pyroxene compositions are characteristic of igneous rather than metamorphic assemblages (Malcolm Ross and J. S. Huebner, oral commun.). No orthopyroxene was found, also in contrast to rock 14310.

Rock 68415 contains about 0.5 weight percent of an interstitial colorless glass rich in K_2O. Plagioclase bordering the glass is slightly enriched in K_2O relative to plagioclase of the same An content elsewhere in the section. Associated with the glass are pyroxferroite, apatite, and other unidentified phosphates.

Rock 68415 contains minor amounts of ilmenite, ulvospinel, troilite, and metallic iron. Single-phase Fe globules have Fe content from 87 to 100 weight percent; polyphase P-rich globules containing schreibersite and a metallic Fe phase have been observed as inclusions in both large plagioclase laths and anhedral plagioclase (O. B. James, oral commun.) in both sections 68415,37 and 68415,134.

Textural evidence indicates that most of the plagioclase and all the other minerals in 68415 crystallized from a melt. The general resemblance of 68415 to rock 14310 suggests that the melt was produced by impact melting with subsequent crystallization near the lunar surface. This hypothesis is supported by (1) the very high plagioclase content (80 percent), even higher than 14310, and (2) the presence of 2 percent anhedral plagioclase whose distinctive composition indicates its origin from metamorphosed anorthosite and is compatible with its being an unmelted residuum. Observation 2 cannot be reconciled with the contention of A. J. Gancarz (Gancarz and others, 1972, p. 326) that complete melting and rehomogenization occurred and that clasts from the soil are absent. Given the lack of overgrowths on the anhedral anorthite grains, however, the possibility that they were picked up by the melt after it had substantially cooled cannot be ruled out.

The petrology of Apollo 17 sample 76055,10, a thermally metamorphosed fragment-laden olivine micronorite hornfels, has been investigated by E. C. T. Chao. It consists of a large clast of olivine micronorite hornfels with well-developed porphyroblastic texture surrounded by highly vesicular olivine micronorite hornfels with incipient development of the porphyroblastic textures. This rock contains xenoliths of granulated dunite, xenocryst-laden olivine-plagioclase rocks, granulated and recrystallized anorthosite, annealed shock-vitrified plagioclase glass, and well polygonalized anorthosite.

Pink spinels with radial anorthite rims occur in both the clast and the surrounding matrix. Many anorthite xenocrysts inside the clast have overgrowths of anorthite separated by a ring of olivine blebs. Olivine and porphyroblasts of orthopyroxenes in the clast are generally slightly more magnesian than those in the surrounding matrix. Plagioclase inside the clast is also slightly more calcic than that outside. The clast is richer in plagioclase and olivine, whereas orthopyroxene is more predominant in the matrix. Nickel-iron particles are present in both parts. Apparently only armalcolite is present inside the clast whereas, in addition to armalcolite with sieve texture, some ilmenite cores surrounded by armalcolite still exist in the surrounding matrix.

The texture of this rock is metamorphic, probably the result of sustained reheating and annealing. The clast and the surrounding matrix were heated to temperatures probably in excess of 1,000°C, assuming an oxygen fugacity between 10^{-12} and 10^{-15} bars.

It is possible that 76055 itself is a clast enclosed in or in contact with some other melt rock. It was not shocked by impact after the thermal metamorphism, and $^{40}Ar/^{39}Ar$ age of 4.0 b. y. (T. Kirsten, oral commun.) is the date of its last metamorphic episode.

Despite the complexity of lunar geology, a limited number of magma series currently are being implied or explicitly postulated by various scientists. In a cogenetic rock series, melt inclusions trapped in early olivine crystals, inclusions trapped in later rock minerals, and late-stage interstitial melt inclusions should delineate a unique line of descent which splits into two lines at the onset of silicate liquid immiscibility. Edwin Roedder (USGS) and P. W. Weiblen (Minnesota Univ.) (1972b, p. 276) have shown that a summary of all their melt inclusion data in the form of a single silica variation diagram suggests that the liquid lines of descent for the various igneous rock types sampled at five landing sites are grossly similar. All these lines appear to end at the high-silica (that is, granitic) melt composition, indicative that late-stage silicate immiscibility has occurred in each of these rocks.

Chromian hercynitic spinel ("pleonaste") grains occur in breccia samples returned from several lunar sites. Roedder and Weiblen (1972a) report that reactions have occurred that have resulted in several narrow concentric zones at the interface between the spinel and the breccia matrix. Electron microprobe analyses and line scans across these zones show that at the edge of the spinel there is a gradational, 5 μm-wide zone strongly enriched in chromium, titanium, and manganese. In addition, some spinels also have minute discrete grains of titanium picotite at the edge. Surrounding each spinel is a 6 to 8 μm zone of almost pure calcic plagioclase, essentially free of pyroxene and opaque minerals, although the breccia matrix contains about 50 percent. The spinel is believed to originate as a stable olivine-plagioclase-spinel cumulate rock which was excavated by large impact events. Under the near-surface, high-temperature, low-pressure metamorphic conditions forming these breccias, the spinel is no longer stable and has reacted, particularly with pyroxene. The occurrence of these spinel clasts thus provides some concrete evidence of the mineral assemblages deep in the lunar crust and is consistent with the high lunar seismic velocities which have been obtained.

Motoaki Sato (Sato and Hickling, 1973) has refined his experimental technique to the extent that even 6.7 mg of olivine separate from rock 12009 produced stable, reproducible results. Results of more than a dozen samples showed that the oxygen fugacity values of lunar rocks varied little at a given temperature, mostly falling within a narrow zone (having width of about 1 log fo_2 unit) midway between the iron-wüstite curve and the iron-ferropseudobrookite-rutile curve on the log fo_2—$(1/T)$ plot. Early minerals, such as olivine phenocrysts in 12009, show only very slightly higher oxygen fugacity values than their respective groundmass or the bulk rock although mineralogically there is evidence that reduction occurred during cooling. The smallness of the fo_2 variation is probably due to the damping effect against lowering of fo_2 by the precipitation of metallic phase. It is fairly conclusive that lunar magmas were in extremely reduced state throughout their cooling history.

Lunar glasses and lunar fines

J. B. Best and J. A. Minkin have studied and analyzed with electron microprobe more than 150 glass particles from Apollo 15 fines and breccias. The CIPW norms of the analyzed glass particles plus those computed from published chemical analyses of Apollo 15 basalts, fines and glasses were plotted on ternary diagrams for comparison and identification of chemical groups. Three types of ternary diagrams were constructed, using major lunar minerals as apices. From these plots and from refractive index data, the Apollo 15 glasses have been classified into 12 distinct groups, arranged in order of increasing average refractive index: (1) Colorless anorthite, approximately An_{96} in composition, (2) colorless and pale-green anorthosite, (3) pale-green anorthositic gabbro, (4) heterogeneous feldspathic basalt and pale-green olivine-normative feldspathic basalt, (5) pale-brown and gold, rich in KREEP components, (6) greenish-gold olivine-normative feldspathic basalt with high normative ilmenite, (7) gold troctolite, (8) yellowish-brown ilmenite-bearing basalt, (9) green peridotite, (10) reddish-brown ilmenite-bearing olivine basalt, (11) reddish-brown Apollo 11-type ilmenite-bearing basalt, and (12) dark-reddish-brown olivine-bearing ilmenite basalt.

Most if not all of the Apollo 15 glasses in this study are of impact rather than igneous origin. Thirty five percent are of mare-basalt-type composition (groups 8, 10, 11 and 12) ; 25 percent are green peridotitic glasses with a narrow range in composition (group 9). Non-mare-type materials are represented by the glasses with high feldspathic and KREEP content.

More than 2,400 particles from the sub-37-μm fraction of 10 Apollo 14 regolith samples were studied by R. B. Finkelman. The pyroxene–plagioclase and olivine–plagioclase ratios are in general higher in this fraction than those reported for Apollo 14 breccias and coarser materials. Among a number of unusual particles found are a few brown birefringent lath-shaped mineral grains with SiO_2 60 weight percent and FeO 34 weight percent ($FeSi_2O_5$?) and glass particles with high lime (20–25 weight percent), low magnesia (0.8 weight percent), very high alumina (40–45 weight percent) and low silica (30 weight percent). The unique composition of the glass particles and their occurrence in the very fine fraction suggest that they may be products of a condensed impact-generated vapor phase from anorthositic source materials.

Superparamagnetism has been observed in all the measured specimens of bulk lunar fines by F. E. Senfle, A. N. Thorp, and C. C. Alexander; it has not been observed in individual glass spherules removed from the fines. Superparamagnetic properties have also been observed in poorly fined vesicular glass shards removed from the fines. The suggested source of superparamagnetism is the iron reduced from the ionic iron originally in the glass. If the glass was formed at temperatures less than 1,530°C (melting point of iron), there is little chance of diffusion of the iron and formation of metallic iron spheres. The reduced iron atoms remain in the glass as individual atoms or clusters forming superparamagnetic centers. In glass formed at higher temperatures the iron diffuses more readily and metallic iron submicroscopic spheres are formed which are often larger than that necessary to produce superparamagnetism.

Age determination and isotopic studies

Isotopic composition of thorium in lunar samples has been investigated by J. N. Rosholt. Lunar breccia and fines samples 14163, 14318, 15505, 15515, and 15600 have ^{231}Pa in radioactive equilibrium with ^{235}U. The ^{234}U daughter is in equilibrium with the ^{238}U

parent in these samples as it is in breccia samples 14063 and 14307. The $^{232}Th/^{230}Th$ activity ratios in these Apollo 14 breccia samples indicate that ^{230}Th is in equilibrium with parent ^{234}U, and no anomalous thorium isotopic composition was found. The situation is different for Apollo 15 crystalline rocks that were analyzed, because none have $^{232}Th/^{230}Th$ activity ratios that agree with the expected ratios calculated from $^{232}Th/^{238}U$. Samples 15065, 15076, 15085, 15476, and 15555 have $^{232}Th/^{230}Th$ activity ratios of 1.0 or less in comparison with expected ratios of about 1.26 as calculated from the observed values of $^{232}Th/^{238}U$. This set of thorium isotopic results for Apollo 15 crystalline rocks is similar to the thorium isotopic results reported for Apollo 12 crystalline rocks. Apollo 15 fines and breccias 15071, 15080, 15505, 15515, and 15600, similar to fines 12070, have $^{232}Th/^{230}Th$ activity ratios slightly less than or equal to the expected $^{232}Th/^{230}Th$ ratios calculated from the $^{232}Th/^{238}U$ ratios. Thus, the same interpretations, with regard to results of thorium isotopic composition, appear as valid for Apollo 15 samples as those described for Apollo 12 samples; namely, the differences in thorium isotopic composition between different sample types suggest the existence of a ^{232}Th isomer of variable isomeric abundance in lunar samples. If such an isomer exists, the isomeric ratio ($^{232m}Th/^{232}Th$) appears to be greatest in mare basalts and least, or nil, in samples with a large KREEP component such as sample 12033.

The U-Th-Pb and Rb-Sr systems of some lunar samples

The U-Th-Pb and Rb-Sr systems of some Apollo 15 samples and U-Th-Pb systems of some Apollo 16 and Luna 20 samples have been studied for dating purposes by Mitsunobu Tatsumoto, P. D. Nunes, R. J. Knight, D. M. Unruh, C. E. Hedge, and B. R. Doe (Tatsumoto, 1973; Tatsumoto, Hedge, and others, 1972; Tatsumoto, Nunes, and Knight, 1973). The studies confirm previous observations that highlands-type soils and the matrix of breccias from the Apollo 14 and 16 and Luna 20 missions continue to be indicative of lead enrichment relative to uranium billions of years ago, whereas mare-type soils and breccias from the Apollo 11, 12, and 15 mare sites continue to portray lead loss relative to uranium billions of years ago.

The uranium and thorium contents in anorthosite 15415 and 60015 are essentially nil, and the correction of U- and Th-derived Pb as a result of radioactive decay in order to derive the initial lead isotopic composition is very small. The $^{206}Pb/^{207}Pb$ of the anorthosites, when they were formed, was calculated by use of a two-stage model that permits one alteration of $^{238}U/^{204}Pb$ since the Moon formed and the $^{238}U/^{204}Pb$ was established in the sample. The value of initial $^{206}Pb/^{207}Pb$ was found to have been 0.67 and 0.74, respectively, for the two anorthosites. This initial ratio indicates that anorthosite 15415 formed 3.87 b.y. ago from an environment with $^{238}U/^{204}Pb \approx 300$, and 60015 formed 3.58 b.y. ago from an environment with $^{238}U/^{204}Pb \approx 220$. The $^{238}U/^{204}Pb$ values estimated for the source material of the anorthosites are perfectly normal for lunar igneous rocks. These ages mean that either the anorthosites were formed during the mare basalt outpourings 3.2 to 3.9 b.y. ago or they and the lunar highlands originated earlier and the anorthosite U-Th-Pb systems were disturbed in the 3.2- to 3.9-b.y. interval. The U-Pb fractionation for these two anorthosites and to a lesser degree that for anorthosite 60025 indicate that gross chemical as well as mineralogical fractionation occurred during anorthosite genesis.

The metamorphosed clastic rock 66095 has an extremely high Pb content compared to its U and Th concentrations. This Pb concentration (14 p/m) is greater than those of all previously reported lunar materials except for the light portion of the metamorphosed clastic rock 12013, but the U and Th concentrations of the light portion of 12013 are about 10 times greater than those of 66095.

Assuming a two-stage U-Pb evolution that permits one alteration of $^{238}U/^{204}Pb$ since the Moon formed and using 4.65 b.y. as the Moon's age, we calculate an age of formation of 3.77 b.y. for 66095. If this two-stage model is correct, rock 66095 must have formed 3.77 b.y. ago from a source with a $^{238}U/^{204}Pb$ ratio of about 570 and a $^{232}Th/^{238}U$ ratio of about 3.85. The Th:U ratio was not detectably altered 3.77 b.y. ago, but the U:Pb ratio decreased by more than a factor of 10. The U and Th concentrations of rock 66095 are about twice as great as those of Apollo 16 soils, which suggests a noritic component (rich in KREEP) may have been incorporated into the source material of 66095. Such a KREEP-like component, however, cannot explain the very high Pb content which at present remains enigmatic.

The studies from all lunar missions revealed that there are three principal classes of lunar crustal rocks: mare basalts (rich in iron), plagioclase-rich noritic rocks, and anorthositic rocks. The lunar highlands region has been considered to consist of very old anorthosites (older than 4.4 b.y.); however, no rock unequivocally older than 4.0 b.y. has been found on the Moon.

Chemical composition

The major, minor, and trace element compositions of 14 igneous rocks and 7 soils returned by the Apollo 15 Mission have been determined and investigated by Frank Cuttitta, H. J. Rose, Jr., C. S. Annell, M. K. Carron, R. P. Christian, D. T. Ligon, Jr., E. J. Dwornik, T. L. Wright and L. P. Greenland. These igneous rocks comprise two chemically defined groups: vesicular, porphyritic basalts (olivine normative) and vuggy, medium-grained gabbros (quartz normative). The rocks are characterized by the highest refractory and the lowest volatile element content of any lunar igneous rocks returned by previous missions.

Effects reflecting magma chamber zoning as a result of temperature gradients are evident in the Apollo 15 rocks (that is, gabbro 15065). Simple fractionation from a homogeneous magmatic source, however, does not adequately explain all the compositional differences seen among lunar basalts. These studies also indicate that the Appollo 15 rocks represent several parent magmas rather than a single magmatic event.

The data indicate that the chemical composition of lunar soils depends largely on the geographical locations from whence they were obtained. The highland soils from the Apennine Front have smaller proportions of the KREEP basalt and meteoritic components than do the Fra Mauro highland soils.

Major, minor, and trace element analyses have been carried out by H. J. Rose, Jr., Frank Cuttitta, Sol Berman, M. K. Carron, R. P. Christian, E. J. Dwornik, L. P. Greenland and D. T. Ligon, Jr., for 10 soils and 12 rocks returned by the Apollo 16 mission. Both the rocks and soils are enriched in CaO and Al_2O_3 in comparison with previous Apollo missions. The soils at stations other than at North Ray crater are relatively homogeneous in major element composition. However, Co and Ni vary by fourfold in concentration, although the Co:Ni ratio remains constant. There is a positive correlation between Ni and Zr. In the rocks, the major variations of the trace elements appear to be controlled by the pyroxene-plagioclase ratio with the breccias richer in plagioclase than the crystalline samples.

REMOTE SENSING AND ADVANCED TECHNIQUES

EARTH RESOURCES OBSERVATION SYSTEMS (EROS) PROGRAM

The EROS program, administered by the USGS for the Department of the Interior, has been actively involved in the evaluation of data acquired by ERTS–1 launched by NASA in July 1972. The ERTS experiments are the first to test data that are being acquired by instrumentation designed to meet Departments of the Interior and Agriculture specifications. Results of research from data obtained in the first 6 months of operation were presented at a symposium in Lanham, Md., in March 1973. Findings having significant values to all resources disciplines, including many from the 44 Department of the Interior investigations, were reported.

ERTS data are available to the public from the EROS Data Center in Sioux Falls, S. Dak. Training programs in the use of ERTS data and user assistance services are also provided by the EROS Program in its effort to assure the benefits of aerial and space remote-sensing systems technology at all levels of government, in educational programs, and in industry. The program also supports the Inter-American Geodetic Survey (IAGS) in developing in-country remote-sensing activities in Latin America. An active training program is maintained for Latin American students at the IAGS facility in the Panama Canal Zone. More than 60 participants have received training and have been encouraged to develop projects within their own countries. Four are underway—in Guatemala, Nicaragua, Colombia, and Peru—and others are in a development stage. Under this program, IAGS lends data gathering and interpretation equipment and provides technical expertise for short periods of time. The host country provides aircraft and local scientists to work on the projects.

The EROS Experiments and Evaluation Office and Users Assistance Center, located at the NASA Mississippi Test Facility, participated in several projects related to the application of remotely sensed data to environmental problems. The office directed the ground-truth collection activities in support of an April 1972 USAF flight over the Atchafalaya River basin, Louisiana, and then assisted in the compilation of a catalog of the total data for 23 State agencies variously involved in the basin, to provide them with a common data base. A joint project of the State of Mississippi, the NASA Earth Resources Laboratory, and the EROS Program has been initiated as the State of Mississippi Land-Use Mapping Program. NASA collected the high-altitude aircraft imagery which will be used in the map compilation, and an interagency steering committee has been established at the State level to decide on a land-use classification system compatible with and modeled after the national land-use classification system now being developed and tested. EROS is training State participants and assisting in the compilation of statistical data. G. W. North has assisted the Mississippi Department of Archives and History by acquiring black and white, infrared, and color-infrared photography over several areas of historical interest including the Grand Village of the Natchez Indians and an 1803 French fort near Natchez, Miss. North and H. T. Svehlak (1973) of General Electric Co. detected many archeological features on the imagery that were confirmed by the State Archeologist. Most significantly, the fort was found to be located 1¼ mi from its suspected site and has now been confirmed on the centerline plot of the proposed Natchez Trace Parkway.

The Arizona Regional Ecological Test Site (ARETS) project of the EROS program was responsible for coordination of project activities with eight departments and commissions of the State of Arizona together with several Federal agencies involved in the evaluation and application of remote-sensor data to earth resources problems in Arizona. The Arizona Land-Use Experiment, a joint venture by NASA, Department of the Interior, and the State of Arizona, was initiated in July 1972. This project has as a major objective the development of a statewide land-use inventory using remote-sensor data. A preliminary land-use classification system has been developed by the Arizona Resources Information System (ARIS), the lead State agency in the experiment. Preliminary evaluation indicates the proposed Arizona system will readily interface with the national land-use classification system under development. In addition, high-altitude aerial photography has been acquired over approximately 85 percent of Arizona by NASA aircraft. The USGS has completed the inspection and indexing of this photography and has prepared more than 250 7½-min orthophotoquads of the State. The design of a geodetic control network necessary for development of more than 1,800 orthophotoquads has been completed by the USGS and supplied to the State of Arizona. Approximately 95 percent of the geodetic control points have been marked and photographed by the Arizona Highway Department in support of the orthophoto program. Under an EROS contract, the Office of Arid Land Studies (OALS) of the University of Arizona has operated the Tucson ARETS data center that houses selected NASA aircraft and satellite imagery of Arizona and has furnished assistance in the use and interpretation of this imagery and equipment for data analysis. The Third Annual ARETS Seminar Workshop was conducted by OALS in the fall of 1972.

The EROS program is coordinating a cost-benefit study being undertaken to evaluate the ERTS–1 product and its applications. The study was requested by the Requirements and Benefits Subcommittee, Earth Resources Survey Program, to assist all Federal, State, and local user agencies and other potential users in making sound judgments about the social and economic utility of future earth resources observations systems which incorporate repetitive coverage, synoptic coverage, and multispectral characteristics. Three groups of companies participated in phase I, design of the cost-benefit study. Their work was completed in September 1972 (General Research Corporation, 1972; Willow Run Laboratories, 1972; and Earth Satellite Corporation/Booz, Allen Applied Research, 1972). In February 1973, phase II, the study itself, was begun by Earth Satellite/Booz, Allen under a contract from the EROS program. Evaluations are based on information derived from the formally selected principal investigations of the ERTS experiments, and from the public, industry, academic, and government users of ERTS data purchased through the EROS Data Center. Representative case studies are being prepared together with a total assessment of benefits attributable to ERTS or a similarly programed operational satellite system. Comparisons with alternative systems are to follow.

SOUTHWESTERN UNITED STATES

The Bureau of Indian Affairs is supervising an EROS-funded contract with Raytheon Company, Autometric Operation, to further develop and test a resources information system for agencies within the Department of the Interior, including the USGS, Bureau of Mines, National Park Service, Bureau of Sports Fisheries and Wildlife, Bureau of Outdoor Recreation, Bureau of Land Management, and Bureau of Indian Affairs. The areas of study include, among others, the California desert, Colorado River area, Four Corners, Black Mesa in Arizona and New Mexico, and Assateague Island, Md. Proceeding from the base established for the Bureau of Land Management and Bureau of Indian Affairs by Boeing Computer Services under a previous contract, this work is expanding the computer software to meet the needs and to be compatible with existing computer facilities of the five added agencies. At least four management decision models are being developed for each agency, incorporating the ability to forecast effects of present land-use practices and activities based on attribute data combinations. For this reason, the system is designed to permit input of multiple data sets by geographic coordinates and also tabulations, and to produce a variety of outputs.

Under an EROS-funded contract, monitored by the Bureau of Indian Affairs, Indians of the Salt River and Gila River Reservations in Arizona used high-altitude and satellite imagery to make a land-use inventory of their reservations that is the basis for developing and implementing a comprehensive regional plan. Repetitive satellite coverage is used to monitor changes in natural conditions. The Topographic Division of the USGS prepared 49 orthophotoquads from the high-altitude photography to serve as base maps for this project. Less than a year was involved between acquiring photography and delivery of the finished maps. This project has also enabled the Salt River Indian Community to tie their south boundary location to this reservation base map. The boundary was established by Secretarial order and located through the use of aerial photography. The location of this boundary as pictured on the orthophotoquads is being used by the tribe as evidence to support its claims in current trespass suits against sand and gravel operators.

Two studies partially funded by EROS have recently been completed in the Chaco Canyon area of New Mexico as part of an ongoing research project in the Chaco Canyon National Monument under the auspices of the New Mexico Archeological Center, National Park Service. T. R. Lyons studied prehistoric irrigation in Kin Bineola Pueblo to determine the effectiveness of photogrammetric procedures in identifying cultural features in an arid area of low relief, to aid in the interpretation and analysis of any identifiable features, and to determine the value of these techniques in helping to plan research strategy. Sixteen prehistoric sites, including canals, diversion dams, and habitation sites, were located by photointerpretation and confirmed by ground survey as compared to three not located by photointerpretation and subsequently located by ground survey. Suspected sites were determined by slight subtleties in elevation differences, soil coloration, unusual terrain scars, suspicious geometric patterns, and vegetation anomalies. Photogrammetric techniques also produced a more accurate and detailed survey than is normally accomplished by field survey methods alone. For these reasons, Lyons, Pouls, and Hitchcock (1972) concluded that such techniques can be used successfully as analytical tools, as well as reconnaissance tools.

G. J. Gumerman (1972) of Prescott College evaluated the capabilities of various types of remotely sensed data and interpretative instruments to delineate prehistoric land routes or road systems in the vicinity of Old Pueblo Alto. The study assessed the information derivable from black and white photography from the ground, from low altitude and from high altitude (1:32,000), color photography, and multispectral imagery and isodensitometer studies based on various road attributes. It became evident that rigid control of the photographic variables during acquisition was essential to success. In addition, seasonal and meteorological variables must be controlled: time of day for shadow effects, following rainfall so that vegetation patterns are strengthened, and clear sky and calm to prevent interference of haze and dust. Inability to identify any roads with multispectral photography using a color additive viewer was believed to be a problem of film density, and lack of success with isodensitometer studies was believed to be caused by the poor resolution of the system used in the test. Of the data evaluated, high contrast aerial photography at a scale between 1:12,000 and 1:32,000 was considered best because it combines easy definition of roads and reduces the number of photographs needed.

Under the direction of the Bureau of Land Management, A. R. Gillespie and G. H. Redmann (1973) of the Jet Propulsion Laboratory investigated the application of digital computer image enhancement and processing techniques for developing a data base from aerial photography to measure recreation impact on the lower Colorado River area. An attempt was made to determine what data items could be extracted and identified from aerial photographs and compared automatically by computer techniques to highlight changes in land use. Three techniques were employed—comparison of digitized versions of photographs from different years, pseudo-color pictures from the same photographs in which no changes are represented by gray, and cluster diagrams or two-dimensional histograms. Results were marginal probably because the test data did not have common characteristics of camera system, scene conditions, and view angle; the photography used had been acquired originally for a variety of purposes. Recommendations called for any further investigation to be based on data with common characteristics to reduce significantly the preprocessing required and to retain some information loss normally removed through such manipulation, or the use of digital MSS data acquired from satellite or high-altitude aircraft.

Scientists from various disciplines, working with the University of Nevada on an EROS contract to determine the optimum use of remote-sensing data from aircraft and spacecraft in arid regions, found that the data provided valuable supplemental information for evaluating land use and environmental problems. Their evaluations were based on individual analyses of aircraft and simulated ERTS data, and on the insight provided by a test of an interdisciplinary system designed to use ERTS data to increase efficiency in environmental management, data gathering, and problem solving. The system requires an interdisciplinary review panel to make primary problem selection and to coordinate and assign needed disciplines to the problem. In this case, a general study was made of the arid regions of Nevada and adjacent states, and two areas, Reno–Lake Tahoe–Pyramid Lake and Las Vegas–Spring Mountains–Lake Mead, were selected for intensive review. It was through the intensive review that specific conclusions were reached. The procedures and specific interpretations are included in a report (University of Nevada System, 1972).

PACIFIC NORTHWEST

The EROS program funded three contracts within the State of Washington aimed at the development of applications of ERTS and related remote-sensing data in the Pacific Northwest, two with the University of Washington and one with the State of Washington, Department of Natural Resources. The projects are complimentary and are coordinated to reach their common purpose.

J. E. Colcord (1972) of the University of Washington prepared a paper on the general topic of remote sensing and photointerpretation that has been particularly useful in introducing these subjects to interested people who are not technically trained.

The Department of Civil Engineering at the University of Washington has developed tests and procedures for calibrating cameras and imagery used to support other projects. Their International Imaging Systems Mark 1 Multiband Camera, acquired to obtain photography in wavelength bands similar to those flown on ERTS–1, has been calibrated for lens transmission curves, shutter consistency, and lens resolution (both aerial and terrestrial). Experiments have been undertaken with an in-camera constant-exposure gray-scale system in which a light-emitting diode exposes a standard spot between the four images to allow calibration and standardization of image contrast for the film that can be correlated for each band. In order to cope with the atmospheric attenuation problem, the department has also developed methodology for obtaining ground photography with the same film-filter combinations for comparison with the multispectral aerial photography.

F. V. Westerlund (1972) of the Department of Urban Planning, University of Washington has made a survey of completed and ongoing research in the use of remote sensing in urban and regional planning to determine potential application of EROS remote-sensing data as applied to planning functions in the Pacific Northwest. The department is continuing two land-use change analysis projects—San Juan Island and the area around Sea–Tac Airport. They are both drawing on as much as 25 yr of data which should substantially improve the analytical models being developed.

The work of the Department of Natural Resources has been primarily aimed at stimulation of interest in and dissemination of information about EROS and ERTS to potential users. In support of these activities they prepared an inventory of data for the Pacific Northwest and sponsored a symposium in Olympia, Wash., on remote-sensing applications and technology in March 1973.

OTHER AREAS

C. J. Frazee of the Remote Sensing Institute of South Dakota State University concluded his research for the Bureau of Indian Affairs on the potential usefulness of aerial multispectral imagery in making soil and range inventories of Indian lands in South Dakota (Frazee and Carey, 1972). Using the Pine Ridge Reservation in southwestern South Dakota as the test site, it was determined that range boundaries delineated by density slicing analysis of color-infrared film were superior to existing range inventory maps. Soil boundaries in both cropland and rangeland were delineated first by density slicing analysis of color-infrared film and then by use of slope gradient information derived by stereoscopic analysis to produce more detailed and accurate soils maps than those existing. The development of these analytical procedures permits the conclusion that remote sensing can be applied to making, updating, and revising soil and range inventories.

Another Department of the Interior ERTS experiment is being conducted by H. K. Nelson, Bureau of Sport Fisheries and Wildlife, in cooperation with the Environmental Research Institute of Michigan and agencies of the Canadian government. The experiment is to determine the value of ERTS–1 data for recognizing and measuring seasonal changes in migratory bird habitat, particularly surface-water conditions. The primary test site, a prime production habitat of waterfowl and other migratory birds, is in a well-documented study area near Woodworth, N. Dak. ERTS–1 data from July 1972 have been processed and recognition maps of ponds and lakes have been produced. Airborne MSS data acquired within 3 d of the ERTS overflight have been similarly processed, and the aggregate data processing has served to demonstrate the feasibility of mapping ponds and lakes using joint spacecraft and aircraft products. It has also demonstrated the importance of supplementing ERTS data with aircraft data.

J. F. Ruff, Colorado State University, under a contract with the Bureau of Reclamation partially funded by EROS, investigated the sources that contribute sediment to the Clarks Fork of the Yellowstone River, Mont., the sediment-producing potential of the basin, and some measures that may be implemented to reduce siltation (Ruff and others, 1972). Data from 40 sampling stations, including determinations of suspended sediment concentration, particle-size analysis, turbidity, and water temperature, were used to correlate with thermal imagery and infrared photography of the river. Evaluation of the data collection, data processing and data analysis techniques, data accuracy, and cost effectiveness of this research effort indicate that aerial color-infrared photography and thermal-infrared imagery are practical tools for locating and identifying existing and potential inflows of sediment-laden water to a river system. Each provides information: color-infrared photography, the identification of small changes in low sediment concentrations; and thermal-infrared photography, an indication of the relative temperature of the scene. Together they provide a unique quasi-synoptic view of the sediment-transport process of a river system. The photography also permits a greater accuracy of interpretation of ground data and more efficient scheduling of fieldwork because of the appreciation of the terrain provided by the photography.

Roger Vickers, Colorado State University, under a contract partially funded by EROS, with the Bureau of Reclamation, has developed a 300–700 mHz radar system designed to penetrate the earth's surface and detect the level of near-surface ground water (8–10 ft). Initial analysis indicated a penetration of approximately 10 ft in clay and gravel. Water flowing in storm drains about 8 ft below the surface was detected without difficulty, and subsurface layering of soils in the first 10 ft was also apparent. The present resolution in soils is approximately 9 in. An effort is now being made to extend development of the system and to field test it on irrigated land where a high water table is known to occur.

A. D. Marmelstein of the National Park Service completed an EROS-funded feasibility demonstration of aerial photographic support for marine archeological surveys. Photography was obtained over the Loggerhead Reef in Fort Jefferson National Monument, Fla., in a 70 mm format using five film-filter combinations. Although in the clear waters of the test site ample depth penetration was provided by conventional color film, both minus-blue filtered color films showed potentially greater depth penetration capability for turbid water conditions. Several sites containing significant ship remains were identified, including one previously unlocated site containing perhaps the most important remains in the national monument. Coordinated use of both large- and small-scale photography proved particularly useful for precisely locating newly identified sites and for providing the capability to easily relocate previously identified sites. This ease of relocation is particularly noteworthy because existing charts contain numerous errors which complicate the task of relocating a site.

The Iowa Remote Sensing Laboratory under a grant from the EROS program, is analyzing an 11-county area in south-central Iowa in an effort to apply ERTS data to the information needs of State and local planners involved in land and water-use management in the area. Maps of land use, water resources, and mineral resources derived from ERTS images have been modified by input from the planners to fit their needs more closely. Additional thematic maps on sanitary landfill suitability and flood-hazard areas are being produced.

ERTS EXPERIMENTS BY OTHER AGENCIES

The EROS program coordinates the departmental participation in NASA's ERTS–1 experiment, in some cases also financially supporting the research involved. The progress of the experiments requiring data showing the march of the seasons has been affected by the delayed launch of ERTS, which prevented the acquisition of data during the spring of 1972. A full year of operation by the satellite, however, is filling this lack, and all the experiments are now well underway. The scope of the experiments being undertaken by Bureaus other than USGS follows:

R. G. Bentley, Jr., Bureau of Land Management, in a Department of the Interior ERTS investigation, is testing the application of satellite and high-altitude imagery to the prediction of ephemeral and perennial range quantity and quality during normal grazing season. This involves using sequential multispectral satellite imagery to chart erratic rainfall patterns over desert areas of the southwest and the resulting growth and development of annual forage; monitoring the effects of grazing such as forage production, soil movement, and vegetation on northern ranges; and testing the ability of resource managers to distinguish different plant communities on satellite imagery over poorly known areas in Alaska.

Application of ERTS imagery to monitoring key ecological changes affecting the fish and wildlife resources of Alaska is the subject under investigation by B. J. Van Tries, Bureau of Sport Fisheries and Wildlife. Imagery from ERTS is being used to study the phenology of wetland vegetation in the Yukon Flats and Yukon-Kuskokwim delta area and thereby evaluate it for recognition and measurement of seasonal changes in migratory bird habitat. The occurrence of leads in sea ice, particularly as they reflect abundance of zooplankton important to fish and marine mammals are being studied in Bristol Bay and Chuckchi Sea for the same purpose.

L. D. Cast, Bureau of Reclamation, in a Department of the Interior ERTS investigation, is using ERTS and high-altitude imagery in the identification of geologic contacts, faults, structures, and possible geothermal activity for evaluation of proposed projects, and for monitoring existing reservoirs and distribution systems for seepage, algae growth and pollutants in reservoirs, and deposits and influx of silt in reservoirs of completed projects in north-central Colorado. Efforts are also being made to map soils and land uses, determine high ground water, and locate zones of soil salinity from these images.

A. M. Woll, Bureau of Indian Affairs, in a cooperative study with the Bureau of Land Management and the State of Washington is using aircraft imagery and subsequent ERTS-1 imagery to evaluate remote sensing as an information tool in management of the high-quality forest of the Pacific Northwest. Based on original delineations from high-altitude imagery that are replicable on ERTS imagery, change detection is being attempted in an effort to monitor the effects of forest management practices. An attempt is also being made to monitor cultural developments as they effect the forest environment and to develop a system warning of environmental stress and hazard conditions from these observations. The investigation is designed to show the utility of ERTS-based delineations for cost-effective inventory sampling schemes, for defining data needs, and for developing resource data into timely and meaningful information for the land manager's decision.

APPLICATIONS TO GEOLOGIC STUDIES

Evaluation of new technique for discriminating geologic units from satellites

A new geophysical technique (U.S. Geological Survey, 1972f, p. A187) used to produce a thermal-inertia map of part of Oman from Nimbus satellite measurements was evaluated on the basis of photogeologic data from ERTS-1 images. The initial comparison of the thermal-inertia map with a 1:2,000,000 reconnaissance geologic map demonstrated gross agreement with most of the geologic units. Some discrepancies resulted from errors on the reconnaissance map, as shown by examination of a more detailed geologic map; other anomalies remained. A comparison among the thermal-inertia map, reconnaissance geologic map, and ERTS-1 images was made by H. A. Pohn. The axis of the Oman mountains appears to be a series of large patches of ophiolite as indicated on the thermal-inertia map rather than a continuous strip as portrayed on the geologic map. Many other anomalies have been correlated to geologic features, but the very high thermal-inertia anomalies do not appear to correlate with textural or albedo differences on the ERTS-1 images.

Kenneth Watson has developed a set of computer routines to apply the technique to digital-tape data from satellites. The reflectance and thermal data are plotted on a grid, rectified for errors in spacecraft orientation, corrected for atmospheric transmission losses, and converted to thermal-inertia values using a thermal model program. Maps of thermal inertia, reflectivity, and temperature can then be displayed as both contour and gray-scale products. The contour maps can be made with a variety of interpretation schemes to accentuate regional or local patterns, and the gray-scale routine has been written to produce maps at various scene contrasts. Initial tests of the program using data for the Arabian Peninsula show good general agreement with the major areas of well exposed geologic units. The computerized technique makes it possible to map the thermal inertia of surficial materials on a worldwide basis from data collected by satellites.

Identification of crustal magnetic anomalies from satellites

R. D. Regan and Isidore Zietz report that magnetic anomalies of suspected crustal origin have been identified in the POGO (Polar Orbiting Geophysical Observatory) and U.S.S.R. Cosmic-49 satellite magnetometer data. Removal of the internal field and correction for external field effects resulted in a global magnetic anomaly map of improved accuracy. Analysis of individual satellite passes over the area of one broad scale anomaly in central Africa reveals a well defined magnetic low. At a mean satellite elevation of 500 km, the anomaly is approximately 1500 km by 700 km, has a maximum value of −10 gammas, and trends east-northeast. Examination of Project Magnet data, obtained at an elevation of 2 km, confirms the presence of this anomaly. At this lower elevation, the anomaly is approximately 900 km by 200 km and has a maximum amplitude of −800 gammas. Interpretation of the satellite and aeromagnetic data indicates a crustal source.

Effective ground penetration from thermal image data

Extraction of geologic information from thermal infrared images requires a suitable mathematical model with which to relate diurnal surface temperatures to incident flux and to surface and near-surface physical properties. Some success has been achieved in discriminating several rock types and mapping thermal-inertia differences based on assuming a semi-infinite solid (Watson and others, 1971; Pohn and others, 1973). The widesread presence of surface effects, however, caused by soils, lichen cover, and coatings suggests the need to extend current models.

J. C. Jaeger's technique (1953) for treating the periodic heating of a solid has been applied by Kenneth Watson to the case of a layer over a semi-infinite solid. Numerical examples for limiting cases demonstrate both the influence of surface coating and the effective penetration of the ground that can be sensed by observing surface temperatures. A 0.01-cm "lichen" layer and 0.1-cm "soil' layer have a negligible effect, whereas a 1-cm "lichen" layer produces a surface temperature similar to that of infinitely thick soil. A 10-cm thickness of "soil" or "lichen" completely masks the underlying rock.

Theoretical modeling for analysis of microwave data

A three-phase investigation was begun by A. W. England of radar scatterometry and microwave radiometry and their application to geophysical remote sensing. The work includes (1) development of mathematical models for radar reflection and radio emission from geologic bodies, (2) correlation of field data with model studies, and (3) laboratory study of the electrical properties of rock and soil. Initial theoretical modeling resulted in a set of microwave brightness temperatures for a radiating halfspace as a function of frequency, temperature gradient, dielectric constant, dielectric loss, electrical conduction, polarization, and view-angle.

Near-infrared reflectivity anomalies associated with volcanic terrain

A particularly striking reflectivity contrast was observed by H. A. Pohn on aircraft multiband images of cinder cones near the Old Dad Mountains, Calif. All the crests of these cones have a high reflectivity beyond 1 μm; no contrast was observed in the image bands below 1 μm or on the boresight photography. The phenomenon was also observed to occur in scattered patches east of the Pisgah Crater flow. Field examination suggests that the high reflectivity anomalies on the cinder cones may be associated with red cinders which contrast with black basalts and with cinders which are slightly more red or orange although no such color difference is apparent among the anomalies east of the Pisgah flow. The cause of the spectral difference is not yet resolved. The absence of significant vegetation rules out the possibility that these anomalies are due to high reflectivity from chlorophyl, and the lack of contrast in visible wavelengths would seem to preclude the possibility that the anomalies are due to differential moisture content.

Mining district defined on thermal images

T. W. Offield has conducted an examination of high-altitude thermal images of the Denver–Front Range area. In the mountains, some quartzite and the north edge of the Pikes Peak batholith can be distinguished thermally, but most of the useful information stems from temperature differences on opposite slopes of coarse topographic features. Linear features are abundant; many of these correspond to known faults, but many others do not. The most significant topographic feature seen is a pair of nested horseshoelike arcs which define the Central City–Idaho Springs mineral district. The arcs are centered on small exposures of Tertiary rock, and the outer arc almost perfectly bounds the area of gold-bearing veins in the district. The arcs cut across geologic units at the surface but match in shape the contours of a low shown on a residual gravity map by G. L. Brinkworth. This topographic feature cannot be seen on topographic or plastic relief maps, but it is unmistakable in the thermal images and seems likely to define the extent of an unexposed pluton. Other curvilinear features are seen at Cripple Creek, through the Ralston Buttes uranium district, at the Jamestown gold area, and elsewhere along the mountain front. In the plains, some linear features may occur because of the presence of soil moisture but most are topographic. South of Denver, 44 lineaments show a pattern indicating a classical synclinal fracture system oriented around the axis of the Denver Basin. If this relationship is real, it means that fractures were produced when the extremely shallow (dips of less than one degree) basinal fold formed during the Laramide uplift and then printed through some 2000 ft of material deposited later.

Thermal features of explosion craters

Several experiments were carried out by T. W. Offield, H. A. Pohn, and W. J. Bonner, Jr., in support of the USAF "Middle Gust" cratering tests and the Defense Nuclear Agency's "Mixed Company" cratering test. Thermal lineaments detected in a series of predawn and postdawn overflights correlated with symmetry or asymmetry observed in the ejecta blankets. Numerous thermal anomalies, however, were observed in the ejecta blankets which correlated, in a general way, with the depth from which the materials originated. Apparent heating of the crater interiors and ejecta materials was also observed. In addition, numerous visual and photographic observations indicated the nature and amount of ground motion during the explosion, and the direction of circumferential motions of ejecta due to turbulence in the explosion clouds.

Thermal surveillance of volcanoes

A combination of infrared images depicting areas of thermal emission and ground calibration points has proved to be particularly useful to J. D. Friedman in plotting time-dependent changes in surface temperatures and radiance and in delimiting areas of predominantly convective heat flow to the earth's surface in the Cascade Range and on Surtsey Volcano, Iceland. Volcano surface temperatures from thermistor arrays are relayed daily to Washington via Data Communication Platform (DCP) transmitters and ERTS–1. Estimates of the magnitude of convective heat flow at several surface thermal manifestations in Lassen Volcanic National Park have also been made. These estimates provide important data on the energy yield at the earth's surface during Lassen's current period of repose. Repetitive aircraft infrared imaging missions have been critical in locating, delimiting, and recording changes in surface thermal anomalies at Lassen, Mount Rainier, Mount St. Helens, Mount Baker, Mount Shasta, and Mount Hood. ERTS–1 MSS imagery has revealed curvilinear structures at Lassen, the full extent of which have not been previously mapped. Interestingly, the major surface thermal manifestations at Lassen are alined along these structures, particularly in the Warner Valley. On Lassen Peak, and possibly at Mount St. Helens, smaller thermal anomalies are controlled by the contact margins of silicic or intermediate extrusive plugs and, particularly at Lassen, may mark a line of structural weakness along Manzanita Creek valley.

Potential of remote sensing for geothermal exploration

A study by Kenneth Watson, S. S. Hart, and W. J. Bonner, Jr., to develop confidence levels for detection of geothermal anomalies from thermal-scanner images was begun in the fall of 1972 at a test site in the Norris Geyser Basin of Yellowstone. Multiband photographs and thermal images were acquired from aircraft; surface and near-surface temperatures, reflectivity, emissivity, soil moisture, density, and insolation were obtained from ground measurements. Maps have been constructed to determine test areas, observable on aircraft image data, which have differing geothermal gradients. A comparison between these data and existing snow-fall and tree-line calorimetry maps suggests that transient changes may be occurring in the near-surface geothermal flux. Additional data will be acquired to test more fully the validity of this hypothesis and determine the accuracy of the calorimetry maps.

Radio and microwave thermal emission originates at depths of centimeters to meters within a geological body, not at the surface. The characteristics of microwave thermal emission may be used in limited cases to infer the dielectric properties with depth (stratification), to measure moisture content, or to infer a temperature gradient. Computer model studies by A. W. England indicate that 5–20 cm wavelength radiometers mounted on an aircraft would reveal many aspects of the dielectric and thermal states for the upper 1 m of a geothermal system.

Mapping erosion features in southern Arizona

An episode of accelerated gullying and sheet erosion commenced about 1890 in southern Arizona, following several thousand years of generally weak erosion. R. B. Morrison and G. R. Hallberg report that ERTS–1 images, supplemented by ultrahigh-altitude (U–2 and RB–57) aerial photographs, are proving effective for producing the first comprehensive maps showing the distribution and seriousness of the post-1890 erosion features, for monitoring new erosion changes, and for assessing the effectiveness of ameliorative measures. Such data are essential for understanding and attacking the erosion problem, an environmental enigma of key importance to this region.

A bonus of this study was the demonstration of the usefulness of ERTS–1 imagery in showing two important effects of a large flood in southeastern Arizona—the extent of inundation and the areas affected by severe sediment deposition and erosion—although the images were made a week and a half after the flood. On October 20 and 21, 1972, the upper Gila River had its second-largest flood on record. Peak flows attained about 42,000 and 82,000 ft^3/s at Duncan and Safford, Ariz., respectively. Six lives were lost, hundreds of people made homeless, and more than 10,000 acres of cropland inundated.

The first ERTS–1 images after the flood were made on November 1 and 2. The inundated area is best displayed on the infrared bands, particularly on band 7, where it appears as a belt along the river that is distinctly darker than the adjoining flood plain. This dark belt does not appear on ERTS images that predate the flood. Presumably, the low infrared reflectance of this belt is caused by still-moist soil. Inundation limits mapped from the ERTS imagery agree well with those obtained by aerial photography during the flood and by ground surveys. Areas of severe sand and gravel deposition and of local strong erosion show on band 5. By comparing before- and after-flood images on this band, a quick assessment can be made of the severely flood-ravaged land.

Geologic application of ERTS-1 imagery in Alaska

In studies of Nimbus IV, E. H. Lathram (1972) identified an extensive set of northwest- and northeast-trending lineaments, possibly crustal structures. Lineaments and faults with the same trends on many ERTS–1 images corroborate this set of poorly known or unsuspected structures. Preliminary analysis (Lathram and Gryc, 1972) suggests this set of structures may have influenced the location of mineralized areas.

ERTS images of northwestern Alaska give a unique perspective of geologic structures that must be understood to evaluate the region's petroleum potential, according to I. L. Tailleur (in Gryc and Lathram, 1972). In the DeLong Mountains, the distribution of folded, flat thrust plates, several marked by limestone and one by remnants of an ultramafic layer, shows clearly on bands 5 and 7. The intricate nature of complex folds in the foothills to the north is portrayed comprehensively for the first time by ERTS–1 images and contrasts markedly with broad folds in younger rocks to the north. Southward deflection of structural trends in the western Brooks Range is seen to coincide with a northwest-trending lineament of the set identified on the Nimbus image.

A previously unknown series of closely spaced northeast-trending fractures in the Alatna hills of west-central Alaska identified by W. W. Patton, Jr. (in Gryc and Lathram, 1972) on an ERTS–1 image lends credence to the conjecture that the Kobuk fault zone is a major east-trending zone of right-lateral strike-slip faulting. The fractures have the trend and pattern of closely-spaced shears expected in areas within such strike-slip fault zones. The nature of movement on the Kobuk fault zone is critical to understanding the history of the northern Alaska and Yukon-Koyukuk petroleum provinces.

A strong east-trending lineament in the Arctic Coastal Plain of Alaska, first recognized by W. A. Fischer on an ERTS–1 image, may have significance for petroleum exploration. E. H. Lathram finds that north of Umiat, site of a shallow oilfield, the lineament in lake and interlake areas parallels westward deflections of ends of folds that trend northwestward in the Umiat area and also parallels deflections in contours of the gravity field and alined anomalies in the magnetic field. The lineament may reflect subsurface structures in rocks potentially favorable for petroleum (Fischer and Lathram, in Gryc and Lathram, 1972).

Arctic coastal processes elucidated by ERTS-1 imagery

An extensive program in the area of the Beaufort Sea by P. W. Barnes, Erk Reimnitz, and J. V. A. Trumbull, using ERTS–1 spacecraft images, has shown the Arctic Shelf of Alaska to be influenced by unique processes, most of which involve or are related to sea ice.

Active sedimentologic process along the Arctic coast are initiated by the melting, flooding, and eventual overflow of rivers onto the sea ice. It is now apparent that only minor amounts of sediment are transported offshore at this stage although scouring of the bottom is significant beneath the strudels (drain holes) which develop in the ice canopy attached to the shore in the region of overflow (Barnes and Reimnitz, 1972).

During the period of maximum sea ice melt in late June and July, temperatures and turbidities decrease offshore while salinities increase then decrease as the pack ice is approached offshore. Areal salinity and turbidity patterns and imagery confirm a consistant influx of colder, clearer, saltier water to the coast just east of the Colville River. Strong (up to 3 knots) bidirectional but intermittent currents often manifest themselves as wakes behind grounded ice. Ice movement vectors generated from repetitive images indicates that drift is closely associated with wind direction especially in shallow bays and displacement of 4 to 22 km were noted in 24 hr. Nearshore topographic highs serve as loci of grounded ice whose keels are of sufficient depth. Side-scan sonar data confirm these areas to be intensively gouged by ice.

Lineament analysis of Nevada using ERTS-1 images

Structural analysis of Nevada by L. C. Rowan and P. H. Wetlaufer using ERTS–1 images shows several previously unrecognized lineaments which may be the surface manifestations of major fault or fracture zones. Principle trends are northeast, northwest, north-northeast–north-northwest, and east-northeast. Two lineament zones, the Walker Lane and Midas Trench Lineament system, transect the predominantly north-northeast – north-northwest –

trending mountain ranges for more than 500 km, and 50 circular features have been identified. Comparison with known Tertiary volcanic centers and consultation with geologic maps suggest eight new major centers.

Preferred distribution of mines and Tertiary volcanic centers along the major lineaments demonstrates the economic importance of these features. The intersection of three previously unmapped lineaments in northwestern Nevada is the location of a highly productive metallogenic district. In the Walker Lane, east-northeast-trending lineaments appear to control partially the occurrence of productive ore deposits.

Mapping Quaternary landforms and materials in the Midwest from ERTS images

R. B. Morrison and G. R. Hallberg report that ERTS–1 multispectral images are proving effective for differentiating many kinds of Quaternary surficial deposits and landforms units in Illinois, Iowa, Missouri, Kansas, Nebraska, and South Dakota. Examples of features that have been distinguished are the more prominent end moraines of the last glaciation; certain possible palimpsests of older moraines mantled by younger deposits; various abandoned river valleys, including suspected ones deeply filled by younger deposits; river terraces; and some known faults and a few previously unmapped lineaments that may be faults. The ERTS images are being used for systematic mapping of Quaternary landforms and deposits in some 20 study areas (mostly $1° \times 2°$ in size) within the project area. Some study areas, already well mapped, provide checks on the reliability of mapping from the images. For other study areas, previously mapped only partly or not at all, the new maps will be the first comprehensive, synoptic ones and should be useful for regional land-use planning and ground-water, engineering-geology, and other environmental applications.

Structural analysis from ERTS-1 images of north-central Arizona

A. F. Goetz and F. C. Billingsly of the California Institute of Technology and D. P. Elston, Ivo Lucchitta, and E. M. Shoemaker (USGS) have conducted an analysis of ERTS–1 multispectral images of north-central Arizona by a combination of photogeologic and computer enhancement techniques. Well developed regional structural patterns are strikingly visible. Computer enhancements using directional spatial filters of different sizes applied to magnetic-tape data reveal area-wide structural grain of varying orientations.

The structural grain of the ancient crust is displayed in sets of strongly developed, north- and northeast-trending lineaments, where the ancient rocks are at the surface. Previously unrecognized extensions can be traced beneath a cover of younger rocks and of unconsolidated materials using both unenhanced and structurally enhanced ERTS images. Part of the San Francisco volcanic field on the Colorado Plateau appears to be localized along an ancient north- and northeast-trending lineament system. An embayment in the Colorado Plateau margin in the northern part of the Verde Valley apparently reflects the existence of several strong, previously unrecognized, east-trending sets of fractures. Near Flagstaff, a set of northwest-trending lineaments that converge toward a north-trending lineament of the Oak Creek Fault was discovered on ERTS frame 1014–17375, and it may mark an area structurally favorable for the location of water in Paleozoic sediments that underlie the basalt cap.

A stereo-orthophoto experiment—a Canadian cooperative project

The Canadian National Research Council (NRC) at Ottawa is cooperating with USGS in experiments evaluating the usefulness of stereoorthophotos in geologic mapping. In the Canadian system both an orthophoto and its stereomate are made for each stereoscopic model of aerial photographs. The orthophoto is scanned from one photograph of the stereopair; the stereomate is scanned from the other. In the orthophoto, image displacements due to topographic relief and (or) camera tilt are removed by photographic or photomechanical methods resulting in a distortion-free, metrically correct photograph. In the stereomate these same image displacements are corrected but mechanically shifted in the x-direction (parallel to the line of scan) according to the height of the terrain. The advantage is that when viewed stereoscopically a smooth, geometrically correct, three-dimensional model is seen at map scale without the distortions and stairstep effects observed using conventional orthophotos paired with uncorrected aerial photographs.

A stereo-orthophoto pair of a part of the Triunfo Pass quadrangle in the Santa Monica Mountains, Calif., was made last spring by the NRC. The orthophoto of this rugged mountainous area fits the topographic map very well, and when viewed with the stereomate, they produce a distinct uniform three-dimensional model of the ground terrain. With the contour map printed on the orthophoto, a unique field tool and mapping medium is presented. Photointerpreted data and field observations mapped on the orthophoto can be transferred either photographically or by simple tracing techniques. Preliminary testing of the stereoorthophotos by C. L. Pillmore suggests that the technique will prove very useful and completely compatible with geologic field mapping.

APPLICATIONS TO HYDROLOGIC STUDIES

Delaware River basin data-relay project

R. W. Paulson reported that hydrologic data from stream gages, ground-water observation wells, and water-quality monitors are being collected several times a day from the Delaware River basin by NASA's ERTS. The data, transmitted by battery-operated radios called DCP's are acquired from the spacecraft by NASA's Goddard Space Flight Center in Greenbelt, Md. Within an hour of the time the data are acquired by NASA, they are sent by landline teletype to the USGS office in Harrisburg, Pa. The data are computer-processed daily and released to the Delaware River Basin Commission and other water-resources agencies. Data relayed by the ERTS–DCS provide the USGS with information on the status of field instrumentaion and provide water-resources agencies with information on the status of hydrologic conditions. This research, sponsored by the Department of Interior's EROS program, is an assessment of the satellite communication system as a tool for water-resources management.

Everglades water-management data-relay project

A. L. Higer reported that DCP's are now collecting and transmitting water-level and precipitation data at 12 sites. Nine stations are located in water-conservation areas and their output is used by water-management agencies. Two stations in Everglades National Park monitor changes in the park's water environment so that these changes can be related to plant and animal communities. One station in the Big Cypress Swamp is used as an index of a pristine area. To provide near real-time data for water management, teletype communications were established between Goddard Space Center in Maryland and the USGS in Miami. Data are received about 1 h after the satellite is within range of southern Florida, and these data are shared by a number of Federal and local governmental agencies.

Plumes in Long Island Sound

The study of circulation patterns in Long Island Sound is an important part of a multidisciplinary, multiagency investigation of the hydrology and ecology of this threatened major water body. Using ERTS data, F. H. Ruggles, Jr., identified plumes formed during the mixing of estuarine and sea water. Plumes differing from ambient water in the sound were delineated for July 28, October 8, October 27, and December 2, 1972, by analyses of the ERTS–1 imagery, using the Stanford Research Institute's ESIAC. The best results were obtained by insertion of multispectral-scanner band-5 imagery into the ESIAC. Analyses of additional images are aimed at producing time-lapse analyses of plume formation and migration as a guide to circulation patterns in Long Island Sound.

Thermal characteristics of Ozarks stream valleys

J. H. Williams (Missouri Div. Geol. Survey and Water Resources) and E. J. Harvey (USGS) reported that during 18 flights a radiometer was used to sense emitted energy variations of Ozarks streams and their drainage basins. In each flight a pair of stream valleys was compared, or losing and gaining reaches of one valley were compared. All the flights were made between September and March during predawn, noon, and postsunset hours under varying weather conditions.

Apparently, predawn flights are the most conclusive and noon or afternoon flights are inconclusive. Generally, during predawn hours in winter the gaining valley is somewhat warmer than the losing valley. At noontime one is like the other. On a warm and sunny September-afternoon flight, the gaining upstream reach of Roubidoux Creek was cooler than the downstream losing reach, and the Big Piney River, a gaining stream throughout its length, was much cooler than the losing reach of Roubidoux Creek.

Antecedent weather influences the emission characteristics of the land. A flight over two basins on the day following gentle rains was inconclusive. Another flight over the same basins 4 days after any appreciable rain showed a marked contrast between the two basins. One of the basins has an annual average runoff of 1.42 in. over 15 yr of record; the other has 12.33 in. of runoff over 22 yr of record.

Many factors control the emission characteristics of Ozarks basins. The best times for distinguishing losing and gaining stream basins are in the predawn summer and winter hours and at noon or early afternoon in the summer.

Satellite imagery for mapping and detection of changes of snow cover on land and on glaciers

M. F. Meier (1973) reported that the area of snow cover on land was determined from ERTS imagery. Snow cover in specific drainage basins was measured by Stanford Research Institute's console electronically superimposing basin outlines on imagery, with video density slicing to measure areas. For a basin with 22.6-percent snow cover, results were repeatable to within 4 percent of the snow-covered area. Snow-covered area and snowline altitudes were also determined by enlarging ERTS imagery to 1:250,000 and using a transparent map overlay. Under very favorable conditions, snowline altitude was determined to an accuracy of about 60 m. Ability to map snow cover or to determine snowline altitude depends primarily on cloud cover and vegetation and, secondarily, on slope, terrain roughness, sun angle, radiometric fidelity, and amount of spectral information available.

Glacier-accumulation-area ratios were determined from ERTS imagery. Also, subtle flow structures, undetected on aerial photographs, were visible. Surging glaciers were identified, and changes resulting from the surge of a large glacier were measured as were changes in tidal-glacier termini.

Measurement of snow cover, using passive microwave radiation

According to M. F. Meier, passive microwave emission has great potential for measuring snow distribution. The snowline mapped from aerial photographs of Mount Rainier on June 18, 1968, is almost identical with the 270-K brightness temperature shown on a microwave image. Microwave brightness temperatures of dry snow, wet snow, and snow-free terrain are unique. Thus the area of snow cover can be calculated from an average brightness temperature for any field of view, and the low resolution limitation of microwave imagers is not of any practical importance.

Aerial measurements of hydrologic phenomena

H. E. Skibitzke reported that instrumentation has been completed for the collection of multiband data for water-resources investigations. Installation of a Texas Instruments AAS–22 infrared imager, a radiometer, a 70-mm Sonne Strip camera, a 9-in. Sonne Strip camera, three 9-in. synchronized mapping cameras, one single mapping camera, a wide-angle 9-in. camera, a long-focal and a short-focal length 9-in. camera, operated by a crew of three in a twin-engined Mohawk airplane having a ceiling of approximately 20,000 ft, provides a complete package of remote-sensing capability. Relay to a ground receiving unit will provide real-time readout as the data are being collected, thus allowing project planners and users to observe the information within seconds. Techniques are being tested and proved in a statewide program to study hydrologic problems in Alabama. The various techniques also are being applied to data collection for the Resources and Land Information program in southern Florida.

Fluorescent spectroscopy as a technique for characterizing surface films

M. C. Goldberg and D. H. Devonald III (1973) have established a relationship between fluorescent spectra obtained by using a light path through the liquid solution and fluorescent spectra obtained by a direct reading of surface reflection. Fluorescent spectroscopic techniques were used to obtain the fluorescent spectra of lubricating oil, crude oil, and lignosulfonic acid in an effort to detect, identify, and quantify these representative fluorescent materials in water solutions. The excitation frequency best suited to stimulate fluorescent emission from these materials was 250 nm. The emission maximum for lignosulfonic acid was 380 nm; absorption maxima occurred at 287, 245, 325 nm. The crude-oil emission maxima were at 300 and 320 nm; the absorption maximum occurred at 220 nm. The lubricating-oil emission maximum varied from the crude-oil maximum and was a single value occurring at 348 nm, but the absorption maximum was broader; it was displayed at 228–292 nm. The emission curves yielded a linear response to the concentration of the fluorescent material as long as the concentration did not vary by more than a factor of 10.

A water sample, taken from the Houston ship channel, exhibited a fluorescent response similar to that of the two oil standards but also exhibited additional fluorescent response from 300 to 400 nm, a longer wavelength response than that of the oil samples.

APPLICATIONS TO CARTOGRAPHIC STUDIES

During fiscal year 1973 the Topographic Division was funded by NASA and the EROS program of the Department of the Interior to investigate cartographic applications of space imagery and high-altitude aircraft photographs. With the launch of ERTS–1 on July 23, 1972, a major emphasis was placed on experiments with images produced by the RBV and the MSS on board the satellite.

Evaluation of precision-processed ERTS images

The data-processing system at NASA Goddard Space Flight Center supplies two types of images from ERTS–1. The system-corrected (bulk-processed) image has radiometric error and some geometric error removed, while the scene-corrected (precision-processed) image is further rectified by reference to the ground control data. The limited capacity at the NASA Data Processing Facility allows precision processing of only about 5 percent of the ERTS images.

An evaluation of a complete set (all spectral bands) of early ERTS precision-processed imagery produced the following technical observations:

1. Perceptual image quality of precision-processed imagery appears to be degraded by about 50 percent as compared with bulk-processed imagery.
2. The precision-processed product with internal crosses as produced by NASA meets NMAS at 1:1,000,000 scale. Image quality rather than geometry appears to be the limiting factor in positional accuracy. These products provide a valuable geometric base for precisely relating ERTS images to the figure of the earth.
3. In an MSS color composite, band 7, because of high contrast, produces bloomed water boundaries and a resulting loss in geometric fidelity. The blooming effect can be reduced by controlling the exposure through the negative of band 7 or by substituting band 6, also controlled to avoid overexposure.
4. The best input bands for precision processing are believed to be MSS 5, MSS 6 (or 7), and the MSS color composite.

In cooperation with the Director of the Canadian Center for Remote Sensing (CCRS), arrangements were made to compare the precision-processing systems of NASA and CCRS. Control data for ERTS imagery covering Canada–U.S. border areas were exchanged. Common coverage will be precision-processed by the two systems; the products will then be exchanged and evaluated and the results reported back to each country.

An ERTS scene of the Lake Tahoe area was precision-processed by NASA and referenced to ground control at a scale of 1:1,000,000. USGS added the UTM grid and a descriptive explanation to the image, which was then lithographed in color as the first map prepared from ERTS and distributed in quantity.

ERTS imagery for delineation of controlled water bodies

ERTS imagery of northern Virginia showed a new large body of water, Lake Anna, site of a nuclear powerplant 20 mi SW. of Fredericksburg. Enlarged transparencies at scales of 1:250,000 and 1:24,000 were prepared, the latter being a $\times$ 140 enlargement of the original 70-mm Electron Beam Recorder (EBR) image at 1:3,369,000 scale. At 1:24,000 scale, picture elements (pixels) that record the water-land boundary measured approximately 69 m (along track) by 60 m (across track). Analysis of the enlargement indicated that the shoreline, sizable bridges, and other related structures can generally be defined to a pixel, except in areas where the waterbody width becomes somewhat less than 2 pixels (130 m) and thus may not be properly recorded as a distinct water signature. A detailed analysis of the capability of ERTS imagery to define the shores of Lake Anna has been undertaken.

Advantages of ERTS remote sensing

A year's experience with ERTS–1 provided valuable information on the advantages of telemetered imagery as compared to photographs obtained by film-return systems:

1. The long life and extensive repetitive coverage of ERTS–1 provided nearly complete cloud-free coverage of the United States in 1 year. Such performance with a film-return system is highly unlikely.
2. MSS imagery is closer to being orthogonal (a requirement for cartographic applications) than photographs produced by any known film-return system.
3. The MSS signals from ERTS are those of a focusing radiometer, which records radiated energy at a range and precision well beyond the capability of any current film system. Thus the imagery, recorded in four wave bands, can be combined to provide optimum signatures for particular scenes or objects.
4. ERTS imagery recorded in the near-infrared wave bands effectively penetrates thin clouds, clearly defines land-water boundaries and vegetative patterns, and emphasizes physiographic structures for geologic interpretation.
5. Telemetered imagery like that of ERTS can be extended into the thermal wavelengths, where-

as film-recorded imagery can not. Thermal imagery has many potential applications in detecting phenomena applicable in environmental studies, such as water pollution, forest fires, volcanic anomalies, and ocean currents.

Gridding space imagery by computer

An IBM 360/65 computer program for gridding small-scale imagery, developed at Ohio State University under NASA–USGS contract in 1970, has been modified to generate instructions for the Calcomp flatbed plotter. The plotter product is a UTM grid on Mylar, annotated and scaled to fit the imagery. Ground control points are photoidentified, and their photocoordinates are measured together with the coordinates of corner fiducial points. The program makes a least-squares fit and computes the photocoordinates of the selected grid intersections. The plotted grid overlay is alined to the graphic by the fiducial points. A fitted grid on the Wilmington 1:250,000-scale ERTS photomap was tested and found to meet NMAS. This production of a 1:250,000-scale image map from bulk ERTS images was a significant milestone in cartographic applications of space imagery.

Data bank of control points for space imagery

Thousands of control points for use in positioning space imagery anywhere in the United States were selected and stored in a data bank before ERTS–1 was launched. The control points, chosen for their high probability of being visible on ERTS imagery, were measured from large- and medium-scale topographic maps. Most points were adequate for their intended purpose, but more useful points are being added to the data bank by selecting points after inspecting the latest space imagery. Provisions were also made to obtain additional control points in Canada and Mexico for positioning images that extend over U.S. borders.

Investigation of ERTS imagery for photomapping

Sample products were made to demonstrate the usefulness of ERTS imagery in compiling small-scale photomaps. The investigations have shown that photomaps which meet NMAS can be made at scales in the range of 1:1,000,000 to 1:250,000, provided that sufficient ground control points can be identified on the imagery.

Experiments in image interpretation and map revision with ERTS data

Comparisons of ERTS imagery and existing maps indicated that some map detail, particularly water bodies, can be revised on maps of scales as large as 1:250,000. The experiments also showed that ERTS imagery is useful in determining which 1:24,000-scale maps should be revised. This finding promises to be of direct economic value in the national topographic program because it indicates that ERTS imagery can be used in lieu of new aerial photographs for evaluating standard maps for revision.

Application of ERTS imagery in thematic mapping

The Autographic Theme Extraction System (ATES) has been used successfully to extract from ERTS imagery several kinds of phenomena that produce a consistent signature in one or more of the recorded spectral bands. For example, the flooded area of the Mississippi River basin, recorded by ERTS sensors, was extracted from the imagery in binary graphic form (black and white) for use in measuring the extent of the flood waters at a known time. Snow and ice, infrared-reflective vegetation, and gross urban areas have also been separated from the rest of the scene. Graphics of extracted themes can be compared with subsequent graphics of the same scene for time-change analysis.

Application of ERTS imagery in polar mapping

ERTS imagery has been investigated for use in (1) supplementing planimetric map data with information on such features as crevasse fields, sastrugi patterns, and glacier flow lines in mapping specific areas of the polar plateau at scales of 1:1,000,000 and smaller, (2) mapping gross ice features, (3) compiling planimetric sketch maps or photomaps of the poorly mapped Antarctic areas, (4) compiling a 1:10,000,000-scale photomap of the entire Antarctic continent north of 82°, (5) compiling small-scale maps of sea ice and recording temporal variations, and (6) detecting changes in glaciological features. Imagery recently evaluated demonstrated the feasibility of revising coastlines, showed gross changes in the northern limits of the three largest ice shelves in the world, and led to the discovery of uncharted mountain ranges.

Cartographic evaluation of ERTS orbit and attitude data

Studies were initiated (1) to develop techniques for using derived satellite position and attitude data for cartographic referencing of high-resolution images, (2) to evaluate the accuracy of derived satellite data theoretically and empirically (by comparison with ground control), and (3) to suggest methods for improving the accuracy of derived satellite position and attitude data. The shutdown of the RBV's materially curtailed these studies. Efforts therefore were diverted to studying the geometry of the MSS image before trying to apply it to mapping without the benefit of ground control.

RBV geometric distortion on ERTS-1

Although the ERTS RBV cameras were turned off in August 1972, a few images were obtained that exhibited high geometric quality. USGS has calibrated all the RBV reseaus, and the bulk-processed images can be compared with the calibrated values. The average rms distortion was 65 m (converted to ground scale) and less than 100 m for all images measured. The ground control points in several RBV scenes were measured and compared with UTM values. The rms fit with a 4-parameter conformal transformation ranged from 100 m to 150 m, an accuracy commensurate with NMAS at the scale of 1:500,000.

RBV calibration analysis

Under contract with USGS, the University of Illinois analyzed the geometric distortion of the RBV system and developed calibration techniques. The distortion pattern was successfully modeled using a pair of 20-term polynomials. The residual errors were 27 m in the x direction and 36 m in the y direction. The mathematical model was then used with a modified reseau of 29 points around the edge and a single point in the center of the frame. The remaining 52 points of the 81 in the original reseau pattern were used as a check. The results gave an rms distortion of 51 m in the x direction and 70 m in the y direction. These results provided the first positive indication that the RBV distortions can be modeled mathematically with a perimeter reseau pattern that does not obstruct the scene.

Resolution targets for ERTS and Skylab imagery

In a cooperative effort with NASA and USAF, USGS prepared plans and specifications for ground resolution targets to be used for evaluating ERTS and Skylab imagery. The parameters studied included target configurations, orientations, sizes, materials, contrasts, and reflectivity as well as location, permanence, and maintenance.

A Siemen's star design with 20 light wedge-shaped elements and 20 matching dark elements per full circle was selected, with an outside radius of 1,000 m and an inner radius of 32 m. The dark elements will be prepared by coating the ground surface with asphalt, and the untreated playa surface will provide the light elements. Bar targets of the same materials will be laid out in the open center of the pattern.

Skylab projects

The following remote sensors of particular significance to cartographic applications were included in the Skylab Earth Resources Experiment Package (EREP):

1. S–190A: A 6-band multispectral assembly of cameras with 153-mm focal length and 70-mm format.
2. S–190B: The Earth Terrain Camera (ETC) with 457-mm focal length and 114-mm format.
3. S–192: A multispectral scanner operating in 13 channels from 0.4 to 12.5 μm.

Several experiments were proposed by USGS and accepted by NASA for studying cartographic applications of EREP data: (1) Cartographic evaluation of Skylab S–192 scanner images, (2) investigation of Skylab imagery for photomapping of the U.S., (3) an experiment in cultural interpretation and map revision from Skylab data, (4) proposal to investigate Skylab imagery for application to thematic mapping, (5) proposal for overall evaluation of Skylab images for cartographic application, and (6) Earth Terrain Camera proposal for Skylab.

Autographic Theme Extraction System (ATES)

The space technology of the 1960's demonstrated that monitoring and cataloging Earth's resources from space would be feasible as well as highly desirable. Under the EROS program, USGS started the development of the Autographic Theme Extraction System (ATES) as a means of isolating and extracting the various resources data.

Hardware development for ATES was completed during the year. ATES consists of three processing units—the density manipulation system, DMS; the video multichannel image analysis system, MIAS (an electronic photolab); and a graphic-arts photolab. DMS is made up of an image analysis system, an interactive display unit, an image scanner-recorder, and a special digital image processor, all individually connected to a minicomputer. A small but resourceful program library allows any type of tape-to-film or film-to-tape transfer of imagery, generation of unsharp masks and neutral density correction filters, and selective image enhancement which may be required to support photomechanical-photochemical theme extraction. MIAS is used to determine electronically which combination of ERTS scene bands, transparency type, and film-processing parameters will produce the optimum theme extraction or image composite. Personnel have been trained in quality control and special photographic processing techniques required for operating ATES. Research continues on new films, chemicals, and techniques required to optimize theme extraction efficiency.

APPLICATIONS TO GEOGRAPHIC STUDIES

LAND USE AND OTHER GEOGRAPHIC STUDIES

Land-use classification and analysis

Land-use policy legislation now pending in the U.S. Congress, requirements of the Environmental Protection Act for environmental impact studies, and an increase in State and local planning activity are creating several new dimensions for land-use analysis. Urbanization and the increasing public demand for an improvement of environmental quality in an urban setting present a striking need for coordinated planning activity.

In 1971, a land-use classification system for use with remote-sensor data was developed through the Inter-Agency Committee on Land-Use Information and Classification to provide a framework for a national land-use and resources data base which could be rapidly, uniformly, effectively, and inexpensively updated in date, scale, and categorization. This two-level classification system has been published in USGS Circular 671, "A Land-Use Classification System for Use with Remote-Sensor Data," transmitted for review and comments to nine Federal agencies engaged in land-use analysis and planning programs, and is being tested in current land-use analysis and monitoring projects in the USGS geography program. The land-use classification system is open ended so that regional, State, and local agencies may develop more detailed systems at the third and fourth levels to meet their particular needs and at the same time remain compatible with each other and with the national system.

In order to coordinate the development of a standard land-use classification system for use by Federal, regional, State, and local planning groups, a series of four symposia, jointly sponsored by the Department of the Interior's Office of Land Use and Water Planning (formerly the Office of Regional Planning) and USGS was held in October 1972. These meetings were attended by 121 officially designated representatives of State and regional planning offices. It was the consensus of these representatives that there is an immediate need for a standardized national land-use classification system. A series of workshops on Land-Use Classification were held in the latter part of May and early June 1973 to discuss the proposed land-use classification system and its potential uses on a national, regional, and statewide basis. In the USGS geography program, many contacts have been made with regional, State, and local users concerning the applications and uses of the land-use data derived from remote-sensor imagery obtained from high-altitude aircraft and satellite overflights. This information is interpreted, categorized, and analyzed to produce comprehensive data in computer-generated map and statistical format by staff members in the geography program on an experimental basis. More detailed information concerning this current work is given below.

Central Atlantic Regional Ecological Test Site (CARETS) project

The CARETS project, designed to test the applicability of ERTS–1 data as an input to a regional land-use and environmental information system, has been guided in formulation and development by the hypothesis that the land use visible to remote sensors is an indicator or a result of a number of interacting environmental and socio-economic processes and that knowledge of these processes and the changing land-use patterns they produce is important to regional planning and management groups. Based upon a sampling strategy involving three levels of land-use data derived from satellite and airborne remote sensors, the CARETS research design calls for a sequence of three interrelated program steps or subtasks:

1. Land-use analysis: Maps and data sets on land use for the approximately 70,000 km^2 (30,000 mi^2) region have been prepared from high-altitude aircraft and satellite (ERTS–1) imagery. Accuracy checks, updating, and preparation of the data for input into a computer-based experimental information system are in progress.

   A CARETS regional mosaic of ERTS images, at a scale of 1:1,000,000 and partitioned into sub-regions having similar characteristics in tone and texture (designated as photomorphic regions), was compared with the land-use map published in the National Atlas. This comparison revealed a close correlation in nonurban regions. If, as suspected, other environmental variables can be correlated with patterns on ERTS imagery, the basic knowledge of environmental processes may be enhanced, and an economical sampling strategy for selecting field checking sites to test the accuracy of land-use mapping may be devised using these photomorphic regions.

The development of automatic data-handling techniques for the CARETS project as well as other geography program research work has been a task of major importance and is reported in more detail in a separate section of this report. Using the CARETS region as a test area, extensive investigation has been made in regard to various computer-based methods of manipulating, digitizing, storing, retrieving, making area measurements, and automatically plotting land use data in polygon form; that is, the digital representation most closely approximating the land-use map formats with which users are familiar.

2. User evaluation: Staff members in the CARETS project have continued to maintain contact with user agencies in the region and to expand the number of such agencies. One of these agencies, the Maryland State Planning Office, has incorporated the Maryland portion of the CARETS high-altitude aircraft data base directly into the Maryland land-use inventory. Another, the Northern Virginia Planning District Commission, is using CARETS land-use data for the district's final water-quality plan and for its Broad Run watershed study because the CARETS land-use information is the most up-to-date available for their areas of concern.
3. Environmental-impact assessment: The physical constraints on development were investigated with respect to factors affecting land use in the Norfolk-Portsmouth Standard Metropolitan Statistical Area (SMSA) and a map of earth materials (such as sand, clay, and peat) showing their distribution at or near the surface was compiled.

Several subtask studies concerning the impact of land-use change on environmental quality have been conducted. In a land-use modeling study, a modular approach was proposed with the initial effort considering air and water quality as functions of land-use within the hydrologic cycle framework. The application of CARETS land-use data to air-quality planning is being demonstrated in the investigation of the climatological effects of land-use patterns and changes in Norfolk and Baltimore. The Norfolk study has demonstrated the relationship of land-use units to the emission, diffusion, and fallout patterns of sulfur dioxide and suspended particulates; the Baltimore study has involved the calibration of multispectral aircraft data to test a newly developed model for the study of the urban heat-island effect. Research on the impact of land use on hydrology has sought empirical relationships among land use and the factors of infiltration, runoff, sediment yield, and water quality. Finally, an evaluation of ERTS imagery of the coastal zone of CARETS has demonstrated the ability to identify, from remote-sensor imagery, areas of environmental vulnerability and sensitivity in the region of the offshore Barrier Islands.

Census Cities project

The Census Cities project is an experiment in urban land-use pattern recognition and change detection which utilizes data from high-altitude aircraft and satellite-based multispectral photography acquired for a rank-size sample of selected U.S. urban areas during the 1970 census. Similar photography obtained in 1972 is providing a basis for analyzing gross land-use changes and for assessing the utility of ERTS satellite imagery for this purpose.

During 1972, controlled and gridded photomosaics and land-use mapping and analyses for 1970 were completed for eight of the urban test sites: Boston, Mass., Cedar Rapids, Iowa, New Haven, Conn., Phoenix, Ariz., Pontiac, Mich., Tuscon, Ariz., San Francisco, Calif. and Washington, D.C. Using 1972 aircraft photography, change-detection analyses have also been completed for Cedar Rapids, Tucson, Washington, and for the largest of the urban test sites, San Francisco. Analyses are also underway for Boston, New Haven, Phoenix, and Pontiac.

The mosaics, land-use information, and corresponding census statistical areas for these urban test sites are being combined as components of a looseleaf "Atlas of Urban and Regional Change." The first atlas sheets for the San Francisco Hayward land-use map, at scales of 1:62,500 and 1:125,000, have been released through open file.

ERTS satellite imagery for each of the eight test sites is being received and analyzed as part of the ERTS-1 experiment. Preliminary examinations of the San Francisco Bay ERTS-1 imagery clearly indicate a real potential for identifying and delimiting the urban fringe. This imagery, particularly the infrared band, has been valuable in identifying intraurban land-use details such as tracts of more than about 10 acres in size that are undergoing development in the San Francisco urban area.

In addition, areas of land-use change in a portion of the Washington test site have been successfully identified on the ERTS multispectral-scanner color enlargements at 1:100,000, in conjunction with the initial change identification obtained from the 1972 high altitude photography. These initial analyses of ERTS satellite imagery demonstrate to what extent the intraurban environment and intraurban environmental changes can be interpreted from imagery demonstrate to what extent the intraurban environment and intraurban environmental changes can be interpreted from imagery in graphic format.

Work is also underway on the analysis of ERTS imagery by computer manipulation of the multispectral-scanner data in digital format. Computer compatible tapes (CCT) for an early ERTS–1 multispectral-scanner image of the San Francisco Bay area are being used to classify and analyze land use in that metropolitan region. NASA aircraft underflight data (aerial imagery taken along with and in support of satellite imagery) and land-use maps from the Census Cities ERTS–1 experiment are providing computer training samples. The tape record has been reformatted for use with the pattern recognition and classification algorithms developed at the Purdue University Laboratory for Applications of Remote Sensing. Trial land-use classification systems are being compared with color-infrared photography and ground-truth data for San Jose and vicinity. Preliminary analyses use 14 different classes of spectral band and spectral density from the ERTS–1 digital record for a sample area 9 by 18 km in size; at a computer printout scale of approximately 1:24,000, one pixel (lowest recording unit) measures just under one-half hectare. These 14 classes are combined into 7 land-use categories. Two of these categories appear to distinguish pre-World War II Residential from later Residential. Transportaion, Livelihood (Commercial and Industrial), Irrigated Open Space, and Non-Irrigated Open Space are also identified. A seventh category is comprised of "threshold uses," pixels which are too light or too dark to classify.

During fiscal year 1973 a growing sample of potential applications of these data and the user agencies concerned with them have been identified. Coordination efforts have been made primarily with potential users of the land-use data and analytical products in each of the eight urban test sites. Among the agencies who have either participated to some degree with the Census Cities work or who have used some of its products are the Metropolitan Washington Council of Governments, Association of Bay Area Governments in San Francisco, Maricopa Association of Governments, Appalachian Regional Commission, and at the Federal level, the Bureau of the Census, Council on Environmental Quality, Office of Emergency Preparedness, and the Urban Studies Program of the USGS as well as numerous other planning and government agencies at the local level. Applications that have been identified are as follows: (1) Calibrate a traffic-flow model and estimate daytime distribution of population, (2) estimate water-use requirements, (3) define "open space" land and assess environmental hazards affecting possible urban expansion, (4) assess environmental hazards on present urbanized land, (5) identify prime land which ought to be preserved for agriculture, (6) calibrate a waste-management model for San Francisco Bay and monitor possible changes in water quality, (7) assess quality of residential environment, and (8) project future population densities and estimate changes in population distribution between censuses.

Ozarks regional land-use pilot project

After a year of preliminary experimentation in land-use mapping with data from remote sensors for the Ozarks region, a cooperative project with the Ozarks Regional Commission was begun in January 1973. A computer data base for the Ozarks region, consisting of (1) land use, (2) land ownership (private, State, Federal by administering agency), (3) river basin and subbasin data, (4) administrative boundaries, and (5) census enumeration districts, is being developed. These data can be cross tabulated with each other in order to display the results in cartographic and statistical formats. Two land-use maps have been compiled at a scale of 1:250,000, using data received from remote sensors in high-altitude aircraft. These maps are for the Springfield, Mo., and the Russellville, Ark., quadrangles. Computer analysis of the 1968 data base of the Springfield quadrangle has provided a summary of land use in the entire area of the quadrangle as well as a county summary and percentage of area of each land-use type within counties. Surveys of user needs and interests have been conducted in the member States of the Ozarks Regional Commission in order to obtain guidance on the future expansion of the data base and computer programs.

Phoenix and southern Arizona land-use mapping project

During fiscal year 1973, research emphasis in this project has been on (1) change detection using a variety of remote-sensor images, (2) testing procedures for updating the computer data bank and automated mapping for the Phoenix 1:250,000 quadrangle area, and (3) enlarging the scope of the data bank to include three additional 1:250,000 quadrangles adjacent to the east, southeast, and south of the Phoenix quadrangle.

Procedures were developed for the interpretation of land-use change with the aid of imagery from the 6-in. metric camera from U–2 high-altitude aircraft overflights and the ERTS-simulation sensor package. Emphasis was placed upon the multiband enhancement of the short focal length photographs mounted in an International Imaging Systems color-additive viewer. Optimum wave-length bands, color filters, and light intensities were developed to enhance different types of land use. This research was undertaken in preparation for the receipt of the ERTS satellite imagery beginning in the fall of 1972.

The aim of both the aerial photointerpretation and the ERTS experiment is to detect as much land-use change as possible from the imagery of the Phoenix quadrangle. In each experiment, land-use change maps were hand compiled for later updating of the computer model prepared last year. During the aerial photointerpretation phase, land-use changes detected at level II of the USGS land-use classification system were recorded. Only level I of the classification system was used for the ERTS image interpretation—mostly for detection of new residential areas and cropland. A rapid increase in the use of circular overhead irrigation was noteworthy. A more complete testing of the proposed land-use classification system has been undertaken, including rigorous field checking for accuracy by both light plane and automobile. The proposed land-use classification system, however, appears to be reasonable for the arid southwestern United Staes.

The field checking of the land-use maps showed that manmade features, including cultivated fields, could be accurately mapped from data interpreted from high-altitude aerial photography. Natural vegetation patterns could be accurately delimited although the species of vegetation could not be determined by interpreters unfamiliar with the region. Nevertheless, the value of this photography for mapping land use, particularly by local users, is well established. Users such as planners, resource managers, and especially tax assessors in Arizona have expressed interest in monitoring land use.

Once the land-use changes were mapped, the new data were entered into the data bank by card input, and maps of land-use change as well as a revised land-use map were plotted out automatically by the USGS Calcomp 763 plotter. For the revised land-use map, a separate plate was plotted for each color representing the first level of the classification system on the finished map. The second-level categories were differentiated by separated symbols within each color code. This revised land use map reflects changes detected for the period February to November 1970.

The largest effort in terms of manpower during the year was the mapping and digitizing of environmental and socioeconomic factors for the three additional 1:250,000 quadrangles of Mesa, Tucson, and Ajo. Data included land use, land ownership, county codes, and drainage basins for all of the areas, and soils and census tract codes for selected counties. The land-use data were interpreted from high-altitude RB–57 aerial photography of the ARETS area and ERTS underflight photographs of selected test areas. Other data were drawn from published sources, but in all cases, special maps had to be prepared with the proper scale and information content to facilitate digitizing on a Faul-Coradi digitizer. Computer programs were prepared to make the digitized data compatible with cellular analysis programs being written by the Raytheon Corp. under contract with the EROS Program.

INTERNATIONAL COOPERATION IN THE EARTH SCIENCES

International cooperation in the earth sciences has been a significant program of the USGS for more than 30 yr. Most of this cooperation has been in the form of technical assistance to developing countries under the auspices of the Department of State's AID and predecessor agencies and at the request of host governments. In recent years, however, the USGS has become progressively more involved in cooperative research and scientific exchange on problems of mutual interest to the United States and other countries; participation in activities of international organizations, commissions, and scientific unions; and arranging advanced study and training for scientists from other countries.

During 1973, major long-range technical assistance projects continued in Brazil, Colombia, Saudi Arabia, and Indonesia. These projects are intended to assist the host countries in establishing or strengthening their geological, hydrological, and cartographic organizations and programs, and concurrently helping to accelerate the investigation and appraisal of resources needed for economic development. A number of short-range cooperative assistance projects were carried out also in other countries as listed in table 2. Many of these involved studies of critical resources, environmental problems, or natural hazards.

Studies of natural disasters and related phenomena in other countries continued to engage the attention of many USGS scientists. In response to the increasing need for federal agencies to respond more effectively to natural disasters in foreign countries, an Interagency Committee on Foreign Disaster Response Coordination was formulated in late 1972 under the aegis of the Department of State and including representatives of the Department of State,

TABLE 2.—*Technical assistance to other countries provided by the USGS during fiscal year 1973*

Country	USGS personnel assigned to other countries: Number	USGS personnel assigned to other countries: Type	Type of activity[1]	Scientists from other countries trained in the United States: Number	Scientists from other countries trained in the United States: Field of training
Latin America					
Argentina				3	Geochemistry.
Bolivia				1	Geophysical prospecting for water.
				2	Digital seismic processing.
Brazil	17	Geologist	A, B, C, D	1	Economic geology.
	8	Hydrologist	A, B, C, D	2	Minerals exploration.
	4	Chemist	D	1	Analytical techniques.
	2	Geophysicist	D	3	Geochemistry.
	2	Metallurgist	D	1	Mineral resources (ultramafic).
	1	Mathematician	D	3	Exploration for radioactive materials.
	1	Mapping instructor	D	9	Remote sensing.
	1	Sample control specialist	D	4	Collection and computation of water resources data.
	1	Cartographer	D	2	Automatic data processing of hydrologic data.
				1	Hydrology and surface water techniques.
				1	Isotope analysis.
Colombia	9	Geologist	A, B, C, D	7	Economic geology.
	1	Driller		1	Geochemistry.
Costa Rica	2	Geologist	D	1	Chemical analysis of water.
Guatemala				1	Remote sensing.
Jamaica	1	Hydrologist	D	2	Hydrologic techniques.
Mexico	1	Physical science technician	D	1	Application of isotopes to hydrology.
Nicaragua	5	Geologist	D	--	
	3	Geophysicist	D	--	
	1	Geologic Field Assistant	D	--	
Surinam				2	Hydrology.
				1	Hydrogeology.
Trinidad				1	Hydrology.
Venezuela				1	Hydrology.
				1	Water data coordination.

[1] See footnote at end of table.

TABLE 2.—*Technical assistance to other countries provided by the USGS during fiscal year 1973*—Continued

Country	USGS personnel assigned to other countries: Number	Type	Type of activity[1]	Scientists from other countries trained in the United States: Number	Field of training
Africa					
Botswana	1	Geologist	D	--	
Canary Islands	2	Hydrologist	D	--	
Ethiopia	1	Hydrologist	A	1	Hydrology.
Kenya	2	Hydrologist	A, D	1	Hydrology.
	1	Geologist	D	--	
	1	Electronics technician	D	--	
Lesotho	1	Geologist	D	1	Remote sensing.
Liberia				1	Analytical chemistry and petrology.
				1	Geophysics and remote sensing.
				1	Analytical chemistry.
				2	Remote sensing.
Mali	2	Geologist	D	2	Remote sensing.
	2	Remote-sensing specialist	D	--	
Nigeria				1	Hydrogeology.
Somalia				1	Hydrogeology.
Sudan				1	Remote sensing.
Swaziland	1	Geologist	D	--	
Tanzania	1	Hydrologist	D	--	
Tunisia	1	Hydrologist	D	2	Remote sensing.
Uganda				2	Hydrology.
Upper Volta				2	Remote sensing.
Union of South Africa	1	Physicist	A	1	Mineralogy, chemistry, and petrology.
West Africa region	2	Geologist	D	--	
Near East–South Asia					
Afghanistan	1	Geologist	D	1	Hydrology.
				1	Mapping techniques.
				1	Hydrologic data collecting methods and streamgaging.
				4	Remote sensing.
India	2	Geologist	A, D	2	Hydrogeochemistry.
	2	Hydrologist	A	1	Ground-water development.
				1	Aerial surveys for radioactive materials.
				1	Techniques and application of project planning to basin-wide water management.
				2	Photogrammetry.
				1	Reproduction and printing of geologic maps.
				1	Atomic minerals exploration.
Iran	3	Geologist	D	--	
	1	Hydrologist	D	--	
	1	Forester	D	--	
	1	Remote-sensing specialist	D	--	
Israel				1	Analytical separation and atomic absorption spectroscopy.
Jordan	1	Geologist	D	1	Groundwater.
				1	Geological engineering.
				1	Surface water and sedimentation.
Nepal	1	Hydraulic engineer	A	5	Ground-water investigations.
	1	Hydrologist	A	--	
Oman	2	Geologist	D	--	
Pakistan	4	Hydrologist	A, D	1	Oil and gas law.
				1	Geology of sedimentary uranium deposits.
Saudi Arabia	17	Geologist	A, B, C, D	1	Geologic names.
	1	Administrative officer		1	Geology.
	3	Mathematician	B	--	
	4	Geophysicist	B, D	--	
	2	Driller		--	
	1	Publication editor		--	
	1	General services officer		--	
	1	Project assistant		--	
	3	Cartographic technician	D	--	
	6	Cartographer	D	--	
	1	Photographer	B	--	
	1	Secretary		--	
	1	Chemist	B	--	
	1	Spectrographer	D	--	
Turkey	2	Geologist	D	1	Mineral exploration.
	1	Geophysicist	D	--	

[1] See footnote at end of table.

TABLE 2.—*Technical assistance to other countries provided by the USGS during fiscal year 1973*—Continued

Country	USGS personnel assigned to other countries: Number	USGS personnel assigned to other countries: Type	Type of activity[1]	Scientists from other countries trained in the United States: Number	Scientists from other countries trained in the United States: Field of training
		Near East–South Asia—Continued			
Yemen	1	Civil engineer technician	B	--	
	3	Cartographic technician	B	--	
	1	Civil engineer	B	--	
	1	Geologist	D	--	
		Far East			
Indonesia	10	Geologist	A, B, D	2	Geologic mapping techniques.
	1	Cartographic technician	B	1	Mineral economics.
	1	Geophysicist	D	1	Petrography and petrology of igneous and metamorphic rocks.
	1	Chemist	D	1	Analytical chemistry.
	3	Remote-sensing specialists	D	1	Hydrography.
				1	Ground-water resource evaluation.
				4	Remote sensing.
Japan				1	Mineral synthesis.
				1	Rock mechanics.
Korea				2	Remote sensing.
				1	Hydrology.
Philippines	3	Geologist	D	1	Remote sensing.
	1	Geographer	D	--	
	1	Hydrologist	D	--	
	2	Remote-sensing specialist	D	--	
Republic of China	2	Geophysicist	D	1	Hydrologic instruments and methods.
	1	Geologist	D	1	Ground-water.
Thailand	6	Geologist	D	1	Water resources development.
	1	Geophysicist	D	3	Water resources engineering.
	1	Hydrologist	D	1	Radiochemistry and neutron activation.
	2	Remote-sensing specialist	D	1	Offshore mining safety.
				1	Hydrology.
		Other			
Australia	2	Hydrologist	D	--	
	1	Geologist	D	--	
Austria	1	Hydrologist	D	1	Geochemical exploration.
	1	Physicist	D	--	
France	2	Hydrologist	D	--	
	1	Geophysicist	D	--	
	1	Geologist	D	--	
Germany	1	Hydrologist	D	1	Micro-earthquake studies.
Great Britain				1	Hydrology.
				1	Isotope investigations.
Romania				1	Exploration for radioactive materials.
Spain	1	Hydrologist	D	1	Analog modeling and hydrology.
Switzerland				1	Earthquake research.
Yugoslavia	3	Geologist	D	--	
	1	Hydrologist	D	--	
	1	Geophysicist	D	--	

[1] A, broad program of assistance in developing or strengthening earth-science institutions and cadres; B, broad program of geologic mapping and appraisal of resources; C, special studies of geologic or hydrologic phenomena or resources; D, short-range advisory help on geologic or hydrologic problems and resources.

AID, National Science Foundation, National Bureau of Standards, Department of Commerce, National Academy of Science, and the USGS. The USGS was designated lead agency in helping to coordinate response whenever the disaster is in its area of competence.

Following the disastrous earthquake of December 23, 1972, scientific teams made geological and geophysical investigations of the Managua area in Nicaragua under the auspices of AID to help in assessing geological conditions as a basis for reconstruction, and recommendations were submitted for use by the local authorities. (Brown and others, 1973)

A prototype volcano monitoring network was installed on volcanoes in Guatemala, Nicaragua, and San Salvador, whereby seismic events indicative of possible volcanic activity are relayed via the ERTS–1 satellite to central receiving stations in the United States. The USGS also participated in the study of the destructive eruption of Helgafell volcano, Heimaey Island, Iceland. Imagery from ERTS–1 proved to be helpful in the studies both in Nicaragua and Iceland.

An important part of the USGS technical assistance in the past year was concerned with the introduction and application of remote-sensing technology for natural-resource surveys. The launch of ERTS–1 in July 1972 led to widespread interest in using imagery from the satellite for experimental mapping of resources and brought many requests for training and assistance in remote sensing. As a result, the USGS conducted training courses or seminars in Iran, Indonesia, Mali (Sahelian seminar), Thailand, Brazil, and the Philippines (East Asian seminar) on behalf of AID and participated in a seminar in Panama; these courses and seminars were concerned with multidisciplinary applications and involved the participation of specialists in agriculture, forestry, and land utilization from several universities in the United States, together with specialists in geology, hydrology, and related subjects from within the USGS.

The Sahelian Remote Sensing Seminar held in Bamako, Mali, April 17 to 28, 1973, had 23 participants: 12 from the host country and others from Chad, Dahomey, France, Mauritania, and Upper Volta. Maurice Grolier (USGS) was chief of the instruction party which included N. H. MacLeod of American University and J. J. Palgen of Earth Satellite Corp. The seminar, which was presented in French, emphasized applications to the Sahelian Zone in the disciplines of agriculture, forestry, hydrology, ecology, geology, and economics.

The East Asian Remote Sensing Seminar held in Quezon City, Republic of the Philippines, May 7 to 18, 1973, had 51 participants and observers: 37 from the host country and others from Afghanistan, Burma, China, Indonesia, Korea, Malaysia, Thailand, and Vietnam. S. J. Gawarecki was chief of the instruction party which included G. E. Stoertz and J. L. Place of the USGS, W. H. Stevenson of NOAA, S. A. Morain of the University of Kansas, and R. C. Bruce of the University of the Philippines. The disciplines to which the seminar was addressed were agriculture, forestry, cartography, geology, oceanography, fishery, and land use.

An international remote sensing training course of 4 weeks' duration was held at the EROS Data Center, Sioux Falls, S. Dak., June 2 to 29, 1973, and attended by 28 participants from 11 countries including Afghanistan, Brazil, Guatemala, Indonesia, Korea, Liberia, Mali, Niger, Philippines, Tunisia, and Upper Volta. USGS personnel who participated in the training were R. G. Reeves, chief of the instruction party, J. R. Walden, D. E. Orr, H. G. Rodis, and C. F. Withington. In addition, nine guest instructors were present from other agencies and from private industry. The course, which emphasized ERTS technology and data applications, covered the disciplines of geology, hydrology, cartography, agriculture, forestry, and soils.

Technical assistance was provided to a number of countries through international organizations. For example, R. M. Hamilton made a seismic study of the Rift Valley of Kenya; F. H. Wang was assigned to help plan a marine mineral exploration program in East Asian offshore areas; and Richard Brown served as consultant to the Government of Tunisia on artificial recharge projects in that country, all on behalf of the U.N. development program. At the request of the Economic Commission for Asia and the Far East (ECAFE), J. M. Goldberg spent 3 mo in Thailand as technical editor of the Proceedings of the Fourth Symposium on the Development of Petroleum Resources of Asia and the Far East. Assistance in topographic surveys was provided to the Government of the Yemen Arab Republic. The USGS continued its assistance to the Central Treaty Organization (CENTO) in Iran, Pakistan, and Turkey on behalf of AID by providing specialists for short-term assignments in field-mapping techniques, stratigraphy, phosphate exploration, recent tectonics, igneous petrology, and remote sensing.

In addition to technical assistance projects, the USGS extended its scientific cooperation into many other countries and new research problems during 1973. In cooperation with NASA, USGS scientists were investigators and advisors on a number of research projects based on the application of satellite imagery. These activities involve experimental applications of ERTS–1 imagery in a wide range of resource problems and mapping techniques. ERTS data were utilized also in other studies; for example, to estimate seasonal hydrologic changes in salars in the interior basins of Argentina, Bolivia, and Chile, and to help determine the factors controlling deposition of salt.

Cooperative research projects with agencies in Yugoslavia continued on crustal structure, rare metals, karst permeability, and geologic factors in earthquake reconstruction, and preparations for new projects on base metals and mining hydrology with agencies in Poland were completed. Bedded barite deposits in the Federal Republic of Germany were studied to develop guidelines for exploring similar deposits in the western United States.

A research project on offshore resources along the coast of Spain was initiated with the National Organization of Mineral Research, under the auspices of the National Science Foundation. USGS participation in the program of the IDOE, also under the auspices of the National Science Foundation, led to completion of a 26,000-mi cruise through coastal areas of Puerto Rico, Venezuela, Trinidad, Mexico, and Liberia in which local scientists participated. (See section on "Marine Geology and Hydrology Investigations.") A study of the Straits of Juan de Fuca involving about 1,700 miles of gravity, magnetic, and seismic profiles was made in cooperation with the Geological Survey of Canada. The USGS also cooperated with the Canadian National Research Council in evaluating use of stereo-orthophotographs in geologic mapping of high altitude photography. (See section on "Remote Sensing and Advanced Techniques.")

USGS scientists continued to participate extensively in international commissions, associations, and scientific programs, and its personnel were involved in many activities of the International Geological Congress in Montreal, Canada, during August 1972, with V. E. McKelvey serving as head of the U.S. delegation. A summary of U.S. cooperative assistance to developing countries was submitted to the Congress by J. A. Reinemund, G. C. Taylor, Jr., and G. L. Schoechle (1972) as a contribution to a symposium on earth science aid. In September 1972, USGS hydrologists were active in the Second International Symposium on Hydrology, as well as the First International Conference on Water Resources Knowledge held at the Colorado State University at Fort Collins.

Scientists of the USGS participated in the work of the Commission for the Geological Map of the World and many other Commissions of the International Union of Geological Scientists; the Sixth International Cartographic Association Conference; the Second National Congress on Photogrammetry, Photointerpretation, and Geodesy; and other scientific unions. The USGS also provided representation for a number of committee meetings sponsored by the U.N. Economic and Social Council including the Committee on Natural Resources, Seabeds, and Outer Space; by the U.N. Educational, Scientific, and Cultural Organization (UNESCO), including the International Hydrological Decade and International Geological Correlation Program; and by the regional U.N. Economic Commissions in the Far East and Africa, and the U.N. Regional Cartographic Conference for Africa. As a contribution to the work of the U.N. Seabeds Committee, a summary of mineral information for 120 countries was issued (J. P. Albers and others, 1973). Survey scientists also participated in the United States–Japan Natural Resources program.

R. H. Lyddan served as Alternate U.S. Member of the Commission on Cartography of the Pan-American Institute of Geography and History (PAIGH) in Panama, April and May 1973; P. F. Bermel was the Vice Chairman and U.S. Corresponding Member of the Committee on Topographic Maps and Aerophotogrammetry of PAIGH, and M. B. Scher, David Landen, and L. V. Roberts were members of working groups or committees of PAIGH. F. J. Doyle attended the International Symposium on Satellite Geodesy in Greece and participated in the annual exchange of scientists program of the United States and the Soviet Union.

As an integral part of the technical assistance programs abroad, 136 earth scientists and engineers from 43 countries pursued academic or intern experience in the United States during fiscal year 1973. Types of assistance to or exchange of scientific experience with each country during the fiscal year are summarized in table 1. Currently, 1,377 participants from 88 countries have completed research, observation, academic, or intern-training programs in the United States under USGS guidance.

Since the technical assistance work began in 1940, more than 1,977 technical and administrative documents authored by USGS personnel have been issued. During calendar 1972, 51 administrative and (or) technical documents were prepared, and 103 reports were published or released in open files (see table 3).

TABLE 3.—*Technical and administrative documents issued in calendar year 1972 as a result of the USGS technical assistance program*

Country or region	Project and administrative reports	Reports or maps prepared: Approved for publication by USGS and counterpart agencies.	Reports or maps prepared: Published in technical journals	Reports or maps prepared: Published or released by USGS
Afghanistan	--	--	--	3
Argentina	--	--	--	2
Brazil	9	3	1	2
Ceylon	1	2	--	2
Chile	--	1	--	--
Colombia	3	3	5	3
Ecuador	--	--	1	1
India	--	--	1	--
Indonesia	5	1	2	1
Iran	--	1	--	--
Jordan	--	1	--	--
Kenya	--	--	1	--
Liberia	6	34	4	4
Libya	--	1	2	--
Pakistan	1	5	1	2
Peru	1	2	1	--
Philippines	1	--	--	--
Saudi Arabia	15	37	11	25
Tunisia	--	--	--	1
Turkey	4	21	1	18
General	5	1	5	3
Total	51	113	36	67

SUMMARY BY COUNTRIES

Unless otherwise noted, the work described in the following paragraphs was sponsored by AID, U.S. Department of State.

AFGHANISTAN

Shallow ground water in the Zamin Dawar area, Helmand Province

As part of a drought-alleviation program, N. E. McClymonds (1973), in cooperation with the Helmand-Arghandab Valley Authority, completed a ground-water reconnaissance of the Zamin Dawar area in south-central Afghanistan. In 1971 the gravity flow of karezes provided about 25×10^6 m^3, and springs provided about 15×10^6 m^3 of water to irrigate about 2,000 hectares of cultivated land that supported a population of about 40,000. In the early 1950's the population of the area was between 60,000 and 70,000, and the flow of karezes and springs was more than double that of 1971. The decrease in water supply and the concurrent decline in population in the area are direct results of a prolonged dry cycle which affected much of Afghanistan during the 10 yr prior to 1971.

ARGENTINA

Reconnaissance of sedimentation in the upper Rio Bermejo basin

Reporting on a 3-mo reconnaissance of sedimentation problems in the upper Rio Bermejo basin, George Porterfield (1972) pointed out that sediment yields in the basin are among the largest recorded in the world. He evaluated sediment-transport conditions at 17 locations and estimated reservoir life at 17 proposed sites in the basin. Among the proposed reservoir sites the estimated life, with no upstream control, ranges from 3 to as much as 750 yr with a median of about 100 yr.

BRAZIL

Training

The USGS program in Brazil during fiscal year 1973 emphasized training of young Brazilian scientists in practical field and laboratory procedures and in the development of modern geochemical laboratories in the Companhia de Pesquisas de Recursos Minerais (CPRM) and other agencies of the Ministry of Mines and Energy. Training in Brazil by teams of USGS specialists, including Norman Herz, W. F. Curtis, L. C. Huff, A. E. Drake, V. J. Hurst, F. C. Frischknecht, W. J. Dempsey, A. P. Marranzino, L. E. Bidwell, C. H. Thorman, A. F. Holzle, T. W. Offield, and H. G. Rodis, consisted of 1- to 2-mo courses in (1) remote sensing, (2) photogeology, (3) geophysical prospecting, (4) principles of field mapping and investigation of saprolite, (5) computer technology and geochemical statistics. More than 200 Brazilian geologists received training in these courses, and an additional 27 were sent to the United States for either inservice training within the USGS or for academic training in universities.

T. W. Offield gave a 3-week course in Rio de Janeiro in remote sensing applied to geology for 34 persons from various Brazilian Government agencies. The course was combined with one on the application of remote sensing to water resources given by H. G. Rodis. As a consequence of this course, a remote-sensing group was organized in CPRM, and equipment was obtained to provide capability for gathering and analyzing remote-sensing data. A. P. Marranzino collaborated in the planning and installation of modern geochemical laboratories to support the rapidly expanding geochemical exploration program of CPRM. These laboratories, which undertake wet chemical analyses and atomic-absorption analyses, are capable of analyzing several hundred samples daily for 30 or more elements.

Amazon River basin exploration

M. G. White (1973) briefly reviewed 21 mineral exploration projects being conducted in the Amazon Valley by agencies of the Brazilian Government and by private companies. The major effort is in development of iron, manganese, aluminum, and tin deposits, with some activity in molybdenum, copper, lead, zinc, and silver. In late 1972 as many as 225 government and company geologists and engineers were involved in field investigations in the Amazon River basin, whereas only a few geologists were working in the basin only 5 or 6 yr ago.

CENTO

A seminar on the application of remote sensing to problems of geology, cartography, geography, hydrology, and oceanography in CENTO regional countries was held in Teheran, Iran. A team of five scientists headed by R. W. Fary, Jr., taught the course, which lasted 21 d and was attended by 30 scientists from Turkey, Iran, and Pakistan. Group lectures were given in the disciplines of geology, geography, cartography, hydrology, oceanography, agriculture, and forestry. Additional group lectures were given in general photointerpretation and the ERTS–1 satellite system.

Following the lectures, a series of classes in individual disciplines were given, and as part of this instruction, a 3-d field trip to the Caspian Sea covered the regional geology, hydrology, and forestry of northern Iran; a second course was led by D. B. Krinsley to the Kavir (playa) Daryachech-ye-Howz-Soltan to study the geology and hydrology of the interior of the country. Attendees of the course prepared several significant reports on problems which might be solved by remote-sensing methods.

CHILE

G. E. Ericksen and M. E. Mrose (1972) reported that high-purity veins of soda-niter ($NaNO_3$) and associated saline minerals are a unique widespread feature of the Chilean nitrate deposits. These veins, which were selectively mined during the 19th and early 20th centuries, consist chiefly of soda-niter and halite, NaCl, and lesser amounts of other saline minerals such as niter, KNO_3; darapskite, $Na_3NO_3SO_4 \cdot H_2O$; glauberite, $Na_2Ca(SO_4)_2$; and bloedite $Na_2Mg(SO_4)_2 \cdot H_2O$. The veins occur in typical nitrate caliche, which is saline-cemented regolith, and in bedrock. They commonly contain 50 percent or more soda-niter. Nitrate-bearing veins of saline minerals also occur sparsely in metaliferous deposits of the Atacama Desert, northern Chile, but are not known elsewhere in the world.

INDIA

Geohydrologic reconnaissance and study plan for water-resources investigations in the Baroda-Broach area, Gujarat

According to P. R. Seaber (1973), the water resources of the Baroda-Broach area are not fully utilized at present, and large potential sources exist in the flow of the Narmada River and in fresh-water alluvial aquifers lying from about 10 to 90 m beneath the surface of the deltaic Gujarat Plain. The ground water at greater depth, however, is saline. Also, salt-water encroachment from the Gulf of Cambay presents a potential threat if overdevelopment of ground water should occur. Sampling of the Narmada River indicated a dissolved-solids content generally less than 350 mg/l. The fresh water in the alluvial aquifers ranges from about 500 to 2,500 mg/l in dissolved-solids content. The study plan presents a 19-point series of recommendations for a 4-yr water-resources investigation of the area by geohydrologists of India's Central Ground Water Board.

INDONESIA

Possible central Java fault zone

A major fault zone crossing central Java in a northwest direction has been postulated by W. H. Condon on the basis of photogeologic interpretation, study of geologic maps, and through field checks. Evidence contributing to the theory includes tectonic lineaments seen in volcanic and sedimentary rocks of Miocene age and volcanic rocks possibly as young as middle Pleistocene, alined fault segments in sedimentary and volcanic rocks, and the alinement of Holocene volcanoes thought to reflect the presence of the fault zone buried beneath them.

The postulated fault zone trends northwest from about 111°45′ meridian at the south coast to the 109°15′ meridian at the north coast. It passes through Mount Sundoro and Mount Merapi, both volcanic cones, and through the Dieng area where geothermal exploration is in progress. Copper mineralization reported near the south end of the alinement suggests that mineralization may be present elsewhere along it.

Geology of Banggai and Sula archipelagos

Reconnaissance geologic mapping of the Banggai and Sula archipelagos east of Sulawesi (Celebes), Indonesia, was completed during the year by D. E. Wolcott of the USGS, and Sukanto, Tjarda, Parwoto, and Sae'un of the Geological Survey of Indonesia (GSI). The mapping provided the basis for a brief description of the geology of these islands.

The Banggai and Sula islands, with the exception of Sulawesi, form a block of continental crust consisting of a basement of metasedimentary rocks and schist intruded by diorite and granite. The oldest sedimentary rocks, consisting of sandstone and shale with some coal and welded tuffs, seemingly grade upward into marine sandstone and shale containing abundant Jurassic mollusks. Cretaceous marls conformably overlie the Jurassic beds. In contrast to nearby areas in eastern Sulawesi, where Neogene rocks have been strongly deformed, the Mesozoic strata of the Banggai and Sula islands have been only mildly deformed.

The oldest rocks on Sulawesi, the southernmost island of the Sula archipelago, are tectonically sheared shale and turbidite sandstone of unknown age. Locally, the deformation produced mica schist and quartz veins. Sandstone, conglomerate, and coal of probable Tertiary age crop out in the southwest part of Sulawesi and have not been strongly deformed. Pliocene to Holocene coral veneers the southern half of Sulawesi and much of Peleng Island, the westernmost island of the Banggai archipelago. The coral has been uplifted to as much as 400 m above sea level on Sulawesi and to 800 m on Peleng.

Geology of western Sumatra

G. W. Leo spent about 10 weeks with Kastowo and other counterpart geologists of GSI making a reconnaissance geologic map of the 1½-degree Padang quadrangle, western Sumatra, under GSI's systematic mapping program. The land portion of the quadrangle straddles the Barisan Range on Sumatra's west coast just south of the equator, and contains several Quaternary volcanoes from 2,500 to 3,000 m high as well as a 20-km long caldera containing Lake Manindjau. The major rock types include andesite (typically containing hypersthene and labradorite-bytownite) from these volcanoes and other less well-defined centers; andesite of possible Tertiary age associated with highly consolidated tuff-breccia; subordinate Tertiary sedimentary rocks; and a sequence of slightly metamorphosed, tilted, and folded limestone, sandstone, siltstone, and shale of pre-Tertiary age (Permian fossils have been reported from the limestone.) Pumiceous tuff overlying andesite in a broad area surrounding the Manindjau caldera may represent late eruptions from this caldera, or may be related to the northwest-trending Great Sumatran fault zone. The latter has been regarded as a right-lateral strike-slip fault, but faults along the zone between pre-Tertiary rocks and Quaternary andesite indicate relatively recent subvertical movements.

Exploration for geothermal energy in the Dieng Mountains

W. L. Danilchek supervised a drilling program in the Dieng area of central Java which is exploring for a source of geothermal energy. The first phase of the project, an undertaking of the Government of Indonesia, requires completion of six drill holes, each 200 m deep, and measurements of temperature, water chemistry, mineral and physical characteristics of wallrock, and other factors.

Remote-sensing training and related activities

The first training course for remote sensing in Indonesia was presented by S. J. Gawarecki at the GSI headquarters in Bandung during 1972. The course covered remote-sensing theory and techniques with applications in geology and hydrology; six of the participants were from the GSI and one each from the National Aeronautics and Space Institute, Indonesian Aerial Survey, Department of Public Works, and the National Coordination Board for Surveying and Mapping.

The second training course in Indonesia was also the first phase of a project involving a multispectral photographic remote-sensing survey of Bali. The project is a demonstration of this relatively inexpensive remote-sensing technique in the disciplines of agriculture, forestry, fishery, geology, hydrology, oceanography, land-use studies, and soils. The course was presented in Jakarta during January 1973 and was attended by 20 participants from 12 different Indonesian agencies and two universities. S. J. Gawarecki (USGS), project director, presented remote-sensing theory, techniques, applications in geology, and hydrology; R. R. Thaman of the University of California at Santa Barbara presented multispectral photographic theory, ERTS technology, and applications to agriculture, forestry, land-use studies, and soil mapping; and K. H. Szekielda of the University of Delaware, College of Marine Studies, covered other satellite programs and remote-sensing applications in oceanography and fishery.

KENYA

Ground-water exploration in northeastern Kenya

According to W. V. Swarzenski (USGS) and Simon Wanyeki (Kenya Water Dept., Ministry of Agriculture), ground-water exploration has been intensified since 1968; the Water Department has drilled 80 test holes in North East Province, Kenya, during the past 4 yr. The majority tap fresh to slightly brackish ground water in fine-grained Pliocene and Pleistocene fluviolacustrine sediments to depths of 600 ft and yield 1,000 to 2,000 gal/h to stock and village wells. Boreholes in Precambrian crystalline or Mesozoic consolidated rocks have considerably lower yields and only about 30 percent can be used. The results of the current drilling program permit delineation of fresh- and saline-ground-water zones in the southern part of the province and indicate availability and quality of ground water elsewhere in the area.

LIBERIA

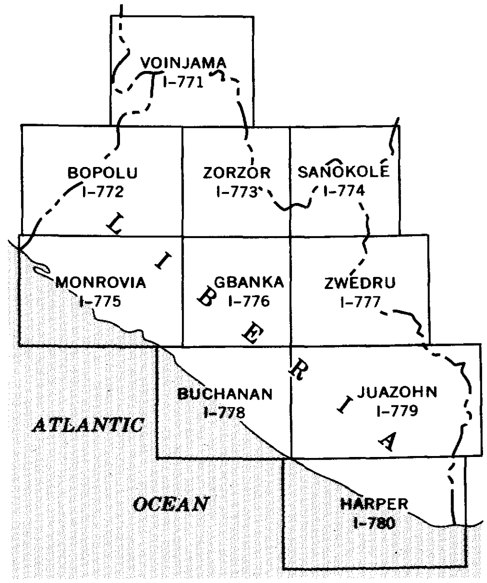
The 10-yr cooperative project between the USGS and the Liberian Geological Survey (LGS) was concluded on June 30, 1972. This AID-sponsored program had as its major objectives: (1) Reconnaissance geological, geophysical, and mineral resources studies of the entire country, (2) development of an organization and staff competent to carry out the functions of a national geological organization, (3) development of fully equipped offices, laboratories, and field support facilities, and (4) establishment of a geological data base to be used by the LGS in future work.

To achieve these objectives, the USGS maintained a staff of trained personnel in Liberia who worked closely with counterparts in the LGS. The staffing level of USGS personnel has ranged from two to as many as nine full-time and six short-term members; 42 USGS personnel have served on the staff at one time or another. The project undertook reconnaissance geological and geophysical studies as well as detailed examinations of selected localities, photogrammetric mapping, participant training, acquisition of laboratory and other supporting facilities, and the advisory functions of a government geological survey.

The major products of these activities are (1) extensive files of basic data (rock samples, thin sections, petrographic and chemical analyses, field notes, analog radiometric and aeromagnetic data, aerial photographs, and derivative photogrammetric data), systematic files of geologic information produced during the project, and some 70 project reports on topical subjects, (2) radiometric and aeromagnetic maps Liberia at scales of 1:40,000, 1:125,000 and 1:250,000, (3) geologic maps (10 quadrangles) of Liberia at 1:125,000 scale, (4) form-line maps of Liberia at scales 1:40,000 and 1:125,000, (5) shaded-relief maps of Liberia at 1:250,000 scale, (6) 14 professional personnel have been trained in the United States in the participant training program as well as locally trained field and laboratory assistants, (7) petrographic, analytical, and photographic laboratory facilities adequate for the continued activities of the LGS, and (8) 31 published reports.

Map compilation

The 10 shaded-relief quadrangle maps (see inset map) at a scale 1:250,000, covering all of Liberia, have been completed, as well as the aeromagnetic and aeroradiometric maps of these quadrangles.



Index to quadrangle maps of Liberia at 1:250,000 scale

Compilation of the corresponding geologic quadrangles at 1:250,000 scale has been completed by M. R. Brock, A. H. Chidester, E. R. Force, J. F. Seitz, C. H. Thorman, R. G. Tysdale, and R. M. Wallace and coordinated by A. H. Chidester, who is also preparing an overall report and map at 1:750,000 scale. Quadrangle maps showing locations of mineral commodities are being prepared by W. L. Coonrad.

Geophysical report

J. C. Behrendt (USGS) and C. S. Wotorson (1972), Director, LGS, have prepared a report on the tectonic map of Liberia. The map, based on aeromagnetic, total-count gamma radiometric, and gravity data, approximately delineates the boundaries between the Liberian province (about 2,700 m.y.) in the northwestern two-thirds of the country, the Eburnean province (about 2,000 m.y.) in the southeastern one-third, and the Pan-African province (about 550 m.y.) in the coastal area of the northwestern two-thirds of the country. Rock foliation and tectonic structural features trend northeast in the Liberian province, east-northeast to north-northeast in the Eburnean province, and northwest in the Pan-African province. Linear residual magnetic anomalies 20 to 80 km wide and 200 to 600 gammas in amplitude follow the northeast structural trend typical of the Liberian province across the entire country and extend into Sierra Leone and Ivory Coast.

Theoretical bodies more than 10 km thick and having apparent susceptibility contrasts in the range of 0.0026 to 0.0043 emu are required to fit the highest amplitude (600 gamma) anomaly, which exceeds 50 km in width. These anomalies are of unknown origin but are possibly associated with the shear zones of Liberian age. The long-wavelength anomalies were only slightly modified by the Eburnean and Pan-African thermotectonic events and can be correlated with similar anomalies reported by others in Sierra Leone, Ivory Coast, and the Guyana shield area in South America. Thus, the Pan-African thermotectonic event merely imprinted older rocks and did not generate new crust in the area of Liberia. As temperatures in these rocks exceeded the Curie isotherm during the Pan-African activity, it is thought that the anomalies must be due to induced magnetization; therefore, they probably are indicative of variations in the amount of magnetite in the underlying rocks.

A zone of diabase dikes, about 80 to 120 km wide, can be traced by means of magnetic data; the zone is about 90 km inland and parallels the coast from Sierra Leone to Ivory Coast. Another zone of diabase dikes, radiometrically dated at 176 and 192 m.y., is at least 70 km wide and is located along the coastal area and beneath the continental shelf northwest of Greenville. These dikes probably were intruded during tectonic activity that preceded the separation of the continents at the southern end of the North Atlantic Ocean.

The radioactivity data adjusted to an altitude of 220 m have a background level less than 100 counts per second (180 cps = 1 μrad/h) over mafic granulite-facies rocks and unmetamorphosed sedimentary rocks in the coastal area. Granitic rocks show the greatest variation. The central part of the country has the highest background-radiation level, large areas showing more than 250 cps; the eastern one-third of the country has a low background level. In general most of the areas having a background level about 150 and all areas above 250 cps are areas of granitic rocks. Diabase sills having radiation levels of 100 to 200 cps show marked contrasts with granulites and sedimentary rocks. The contact between the coastal granulite zone and granitic gneiss inland is apparent in the radioactivity data. Metasedimentary iron-formation and mafic metamorphic rocks within the predominantly granitic gneiss terrane are easily delineated. The radioactivity data show many anomalies above 500 cps; some reach amplitudes of more than 750 cps. Total-count radiation levels have a significant correlation with the percent of K_2O analyzed in bedrock samples, but anomalous amounts of thorium and uranium must be present to account for the highest amplitude anomalies. A few specific anomalies have been correlated with concentrations of monazite and zircon in bedrock as well as in beach deposits.

A 50 to 60 mGal positive Bouguer anomalous area extends along the coast from Sierra Leone to Ivory Coast. This anomaly correlates with mafic granulite in the Monrovia region where the gradient is too steep to be entirely due to crustal thickening at the continental margin. The only major break in this positive anomaly above basement rocks along the entire coast of Liberia is above granitic gneiss adjacent to (and presumably underlying) the only onshore basins on the Liberian coast. Local negative Bouguer anomalies exist over two Cretaceous basins in the coastal area. The high mean free-air anomaly of +22 mGal (exclusive of the coastal anomaly) suggests that the approximately 200-m mean elevation of Liberia is not compensated, at least over the Liberia region.

PAKISTAN

Hydrologic evaluation of salinity control and reclamation projects in the Indus Plain of West Pakistan

In 1972 a team of hydrologists, including M. J. Mundorff, P. H. Carrigan, Jr., T. D. Steele, and A. D. Randall, completed a 3-mo hydrologic evaluation of SCARP (salinity-control and reclamation projects) in the Indus Plain. They reviewed the cause-and-effect relationships of the hydrologic phenomena that led to implementation of the present SCARP and the operational history of the projects. They also presented alternatives for water management in the region.

PERU

G. E. Ericksen and George Plafker reported on geologic control of destruction during the Peru earthquake of May 31, 1970. The extensive destruction and loss of life in Peru was due largely to (1) poor construction of buildings, chiefly adobe, which had little shear resistance to lateral forces imposed by earthquake shock, and (2) the Huascarán debris avalanche that buried Yungay and parts or all of several smaller communities and destroyed extensive areas of farmlands. To a lesser, but significant, degree destruction was caused by widespread landslides and by differential compaction, landspreading, and fissuring in unconsolidated foundation materials. Geologic conditions influenced the distribution of the landslides and foundation failures.

Large landslides and debris avalanches and flows constitute the major geologic hazard in the mountainous regions of Peru. Steep slopes are extremely unstable and are periodically subject to sliding, particularly if the ground becomes saturated during annual rainy seasons. Earthquakes often cause downslope movement of material and may trigger some slides larger than those that would normally be expected to occur sporadically in mountainous regions. Failure of unstable dams (moraine, alluvium, and landslide debris) that impound lakes in steep-walled glacial valleys may result in disastrous floods and debris flows during earthquakes. Such a debris flow, triggered by the January 6, 1725, earthquake, destroyed the town of Ancash.

Differential compaction, landspreading, and fissuring can cause extensive destruction during large earthquakes, particularly in cities and towns that are built on water-saturated fine unconsolidated deposits or on poorly compacted natural or artificial dry materials. In Peru, these materials are usually most widespread in valleys of the coastal regions commonly the areas of highest population density. Also affected, but to a lesser degree, were alluvium and glacial deposits in the mountainous region.

Only the 1946 Ancash and 1969 Pariahuanca earthquakes in Peru have had associated surface faulting (Silgado F., 1968; E. M. Deza and Daniel Huaco, oral commun., June 1970) and, because most known active faults in Peru occur in remote, sparsely populated areas, damage by direct fault displacement does not appear to be a major hazard. Active faults, however, are serious hazards in most earthquake-prone regions, and movement on them can cause extensive destruction to works of man.

PHILIPPINE ISLANDS

Ground-water supply at Clark Air Base

In a study made for the USAF, D. A. Davis reported that the most productive aquifer at Clark Air Force Base is in alluvial-fan deposits, which lie along the foot of the Zambales Range on the west side of the Central Luzon Valley. The deposits consist of sand, gravel, and boulders in highly variable mixtures with clay and silt. Most of the sand is made up of feldspar grains; the gravel and boulders consist largely of fragments of granitoid rock having intermediate composition. Locally, pebbles of pumice are common. In places the deposits are slightly consolidated by compaction and cementation. Beneath the fan deposits is a thick section of sandy clay and fine clayey sand.

The ability of the fan deposits to yield water to wells varies greatly from place to place. Among twelve 8- and 10-in.-diameter wells tapping the deposits, the specific capacities at pumping rates of 500 to 600 gal/min range from about 20 to about 120 gal $min^{-1}ft^{-1}$ of drawdown. In some places, small parts of the aquifer are confined. Wells tapping the clayey section under the fan deposits have specific capacities of 2 to 4 gal $min^{-1}ft^{-1}$ of drawdown.

SAUDI ARABIA

The USGS program of cooperative work with the Kingdom of Saudi Arabia continued during 1972. As in previous years, emphasis was placed on institutional development and the training of Saudi Arabian scientists through their involvement in studies of the Precambrian shield of the Arabian Peninsula.

During the year, field mapping on the equivalent of eight 30-min quadrangles was completed at 1:100,000 scale by W. R. Greenwood, D. G. Hadley, D. L. Schmidt, and Saudi Arabian geologists on a full-time basis, and by H. R. Cornwall, W. C. Prinz, and J. C. Ratté, each on 3-mo temporary assignment. This brings the total number of quadrangles mapped by the project to 26.

Geologic mapping

A Precambrian to Cambrian taphrogeosynclinal sequence of terrigenous clastic rock, volcanic rock, and limestone, the J'Balah Group, that crops out in the northwestern part of the Arabian Shield has been described by D. G. Hadley. These rocks were deposited in depressed fault blocks contemporaneous with subsidence along active boundary faults in a sedimentary-tectonic setting similar to the Newark and Keweenawan troughs of North America. The faults belong to the Najd fault system which consists of four major northwest-trending left-lateral shear zones spaced about 60 to 70 km apart.

The J'Balah Group is 850 m thick and was deposited in three stages. The first stage consists of conglomerate and terrigenous clastic rocks that were rapidly deposited initially, but later as fault activity diminished, the rate of deposition and coarseness of the sediment decreased. During the second stage, subaerial basaltic flows spread across the basin. The volcanic material was probably extruded from along the boundary faults as fissure-type eruptions. Marine conditions prevailed in the third stage during which shallow-water limestone and dolomite were deposited along with subordinate mudstone, shale, and thin basaltic flows.

After deposition, left-lateral displacement on the Najd faults folded the J'Balah Group, which marked the final event prior to cratonization of the Arabian Shield.

Economic geology

Exploration projects in Saudi Arabia carried out prior to 1972 have recently been re-evaluated by R. J. Roberts. Many deposits in volcanic and associated sedimentary rocks were formerly considered by project geologists to be synvolcanic. Re-examination of massive sulfide bodies at Wadi Bidah, Jabal Sayid, and Nuqrah, however, indicates that the ore bodies may be epigenetic.

This suggestion is supported by several lines of evidence. First, the metal suites and mineral assemblages of these deposits are typical of epigenetic hydrothermal deposits elsewhere in the world. Second, quartz-sulfide veins containing similar assemblages cut the ore bodies; these have been interpreted as remobilized ores, but they may have formed essentially contemporaneously with the massive sulfide ore. Third, though many ore bodies are generally parallel to bedding, others in fault zones cut sharply across folded bedding, indicating that metallization postdates folding and is therefore distinctly younger than volcanism. It is also noteworthy that most metallization is associated with carbonate-bearing units, and the ore bodies could be replacement bodies formed during a later metallogenic epoch.

The massive sulfide deposits also commonly have distinct halos of propylitic alteration. These halos have been considered synvolcanic, but alternatively may be related to epigenetic mineralization.

If the ore deposits are indeed epigenetic, then exploratory work should be oriented toward deeper and wider-ranging objectives than formerly. It is even possible that disseminated ore bodies and mineralized intrusives of porphyry type underlie some districts.

Mahd adh Dhahab

R. W. Luce and R. J. Roberts report that the Mahd adh Dhahab mine in the central Arabian Shield warrants extensive exploration. The mine was productive at two previous periods—during the Abbasid caliphate (750–1250 A.D.) producing an estimated 250,000 oz. of gold, and during 1937 to 1954 when the Saudi Arabian Mining Syndicate mined 766,000 oz. of gold plus 1,002,000 oz. of silver. Calculations using present metal prices show that more than $11 million worth of reserves remain in dumps, tailings, and old stopes.

Metallization in areas already mined is mostly in an agglomerate and rhyolite of late Precambrian age. As a result of geologic remapping on a scale of 1:2,500, alteration studies and geochemical sampling have recently identified mineralized fault zones extending south and west of the productive workings. A conglomerate (lapilli tuff) unit south of the main workings was recently recognized as having been an especially good host rock for deposition of potassium feldspar and carbonate-bounded quartz veins containing chalcopyrite, pyrite, tetrahedrite, native gold, sphalerite, and galena. The remapping has shown a greater extent for the conglomerate than previously recorded and the existence of an adjacent rhyolite unit. The latter may be the local intrusive source in the same way that a rhyolite next to the agglomerate was thought to be. Also emerging from fieldwork is a district-wide pattern of quartz veins and faults trending northeasterly, northwesterly, and northerly. A laboratory program of detailed analysis of ore minerals and alteration assemblages is leading toward an understanding of the paragenesis of the district as a whole.

Kushaymiyah

An area in which members of the USGS have previously discovered anomalous values of tungsten and molybdenum in concentrates derived from surficial debris has been studied by F. C. W. Dodge. The area, which occupies a part of the southern portion of the Uyaijah ring complex of silicic plutonic rocks has been geologically mapped at a scale of 1:10,000 and has been extensively sampled. Although powellite, the calcium molybdate–calcium tungstate mineral, has been found throughout a rather large area, both in quartz pods and in thin calchornfels bands in a metasedimentary sequence near a contact with quartz monzonite, minable metal concentrations have not been found. Paradoxically, one small tactite pod discovered during mapping is void of tungsten or molybdenum mineralization. A second area in the central part of the ring complex is currently being investigated, and substantial numbers of molybdenite-bearing quartz veins in quartz monzonite have been mapped.

Magnetic study of the Red Sea rift valley

Adjacent magnetic surveys across the Red Sea and Arabian Shield indicate three magnetically distinct regions. First, the Arabian Shield is characterized by complicated, localized anomalies due mainly to near-surface or surface bodies. The anomalies trend in many directions and are of variable amplitude and frequency. Second, the margins of the Red Sea display a series of parallel smooth low-frequency anomalies trending predominately along the Red Sea in a northwest direction. The anomalies are of intermediate amplitude (250–300 gammas), and some wavelengths are as large as 60 to 80 km. Third, over the axial trough of the Red Sea the anomalies become large-amplitude linear features corresponding to the familiar sea-floor-spreading magnetic pattern. The anomalies are parallel to the axial trough; several offsets indicate possible transform faults.

TANZANIA

Water resources and land-capability investigation, Arusha Region, Tanzania

In cooperation with the Tanzanian Ministries of Water Development and Power and of Agriculture, E. D. Gordon (USGS) and J. F. O'Rourke (U.S. Forest Service) (1973) made a 3-mo water-resources and land-capability reconnaissance of the Arusha Region. They reported that in the cooler, higher, and water-rich areas of the region, subsistence and cash-crop farming provide the economic base; but in the warmer, lower, and water-deficient areas, the economy is predominantly pastoral. The chief water and land-use problems are (1) insufficient water supplies in some of the drier areas for minimum human consumption, (2) insufficient water and forage to meet requirements of wildlife and livestock, and (3) increasing human, livestock, and agricultural pressures on the land and water resources of some areas, with consequent deterioration of the wildlife habitat. Gordon and O'Rourke recommend a comprehensive 4-yr survey to develop a master water plan for the region.

THAILAND

Twenty-seven participants from agencies of the Governments of Thailand, Nepal, Malaysia, Sri Lanka, Laos, and Afghanistan attended a four-week course in application of remote sensing to problems in geology, agriculture, forestry, land use, and hydrology. Nine scientists from the United States under the direction of M. D. Kleinkopf (USGS) and Joseph Morgan (AID) served as instructors. In the field of geology, emphasis was given to training in the use of ERTS data and of aerial multiband data from a camera available in Thailand. In a 3-d class exercise, ERTS frames covering most of Thailand were mapped at a scale of 1:1,000,000. The map principally showed topographic or tonal features, although some geomorphic or stratigraphic boundaries also were drawn. Even in this first attempt by students, tectonic provinces could be defined which have interesting possible correlations with the known distribution of mineral showings. Subsequently, a program of ERTS mapping was started in two divisions of the Thailand Department of Mineral Resources.

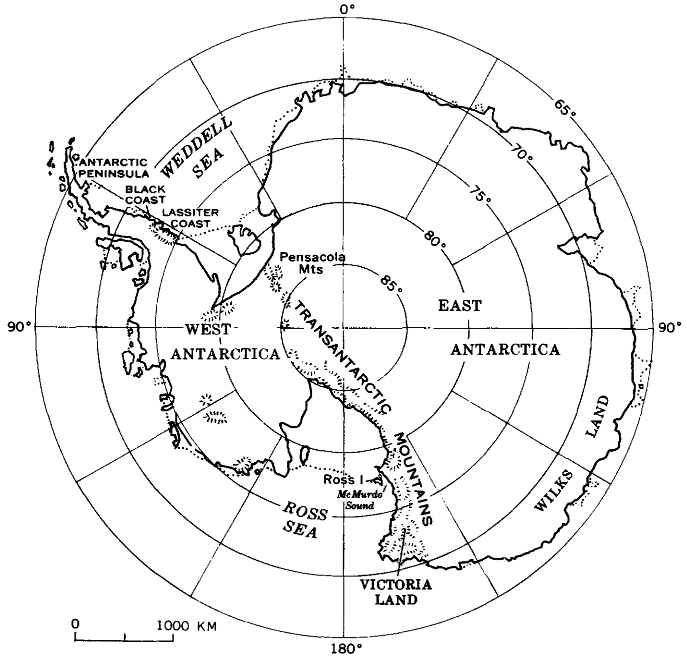
TURKEY

Age determinations in central Turkey

Potassium-argon ages have been determined by R. F. Marvin and H. H. Mehnert for a suite of volcanic and intrusive rocks associated with a variety of sedimentary rocks in the Kuluncak-Sofular area, mapped by G. W. Leo, Ercan Onder, Mehmet Kilic, and Murat Avci (1973) in northwestern Malatya province, east-central Turkey. Alkali diabase intrusive into the Upper Cretaceous Tohma Group was dated at 75.5±2.1 m.y.; alkali syenite intrusive into probable Upper Cretaceous limestone at 65.2±1.6 m.y.; and volcanic rocks including basalt, andesite, and dacite overlying middle Eocene sediments over a range of 18.7±0.5 m.y. to 14.1±0.4 m.y. The determined ages are generally in good agreement with observed field relations. Attempts to date gabbro from a pre-Middle Cretaceous alpine-type serpentinite-gabbro complex, which forms the depositional basement in the area, were inconclusive.

ANTARCTICA

During the 1972–73 austral summer, USGS personnel carried out geologic field studies in the Antarctic Peninsula ranges of the northern Lassiter Coast and southern Black Coast, and shipboard studies on the DSDP vessel *Glomar Challenger* in the Ross Sea and the southeast Indian Ocean near Wilkes Land. (See index map.) International cooperation is emphasized in articles of the Antarctic Treaty, and it is noteworthy that a Soviet exchange scientist participated for the first time on a USGS expedition on the Lassiter Coast project. These field activities, as well as laboratory studies in petrology, geophysics, geochemistry, and paleontology on Ant-



arctic material collected during previous expeditions, are part of the U.S. Antarctic Research Program (USARP) sponsored by the Office of Polar Programs of the National Science Foundation. The fieldwork is supported by the U.S. Navy's Operation Deep Freeze. Progress in Antarctic aerial phototography and topographic mapping, which are functions of the USGS, is reported in the section "Mapping in Antarctica."

Cretaceous plutonic rocks of the southeastern Antarctic Peninsula

During the 1972–73 field season, E. N. Kamenev (Soviet exchange scientist, Research Institute of the Geology of the Arctic, Leningrad), together with P. D. Rowley, S. J. Boyer, K. S. Kellogg, W. R. Vennum, and R. B. Waitt, Jr., (USGS) conducted reconnaissance geologic mapping in the northern Lassiter Coast and southern Black Coast of the Antarctic Peninsula. The rocks are similar to those mapped in two previous seasons farther south on the Lassiter Coast (P. L. Williams and others, 1972); that is, they consist of a thick sequence of black, fine-clastic Jurassic sediments of the Latady Formation that are overlain by volcanic rocks, all of which have been tightly folded around north-northeast-trending axes and intruded by plutonic rocks. The plutonic rocks are in discrete bodies characterized by sharp contacts with the folded, bedded rocks. The country rocks are metamorphosed to a grade rarely higher than andalusite hornfels. Rock types range from diorite to granite, with quartz diorite and granodiorite most abundant. Whereas some individual plutons are homogeneous in composition and concentrically or irregularly zoned, others are of multiple nature. There are several intrusive events, the youngest generally the most silicic. Preliminary results of potassium-argon age dating, in progress by A. H. Clark (Dept. of Geol. Sciences, Queen's Univ., Kingston, Ontario), show that at least some of the plutons are Middle Cretaceous.

The plutonic rocks mapped during the 1972–73 season differ in some respects from those studied in past seasons in ranges to the south. Several large batholiths, with dimensions at least 65 km by 30 km, are exposed in the north, while to the south, the bodies are stocks with long diameters rarely exceeding 15 km. Plutonic rocks are exposed over a much greater area in the north than in the south. North- to northeast-trending plutons in the Lassiter Coast are more elongate in the north than in the south. Furthermore, in the north, quartz diorite is less abundant, and quartz monzonite or granite is more abundant. The variations appear to be gradational and may reflect greater depth of erosion in the north caused by a general southward structural plunge.

Ross Sea drilling

Leg 28 of the DSDP, from December 20, 1972, to February 27, 1973, was the first of several scheduled cruises in Antarctic waters of the drilling vessel *Glomar Challenger*. A total of 16 holes were drilled at 11 sites, 6 in the southeast Indian Ocean and 5 in the Ross Sea, from which about 1,400 m of sediment core were recovered. A. B. Ford and other members of the scientific staff DSDP (1973) report that about 385 m of glacial sediments in the southernmost hole, site 270 near the Ross Ice Shelf, range in age from Recent to probable Oligocene, thus demonstrating the antiquity of the glaciation of Antarctica. Much past speculation about the origin of the Ross Sea continental embayment and its role in continental drift reconstructions has been based on a virtual absence of information on the character of basement materials in this area. The penetration of a continental-type metamorphic terrane beneath the glacial sequence is therefore a highly significant result of the cruise. Although no direct evidence for dating the basement rocks was obtained, lithologic similarities suggest correlation with probable early Paleozoic terrane of the Transantarctic Mountains near McMurdo Sound. The successful program of leg 28 demonstrated the feasibility of high-altitude drilling operations not only under conditions of severe weather and iceberg-filled seas which require constant icebreaker support, but also on the continental shelf in relatively shallow water depths of about 500 m that allow only little offsite drift of the vessel.

Antarctic fossil wood

Study of a wide variety of Permian fossil wood from Antarctica was carried out by H. K. Maheshwari (1972) of the Birbal Sahni Institute of Palaeobotany, with assistance of the U.N. development program administered by UNESCO. The wood collections were investigated at the USGS Coal Geology Laboratory in Columbus, Ohio, under the supervision of J. M. Schopf, and the number of Antarctic plant groups thus identified has been greatly supplemented. Of eight genera recorded, only one, *Antarcticoxylon*, is apparently restricted to Antarctica. Six genera are known to be represented within the other Gondwana territories of South Africa, India, Falkland Islands, and Brazil, and two have more general distribution. All the specimens show growth rings, some of which are broad enough to suggest they were formed during a long growing season under conditions favorable for growth. Others have relatively narrow growth rings, perhaps a response indicative of diversity in habitat. Although *Noeggerathiopsis*, a cordaitean type of tree, is present in Antarctica, other genera such as *Glossopteris* and *Gangamopteris* which are defined on the basis of their foliage, commonly are not considered to be woody. The diversity of the Antarctica fossil wood, however, shows that a variety of woody gymnospermous plants existed. Possibly some of these are included among the *Glossopteris-Gangamopteris* complex which is abundantly represented in beds associated with the wood. In that case, an arborescent rather than a shrubby or herbaceous vegetation may have characterized the Gondwana landscape. The generally separate preservation of wood and leaves is inevitable if the plants were deciduous, as *Glossopteris* and *Gangamopteris* are usually considered to be.

Magnetic models illustrate stratigraphy of Dufek intrusion

Magnetic anomalies approaching 2,000-gammas amplitude are associated with the Dufek intrusion. The decrease in amplitudes of one to two orders of magnitude from the northern Forrestal Range to the southern Dufek Massif (82°30′–83°30′ S., 45°–55° W.) is consistent with measured magnetic properties (including normal and reversed remanent magnetization). Theoretical magnetic models calculated by J. C. Behrendt, J. R. Henderson, L. J., Meister, and W. Rambo (1973) suggest a 4-km-long fault across the front of the Dufek Massif, down to the northwest. Models constructed for 100 to 200 gamma anomalies over the southern Dufek Massif require a basal section 1 to 2 km thick having magnetization higher than that measured from rocks in the lowest exposed part of the section, or infinitely thick bodies of the low magnetization actually observed. The first hypothesis is the more acceptable and suggests the presence of a possible basal ultramafic layer.

Pyroxenes from layered gabbros of the Dufek Massif

Pyroxenes from the lower exposed part of the Dufek intrusion have been studied with the electron microprobe analyzer by G. R. Himmelberg of the University of Missouri. The pyroxenes are highly exsolved; calcium-poor varieties are mostly inverted pigeonites. Both the calcium-poor and the coexisting calcium-rich pyroxenes show iron-enrichment trends that are related to increasing stratigraphic position (G. R. Himmelberg and A. B. Ford, 1973). Analysis of pyroxenes from 15 specimens shows compositions in the range $Ca_{36.4}Mg_{48.7}Fe_{14.8}$ to $Ca_{35.0}Mg_{38.0}Fe_{27.0}$ for the calcium-rich series, and $Ca_{3.5}Mg_{69.1}Fe_{27.4}$ to $Ca_{11.2}Mg_{47.5}Fe_{41.3}$ for the calcium-poor series. A strong trend of iron enrichment during differentiation of the Dufek basaltic magma is shown by the wide range in the mafic index of rocks of the layered series, from a value of about 40 near the base of the lower exposed section in the Dufek Massif to nearly 90 in the uppermost section in the Forrestal Range, according to A. B. Ford. Cumulus magnetite, which is absent in most of the Dufek Massif section, becomes common in the Forrestal Range section and even locally dominant in thin layers of magnetite. Preliminary analytical results indicate that the pyroxenes continue to become more iron enriched in rocks higher in the Forrestal Range.

TOPOGRAPHIC SURVEYS AND MAPPING

OBJECTIVES OF THE NATIONAL TOPOGRAPHIC PROGRAM

A major function of the USGS is to prepare and maintain maps of the national topographic map series, covering the United States and its outlying areas. The several series, at various scales, constitute a fundamental part of the basic data needed to inventory, develop, and manage the natural resources of the country. Other mapping functions of the USGS include the production of special maps and research and development in mapping techniques and instrumentation.

Procedures for obtaining copies of the map products are given under "How To Obtain Publications" in the section "U.S. Geological Survey Publications."

FEDERAL MAPPING COORDINATION

Since 1967, when responsibility for government-wide coordination of federally funded domestic surveying and mapping activities was given to the Department of the Interior (and subsequently to the USGS) by the OMB (Office of Management and Budget), significant progress has been made toward achieving more effective coordination. Channels of communication have been established with other agencies, and surveying and mapping needs, products, programs, and capabilities have been identified.

Little duplication of the basic mapping of the national topographic program has been found. Other agency programs that contribute to the national topographic program are well coordinated with the USGS. It has been determined that many Federal, State, and local agencies are making excellent applications of USGS maps as the basic structure for special-purpose maps. The USGS recommended revision of OMB Circular A–16 (and related exhibits) and broadened coordination to include mapping beyond that which contributes to the current national topographic program.

A report on history and activity of Federal mapping coordination was forwarded to the OMB. Copies of this report were distributed (1) by the Department of Housing and Urban Development (HUD) to the Directors of HUD's region and area offices and to the program directors in the Washington headquarters office and (2) by the Federal Highway Administration to its regional and headquarters offices and to all State highway departments.

Coordination activities were modified to assist an OMB Task Force on Mapping, Charting, and Geodesy (MC&G). Efforts were concentrated on determining the MC&G products and activities of Federal agencies, the funds and manpower expended, and information about how and by whom these products are used.

The extent of mapping activities and expenditures resulting from various HUD programs was determined. To obtain the desired information, meetings were held with representatives of the Office of Community Development, Community Planning and Management, Federal Insurance Administration Research and Technology, Data Systems and Statistics, and Housing Production and Mortgage Credit.

HUD area offices were visited to obtain information on the requirements of, and the procedures used by, local governments in acquiring Comprehensive Planning Assistance grants (HUD "701" program), which are frequently used to finance mapping in urban areas.

Meetings were held with Federal Highway Administration (FHWA) and State highway department representatives to discuss State mapping programs and needs, to coordinate revision programs, and to prevent duplication of mapping. In response to FHWA requests, training sessions in scribing techniques were held for members of State highway departments at USGS facilities, and briefings on orthophotomapping were arranged for participants of the highway planning training program at the Department of Transportation.

An urban-mapping study was initiated in response to an increasing number of requests from Federal, State, and local map-using agencies for metropolitan area maps at scales larger than those of the current national topographic program. The objective of the study is to determine how the functions of various agencies concerned with problems of metropolitan areas can be served better by additional or different maps or related cartographic data. If it is established that a national urban map series is desirable, this study will provide valuable information on the requirements and specifications of such a series.

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 90 percent of the total area of the 50 States, Puerto Rico, the Virgin Islands of the United States, Guam, and American Samoa. Included in this coverage is about 7 percent of the total area which is not yet published but which is available as advance manuscript prints.

During fiscal year 1973, 1,775 maps were published covering previously unmapped areas, equivalent to about 3 percent of the area of the 50 States and territories referred to above. In addition, 527 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) which did not meet present needs. Figure 5 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 1973, 1,006 general-purpose quadrangle maps of the 7½-min series (1:24,000 scale) were revised. Most of these revised maps are in expanding urban areas or in States that are completely mapped in the 7½-min series. About 77 percent of the 1,900 maps currently in the revision program (fig. 6) are being updated by photorevision (interim revision)—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. Manuscript prints showing the information used in first, second, and subsequent revisions are available to map users who need chronological information.

A photoinspection program, initiated in fiscal year 1972, has contributed substantially to reduction of the apparent revision backlog. About 500 of 1,100 quadrangles reviewed were determined not to need revision and thus will receive only the photoinspection date at time of reprint.

About 23 percent of the maps in the revision program are revised by photogrammetric, field, and cartographic operations (standard or complete revision).

In fiscal year 1973, about 1,600 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 1:250,000-scale maps originally prepared as military editions by the U.S. Army Map Service (now Defense Mapping Agency, Topographic Center). These maps are revised and maintained by the USGS with certain changes and additions to make them more suitable for civil use. The USGS is replacing its Alaska reconnaissance map series at 1:250,000 scale with an improved series based on larger scale source material and on new photogrammetric compilations. Figure 7 shows revision in progress on 1:250,000-scale maps.

State map series

State maps are published at scales of 1:500,000 and 1:1,000,000 for all States except Alaska. State maps of Alaska are published at scales of 1:1,584,000, 1:2,500,000, 1:5,000,000, and 1:12,000,000. The series of State maps compiled according to modern standards now includes 46 maps covering 50 States and the District of Columbia (fig. 8). All these maps are published in planimetric editions; contour and shaded-relief editions are also available for most of them. Sixteen of the maps—Alaska, Arizona, Illinois, Kentucky, Maine, Maryland–Delaware, Massachusetts–Rhode Island–Connecticut, New Hampshire–Vermont, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Utah, and Virginia—are being revised, and new topographic maps are being prepared for Indiana and Oklahoma. Other States are covered by an earlier series, also shown in figure 8.

National park map series

Maps of 43 of the 214 national parks, monuments, historic sites, and other areas administered by the National Park Service have been published. These usually are made by combining the existing quadrangle maps of the area into one map sheet, but occasionally surveys are made covering only the park

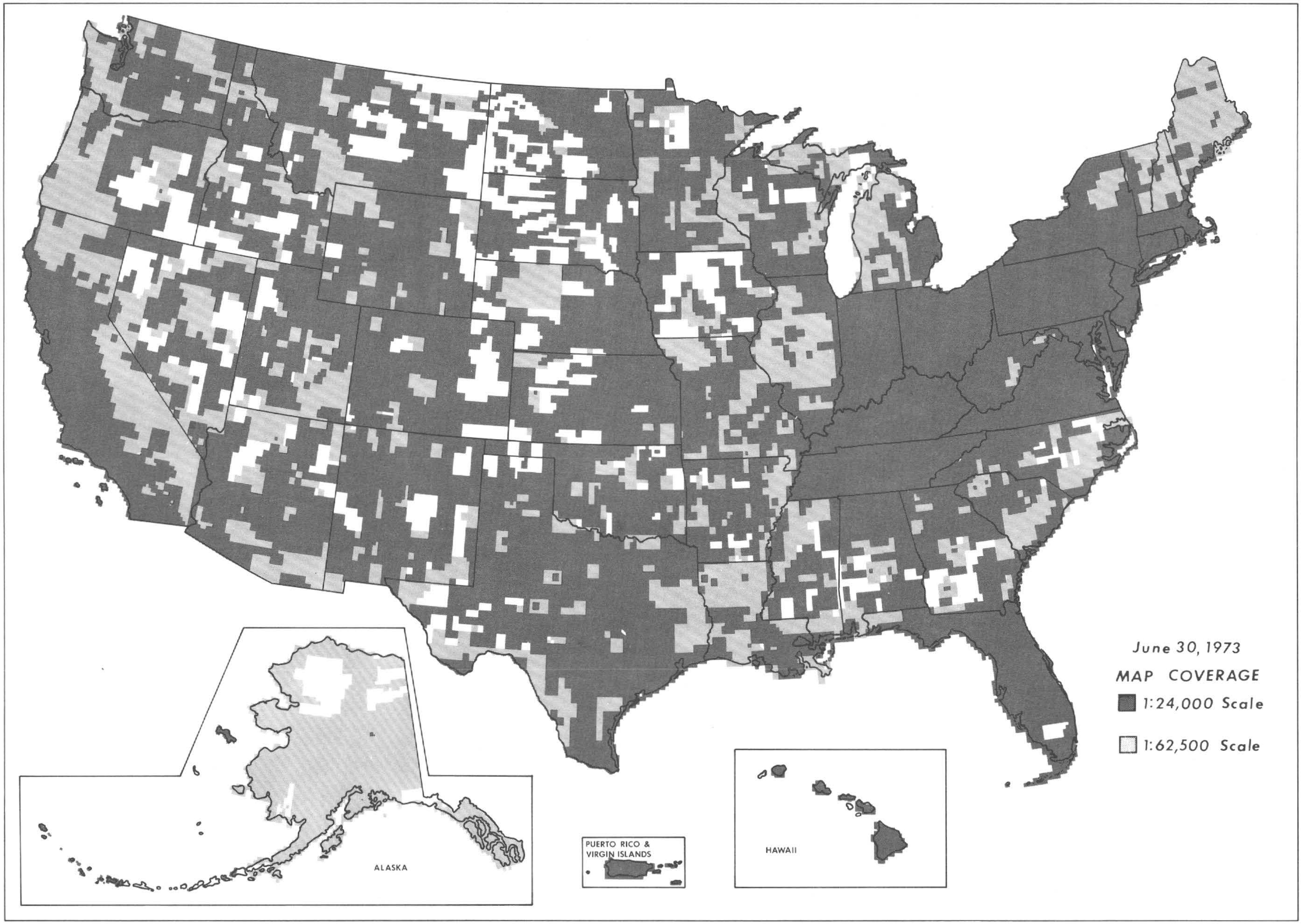


FIGURE 5.—Status of 1:24,000- and 1:62,500-scale mapping.

FIGURE 6.—Revision in progress, 1:24,000-scale topographic maps.

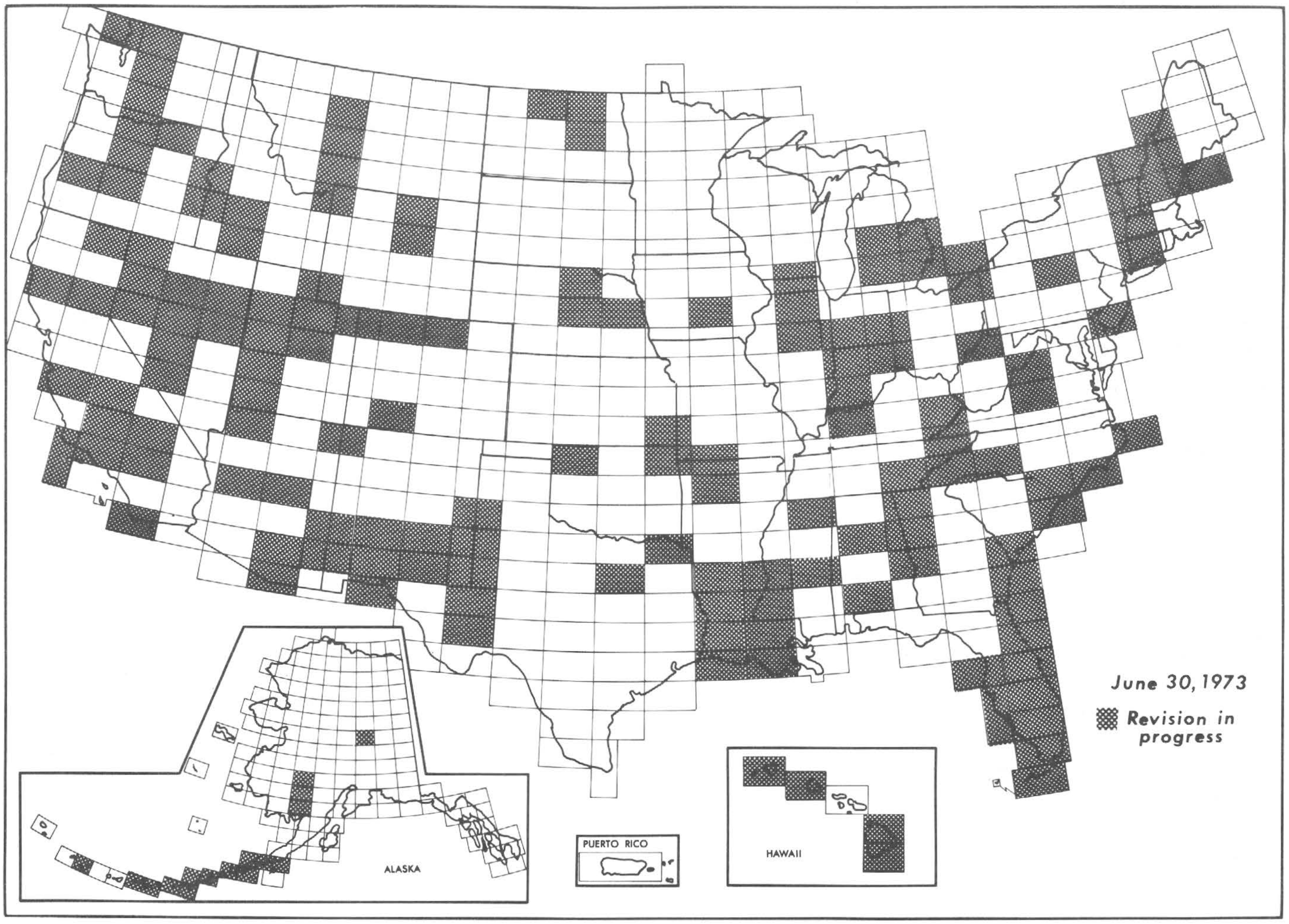


FIGURE 7.—Revision of 1:250,000-scale topographic maps.

area. Most of the other parks, monuments, and historic sites are shown on maps in the general-purpose quadrangle series. Published maps in the national-park series include:

Acadia National Park, Maine
Badlands National Monument, S. Dak.
Bandelier National Monument, N. Mex.
Black Canyon of the Gunnison National Monument, Colo.
Bryce Canyon National Park, Utah
Canyon de Chelly National Monument, Ariz.
Canyonlands National Park, Utah
Carlsbad Caverns National Park, N. Mex.
Cedar Breaks National Monument, Utah
Colonial National Monument (Yorktown Battlefield), Va.
Colorado National Monument, Colo.
Crater Lake National Park, Oreg.
Craters of the Moon National Monument, Idaho
Custer Battlefield, Mont.
Devils Tower National Monument, Wyo.
Dinosaur National Monument, Colo.-Utah
Franklin D. Roosevelt National Historic Site, N.Y.
Glacier National Park, Mont.
Glen Canyon National Recreation Area, Utah-Ariz.
Grand Canyon National Monument, Ariz.
Grand Canyon National Park, Ariz.
Grand Teton National Park, Wyo.
Great Sand Dunes National Monument, Colo.
Great Smoky Mountains National Park, N.C.-Tenn. (2 sheets)
Great Smoky Mountains National Park and Vicinity, N.C.-Tenn.
Isle Royale National Park, Mich.
Lassen Volcanic National Park, Calif.
Mammoth Cave National Park, Ky.
Mesa Verde National Park, Colo.
Mount McKinley National Park, Alaska
Mount Rainier National Park, Wash.
North Cascades National Park, Wash.
Olympic National Park, Wash.
Petrified Forest National Park, Ariz.
Rocky Mountain National Park, Colo.
Scotts Bluff National Monument, Nebr.
Sequoia and Kings Canyon National Parks, Calif.
Shenandoah National Park, Va. (3 sheets)
Vanderbilt Mansion National Historic Site, N.Y.
Vicksburg National Military Park, Miss.

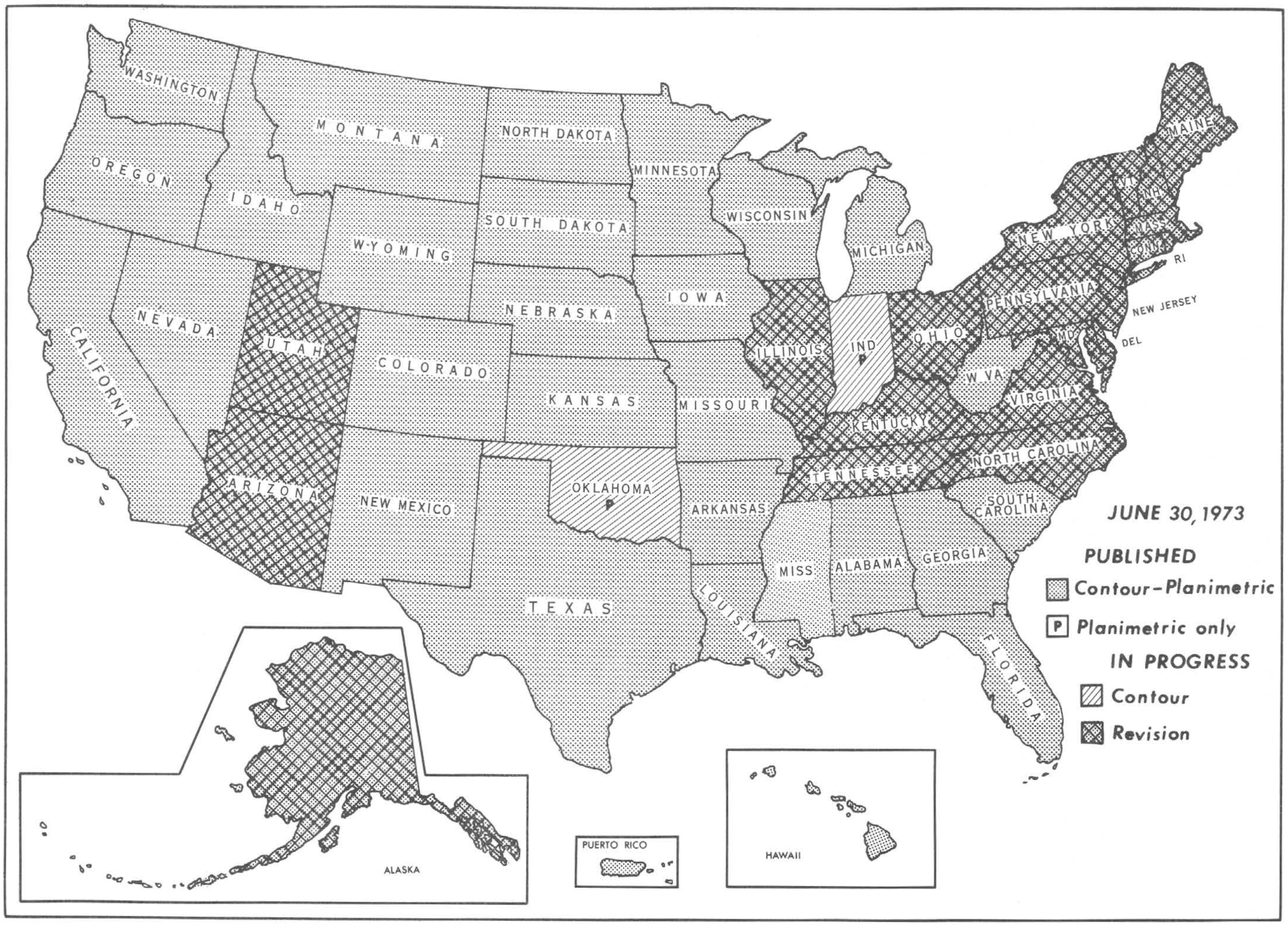


FIGURE 8.—Status of State maps.

Wind Cave National Park, S. Dak.
Yellowstone National Park, Wyo.-Mont.-Idaho
Yosemite National Park, Calif.
Yosemite Valley, Calif.
Zion National Park (Kolob section), Utah
Zion National Park (Zion Canyon section), Utah

Maps of the Big Bend, Glacier, Great Smoky Mountains, Mammoth Cave, Mesa Verde, and Mount McKinley National Parks; Point Reyes National Seashore; and Channel Islands and Death Valley National Monuments are being compiled or revised.

Million-scale map series

The worldwide million-scale series of topographic quadrangle maps was originally sponsored by the International Geographical Union and designated the International Map of the World on the Millionth Scale (IMW). Twenty-five of 53 maps required to cover the conterminous United States have been published.

From 1955 to 1959, the U.S. Army Map Service (Defense Mapping Agency, Topographic Center) published 27 maps of the conterminous United States and 13 maps of Alaska in a military series at the scale of 1:1,000,000. Although these maps do not meet the IMW specifications in all respects, they are recognized by the United Nations Cartographic Office as provisional editions in the IMW series (fig. 9).

Two of the maps, Hudson River and San Francisco Bay, are no longer available as IMW maps, but the areas are covered by maps in the military series. Maps of both the IMW and the military series are available for Boston, Chesapeake Bay, Hatteras, Mississippi Delta (also designated White Lake), Mount Shasta, and Point Conception. In addition, the American Geographical Society published the Sonora, Chihuahua, and Monterrey maps; and

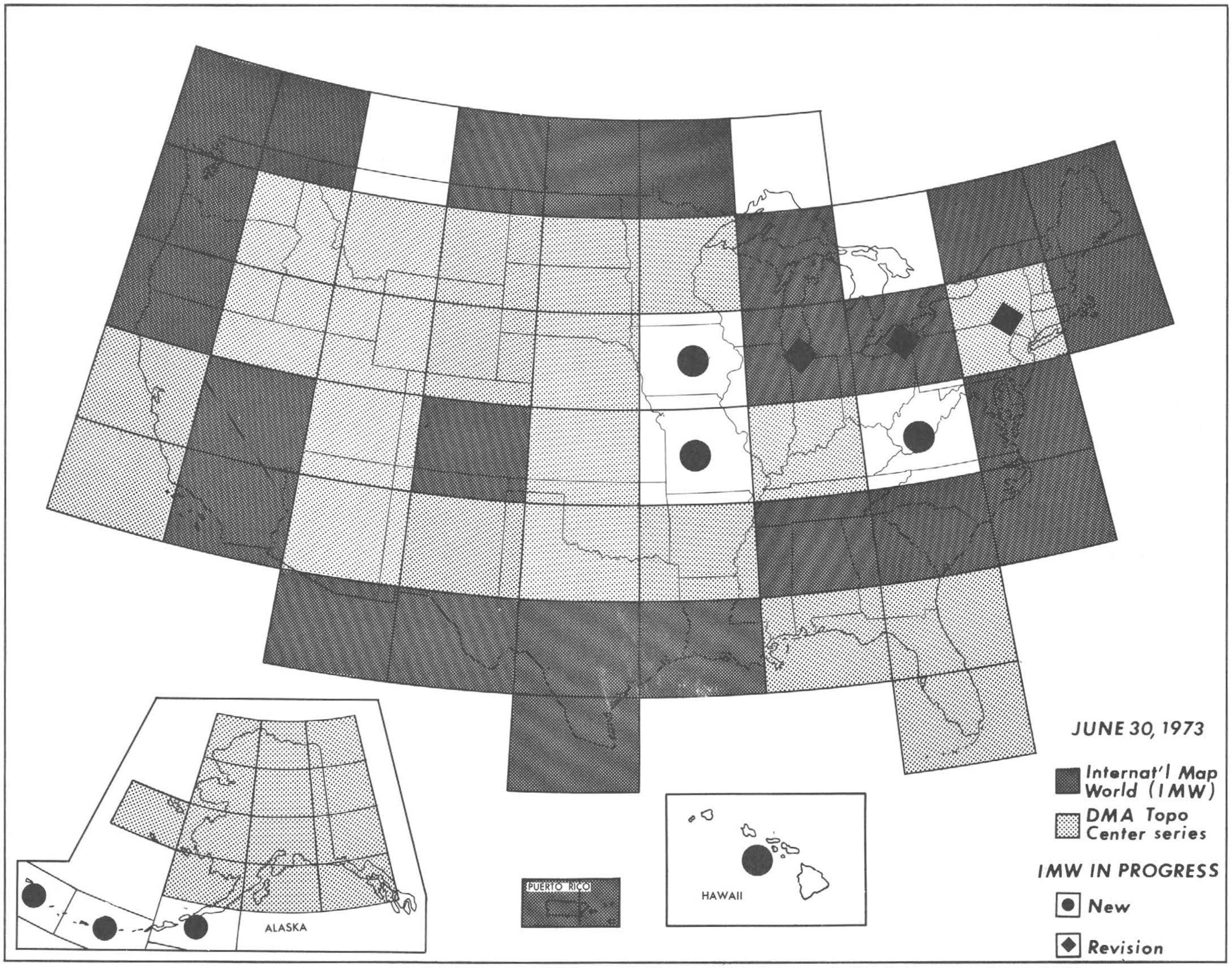


FIGURE 9.—Status of publication of 1:1,000,000-scale topographic maps. Work in progress is being done by the USGS.

Canada published the Kootenay Lake, Lake of the Woods, Ottawa, Prince Rupert, Regina, Sudbury, Vancouver, and Winnipeg maps. Puerto Rico is covered by two maps compiled by the American Geographical Society and published by both the society and the Defense Mapping Agency. Work in progress includes seven new maps and three maps being revised: Andreanof Islands, Attu Island, Blue Ridge, Chicago, Cold Bay, Des Moines, Hawaii, Hudson River, Lake Erie, and Ozark Plateau.

Orthophotomapping

Orthophotomaps have been established as the standard 1:24,000-scale publication for many areas where conventional cartographic symbolization cannot adequately portray the terrain, such as swamps and deserts. About 77 orthophotomaps have been published at 1:24,000 scale, with more than 500 additional quadrangles in the current orthophotomapping program.

Orthophotoquads are orthophotographs or orthophotomosaics in 7½-min quadrangle format with limited cartographic treatment. There has been an accelerating demand for this product, either as an interim map in unmapped areas or as a companion product to a published 7½-min quadrangle. Approximately 500 orthophotoquads were produced by the USGS in fiscal year 1973.

County map series

A county map series was established in fiscal year 1973 to meet a developing national need for maps on a county basis. Publication scales are expected to range from 1:50,000 to 1:125,000, depending on the particular requirement. A uniform scale will be maintained within each State to insure county-by-county compatibility. Preparation of five county maps of Pennsylvania was begun in fiscal year 1973.

Greater Pittsburgh regional studies

A map of the Greater Pittsburgh, Pa., area was published in fiscal year 1973 at the scale of 1:250,000. This regional map includes Allegheny, Armstrong, Beaver, Butler, Washington, and Westmoreland Counties and covers an area of about 4,500 mi^2. Within 1 week of publication it had been used by the Southwestern Pennsylvania Regional Planning Commission in a public hearing on the regional transportation plan; it has been put to use also by State and County agencies, by private industry, and by many individuals. The value of such regional maps had already been demonstrated by the similar-scale San Francisco Bay region maps. Regional maps are planned or considered for other major metropolitan areas to meet the needs of urban and regional planners, administrators, and environmentalists.

MAPPING IN ANTARCTICA

The USGS has assisted the National Science Foundation (NSF) in its U.S. Antarctic Research Program (USARP) by assigning field engineers to various projects in Antarctica for the past 16 consecutive years. The field operations for the 1972–73 season included an austral-summer project to establish control in support of the USARP Lassiter Coast 1:250,000-scale topographic mapping program and the start of a continuing Doppler satellite research program in cooperation with the U.S. Navy and the Applied Research Laboratory, University of Texas (ARL/UT). Six men from the USGS Topographic Division and three from the University of Texas were assigned to Antarctica for these projects.

Topographic field operations

As a direct result of the successful test of the USGS/APL (Johns Hopkins University, Applied Physics Laboratory) Doppler satellite project during the 1971–72 austral-summer season, plans were made to use Geoceiver tracking equipment this year to establish control for 1:250,000-scale mapping in the Lassiter Coast area between the Sweeney Mountains and the Ferguson Nunataks. Plans were to use the Geoceiver in a translocation mode (one data-receiving station had a known position) with a master tracking unit at Palmer Station. The party included J. R. House (party chief), H. E. Fiebelman, and J. W. Schoonmaker, Jr. However, because of limited air-transport capabilities and bad weather, the project was canceled in December 1972. The project will be resumed as soon as air support becomes available, possibly during the 1974–75 season.

The topographic survey party, acting on supplemental project orders, deployed to Byrd and Pole Stations to reobserve the geodetic station (Astro Pier) occupied in last season's test program. Four days were spent in continuous collection of data from Navy satellites 60 and 68. The data were reduced, and the 1972–73 derived positions are lat 80°00′36.689″ S., long 119°30′04.493″ W. at Byrd Station and lat 89°59′29.276″ S., long 26°14′14.104″ W. at Pole Station.

Other survey work of the House field party included establishing positions for the Lake Bonnie drill-hole site selected for the Dry Valley project and rechecking a traverse line established during the 1971–72 field season for 1:50,000-scale orthophotomapping.

The Doppler research projects at Pole, Casey, and Palmer Stations require continual satellite observation in support of the worldwide geodetic net, ice-movement investigations, and polar-motion and scintillation studies. These investigations are expected to continue through the 1974–75 austral winter season. The stations are also providing support for roving teams of Geoceiver observers deployed in support of national and international geophysical and mapping projects. The tracking equipment at Palmer Station is operated by D. L. Yates and P. D. Smith (ARL/UT); at Pole Station, by R. D. Worcester and D. W. Bennett (USGS); and at Casey Station, by H. L. Supp (ARL/UT) and R. F. Wilson (USGS).

The survey teams became operational at Palmer Station on December 3, 1972, at Casey Station on January 22, 1973, and at Pole Station on February 11, 1973. Data acquisition at all three stations has been excellent. Except for communications blackouts between McMurdo and the other stations, the data have been transmitted to APL without significant delay.

Data reduction and analysis were completed through day 109 (Apr. 19), and the results were relayed to the appropriate stations. These include positions for the four geophysical sites established by R. F. Wilson during the first leg of the Australian traverse from Casey Station, which is in support of the International Antarctic Glaciological Program.

ERTS experiments in polar regions

Investigations of ERTS–1 imagery in several experiments under NASA-funded project SR–149, "The Cartographic Application of ERTS/RBV Imagery in Polar Regions," principal investigator, W. R. MacDonald, were initiated. The results of the investigations clearly demonstrate that small- and medium-scale map revision and small-scale mapping are possible for the polar regions using ERTS–1 satellite imagery.

During the experiments new land features, map-position changes of islands, advancement of the ice front of large ice shelves, and glaciological changes were detected. ERTS–1 investigations of the Arctic and Antarctic are continuing.

Cartographic activities

The status of USGS topographic mapping in Antarctica is shown in figure 10. Two 1:250,000-scale sheets, Mount Berlin and Grant Island of the Hobbs Coast–Marie Byrd Land area, were prepared for printing. Production continues on 14 1:250,000-scale topographic maps.

Compilation also continues on the 1:500,000-scale sketch map covering about 56,000 mi² of Palmer Land, the 1:1,000,000-scale map of the McMurdo Sound region, and on the eight 1:50,000-scale orthophotoquads of the Dry Valley area. Pending funding approval from NSF, source materials for 21 additional maps at 1:250,000-scale are available for compilation.

NATIONAL ATLAS

The National Atlas of the United States of America was published early in 1971. The Atlas was compiled as a reference tool of high quality for use by public officials, business and industrial organizations, libraries, educational institutions, and scholars throughout the world who seek information about the United States. The 431-page volume required 8 yr of work and involved the cooperation of more than 80 Federal agencies and numerous commercial firms, specialists, and consultants. It contains 336 pages of multicolored maps and an index with more than 41,000 entries. The following individual map sheets are available as 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
Distribution of principal kinds of soils: orders, suborders, and great groups
Potential natural vegetation of Alaska and Hawaii
Potential natural vegetation (conterminous United States)
Monthly sunshine
Annual sunshine, evaporation and solar radiation
Population distribution, urban and rural: 1960
Federal lands
Population trends
Congressional districts for the 91st Congress
Shaded relief (conterminous United States)
Shaded relief (Alaska)

INTERNATIONAL ASSISTANCE PROGRAMS

Liberia

The geological exploration and resources appraisal project in Liberia was completed on June 30, 1972. Two of the ten 1:250,000-scale geographic shaded-relief maps of Liberia were published in color. Advance composite monochromatic copies of the other eight are available on request. It is expected that all quadrangles will be published in 1973.

Saudi Arabia

The USGS is continuing to assist the Ministry of Petroleum and Mineral Resources of the Kingdom of Saudi Arabia in assessing the mineral potential of the Precambrian shield area of central and western Saudi Arabia. The USGS has continued to assign a photogrammetric specialist and a geodetic specialist to this program. Maps of special areas of geologic interest have been controlled in Saudi Arabia for compilation there and in the United States for use as base maps for geologic investigations and reports.

Yemen Arab Republic

The USGS has agreed to assist the Yemen Arab Republic in the preliminary investigations of an important irrigation and development project in the Wadi Mawr area near the Red Sea. The project will consist of providing photogrammetrically compiled manuscripts of an area approximating 290 mi². Five engineers from the USGS were dispatched to the Yemen Arab Republic in June 1973 to establish the horizontal and vertical field control for this topographic mapping.

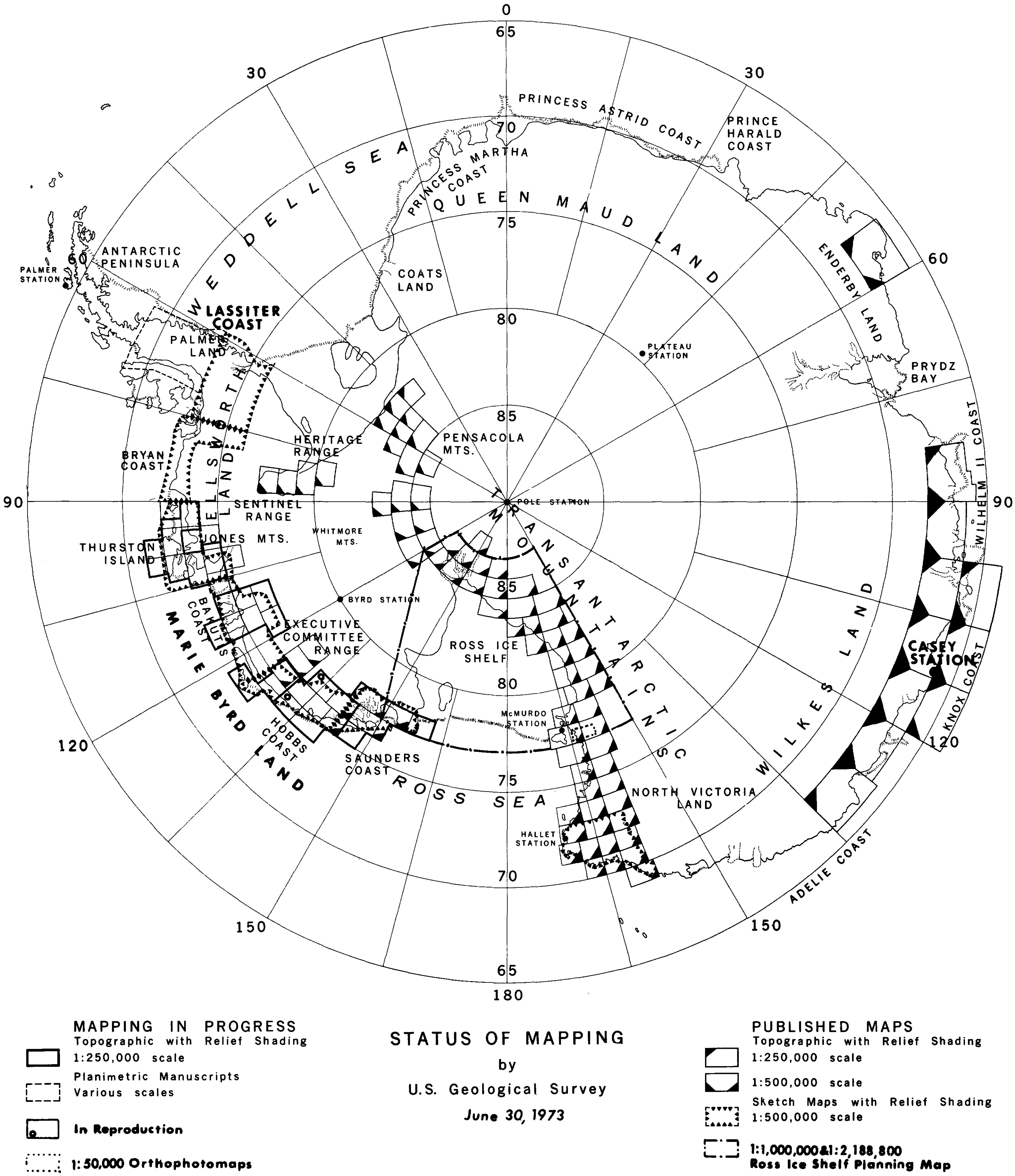


FIGURE 10.—Index map of Antarctica, showing status of topographic mapping.

Pan American Institute of Geography and History (PAIGH)

The USGS provided the administrative and staff support for the United States member of the Commission on Cartography and for the chairman of the Committee on Topographic Maps and Aerophotogrammetry. Eight USGS personnel are actively participating in PAIGH activities. The X General Assembly and the XII Consultation on Cartography were held in Panama during April–May 1973. Five USGS personnel attended these meetings as official members of the U.S. delegation.

Training programs and inquiries

Training and extended briefings in mapping operations were provided for participants and exchange scientists from Afghanistan, India, Indonesia, France, Finland, Mexico, and Australia. The participants were sponsored by the United Nations, AID, or special fellowship funds. Additionally, technical tours to the production and research facilities of USGS and other surveying and mapping agencies were arranged for many foreign visitors. Technical reports and publications, information on sources of equipment, instructions on new mapping techniques, and proposed solutions of mapping problems were provided to foreign countries in response to their requests.

RESEARCH AND DEVELOPMENT

FIELD SURVEYS

Geodetic control

The USGS continued to execute basic horizontal geodetic control to second-order standards for inclusion in the National Geodetic Network. The control surveys are accomplished under formal agreement with the National Geodetic Survey. During the fiscal year, the USGS completed second-order horizontal control surveys covering an area of about 9,300 mi^2 (either electronic-distance traverse or triangulation). The amount of horizontal control surveys required for mapping decreases each year because of the continuing improvement in analytical aerotriangulation techniques for establishing mapping control.

In fiscal year 1973 the USGS ran about 5,000 mi of monumented leveling to be used for extending vertical mapping control. A backlog of unadjusted level networks was substantially reduced by computer processing.

Doppler positioning

The encouraging results of the 1971–72 test of Doppler satellite positioning led to greater application of this surveying technique in Antarctica. The results indicate that an accuracy of better than 1 m in position and elevation can be expected in a 40 km translocated line when one position is known. This accuracy was obtained by tracking 28 satellite passes with U.S. Navy Geoceivers and computing the satellite positions using the predicted ephemeris. Using the same equipment in the navigation mode (positions unknown but later compared with test points), 56 selected passes gave a precision, at 95-percent confidence level, of about ± 14 m in position and about ± 5 m in the height above the ellipsoid. This is a much higher accuracy than was obtained by astronomic observations and barometric altimetry, the methods previously used.

In Antarctica additional satellite tracking stations are needed to improve the accuracy of the polar motion values, to study the scintillation of satellite-to-ground radio signals caused by variations in the ionosphere, to improve the gravity model of the Earth, and to measure the amount of ice movement at Pole Station. The USGS in a cooperative program with the U.S. Navy and the University of Texas, established three permanent tracking stations last season. Tracking equipment manned by three University of Texas graduate students and one USGS engineer was in operation at Palmer and Casey Stations. Two USGS engineers were operating a geoceiver at Pole Station. These three stations will also provide better tracking coverage of the five Navy navigational satellites and, therefore, allow more accurate determination of the orbit parameters.

Equipment improvements

Aluminum boxes were specially fabricated for transporting the new metric level rods now in use. The boxes give better protection and less wear to the rods, are more convenient to use, and weigh less than the end-opening wooden boxes available commercially.

Programable desk calculators were applied to geodetic computations in all mapping centers. Programs for these calculators are documented with operating instructions and are recorded on magnetic cards or magnetic tape in cassettes. Programs are interchangeable only between identical machine models of one manufacturer.

The principal geodetic programs now available for all machines are geodetic inverse, geodetic position, coordinate conversion, and triangle solutions. In addition, a number of programs reduce or check fieldnotes for a particular operation, type of measurement, or instrument.

PHOTOGRAMMETRY

Horizontal control distribution for mapping

Two independent tests for determining the optimum configuration of horizontal control for mapping projects were conducted. The first test concerned requirements for fully analytical aerotriangulation with high-altitude photographs. A project area 1,300 mi^2 covered by wide-angle photographs taken at 45,000 ft was chosen for the test. Preliminary evaluations of six different patterns of control indicated that less control can be used than is now specified. The conclusion was based on rms errors of less than 24 feet at test points. The tests will be continued to confirm the conclusion and to establish minimum requirements.

The other study concerned the control requirements for semianalytical aerotriangulation with compilation photographs. In the completed first phase, a simultaneous block adjustment was used with data from three projects that had already been aerotriangulated as regular mapping projects. Three blocks of quadrangles were solved, with only perimeter control at 7½-min spacing, first with long, striplike (rectangular) subblock configurations and then with approximately square subblocks. Both second- and third-degree solutions were applied. The results showed that perimeter control only, at 7½-min spacing (without interior control), is entirely adequate for blocks at least as large as 12 quadrangles. Third-degree solutions with square subblocks produced the best results. In the second phase of the study, the density of perimeter control will be reduced still further, and errors will be deliberatly introduced in the control to determine the ability of the solution to detect significant errors when control density is reduced.

Photogrammetric map accuracy evaluation

Research was continued on the practicality of using photogrammetric methods for evaluating horizontal map accuracy. In previous studies, 32 early-vintage maps were evaluated by comparing the scaled positions of selected map points with positions determined by fully analytical aerotriangulation with 1:70,000-scale, superwide-angle photographs. As a result, 6 maps were rated unacceptable in horizontal accuracy. The rms error for all the map points on all the maps was 27.5 ft.

As an extension of the research, 16 of the same quadrangles (including the 6 declared unacceptable) were evaluated by semianalytical aerotriangulation to obtain comparisons of accuracy, time, and cost for the 2 methods. Model coordinates for the previously mentioned superwide-angle photographs were measured on a digitized Wild B8 stereoplotter, and the models were adjusted to basic control and to each other using a simultaneous least-squares method involving a second-degree transformation.

The rms error of the residuals for all the map points was 28.9 ft, and the same maps were again rejected, showing that the two methods provide virtually the same accuracy evaluations. However, the cost in man-hours for the semianalytical method was only half as much as for the fully analytical method.

Analytical aerotriangulation

As a means of increasing productivity of fully analytical aerotriangulation and reducing the amount of vertical ground control needed, superwide-angle photographs were taken at higher-than-normal flight heights to establish pass points for wide-angle compilation photographs on the Louisburg, N.C., project. Eight 7½-min quadrangles to be mapped with a 10-ft contour interval make up the project. About 350 wide-angle photographs were taken in 10 east-west flight strips at a flight height of 9,500 ft for compilation, and 28 superwide-angle photographs were taken in 4 north-south flight strips at a flight height of 22,000 ft. For aerotriangulation by the direct geodetic constraint method, 30-percent sidelap was allowed. For safety, another 104 superwide-angle photographs were taken in 5 east-west strips to cover the area at a flight height of 11,000 ft.

More than 90 vertical control points and 12 horizontal points were targeted with 20- or 40-ft formée crosses before photography. Pass points were selected on the 9,500-ft compilation photographs and transferred to both the 11,000-ft and 22,000-ft aerotriangulation photographs. The horizontal and vertical ground control and a network of vertical test points were identified on all three sets of photographs. The data will be processed by the direct geodetic constraint program.

New photogrammetric techniques

Film diapositives were found to be an acceptable substitute for glass diapositive plates in plotting systems for both aerotriangulation and map compilation. The major objection to the film was a slight loss of image quality, but the cost saving had a counterbalancing effect.

A system of storing photocontrol data obtained in standard mapping operations was proposed. Generally, the system is designed for a document file of very-high-altitude photographs for annotation of control points, with many points on a single photograph. Another document file would contain aperture-punch cards—one card per point to store numerical data and a film chip of the point. An index record file, one record per point, would be set up for computer storage. Besides reference to the documents, index records would contain such information as geographic coordinates, elevation, State, project, and quadrangle. Paneled ground control and analytically derived points would be included. Each mapping center would set up and maintain its own data bank and would make the data available to the public.

A policy statement issued near the close of the year on interim revision established the practical and economical expediency of a second consecutive interim revision for selected maps. The policy eliminates the requirement of complete remapping instead of a second interim revision. The same purple color will apply for both the second revision and the first revision.

Vision-care program

The vision-care program for photogrammetrists, introduced in 1967 in two map production centers, became effective in all five production centers. Participation reached 100 percent in late 1972 when the program was started in the Menlo Park, Calif., and Rolla, Mo., offices. Special on-the-job and clinical examinations are conducted by an optometrist specializing in eye-fatigue studies. Task-oriented prescription glasses are provided for photogrammetrists according to their individual needs. Benefits of the program include reduction of eye fatigue, greater productivity, improvements in map quality, and extended efficiency for older, experienced employees.

Autoline-Orthophotomat system

Orthophoto products have gained popularity and importance as output of the USGS and new instrumentation is being developed to meet the increased demand. One of the systems under development is the Autoline-Orthophotomat, a semiautomatic, offline instrument on which orthophotographs are produced with the exposing projector under automatic control of analog profiles. The system uses a two-step procedure for preparing orthophotographs. Analog profiles, derived in various ways, are tracked by the Autoline, an automatic line-following device, which, in turn, controls the scanning and exposing operation of the Orthophotomat. Input profiles are generated in two different ways: (1) With the analog profiler, a variable-speed device that can be used on either ER–55 or Kelsh-type plotters, or (2) with a computer from three-dimensional digital terrain models formed by digitizing contour plates.

Since the last report, the Autoline-Orthophotomat system design has undergone refinement and modification. The analog profiler doubles the x separation of the plotted profiles so that adjacent profiles in steep terrain are not too close for the Autoline to discriminate between them. The Autoline scanning capacity is increased to incorporate the same physical distance as on the Orthophotomat. The main frame of the Orthophotomat is strengthened to accommodate a K–100 projector with a 570-mm inverse lens that improves light distribution and resolution.

Aerial photography

During the year contracts were issued for aerial photography of approximately 164,000 mi^2 at a cost of $540,000. Of the total, 25,000 mi^2 was for high-altitude quad-centered photographs. The USGS helped the Bureau of Indian Affairs and Defense Mapping Agency, Hydrographic Center, in obtaining aerial photographs of areas of special interest. The coverage ranged from relatively low-altitude photographs of military installations to quad-centered high-altitude coverage of a western Indian reservation.

Aerial photography guidelines recommended by a work group on orthophoto quality control were put into effect. The new procedures call for the use of Type 2402 (Plus-X) film instead of Type 2405 (Double-X), used in the past, and for exposure and processing that will yield a gamma (contrast ratio) of approximately 1.8. The guidelines also specify allowable base-plus-fog and minimum-image densities on the negatives.

Superwide-angle photography exhibited both discouraging and encouraging developments. Some photographs taken with the Wild RC–9 camera were found to have metric deficiencies not apparent in normal inspection, such as random parallax or false depressions in stereomodels. A suggested cause is vacuum failure in holding the film against curved platens. The new Wild RC–10 and Zeiss superwide-angle cameras appeared in lists of equipment offered by contractors. The first data obtained indicate that these cameras should be better in both resolution and distortion characteristics, and both have flat film platens.

Effective April 1, 1973, the calibration services for all aerial cameras and lenses provided by the National Bureau of Standards were transferred to the USGS.

CARTOGRAPHY

Slope mapping

Slope maps are special-subject maps that are built on standard map bases. They portray different zones of slope of the land by means of colors or gray patterns. Slope maps find considerable application in assessing potential environmental effects of construction and flooding. Research continued during the year on photomechanical methods of slope map production. Since the production in 1970 of the first slope map, Mount Sizer, Calif., 1:24,000 scale, two more experimental slope maps have been printed. Lancaster, Ohio, at 1:24,000 scale shows five slope zones, and Columbus, Ohio, at 1:250,000 scale shows four slope zones. The zones were photomechanically generated. Both maps portray the flattest zone in yellow and the steeper zones in various tones of brown.

To compare the relative accuracy of slope maps prepared by various methods, one slope band was generated for the Hershey, Pa., 7½-min map, contour interval 20 ft, by three methods: (1) From 1:24,000-scale copy with original contour lines, (2) from 1:24,000-scale copy with modified contours (all single-lineweight contours, photomechanically modified), and (3) from copy reduced to 1:48,000 scale with original contour lines. In each version the elevation numerals were deleted and the broken contours connected. The results showed that far less anomalies were generated from the modified contours at 1:24,000 scale, yet the slope zones produced from 1:48,000-scale copy with original contours closely resembled those produced from modified contours. Therefore, the method using scale-reduced copy seemed to have the most potential because of the combination of relatively high accuracy and economy in processing.

Equipment developments

Prototypes of a new instrument for making dashed symbols were evaluated. The instrument, called the O-Pake-A Dasher, is basically an opaquing device that converts a solid scribed line into a dashed line by intersecting the scribed line with evenly spaced inked lines. Adjustments to the built-in spacing guide allow for a wide range of uniform lengths and combinations of long and short dashes. A floating penpoint insures uniform inking pressure and lineweights. The instrument's most outstanding feature is its versatility—with a simple adjustment the inking pattern can be set for dashes to symbolize roads, railroads, power transmission lines, telephone and telegraph lines, pipelines, boundary lines, contour lines, or drainage lines.

The design for a hand-operated scribecoat tester was obtained from the Defense Mapping Agency, Topographic Center, and modified for use as an attachment to an automatic plotter to test scribing materials before awarding a purchase contract. The scribing pressure test can be performed more objectively and more accurately with the new tester than with the regular scribing head of the plotter or a hand-held scribing tool. Another test with the new attachment is for abrasives in the scribecoat, performed by scribing 2,000 continuous inches of line and comparing the line widths at the start and finish.

A new metric coordinate reader, termed the CR–1, was designed. Made of clear plastic, the new reader has scales marked to read directly in meters at map scales of 1:250,000, 1:500,000, and 1:1,000,000. The CR–1 complements the already available coordinate reader CR–2 with scales for reading at map scales of 1:10,000, 1:24,000, 1:62,500 and 1:125,000.

The Datagrid Digitizer proved useful in several cartographic applications, such as manual digitizing of contours on a 1:24,000-scale color separate and land parcel boundaries for land-use studies. It also was used to measure positions of test points on RBV and MSS scenes from ERTS and to provide measurements of control positions for the recently published map of the Martian south pole, made from Mars Mariner photographs.

Software systems for automated cartography

During the year, programs for utilizing manually digitized map data were made operational. Two means of data correction are available, punched cards and tape-to-tape. The data can be replotted for visual inspection. Thus far, most of the work has been done with three-dimensional terrain data. One application for contour data is the plotting of profiles used as copy for the Autoline in controlling the Orthophotomat as it produces an orthophotograph. The digitized data can also be displayed as a three-dimensional projection to obtain perspective views from any compass point. The system has been designed to accommodate data from a scanner-digitizer with maximum efficiency.

Version III of the Autoplot base-sheet plotting program became operational. It provides some new labor-saving operations, such as plotting of UTM grid ticks on base sheets and plotting of extra sheets. The savings in labor were, however, partly offset by an increase in computer costs.

An improved text editing program WYLBUR allows geographic name information to be edited and stored through a computer terminal. The same equipment can be used to retrieve stored information to answer inquiries, to prepare copy for small publications, or to interface with high-speed printers or automatic plotters. Other applications could provide reproducible copy in a variety of line lengths and formats, such as docket lists and decision lists of the Board on Geographic Names, lists of standardized names and descriptions, and copy for file card systems.

New cartographic techniques

A new procedure was tested in which color-separation materials are combined in the mapping centers for lithographic printing. All drawings of the same color are combined into a single film negative, with any needed screens interposed. The negatives are used directly for press-plate processing and are retained on file in the printing plant. The procedure is designed to reduce photographic work in the printing plant and to reduce the time and cost of returning materials to the mapping centers. Three 7½-min quadrangles were chosen for a pilot project: Holley, Fla. (new); Massies Corner, Va. (standard revision); and Mason-Dixon, Md.-Pa. (interim revision). The maps were printed and examined and found to be at least equal to those processed by earlier methods.

In the lithographic reproduction of photoimagery, the conventional halftone screen has serious limitations. It breaks up the image and obscures fine detail, alters textures, and may create objectionable moire patterns. The problems can be minimized by creating a fine pattern of random dots rather than the repetitive, rectilinear dot pattern of the halftone screen. Several methods of generating random-dot patterns have been developed. The method recommended consists of two main steps, (1) preparing a low-contrast positive from the aerial negative by photolysis and (2) printing the low-contrast positive onto high-contrast lithographic film to form the random-dot image. Last year the photolysis system of preparing random-dot lithonegatives was put into operation in the mapping centers. The system simplifies procedures and is subject to dependable control. The dot pattern is uniform, holds resolution, and yields an expanded tonal range on the presses.

Metric map project

After a 2-yr study by the National Bureau of Standards, legislation is pending in Congress for conversion to the metric system. The conversion would be effected gradually over 10 years. In support of the transition, a work group on metrication devised a project to show the effects of metrication on map appearance. The Abbott 3 NE quadrangle, N. Mex., was selected, based on relatively low relief, scarcity of cultural development, and existence of public land subdivisions. The project consists of the following: (1) 1:24,000-scale standard quadrangle—all English units, (2) 1:24,000-scale standard quadrangle—English-unit contours with metric equivalents shown in parentheses, (3) 1:25,000-scale quadrangle—all metric units, (4) 1:25,000-scale quadrangle—all metric units with English equivalents shown in parentheses, (5) 1:20,000-scale quadrangle—all metric units, and (6) 1:20,000-scale quadrangle—all metric units with English equivalents shown in parentheses. A contour interval of 10 ft was considered appropriate for the trial quadrangle, with 2.5 m as the interval for the metric compilation. The similarity of the two compilations was considered exceptional.

Orthophoto projects

Orthophotoquads are distortion-corrected black-and-white photoimage maps. A fine-line reference grid, latitude and longitude ticks, and orientation data are superimposed on the photoimagery, and the map margin is in the same format as conventional topographic maps. Forty-nine orthophotoquads covering Phoenix and 3,000 mi^2 of south-central Arizona were the first editions in this new 1:24,000-scale map series. Although similar products had been prepared previously, these were the first orthophotoquads to be mass-produced (lithographed) and placed on public sale at 75 cents per sheet.

The photographs for producing the orthophotoquads were taken during the summer of 1971. The topographic map coverage available for the area includes 48 1:24,000-scale quadrangles revised from 5 to 15 yr ago. Thus the orthophotoquads provide more recent information, not to mention a wealth of fine detail, and should be used along with their companion maps. Orthophotoquads also serve as useful interim map substitutes for areas not yet topographically mapped at 1:24,000 scale.

Production of 1,870 orthophotoquads scheduled to cover the Arizona Land-Use Experiment started with the receipt of NASA 1:120,000-scale U-2, RC-10 photographs (partial coverage) in May 1972. Scaling and registering orthonegatives to the base sheets was accelerated by modifying the Wang 700B linear transformation program to include an inverse transformation, allowing the projection corners to be plotted on the orthonegative while still mounted on the Haag-Streit coordinatograph. This permitted the 1:24,000-scale negative to be registered to the base quickly and accurately without reference to the machine-marked pass points used to scale the negative.

The USGS aided HUD in investigating the problems and costs of photogrammetrically producing flood-zone orthophotomaps. A flood-plain area in Jackson, Mo., was mapped at 1:6,000 scale, using photographs for plotting 3-ft contours and deriving creek cross-section data. The maps showed outlines of the projected 100-yr and 500-yr flood plains.

Four orthophotoquads of the Bear Valley, 15-min quadrangle, Idaho, were prepared in duplicate to compare the products of the Orthophotoscope and the Hobrough Gestalt Photo Mapper (GPM). The aerial photographs were 7½-min quad-centered at 40,000-ft flight height. Control was provided by fully analytical aerotriangulation; numerous test points were chosen and coordinates were read on the Wild A7. In each system, the original orthonegative required enlargement to 1:24,000 scale, about ×1.2 (orthophotoscope) and ×3.3 (GPM). After scaling, the orthonegatives were fitted to the base sheets, with projection lines and border information, to form composite negatives. Test-point residuals were determined before the orthonegative was enlarged and after the composite negative was made, the accuracy tests showed little difference in the horizontal accuracy attainable with either system. The Hobrough orthophotoquads contained fewer image discontinuities, but they were produced at about 50 percent higher instrument cost.

The USGS developed specifications and is serving as technical monitor for urban mapping by commercial contract. The first two contract projects are for 1:2,400-scale mapping of Ft. Wayne, Ind., and Charleston, S.C. The Ft. Wayne project consists of (1) approximately 440 1:2,400-scale monochromatic orthophotographic maps, each covering a half-section of the public-land net, (2) a semicontrolled photomosaic covering 220 mi^2 at 1:15,840 scale, and (3) stereoplotted contour drawings registered to the orthophotographic maps covering a 2-mi^2 area. The USGS furnished 6-in. and 12-in. photocoverage and specifications for control and resolution test targets. This pilot project will investigate the value of orthophoto base maps in municipal operations, land management, surveys, and planning studies.

The Charleston project is being conducted in cooperation with the Tricounty Planning Commission of Charleston, S.C. Contract specifications were prepared for covering a 500-mi^2 area with about 590 1:2,400-scale monochromatic orthophotographic maps. The USGS will furnish 6-in. photographs at two flight heights. Each map will consist of a quadrangle 5,000-ft on a side based on the State plane-coordinate system.

Strict quality control measures must be applied in all phases of orthophoto production so that satisfactory and uniform image quality can be achieved in the final products. Guidelines were developed for controlling and improving image quality. The guidelines cover all steps in production including orthophoto project planning, aerial photography procurement, photolab procedures, simple and differential rectification, preparation of orthophotomosaics, photolysis processing of random-dot lithonegatives, and combining lithonegatives for printing. The guidelines also recommend the establishment of a quality-control system in each production shop, with the system headed by a quality-control expert authorized to administer the orthophoto production program.

A test was conducted to determine the accuracy with which stereomodels formed with low-altitude photographs can be scaled to orthophotoimagery prepared from quad-centered photographs. The objective was to discontinue generating pass points for controlling low-altitude stereomodels on future projects scheduled for orthophotomapping from dual-altitude photographic coverage. Pass points for the low-altitude superwide-angle photographs (6,000-ft flight height) were established from quad-centered photographs by semianalytical aerotriangulation. Horizontal scale solutions were determined for each stereomodel by a best fit to the orthophotoimagery, constraining to pass points. For 29 points the rms error was 23 ft. A maximum error of 47 ft occurred on a pass point in a model void of cultural features; in the adjoining flight, the same point had an error of 12 ft. On the basis of the test, approximately 25 pass points will be established for each quadrangle from the quad-centered photographs, selected in areas of sparse culture to facilitate scaling to the orthophotoimagery. It is expected that point transfer from high- to low-altitude photographs can be bypassed.

COMPUTER TECHNOLOGY

During 1973 the USGS continued to expand its computer facilities along the lines established during the past several years. It also began to explore new directions and to adopt new techniques in its application of computer technology to the earth sciences.

EXPANSION OF CENTRALIZED COMPUTER SYSTEM

Several changes were made to the IBM 360/65 computer to keep pace with the growing demand for services within the USGS. One of these changes was the substitution of the new higher performance tape drives in place of the eight older tape drives that originally were delivered with the system. These new tape drives substantially increased the capacity of the system to process tape-oriented applications.

A second improvement was the installation of a million bytes of bulk memory to supplement the million bytes of main memory already in the system. This addition allowed larger programs to be run and more programs to run concurrently, which increased the versatility and throughput capacity of the computer and helped to relieve some of the capacity problems that had resulted from the growth in demand for computer services.

An expansion of the on-line disk storage capacity of the computer occurred this year. A third disk subsystem was added to improve performance and throughput of disk-oriented jobs and to provide more space for temporary—and input/output-data storage. In addition, several applications converted their data files to an on-line mode through the acquisition of dedicated disk files. This has allowed the data to be more readily available to USGS scientists and has improved the ability of the USGS to furnish timely information to its cooperators and to the public.

A number of new remote terminals were added to the system this year, particularly in the Water Resources Division field offices. The Computer Center now serves more than 80 different locations from its centralized system. To keep pace with this increase in telecommunications, a new communications control unit was acquired. This new control unit has provided not only increased capacity, but also new capabilities and increased speed of communications. The teleprocessing orientation of the computer system is expected to continue and to be the area of the most rapid growth in the next few years.

The steady increase in demand for computer services by USGS scientists has caused the workload to exceed the capacity of the present computer system. Plans are underway to add a second computer to the system, with the installation to coincide with the occupancy of the new National Center building at Reston, Va. A great deal of planning and preparation has been done to insure that the USGS will have ample computational support for its activities at Reston.

NEW SOFTWARE SUPPORT

As new advances in computer technology become available, the Computer Center attempts to provide those that seem to offer benefits to its users. During the year, several new software items were procured to add to the capabilities of the computer system.

Some of these items are new language compilers. IBM has made significant improvements to its compilers that make them, and the programs they produce, more efficient than the compilers originally developed for the 360 computer series. The Computer Center has made these improved compilers available to its users on an optional basis. The languages supported by these new compilers are PL/I, COBOL and 360 Assembly Language. A new version of the Sort/Merge program is also available.

Another software item that was added to the system is the Mathematical Programming System Extended (MPSX) program product. This program was acquired to support the growing interest in mathematical modeling of natural phenomena. It is an improved version of the previous MPS program.

COMPUTER GRAPHICS

An area of application for computer technology that has been receiving increased attention in the USGS is computer graphics, since many USGS programs deal with the graphical presentation of earth science information. To support these activities, the

Computer Center has added several items of graphic equipment and software to its facilities and is developing greater expertise in the handling of graphic data. A major addition to the Computer Center was the purchase of a large Calcomp flatbed plotter. This device can generate high quality, precise maps and charts in up to four colors and covering an area of up to 4 by 6 feet; it augments the existing Calcomp drum plotter in Washington and the two other general-purpose plotters at Denver, Colo., and Menlo Park, Calif.

To make more effective use of this new equipment and to provide general graphic support, the Computer Center also acquired three software packages for the Calcomp plotters. These are the General Purpose Contouring Program, the Three-Dimensional Plotting Program, and the Calcomp Functional Plotting software. These programs make it possible for people with little or no programming experience to use the plotters to transform numeric data into graphic form.

NEW FACILITIES

The Computer Center added three new types of facilities to its services this year. The most significant is the selection and procurement of a new computer system, a DEC System 1070, at the Denver Field Center. This new computer, when it is installed and operational, will enhance the computing capabilities available to Denver scientists and allow several new computer-related projects to be developed; it will provide extensive support to Denver geoscientists for interactive graphics, laboratory instrumentation control, and magnetic tape processing.

In a second equipment acquisition, a Data 100 Model 78 terminal was installed in Menlo Park to provide access to the IBM 360/65, and to local computer systems as well. This permits the continued use of the centralized system in Reston, as well as a more convenient means of access to computers in the Menlo Park area.

Both in response to user interest and in the interest of economy and ecology, the Computer Center installed a computer output microfilm (COM) device as part of the IBM 360/65. This form of computer output is especially well suited to large-volume reports and for compact archival storage of information. The use of COM not only reduces the amount of paper consumed, but also improves the overall service to the users by increasing job throughput.

APPLICATIONS

Three-dimensional ground subsidence by the finite-element method

A research project is being undertaken by Pat Doherty of the Computer Center Division, Menlo Park. The project will include the writing of a computer program to investigate the effects of water injection or withdrawal in a three-dimensional solid.

This program will calculate the deformation of the ground in an artesian aquifer caused by the withdrawal of ground water. It will be the prototype for a family of applications involving the analysis of structural deformation in three dimensions. When deformation is caused by withdrawal (or injection) of water in a porous solid, the equations of elastic equilibrium for the solid are coupled to the equation of Darcian flow in a saturated porous deforming medium. Numerical solution is accomplished by the finite-element method featuring tri-cubic shape functions defined on the corners of a rectangular brick-shaped element. Discretization is accomplished by the Galerkin method applied to the governing differential equations. The techniques incorporated in this program may contribute to the study of plastic deformation in three-dimensional rock formations (with or without fluid interaction) and may be useful in predicting the effects of fluid injection into the ground, either for the disposal of fluid waste or for the modification and control of movement along faults.

Performance measurement

The Computer Center has acquired a proprietary system that can be used to measure the performance of a computer and to make improvements on individual jobs or on overall system throughput. A project is underway to apply these techniques to the present IBM 360/65 to make better use of the available computer resources. This project will extend to the computer at Reston. By means of this project, the Computer Center plans to optimize the investment in computer hardware and software and to provide the most cost-effective computing services possible.

U.S. GEOLOGICAL SURVEY PUBLICATIONS

PUBLICATIONS PROGRAM

Books and maps

Results of research and investigations by the U.S. Geological Survey are made available to the public through professional papers, bulletins, water-supply papers, circulars, miscellaneous reports, and several map and atlas series, most of which are published by the Geological Survey. Of these reports, books are printed and sold by the U.S. Government Printing Office, and maps are printed and sold by the Survey.

All books, maps other than topographic quadrangle maps, and related Geological Survey publications are listed in the catalogs "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, National Center, Reston, VA. 22092.*

State lists of publications on hydrology and geology

"Geologic and Water-Supply Reports and Maps, [State]," a series of booklets, provides a ready reference to these publications on a State basis. The booklets also list libraries in the subject State where Geological Survey reports and maps may be consulted; these booklets are available free on request to the Geological Survey.

Surface-water and quality-of-water records

Beginning with the 1961 water year, surface-water records have been released on a State-boundary basis in separate annual reports entitled "Water Resources Data for [State]: Part 1, Surface Water Records." The records will also be published in the Geological Survey series of water-supply papers at 5-year intervals. The first group of "Surface Water Supply" papers covers the water years 1961–65.

Publication of quality-of-water records began in the annual State series in 1964 as "Water Resources Data for [State]: Part 2, Water Quality Records." The annual publication in the Geological Survey water-supply papers of "Quality of Surface Water of the United States" by drainage basins has been continued. Distribution of the State water-resources data, Parts 1 and 2, is limited and primarily for local needs. These reports are free on request to Water Resources Division district offices (listed on p. 321, 322) in areas for which records are needed.

Indexes, by drainage basins, of surface-water records to September 30, 1970, are published in the Geological Survey series of circulars, issues of which are free on application to the *U.S. Geological Survey, National Center, Reston, VA 22092.* These indexes list all streamflow and reservoir stations for which records have been published in Geological Survey reports.

State water-resources investigations folders

A series of folders entitled "Water Resources Investigations in [State]" is a project of the Water Resources Division to inform the public about its current program in the 50 States and Puerto Rico, the Virgin Islands (U.S.), Guam, and American Samoa. As the programs change, the folders are revised. The folders are available free on request to the *U.S. Geological Survey, National Center, Reston, VA 22092,* or to the Water Resources Division district offices listed on pages 321, 322.

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 press releases or other forms of public announcement. A Survey publication, listing all reports and maps released only in the open files, is published annually in the circular series. Most open-file reports are placed in one or more of the three Geological Survey libraries: National Center, Reston, Va.; Building 25, Federal Center, Denver, Colo.; and 345 Middlefield Road, Menlo Park, Calif. Other depositories may include one or more of the Geological Survey offices listed on pages 316–323 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 new bimonthly periodical designed to provide relatively rapid publication of short scientific papers by Survey personnel. It replaces the short-papers chapters of the annual Geological Survey research series of professional papers.

PUBLICATIONS ISSUED

During fiscal year 1973, the Geological Survey published 5,907 maps comprising some 20,986,945 copies, as follows:

Kind of map	1973
Topographic	5,463
Geologic and hydrologic	260
Maps for inclusion in book reports	107
Miscellaneous (includes maps for other agencies)	77
Total	5,907

In addition, 3 issues of a periodical comprising about 17,400 copies, 173 technical book reports, and 142 leaflets and maps of flood-prone areas were published.

At the beginning of the fiscal year, more than 91 million copies of maps and book reports were on hand in the Geological Survey's distribution centers. During the year 10,271,225 copies of maps, including 565,525 index maps, were distributed. Approximately 7.2 million maps were sold, and $2,999,367 was deposited to Miscellaneous Receipts in the U.S. Treasury.

The Survey also distributed 451,700 copies of technical book reports, without charge and for official use, and 1,815,700 copies of booklets, free of charge, chiefly to the general public; 208,200 copies of the monthly publications announcements and 212,000 copies of a sheet showing topographic map symbols were sent out.

The total distribution resulted from receipt of 627,825 individual orders. The following table compares Survey map and book distribution (including booklets but excluding symbol sheets and monthly announcements) during fiscal years 1972 and 1973.

Distribution points	Fiscal year		Change (percent)
	1972	1973	
Eastern (Arlington, Va.)	6,347,842	6,522,161	+3
Western (Denver, Colo.)	5,029,615	5,614,462	+12
Alaska (Fairbanks)	113,590	128,205	+13
12 other Survey offices	809,283	839,335	+4
Total	12,300,330	13,104,163	+7

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Maps and charts may be purchased at the following U.S. Geological Survey offices:

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Room 1028, General Services Administration Bldg., 19th and F Sts., NW. Washington, D.C.
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Indexes showing topographic maps published for each State, Puerto Rico, the Virgin Islands (U.S.), Guam, and American Samoa are available free on request. Publication of revised indexes to topographic mapping is announced in the monthly "New Publications of the Geological Survey." Each index also lists special and United States maps, as well as Geological Survey offices from which maps may be purchased and local dealers who sell the Survey's maps.

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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. Information concerning the ordering of these items is contained in the text of the indexes. Requests for the indexes or inquiries concerning the availability of advance material should be directed to the *Map Information Office, U.S. Geological Survey, National Center, Reston, VA 22092.*

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Book publications listed as out of print can no longer be obtained from the Superintendent of Documents, Washington, D.C. However, some books listed as out of print are available for purchase from these authorized agents: U.S. Geological Survey offices at National Center, Reston, VA 22092; Room 1028, General Services Administration Bldg., 19th and F Sts., NW., Washington, DC 20244; Room 1012, Federal Bldg., 1961 Stout St., Denver, CO 80202; Room 8102, Federal Bldg., 125 S. State St., Salt Lake Ciy, UT 84138; Room 1C45, 1100 Commerce St., Dallas, TX 75202; Room 7638, Federal Bldg., 300 N. Los Angeles St., Los Angeles, CA 90012; Room 504, Custom House, 555 Battery St., San Francisco, CA 94111; Room 678, U.S. Court House, West 920 Riverside Ave., Spokane, WA 99201; and Room 108, Skyline Bldg., 508 2d Ave., Anchorage, AK 99501.

Maps, charts, folios, and atlases that are out of print can no longer be obtained from any official source. These may be consulted at many libraries, and some can be purchased from secondhand-book dealers.

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COOPERATORS AND OTHER FINANCIAL CONTRIBUTORS DURING FISCAL YEAR 1973

[Cooperators listed are those with whom the U.S. Geological Survey had a written agreement for fiscal cooperation in fiscal year 1973, 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

Atomic Energy Commission:
- Division of Applied Technology
- Division of Headquarters Services
- Division of Reactor Development and Technology
- Idaho Operations Office
- Knolls Atomic Power Laboratory
- Nevada Operations Office
- Oak Ridge Operations Office
- Richland Operations Office
- San Francisco Operations Office
- Savannah River Operations Office

Department of Agriculture:
- Agriculture Research Service
- Forest Service
- Soil Conservation Service

Department of the Air Force:
- Air Force Academy
- Alaskan Air Command
- Cambridge Research Laboratory
- Headquarters (AFTAC/AC)
- Homestead Air Force Base
- Kirtland Air Force Base
- Vandenburg Air Force Base
- Weapons Laboratory

Department of the Army:
- Army Electronics Command
- Army Research Office
- Cold Regions Research and Engineering Laboratory
- Corps of Engineers
- White Sands Missile Range

Department of Commerce, National Oceanic and Atmospheric Administration:
- National Marine Fisheries Service
- National Weather Service

Department of Defense:
- Advanced Research Projects Agency
- Defense Nuclear 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 Reclamation
- Bureau of Sport Fisheries and Wildlife
- National Park Service
- Office of Saline Water
- Office of Water Resources Research

Department of the Navy:
- Key West Naval Station
- Marine Corps, Camp Pendleton
- Marine Corps, Twentynine Palms
- 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

Environmental Protection Agency:
- Office of Solid Waste
- Office of Water Programs
- Pacific Northwest Environmental Research Laboratory

National Aeronautics and Space Administration

National Science Foundation

Office of Emergency Preparedness

Tennessee Valley Authority

Veterans Administration

STATE, COUNTY, AND LOCAL COOPERATORS

Alabama:
- Alabama Highway Department
- City of Mobile
- County of Jefferson
- Geological Survey of Alabama

Alaska:
- Alaska Department of Aviation
- Alaska Department of Highways
- Alaska Department of Natural Resources
- City and Borough of Juneau
- City of Anchorage
- City of Cordova
- City of Kenai
- City of Kodiak
- Department of Environmental Conservation
- Greater Anchorage Area Borough
- Kenai Borough

Arizona:
- Arizona Game and Fish Department
- Arizona Highway Department
- Arizona Water Commission
- City of Flagstaff
- City of Safford
- City of Tucson
- City of Williams
- Flood Control District of Maricopa County
- Gila Valley Irrigation District
- Lyman Water Company
- Maricopa County Municipal Water Conservation District No. 1
- Navajo Tribal Council
- Pima County Board of Supervisors
- Salt River Valley Water Users' Association
- San Carlos Irrigation and Drainage District
- Show Low Irrigation Company

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 Conservatior 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
- Casitos Municipal Water District
- City and County of San Francisco:
  - Hetch Hetchy Water Supply
  - Water Department
- City of Modesto, Public Works Department
- 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

California—Continued
- County of Del Norte
- County of Modoc
- County of Sacramento, Department of Public Works
- County of San Diego, Board of Supervisors
- County of San Mateo
- Desert Water Agency
- East Bay Municipal Utility District
- Georgetown Divide Public Utility District
- Goleta County Water District
- Imperial Irrigation District
- Indian Wells Valley County Water District
- Irvine Ranch Water District
- Kern County Water Agency
- Lake County Flood Control and Water Conservation District
- 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
- Montara Sanitary District
- Montecito County Water District
- Monterey County Flood Control and Water Conservation District
- Napa County Flood Control and Water Conservation District
- Orange County Flood Control District
- Orange County Water District
- Orbville-Wyandotte Irrigation District
- Paradise Irrigation District
- Placer County Department of Public Works
- Rio San Diego Municipal Water District
- Riverside County Flood Control and Water Conservation District
- San Benito County Water Conservation and Flood Control District
- San Bernardino County Flood Control District
- San Bernardino Valley Municipal Water District
- San 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 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, School of Forestry and Conservation

California—Continued
- Ventura County Flood Control District,
- Western Municipal Water District, Riverside County
- Woodbridge Irrigation District
- Yolo County Flood Control and Water Conservation District

Colorado:
- Arkansas River Compact Administration
- City of Aspen
- City of Aurora, Department of Public Utilities
- City of Colorado Springs, Department of Public Utilities
- City and County of Denver, Board of Water Commissioners
- Colorado 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 State Mining Industrial Development Board
- Colorado Water Conservation Board
- Pikes Peak Area Council of Governments
- Rio Grande Water Conservation District
- San Luis Valley Water Conservation District
- Southeastern Colorado Water Conservancy District
- State of Colorado, Department of Highways
- Urban Drainage and Flood Control District

Connecticut:
- City of Hartford, Department of Public Works
- City of New Britain, Board of Water Commissioners
- City of Torrington
- Connecticut Geological and Natural History Survey
- 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:
- 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 Green Cove Springs
- City of Hallandale
- City of Hollywood
- City of Jacksonville
- City of Juno Beach

Florida—Continued
- 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 Venice
- Collier County
- Collier County Water Management District No. 1
- Collier County Water Management District No. 7
- Dade County Port Authority
- Dade County Water and Sewer Authority
- East Central Florida Regional Planning Council
- Englewood Water District
- Escambia County
- Florida Department of Natural Resources
- Florida Department of Natural Resources:
  - Bureau of Geology
  - Division of Parks and Recreation
- Florida Department of Transportation
- Hillsborough County
- Jacksonville Area Planning Board
- Lake County
- Lee County
- Marion County
- Metropolitan Dade County
- Orange County
- Osceola County
- Palm Beach County
- Pinellas County
- Reedy Creek Improvement District
- Sarasota County
- Seminole County
- Southwest Water Management District
- Suwanee River Authority
- Tampa Bay Regional Planning Commission
- Tampa Port Authority
- Trustees of the Internal Improvement Trust Fund
- Volusia County
- Walton County

Georgia:
- Chatham County
- City of Brunswick
- Georgia Department of Environmental Protection
- Georgia Department of Natural Resources, Division of Earth and Water
- Georgia Department of Transportation

Hawaii:
- City and County of Honolulu
- Honolulu Board of Water Supply
- State Department of Land and Natural Resources
- State Department of Transportation

Idaho:
- City of Kellogg
- Idaho Department of Highways
- Idaho Department of Water Administration
- Idaho Water Resources Board

Illinois:
- City of Springfield
- Cook County, Forest Preserve District
- Du Page County
- 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

Iowa:
- City of Cedar Falls
- 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
- University of Iowa, Institute of Hydraulic Research

Kansas:
- City of Wichita
- Kansas State Department of Health
- Kansas State Water Resources Board
- Kansas-Oklahoma Arkansas River Commission
- State Geological Survey of Kansas
- State Highway Commission of Kansas

Kentucky:
- Kentucky Geological Survey, University of Kentucky
- University of Kentucky Research Foundation

Louisiana:
- Louisiana Department of Highways
- Louisiana Department of Public Works
- Sabine River Authority of Louisiana

Maine:
- Maine Department of Economic Development
- Maine Public Utilities Commission
- Maine State Highway Commission

Maryland:
- City of Baltimore, Water Division
- 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 Public Works
- 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 Natural Resources:
  - Geological Survey Division
  - Water Resources Commission

Minnesota:
- Metropolitan Council of the Twin Cities Area
- Minnesota Department of Administration, Minnesota Geological Survey
- Minnesota Department of Highways
- Minnesota Department of Iron Range Resources and Rehabilitation
- Minnesota Department of Natural Resources, Division of Waters, Soils, and Minerals
- Minnesota State Planning Agency

Mississippi:
- City of Jackson
- Harrison County Development Commission
- 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

Missouri:
- Curators of the University of Missouri
- Metropolitan St. Louis Sewer District
- Missouri Department of Business and Administration, Division of Geological Survey and Water Resources
- Missouri State Highway Commission
- Missouri Water Pollution Board
- St. Louis County

Montana:
- Endowment and Research Foundation—Montana State University

Montana—Continued
- Lewis and Clark County, Board of County Commissioners
- Montana Bureau of Mines and Geology
- Montana Department of Health and Environmental Sciences
- Montana State Fish and Game Department
- Montana State Highway Commission
- Montana Water Resources Board

Nebraska:
- Clay County Ground Water Conservation District
- Fillmore County Ground Water Conservation District
- Hamilton County Ground Water Conservation District
- Lower Platte South Natural Resources District
- Nebraska Department of Water Resources
- Nebraska Game and Parks Commission
- Nebraska Natural Resources Commission
- Seward County Ground Water Conservation District
- State Department of Roads
- University of Nebraska, Conservation and Survey Division
- York County Ground Water Conservation District

Nevada:
- Nevada Bureau of Mines
- Nevada Department of Conservation and Natural Resources
- Nevada State Highway Department

New Hampshire:
- New Hampshire Department of Resources and Economic Development
- New Hampshire Water Resources Board

New Jersey:
- County of Bergen
- Delaware River Basin Commission
- Mercer County
- New Jersey Department of Agriculture, State Soil Conservation Committee
- New Jersey Department of Environmental Protection
- North Jersey District Water Supply Commission
- Passaic Valley Water Commission
- Rutgers State University

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

New York—Continued
- City of New York:
  - Board of Water Supply
  - Environmental Protection Agency
- County of Chautauqua
- County of Cortland
- County of Dutchess, Board of Supervisors
- County of Nassau, Department of Public Works
- County of Onondaga:
  - Department of Public Works
  - Water Authority
- County of Orange
- County of Suffolk:
  - Department of Environmental Control
  - Water Authority
- County of Ulster, Ulster County Legislature
- County of Westchester Department of Public Works
- Department of Environmental Conservation:
  - Environmental Management
  - Environmental Quality
  - Environmental Research
- Department of Transportation
- 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 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 Highway Commission
- Wilson County

North Dakota:
- North Dakota Geological Survey
- Oliver County, Board of County Commissioners
- State Highway Department
- State Water Commission

Ohio:
- City of Columbus, Department of Public Service
- Miami Conservancy District
- Ohio Department of Natural Resources
- Ohio Department of Transportation
- Ohio Department of Transportation, Division of Highways
- Ohio Environmental Protection Agency
- Three Rivers Watershed District

Oklahoma:
- City of Oklahoma City, Water Department
- Oklahoma Department of Highways
- Oklahoma Geological Survey
- Oklahoma Soil Conservation Board
- Oklahoma Water Resources Board
- State Department of Health, Environmental Health Service

Oregon:
- Burnt River Irrigation District
- City of Astoria
- City of Eugene, Water and Electric Board
- City of McMinnville, Water and Light Department
- City of Portland, Bureau of Water Works
- City of The Dalles
- City of Toledo
- 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 Engineer
- Oregon State Game Commission
- Oregon State Highway Commission
- Oregon State Water Resources Board
- Port of Portland

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
- 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 State University, College of Earth and Mineral Sciences
- 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
- State Development Board
- State Highway Department
- State Land Resources Conservation Commission

South Carolina—Continued
- State Pollution Control Authority
- State Public Service Authority
- State Water Resources Commission

South Dakota:
- Black Hills Conservancy Subdistrict
- City of Rapid City
- City of Sioux Falls
- East Dakota Conservancy Subdistrict
- South Dakota Department of Highways
- South Dakota State Geological Survey
- South Dakota State Water Resources Commission

Tennessee:
- City of Chattanooga
- City of Lawrenceburg
- City of Memphis, Board of Light, Gas, and Water Commissioners
- 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 Game and Fish Commission

Texas:
- City of Dallas, Public Works Department
- City of Fort Worth
- City of Houston
- County of Dallas
- General Land Office
- 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

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
- City of Norfolk, Division of Water Supply
- City of Roanoke
- City of Staunton
- County of Chesterfield
- County of Fairfax

Virginia—Continued
- 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:
- 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
- Lummi Indian Tribe
- Muckleshoot Tribal Council
- Municipality of Metropolitan Seattle
- Nisqually Community Council
- Port of Seattle
- Skokomish Tribal Council
- The Evergreen State College
- 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

Wisconsin—Continued
- 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

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 Geological Survey
- Wyoming State Agriculture Commission
- Wyoming State Engineer

OTHER COOPERATORS AND CONTRIBUTORS

Government of American Samoa

Government of Guam

Government of Saudi Arabia

Permittees and licensees of the Federal Power Commission

Puerto Rico:
- Puerto Rico Department of Public Works
- Puerto Rico Environmental Quality Board
- Puerto Rico Mining Commission

Trust Territory of the Pacific Islands

United Nations

Virgin Islands, Department of Public Works

U. S. GEOLOGICAL SURVEY OFFICES

MAIN OFFICES

Headquarters: National Center, Reston, Va. 22092; 703 860-7000
Eastern Region: National Center, Reston, Va. 22092; 703 860-7000
Central Region: Federal Center, Denver, Colo. 80225; 303 234-3131
Western Region: 345 Middlefield Road, Menlo Park, Calif. 94025; 415 323-8111

SELECTED FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices are not included; list is current as of July 1, 1973. Correspondence to the following offices should be addressed to the Post Office Box, if one is given]

COMPUTER CENTER DIVISION

Location	*Official in charge and telephone number*	*Address*
Arizona, Flagstaff 86001	James E. Crawforth (602 774-8863)	601 East Cedar Ave.
California, Menlo Park 94025	James L. Mueller (415 323-2661)	345 Middlefield Rd.
Colorado, Denver 80225	Frederick B. Sower (303 234-2551)	E2608, Bldg. 53, Federal Center.
Missouri, Rolla 65401	Glenn A. Ridgeway (314 364-6985)	P.O. Box 41.
South Dakota, Sioux Falls 57198	Gary I. Selner (605 336-2381)	EROS Data Center.

CONSERVATION DIVISION

REGIONAL OFFICES

Location	*Official in charge and telephone number*	*Address*
Central Region: Denver, CO 80225	George H. Horn, Acting Regional Conservation Manager (303 234-4435).	Bldg. 25, Federal Center.
Eastern Region: Washington, DC 20006	Reid T. Stone, Regional Conservation Manager (202 343-7511).	1825 K St., NW.
Gulf of Mexico Outer Continental Shelf Operations: Metairie, LA 70011	Robert F. Evans, Acting Conservation Manager (504 527-3381).	P.O. Box 7944; 336 Imperial Office Bldg., 3301 North Causeway Blvd.
Western Region: Menlo Park, CA 94025	Willard C. Gere, Regional Conservation Manager (415 323-2563).	345 Middlefield Rd.

AREA AND DISTRICT OFFICES

Location	*Responsible officials and telephone numbers*	*Address*
Alaska, Anchorage 99510	Rodney A. Smith (907 277-0579). Alexander A. Wanek (907 277-0570).	P.O. Box 259; 210—214 Skyline Bldg., 218 E St.
Arizona, Phoenix 85004	James W. Hager (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 (805 323-7201)	Rm. 309, Federal Bldg., 800 Truxtun Ave.
Menlo Park 94025	Leo H. Saarela (415 323-2563). E. Vernon Stephens (415 323-2184).	345 Middlefield Rd.
Sacramento 95825	Kenneth W. Sax (916 484-4219)	Rm. W-2231, Federal Bldg., 2800 Cottage Way.
Colorado, Denver 80202	Robert G. Dickinson (303 837-4752). John P. Storrs (303 837-4751). Henry D. Tefft, Jr. (303 837-4753).	P.O. Box 3521; Rm. 6023, 6025, and 6029, Federal Bldg., 1961 Stout St.
Denver 80225	Daniel A. Jobin (303 234-4435)	Bldg. 25, Federal Center.
Durango 81302	Jerry W. Long (303 247-5144)	P.O. Box 1809; 3473 North Main St.
Idaho, Pocatello 83201	John T. Skinner (208 235-6262)	P.O. Box 1610; Federal Bldg., 150 South Arthur St.
Louisiana, Lafayette 70501	Elmo Hubble George Kinsel, Robert O. Schrott (318 232-6037).	P.O. Box 52289; 239 Bendel Rd.
Metairie 70011	Gayle A. Oglesby (504 527-3341). Donald W. Solanas (504 527-3333).	P.O. Box 7944; 336 Imperial Office Bldg., 3301 North Causeway Blvd.
Missouri, Rolla 65401	C. V. Collins (314 364-8411)	P.O. Box 936; Suite 101, 400 Main St.
Montana, Billings 59103	Albert F. Czarnowsky (406 245-6368). Jim S. Hinds (406 245-6367). 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). Larry Godwin (505 885-9082).	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 (505 622-9857).	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 73102	Charley W. Nease (405 231-4806)	Rm. 4321, Federal Courthouse and Office Bldg., 220 NW. 4th St.
Tulsa 74103	Edward L. Johnson (918 581-7638). Floyd L. Stelzer (918 581-7631).	Rm. 4562 and 3413, New Federal Bldg., 333 West 4th St.
Oregon, Portland 97208	Jesse L. Colbert (503 234-4796)	P.O. Box 3203, 830 NE. Holladay St.
Utah, Salt Lake City 84111	Howard F. Albee (801 524-5643). Gerald R. Daniels (801 524-5650). Jackson W. Moffitt (801 524-5646).	Rm. 8422, 8416, and 8432, Federal Bldg., 125 South State St.
Washington, Tacoma 98401	Gordon C. Giles (206 383-5830)	P.O. Box 1152; Rm. 244, Federal Bldg.
Wyoming, Casper 82601	Charles J. Curtis (307 265-3405). 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; 214 West Main St., Masonic Temple Bldg.
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.

Location	*Responsible officials and telephone numbers*	*Address*
Wyoming, Thermopolis 82443	Charles P. Clifford (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, NASA Mississippi Test Facility.

GEOLOGIC DIVISION

REGIONAL OFFICES

Location	*Official in charge and telephone number*	*Address*
Central Region:		
Denver, CO 80225	Thomas A. Hendricks, Regional Geologist (303 234-3625).	Bldg. 25, Federal Center.
Eastern Region:		
Washington, DC 20244	John P. Albers, Associate Chief Geologist (202 343-2126).	Rm. 4244, GSA Bldg., 18th and F St. NW.
Western Region:		
Menlo Park, CA 94025	Robert E. Wallace, Regional Geologist (415 323-3624).	345 Middlefield Rd.

OFFICES

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage 99501	Donald H. Richter (907 272-8228)	216 Skyline Bldg., 218 E St.
College 99701	Florence R. Weber (907 479-7245)	P.O. Box 80586.
Arizona, Flagstaff 86001	John F. McCauley (602 774-5261, ext. 1455).	601 East Cedar Ave.
	John D. Strobell (602 774-5261, ext. 1463).	
California, La Jolla 92037	George W. Moore (714 453-2820, ext. 341).	P.O. Box 271; 8604 La Jolla Shores Dr.
Hawaii, Hawaii National Park 96718	Donald W. Peterson (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 (617 548-8533)	U.S. Geological Survey, Woods Hole Oceanographic Institution.
Ohio, Columbus 43210	James M. Schopf (614 421-2393)	Orton Hall, Ohio State Univ., 155 South Oval Dr.
Puerto Rico, San Juan 00936	John M. Aaron (809 766-5340)	GPO Drawer 2230.
Tennessee, Knoxville 37902	Robert A. Laurence (615 524-4011, ext. 4268).	301 West Cumberland Ave.
Texas,		
Corpus Christi 78411	Louis E. Garrison (512 883-5293)	P.O. Box 6732; Univ. of Corpus Christi.
Utah, Salt Lake City 84111	Lowell S. Hilpert (801 524-5640)	Rm. 8426, Federal Bldg., 125 South State St.
Washington, Spokane 99201	Frank C. Armstrong (509 456-4677).	West 920 Riverside Ave.
Wisconsin, Madison 53706	Carl E. Dutton (608 262-1234, ext. 1854).	222 Science Hall, Univ. of Wisconsin.
Platteville 53818	Walter S. West (608 348-6486)	Wisconsin State Univ., Roundtree Hall.
Wyoming, Laramie 82070	J. David Love (307 745-4495)	Box 3007, Univ. Station, Geology Hall, Univ. of Wyoming.

RESPONSIBLE OFFICERS FOR INDIVIDUAL STATES

[Inquiries about Geologic Division programs should be directed to the appropriate officer listed below]

State	*Responsible officer and telephone number*	*Address*
Alabama	Gordon H. Wood, Jr., Chief Branch of Coal Resources (202 282-7251).	U.S. Geological Survey, Bldg. 10, Washington, DC 20244.
Alaska	George Gryc, Chief Branch of Alaskan Geology (415 323-2231).	345 Middlefield Rd., Menlo Park, CA 94025.
Arizona	George W. Walker, Chief, Branch of Western Mineral Resources (415 323-2651).	Do.
Arkansas	Peter R. Rose, Chief, Branch of Oil and Gas Resources (303 234-4750).	Bldg. 25, Federal Center, Denver, CO 80225.
California	Robert E. Wallace, Regional Geologist, Western Region (415 323-3624).	345 Middlefield Rd., Menlo Park, CA 94025.
Colorado	Raymond L. Parker, Chief, Branch of Central Mineral Resources (303 234-3830).	Bldg. 25, Federal Center, Denver, CO 80225.
Connecticut	M. H. Pease, Jr., Chief, Massachusetts Cooperative (617 223-7202).	80 Broad St., Boston, MA 02110.
Delaware	N. L. Hatch, Jr., Chief, Branch of Eastern Environmental Geology (301 344-2438).	U.S. Geological Survey, Bldg. 420, Agricultural Research Center, Beltsville, MD 20705.
Florida	Louis E. Garrison, Chief, Branch of Atlantic--Gulf of Mexico Geology (512 883-5293).	U.S. Geological Survey, P.O. Box 6732, Corpus Christi, TX 78411.
Georgia	Frank G. Lesure, Chief, Branch of Eastern Mineral Resources (202 282-7144).	U.S. Geological Survey Bldg. 10, Washington, DC 20244.
Hawaii	Donald W. Peterson, Scientist-in-Charge, Hawaiian Volcano Observatory (808 967-7485).	Hawaii National Park HI 96718.
Idaho	Edward T. Ruppel, Chief, Branch of Central Environmental Geology (303 234-2650).	Bldg. 25, Federal Center, Denver, CO 80225.
Illinois	Wilds W. Olive, Chief, Branch of Kentucky Geology (606 252-2552).	U.S. Geological Survey, 2035 Regency Rd., Lexington, KY 40503.
Indiana	do	Do.
Iowa	do	Do.
Kansas	P. R. Rose	See Arkansas.
Kentucky	W. W. Olive	See Illinois.
Louisiana	do	Do.
Maine	F. G. Lesure	See Georgia.
Maryland	N. L. Hatch, Jr.	See Delaware.
Massachusetts	M. H. Pease, Jr.	See Connecticut.
Michigan	F. G. Lesure	See Georgia.
Minnesota	R. L. Parker	See Colorado.
Mississippi	W. W. Olive	See Illinois.
Missouri	R. L. Parker	See Colorado.
Montana	E. T. Ruppel	See Idaho.
Nebraska	do	Do.
Nevada	G. W. Walker	See Arizona.
New Hampshire	M. H. Pease, Jr.	See Connecticut.
New Jersey	N. L. Hatch, Jr.	See Delaware.
New Mexico	E. T. Ruppel	See Idaho.
New York	N. L. Hatch, Jr.	See Delaware.
North Carolina	do	Do.

State	Responsible officer and telephone number	Address
North Dakota	P. R. Rose	See Arkansas.
Ohio	W. W. Olive	See Illinois.
Oklahoma	P. R. Rose	See Arkansas.
Oregon	Howard D. Gower, Chief, Branch of Western Environmental Geology (415 323-2353).	345 Middlefield Rd., Menlo Park, CA 94025.
Pennsylvania	G. H. Wood, Jr.	See Alabama.
Rhode Island	N. L. Hatch, Jr.	See Delaware.
South Carolina	F. G. Lesure	See Georgia.
South Dakota	R. L. Parker	See Colorado.
Tennessee	F. G. Lesure	See Georgia.
Texas	E. T. Ruppel	See Idaho.
Utah	G. W. Walker	See Arizona.
Vermont	N. L. Hatch, Jr.	See Delaware.
Virginia	do	Do.
Washington	H. D. Gower	See Oregon.
West Virginia	G. H. Wood, Jr.	See Alabama.
Wisconsin	F. G. Lesure	See Georgia.
Wyoming	E. T. Ruppel	See Idaho.

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.
Texas, Dallas 75202	Mary E. Reid (214 749-3230)	Rm. 1 C 45, 1100 Commerce St.
Utah, Salt Lake City 84138	Wendy R. Hassibe (801 524-5652)	Rm. 8102, Federal Bldg., 125 South State St.
Washington, Spokane 99201	Eula M. Thune, acting (509 456-2524).	Rm. 678, U.S. Court House, West 920 Riverside Ave.

MAP DISTRIBUTION CENTERS

[Survey maps are distributed by mail from the following centers]

Location	Official in charge and telephone number	Address
Virginia, Arlington 22202[1]	John J. Curry (703 557-2751)	1200 South Eads St.
Colorado, Denver 80225[2]	Dwight F. Canfield (303 234-3832)	Bldg. 41, Federal Center
Alaska, Fairbanks 99701[3]	Natalie A. Cornforth, acting (907 452-1951, ext. 174).	310 First Ave.

1/ For maps of areas east of the Mississippi River (including Minnesota).
2/ For maps of areas west of the Mississippi River (including Louisiana).
3/ For residents of Alaska.

TOPOGRAPHIC DIVISION

Location	*Engineer 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 Elm Sts.
South Dakota, Sioux Falls 57198	Glenn H. Landis (605 339-2270)	10th and Dakota Ave.
Virginia, Arlington 22201	Peter F. Bermel (703 557-0927)	1109 North Highland St.
Reston 22090	Roy E. Fordham (703 471-1711)	1925 Newton Square East.

WATER RESOURCES DIVISION

REGIONAL OFFICES

Location	*Official in charge and telephone number*	*Address*
Northeastern Region: Arlington, VA 22209	Joseph T. Callahan, Regional Hydrologist (202 343-8841).	Rm. 317, George Washington Bldg., Arlington Towers, 1011 Arlington Blvd.
Southeastern Region: Atlanta, GA 30309	Rolland W. Carter, Regional Hydrologist (404 526-5395).	Suite 200, 1459 Peachtree St. NE.
Central Region: Denver, CO 80225	Tyrus B. Dover, acting Regional Hydrologist (303 234-3661).	Bldg. 25, Federal Center.
Western Region: Menlo Park, CA 94025	Elwood R. Leeson, Regional Hydrologist (415 323-2337, 2338, 2339, 2487).	345 Middlefield Rd.

DISTRICT OFFICES

Location	*Official in charge and telephone number*	*Address*
Alabama, Tuscaloosa 35486	William J. Powell (205 345-8221)	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 85717	Horace M. Babcock (602 792-6391, 6395).	P.O. Box 4070, 2555 East First St.
Arkansas, Little Rock 77201	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 (303 234-3815)	Bldg. 25, Federal Center.
Connecticut, Hartford 06101	John A. Baker (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 32304	Clyde S. Conover (904 377-4251)	903 West Tennessee St.
Georgia, Atlanta 30309	John R. George (404 526-3981)	Rm. 301, 900 Peachtree St., NE.
Hawaii, Honolulu 96814	Willis L. Burnham (808 546-5692, 5693, 5694, 5695).	Rm. 337, First Insurance Bldg., 1100 Ward Ave.
Idaho, Boise 83702	Hal K. Hall (208 342-2538)	P.O. Box 036, FBUSCH; Rm. 365, Federal Bldg. and U.S. Courthouse, 550 West Fort St.
Illinois, Champaign 61820	Davis W. Ellis (217 356-1137)	P.O. Box 1026; 605 North Neil St.
Indiana, Indianapolis 46202	James L. Cook (317 633-7398)	1819 North Meridian St.
Iowa, Iowa City 52240	Sulo W. Wiitala (319 338-5475)	Suite F, 1041 Arthur St.

Location	Official in charge and telephone number	Address
Kansas, Lawrence 66044	Charles W. Lane (913 864-4321)	1950 Avenue "A"—Campus West, Univ. of Kansas.
Kentucky, Louisville 40202	Robert V. Cushman (502 582-5241, 5242, 5243).	Rm. 572, Federal Bldg., 600 Federal Place.
Louisiana, Baton Rouge 70806	Albert N. Cameron (504 348-4281)	P.O. Box 66492; 6554 Florida Blvd.
Maine, Augusta 04330	Gordon S. Hayes (207 289-3484)	State House Annex, Capitol Shopping Center.
Maryland, Parkville 21234	Walter F. White, Jr. (301 661-4664)	8809 Satyr Hill Rd.
Massachusetts, Boston 02114	Charles E. Knox (617 223-2822)	10th floor, 150 Causeway St.
Michigan, Lansing 48864	Timmy R. Cummings (517 372-1561).	2400 Science Parkway, Red Cedar Research Park, Okemos.
Minnesota, St. Paul 55101	Charles R. Collier (612 725-7841, 7842).	Rm. 1033, Post Office Bldg.
Mississippi, Jackson 39206	Lamar E. Carroon (601 948-2326)	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 (402 475-3643).	Rm. 127, Nebraska Hall, 901 North 17th St.
Nevada, Carson City 89701	George F. Worts, Jr. (702 882-1388)	Rm. 229, Federal Bldg., 705 North Plaza St.
New Hampshire	Charles E. Knox (617 223-2822)	See Massachusetts District Office.
New Jersey, Trenton 08607	John E. McCall (609 599-3511, ext. 212, 213).	P.O. Box 1238; Rm. 420, Federal Bldg., 402 East State St.
New Mexico, Albuquerque 87106	William E. Hale (505 766-2246)	P.O. Box 4369; Geology Bldg., Univ. of New Mexico.
New York, Albany 12201	Robert J. Dingman (518 472-3107)	P.O. Box 948; Rm. 343, U.S. Post Office and Custom House.
North Carolina, Raleigh 27602	Ralph C. Heath (919 755-4510)	P.O. Box 2857; Rm. 440, Century Sta. Post Office Bldg.
North Dakota, Bismarck 58501	Robert C. Williams (701 255-4011, ext. 227, 228).	P.O. Box 778; Rm. 348, New Federal Bldg., 3d St. and Rosser Ave.
Ohio, Columbus 43212	John J. Molloy (614 469-5553, 5554).	975 West 3d Ave.
Oklahoma, Oklahoma City 73102	James H. Irwin (405 231-4256)	Rm. 4301, Federal Bldg. and U.S. Court House, 200 NW. 4th St.
Oregon, Portland 97208	Stanley F. Kapustka (503 234-4776, 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	Donald G. Jordan (809 783-4660, 4469, 4788).	Bldg. 652, Fort Buchanan.
Rhode Island	Charles E. Knox (617 223-2822)	See Massachusetts District Office.
South Carolina, Columbia 29204	John S. Stallings (803 765-5966)	Suite 200, 2001 Assembly St.
South Dakota, Huron 57350	John E. Powell (605 352-8293, 8294).	P.O. Box 1412; Rm. 231, Federal Bldg.
Tennessee, Nashville 37203	Harry H. Barnes, Jr. (615 749-5424)	Rm. 144, Federal Bldg.
Texas, Austin 78701	I. Dale Yost (512 397-5766)	Rm. 630, Federal Bldg., 300 East 8th St.
Utah, Salt Lake City 84111	Theodore Arnow (801 524-5663)	Rm. 8002, Federal Bldg., 125 South State St.
Vermont	Charles E. Knox (617 223-2822)	See Massachusetts District Office.
Virginia, Richmond 23220	William E. Forrest (703 782-2427)	Rm. 304, 200 West Grace St.
Washington, Tacoma 98402	Leslie B. Laird (206 383-5384)	Rm. 300, 1305 Tacoma Ave., South.
West Virginia, Charleston 25301	Edwin E. Harris (304 343-1310, 1311).	Rm. 3303, Federal Bldg. and U.S. Court House, 500 Quarrier St., East.
Wisconsin, Madison 53706	Charles L. R. Holt, Jr. (608 262-2488).	Rm. 200, 1815 University Ave.
Wyoming, Cheyenne 82001	Robert L. Cushman (307 778-2111)	P.O. Box 2087; 215 East 8th 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.
Salvador	do	U.S. Geological Survey, c/o American Consulate, USAID/USGS/Salvador, APO New York 09676.
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.

WATER RESOURCES DIVISION

Location	Officer in charge	Address
Brazil, Rio de Janeiro	Woodrow W. Evett	U.S. AID Rio/ENRN/USGS, APO New York 09676.
Ethiopia, Addis Ababa	Harold E. Gill	U.S. AID, APO New York 09319.
Kenya, Nairobi	Wolfgang V. Swarzenski	U.S. AID/Nairobi, U.S. Dept. of State Washington, DC 20521.
Nepal, Katmandu	G. Chase Tibbitts, Jr.	U.S. Geological Survey, USAID/Katmandu (ID), U.S. Dept. of State, Washington, DC 20521.
Pakistan, Lahore	Paul R. Seaber	U.S. Geolgical Survey, USAID/Lahore, U.S. Dept. of State, Washington, DC 20521.
India, Bangalore	Neal E. McClymonds	U.S. Geological Survey, USAID/Bangalore, U.S. Dept. of State, Washington, DC 20521.
New Delhi	James R. Jones	U.S. Geological Survey, USAID/New Delhi, U.S. Dept. of State, Washington, DC 20521.

INVESTIGATIONS IN PROGRESS IN THE CONSERVATION, GEOLOGIC, AND WATER RESOURCES DIVISIONS

Investigations in progress during fiscal year 1973 are listed below, together with the names and headquarters of the individuals in charge of each. Headquarters at main centers are indicated by (W) for Washington, D.C., (D) for Denver, Colo., and (M) for Menlo Park, Calif.; headquarters in other cities are indicated by name (see list of offices, p. 316, for addresses). Inquiries regarding projects for which no address is given in the list of offices should be directed to the appropriate Division of the Geological Survey, Washington, D.C., 20242. The lowercase letter after the name of the project leader shows the Division technical responsibility: c, Conservation Division; w, Water Resources Division; no letter, Geologic Division.

The projects are classified by principal topic. Most geologic-mapping projects involve special studies of stratigraphy, petrology, geologic structure, or mineral deposits, but are listed only under "Geologic Mapping" unless a special topic or commodity is the primary justification for the project. A reader interested in investigations of volcanology, for example, should look under the heading "Geologic Mapping" for projects in areas of volcanic rocks, as well as under the heading "Volcanology." Likewise, most water-resources investigations involve special studies of several aspects of hydrology and geology, but are listed only under "Water Resources" unless a special topic—such as floods or sedimentation—is the primary justification for the project.

Areal geologic mapping is subdivided into mapping at scales smaller than 1 inch to 1 mile (for example, 1:250,000), and mapping at scales of 1 inch to 1 mile, or larger (for example, 1:62,500; 1:24,000).

Abstracts. *See* Bibliographies and abstracts.
Aluminum:
  Resources of the United States (S. A. Patterson, Beltsville, Md.)
Analytical chemistry:
  Activation analysis (J. J. Rowe, W)
  Analytical methods—water chemistry (M. W. Skougstad, w, D)
  Analytical services and research (J. I. Dinnin, W; C. Huffman, Jr., D; C. O. Ingamells, M)
  Hydrologic applications:
    Identification and behavior of organic materials in water (M. C. Goldberg, w, D)
    Organic geochemistry (R. L. Malcolm, w, D)
  Instrumentation (J. F. Abell, W)
  Mineral deposits, characteristic analysis (J. M. Botbol, D)
  Natural organic, macromolecules in water (R. L. Wershaw, w, D)
  Organic geochemistry and infrared analysis (I. A. Breger, W)
  Organic substances in water (D. F. Goerlitz, w, M)
  Plant laboratory support (J. J. Connor, D)
  Puerto Rico laboratory, training and technical aid (A. P. Marranzino, D)
  Radioactivation and radiochemistry (H. T. Millard, D)
  Radiometric methods of analysis (L. L. Thatcher, w, D)
  Rock chemical analysis:
    General (L. C. Peck, D)
    Rapid (L. Shapiro, W)
  Sample control (H. Bastron, M)
  Services (J. L. Ramisch, W; L. B. Riley, D)
  Spectrochemistry (E. L. Mosier, D)
  Trace analysis methods, research (F. N. Ward, D)
  Ultratrace analysis (H. T. Millard, D)
  Water analysis, quality control (E. Brown, w, D) *See also* Spectroscopy.
  X-ray spectrometer for Viking lander (P. Toulmin, III, W)
Arctic engineering geology (R. Kachadoorian, M)
Artificial recharge:
  Artificial recharge of fractured carbonate rocks (H. O. Reeder, w, St. Paul, Minn.)

Artificial recharge—Continued
  States:
  Florida:
    Floridan aquifer, Peace-Alafia (R. W. Coble, w, Tampa)
    Floridan aquifer, west-central area (W. C. Sinclair, w, Tampa)
    Injection of wastes in deep wells (C. W. Pascale, w, Ocala)
    Subsurface waste storage, Pinellas County (R. N. Cherry, w, Tampa)
    Subsurface waste storage, statewide (M. I. Kaufman, w, Tallahassee)
  Kansas, artificial recharge in western Kansas (J. B. Gillespie, w, Lawrence)
  New York:
    Prediction of movement in zone of aeration, Long Island (R. C. Prill, w, Mineola)
    Treated sewage through an injection well, Bay Park, Long Island (J. Vecchioli, w, Mineola)
Barite: Geology, geochemistry, and resources of barite (D. A. Brobst, D)
Base metals. *See base-metal names.*
Bibliographies and abstracts:
  Geophysical abstracts (J. W. Clarke, W)
  Lunar bibliography (J. H. Freeberg, M)
  Vanadium, geology and resources, bibliography (J. P. Ohl, D)
  Water-resources selected abstracts, bibliography, index, input to Water Resources Scientific Information Center (J. W. Lang, w, W)
  States:
  Indiana:
    Water resources bibliography (M. J. Wilson, w, Indianapolis)
  Kansas:
    Report processing (H. E. McGovern, w, Lawrence)
Borates:
  California:
    Furnace Creek area (J. F. McAllister, M)
    Searles Lake area (G. I. Smith, M)
Chromite. *See* Ferro-alloy metals.

Clays:
- Appalachia, northern part (J. W. Hosterman, Beltsville, Md.)
- *State:*
- Georgia, kaolin investigations (S. H. Patterson, Beltsville, Md.)

Coal:
- Resources of the United States (P. Averitt, D)
- *States:*
- Alaska:
  - Bering River coal field (A. A. Wanek, c, Anchorage)
  - Cape Beaufort-Corwin Bluff coal field (A. A. Wanek, c, Anchorage)
  - Kukpowruk River coal field (A. A. Wanek, c, Anchorage)
  - Nenana (C. Wahrhaftig, M)
- Arizona:
  - Cummings Mesa quadrangle (F. Peterson, c, D)
  - Gunsight Butte SW quadrangle (F. Peterson, c, D)
- Colorado:
  - Buckhorn Lakes quadrangle (R. G. Dickinson, c, D)
  - Citadel Plateau (G. A. Izett, c, D)
  - Courthouse Mountain quadrangle (R. G. Dickinson, c, D)
  - Denver basin, Tertiary coal zone (P. E. Soister, c, D)
  - Disappointment Valley, eastern (D. E. Ward, D)
  - Kremmling quadrangle (G. A. Izett, c, D)
  - Middle Park–North Park area (G. A. Izett, c, D)
  - Rangely NE quadrangle (H. L. Cullins, c, Metairie, La.)
  - Savery quadrangle (C. S. V. Barclay, c, D)
  - Smizer Gulch and Rough Gulch quadrangles (W. J. Hail, D)
  - Strasburg NW and SW quadrangles (P. E. Soister, c, D)
  - Washboard Rock quadrangle (R. G. Dickinson, c, D)
  - Watkins and Watkins SE quadrangles (P. E. Soister, c, D)
- Montana:
  - 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 (G. L. Galyardt, c, Casper, Wyo.)
  - Ranchester quadrangle (B. E. Barnum, c, D)
  - 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.)
  - Dengate quadrangle (C. S. V. Barclay, c, D)
  - Glen Ullin quadrangle (C. S. V. Barclay, c, D)
  - Heart Butte and Heart Butte NW quadrangles (E. V. Stephens, c, M)
  - New Salem quadrangle (H. L. Smith, c, D)
  - North Almont quadrangle (H. L. Smith, c, D)
  - White Butte 15-minute quadrangle (K. S. Soward, c, Casper, Wyo.)
- Pennsylvania:
  - Claysville-Avella area (S. P. Schweinfurth, W)
  - Greater Pittsburgh region:
    - Deep mine distribution (S. Cortis, Carnegie)
    - Overburden, Pittsburgh coal bed (J. Craft, Carnegie)
  - Northern anthracite field (M. J. Bergin, W)
  - Southern anthracite field (G. H. Wood, Jr., W)
  - Western Middle anthracite field (H. Arndt, D)

Coal–Continued
- Utah:
  - Basin Canyon quadrangle (F. Peterson, c, D)
  - Big Hollow Wash quadrangle (F. Peterson, c, D)
  - Blackburn Canyon quadrangle (F. Peterson, c, D)
  - Butler Valley quadrangle (W. E. Bowers, c, D)
  - Canaan Creek quadrangle (H. D. Zeller, c, D)
  - Canaan Peak quadrangle (W. E. Bowers, c, D)
  - Carcass Canyon quadrangle (H. D. Zeller, c, D)
  - Collet Top quadrangle (H. D. Zeller, c, D)
  - Cummings Mesa quadrangle (F. Peterson, c, D)
  - Dave Canyon quadrangle (H. D. Zeller, c, D)
  - Death Ridge quadrangle (H. D. Zeller, c, D)
  - East-of-the-Navajo quadrangle (F. Peterson, c, D)
  - Fourmile Bench quadrangle (W. E. Bowers, c, D)
  - Griffin Point quadrangle (W. E. Bowers, c, D)
  - Gunsight Butte SW quadrangle (F. Peterson, c, D)
  - Henrieville quadrangle (W. E. Bowers, c, D)
  - Horse Mountain quadrangle (W. E. Bowers, c, D)
  - Jessen Butte quadrangle (E. M. Schell, c, Casper, Wyo.)
  - Needle Eye Point quadrangle (H. D. Zeller, c, D)
  - Pete's Cove quadrangle (H. D. Zeller, c, D)
  - Pine Lake quadrangle (W. E. Bowers, c, D)
  - Seep Flat quadrangle (E. V. Stephens, c, D)
  - Ship Mountain Point quadrangle (H. D. Zeller, c, D)
  - Sooner Bench quadrangle (F. Peterson, c, D)
  - Sunset Flat quadrangle (F. Peterson, c, D)
  - Upper Valley quadrangle (W. E. Bowers, c, D)
  - Wide Hollow Reservoir (E. V. Stephens, c, M)
- Virginia, Pocahontas coal beds (K. J. Englund, W)
- West Virginia:
  - Beckwith-Fayetteville area (B. H. Kent, D)
  - Duty quadrangle (C. R. Meissner, Jr., W)
- Wyoming:
  - Alpine quadrangle (H. F. Albee, c, Salt Lake City, Utah)
  - Bailey Lake quadrangle (M. L. Schroeder, c, D)
  - Bodgen Creek area (W. J. Mapel, D)
  - Browns Hill quadrangle (C. S. V. Barclay, c, D)
  - Bull Creek quadrangle (M. L. Schroeder, c, D)
  - Cache Creek quadrangle (D. A. Jobin, c, D)
  - Cottonwood Rim quadrangle (C. S. V. Barclay, c, D)
  - Creston Junction quadrangle (R. B. Sanders, c, D)
  - Deer Creek quadrangle (D. A. Jobin, c, D)
  - Ferry Peak quadrangle (D. A. Jobin, c, D)
  - Gillette area geology (P. T. Hayes, D)
  - Gillette Coal Field (W. L. Rohrer, c, Casper)
  - Grieve Reservoir quadrangle (C. S. V. Barclay, c, D)
  - Hoback Peak quadrangle (D. A. Jobin, c, D)
  - Ketchum Buttes quadrangle (C. S. V. Barclay, c, D)
  - Monarch quadrangle (B. E. Barnum, c, D)
  - Observation Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)
  - Oil Mountain quadrangle (W. H. Laraway, c, Casper)
  - Pickle Pass quadrangle (D. A. Jobin, c, D)
  - Poison Spider quadrangle (W. H. Laraway, c, Casper)
  - Ranchester quadrangle (B. E. Barnum, c, D)
  - Reid Canyon (W. H. Laraway, c, Casper)
  - Riner quadrangle (R. B. Sanders, c, D)
  - Savery quadrangle (C. S. V. Barclay, c, D)
  - Sheridan Pass quadrangle (W. L. Rohrer, c, D)
  - Ship Mountain Point quadrangle (H. D. Zeller, c, D)
  - Square Top Butte quadrangle (W. H. Laraway, c, Casper)
  - Stewart Peak quadrangle (D. A. Jobin, c, D)
  - Tullis quadrangle (C. S. V. Barclay, c, D)

Engineering geologic studies. *See* Construction and terrain problems; Urban geology.
Environmental geology:
Colorado, mountain soils of the Front Range urban corridor (K. L. Pierce, D)
Pennsylvania, Greater Pittsburgh regional studies (R. P. Briggs, Carnegie)
See also Construction and terrain problems; Urban geology
Evaporation:
Evaporation from lakes and reservoirs (A. M. Sturrock, Jr. w, D)
North Carolina, Hyco Lake, evaporation and thermal loading analysis (W. L. Yonts, w, Raleigh)
See also Hydrologic instrumentation.
Evaporation suppression, Mechanics of evaporation suppression and evaporation (G. E. Koberg, w, D)
Evapotranspiration:
Collection of data on evapotranspiration and variables controlling it (T. E. A. van Hylckama, w, Lubbock, Tex.)
States:
Arizona:
Phreatophyte project, Gila River (R. C. Culler, w, Tucson)
Study of effects of vegetation manipulation on surface runoff, Sycamore Creek (H. W. Hjalmarson, w, Phoenix)
California, root-zone conditions and plant-physiological processes as factors in phreatophyte evapotranspiration (O. M. Grosz, w, M)
Extraterrestrial studies:
Lunar and planetary analog studies:
Deep seated inclusions (H. G. Wilshire, M)
Explosion craters (D. J. Roddy, Flagstaff, Ariz.)
Impact metamorphism (E. C. T. Chao, W)
Peruvian coastal desert (E. C. Morris, Flagstaff, Ariz.)
Lunar data synthesis:
Apollo 15-17 photogeology (H. J. Moore, M)
Apollo 17 electromagnetic sounder (R. E. Eggleton, Flagstaff, Ariz.)
Apollo orbital science data (H. Masursky, Flagstaff, Ariz.)
Lunar metric studies (S. Wu, Flagstaff, Ariz.)
Lunar morphologic studies (R. J. Pike, Jr., M)
Lunar field geology:
Apollo 11-15 (G. A. Swann, Flagstaff, Ariz.)
Apollo 16, 17 (W. A. Muehlberger, Austin, Tex.)
Lunar mapping:
Far side, center (D. E. Stuart-Alexander, M)
Far side, east limb (D. E. Wilhelms, M)
Far side, west limb (D. H. Scott, Flagstaff, Ariz.)
Large scale science sites (M. N. West, Flagstaff, Ariz.)
North Pole (B. Lucchitta, Flagstaff, Ariz.)
Selected revisions (J. F. McCauley, Flagstaff, Ariz.)
South Pole (K. A. Howard, M)
Volcanic provinces (L. A. Soderblom, Flagstaff, Ariz.)
Lunar sample investigations:
Chemical and X-ray fluorescence analysis (H. J. Rose, Jr., W)
Feldspars (D. E. Appleman, W)
Glass, magnetic properties (F. E. Sentfle, W)
Impact metamorphism (E. C. T. Chao, W)
Isotopic composition of uranium, thorium, and protactinium (J. N. Rosholt, D)
Mass spectrometry (M. Tatsumoto, D)
Oxygen fugacities and crystallization sequence (M. Sato, W)
Petrographic identification (H. G. Wilshire, M)
Petrographic, mineralogic, and size-frequency analysis (G. A. Sellers, W)
Petrologic studies (E. Roedder, W)
Pyroxenes (M. Ross, W)

Extraterrestrial studies—Continued
Lunar sample investigations—Continued
Specific heats (R. A. Robie, W)
Water contents, deuterium, C^{13} and O^{18} analysis (I. Friedman, D)
Planetary investigations:
Geochemical requirements and instrumentation (F. Cuttitta, W)
Geologic mapping of Mars (D. H. Scott, J. F. McCauley, Flagstaff, Ariz.)
Image processing studies (L. A. Soderblom, Flagstaff, Ariz.)
Mariner Jupiter-Saturn (L. A. Soderblom, Flagstaff, Ariz.)
Mariner Mars 1971 TV (H. Masursky, Flagstaff, Ariz.)
Mariner Venus-Mercury TV (N. J. Trask, W)
Mars cartography (R. M. Batson, Flagstaff, Ariz.)
Mars mineralogy and chemistry—Viking lander (P. Toulmin, III, W)
Mars topographic synthesis (S. S. C. Wu, Flagstaff, Ariz.)
Planetary remote sensing (L. C. Rowan, W)
Radar applications (G. G. Schaber, Flagstaff, Ariz.)
Viking lander (E. C. Morris, Flagstaff, Ariz.)
Viking orbiter TV (M. H. Carr, M)
Viking—physical properties of Mars (H. J. Moore, M)
Viking site analysis (H. Masursky, Flagstaff, Ariz.)

Ferro-alloy metals:
Chromium resource studies (T. P. Thayer, W)
Manganese, zoning in epithermal deposits (R. G. Worl, D)
Molybdenum, Maine and New Hampshire, with porphyry copper (R. G. Schmidt, W)
Molybdenum-rhenium resource studies (R. U. King, D)
Tungsten, North Carolina, Hamme district (J. E. Gair, W)
Tungsten resources of the United States (J. E. Elliott, D)
States:
Montana, chromite resources and petrology, Stillwater complex (E. D. Jackson, M)
Oregon, John Day area (T. P. Thayer, W)

Flood characteristics of streams at selected sites:
Alabama, flood studies and bridge-site investigations (C. O. Ming, w, Montgomery)
Alaska, flood insurance studies (R. D. Lamke, w, Anchorage)
Florida, bridge-site investigations statewide (W. C. Bridges, w, Tallahassee)
Iowa, flood information at selected bridge sites (O. G. Lara, w, Iowa City)
Kentucky, bridge-site investigations (C. H. Hannum, w, Louisville)
Mississippi, bridge-site flood investigations (C. H. Tate, w, Jackson)
Montana, bridge-site investigations (M. V. Johnson, w, Helena)
New Mexico, peak flood-flow characteristics of small streams (A. G. Scott, w, Santa Fe)
North Dakota (O. A. Crosby, w, Bismarck)
Ohio (R. I. Mayo, w, Columbus)
Oregon, flood profiles, Umpqua River and tributaries (D. D. Harris, w, Portland)
South Carolina (B. H. Whetstone, w, Columbia)
Tennessee (W. J. Randolph, w, Nashville)
West Virginia (P. M. Frye, w, Charleston)
Wyoming, flood studies and bridge-site investigations (S. A. Druse and D. J. O'Connell, w, Cheyenne)

Flood discharge from small drainage areas:
Colorado (G. L. Ducret, Jr., w, D)
Connecticut (M. D. Thomas, w, Hartford)
Delaware (R. H. Simmons, w, Dover)
Florida (W. C. Bridges, w, Tallahassee)
Georgia (C. M. Bunch, w, Atlanta)
Idaho (C. A. Thomas, w, Boise)

Flood discharge from small drainage areas—Continued
Illinois (J. W. Curtis, w, Champaign)
Iowa (O. G. Lara, w, Iowa City)
Maine (R. A. Morrill, w, Augusta)
Maryland (D. H. Carpenter, w, College Park)
Massachusetts (C. G. Johnson, Jr., w, Boston)
Minnesota (L. C. Guetzkow, w, St. Paul)
Mississippi (J. W. Hudson, w, Jackson)
Montana (M. V. Johnson, w, Helena)
North Dakota (O. A. Crosby, w, Bismarck)
Ohio (E. E. Webber, w, Columbus)
Rhode Island (C. G. Johnson, Jr., w, Boston, Mass.)
South Carolina (B. H. Whetstone, w, Columbia)
South Dakota (L. D. Becker, w, Huron)
Vermont (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)
Colorado, Denver metropolitan area (G. L. Ducret, Jr., w, D)
Iowa (O. G. Lara, w, Iowa City)
Kentucky, magnitude and frequency (C. H. Hannum, w, Louisville)
Louisiana:
Flood frequency of small areas (L. A. Martens, w, Baton Rouge)
Hydrology and hydraulics for highways (B. L. Neely, w, Baton Rouge)
New Jersey, magnitude and frequency and effect of basin characteristics (S. J. Stankowski, w, Trenton)
North Carolina, flood frequency and high-flow studies (N. M. Jackson, Jr., w, Raleigh)
Tennessee, magnitude and frequency of floods on small streams (H. C. Wibben, w, Nashville)
Utah, magnitude and flood frequency (F. K. Fields, w, Salt Lake City)
Wisconsin, magnitude and frequency (D. H. Conger, w, Madison)
Flood hazard mapping:
United States (E. J. Kennedy, w, W)
Arkansas (M. S. Hines, w, Little Rock)
Connecticut (F. H. Ruggles, w, Hartford)
Hawaii (R. H. Nakahara, w, Honolulu)
Indiana (R. E. Hoggatt, w, Indianapolis)
Iowa (O. G. Lara, w, Iowa City)
Maine (R. A. Morrill, w, Augusta)
Maryland (W. B. Solley, w, Parkville)
Michigan (P. C. Bent, w, Okemos)
Missouri (E. E. Gann, w, Rolla)
Montana (M. V. Johnson, w, Helena)
Nebraska (F. B. Shaffer, w, Lincoln)
New Jersey (R. E. Gatton, Jr., w, Trenton)
New York (B. Dunn, w, Albany)
Ohio (D. K. Roth, w, Columbus)
Pennsylvania (L. V. Page, w, Harrisburg)
Utah (R. W. Cruff, w, Salt Lake City)
Virginia (E. M. Miller, w, Richmond)
Washington (E. G. Nassar, w, Tacoma)
West Virginia (G. S. Runner, w, Charleston)
Wisconsin (W. B. Gannon, w, Madison)
Flood insurance studies:
Alabama (J. R. Harkins, w, Tuscaloosa)
Alaska (R. D. Lamke, w, Anchorage)
Arizona (B. N. Aldridge, w, Tucson)
Colorado (R. U. Grozier, w, D)
Connecticut (M. A. Cervione, w, Hartford)
Florida (R. B. Stone, w, Tallahassee)
Hawaii (C. J. Ewart, w, Honolulu)

Flood insurance studies—Continued
Illinois (R. T. Mycyk, w, Oak Park)
Indiana (P. B. Rohne, Jr., w, Indianapolis)
Minnesota (L. C. Guetzkow, w, St. Paul)
Missouri (E. E. Gann, w, Rolla)
New Jersey (R. E. Gatton, w, Trenton)
Oregon (D. D. Harris, w, Portland)
Texas (J. D. Bohn, w, Austin)
Vermont (C. G. Johnson, w, Boston, Mass.)
Wisconsin (W. B. Gannon, w, Madison)
Flood-inundation mapping:
Alabama, Jefferson County floodway evaluation (J. R. Harkins, w, Tuscaloosa)
Arizona, flood-plain mapping (B. N. Aldridge, w, Tucson)
Georgia (M. Price, w, Atlanta)
Idaho (W. A. Harenberg, w, Boise)
Illinois, northeastern (A. W. Noehre, w, Oak Park)
Kentucky (C. H. Hannum, w, Louisville)
Minnesota, flood-plain mapping (L. C. Guetzkow, w, St. Paul)
Missouri:
Hydrology of streams, St. Louis County (T. W. Alexander, w, St. Louis)
Metropolitan St. Louis Sewer District (D. W. Spencer, w, St. Louis)
Puerto Rico (W. J. Haire, w, San Juan)
Urban flood inundation, Rio Piedras basin (V. J. Latkovich, w, San Juan)
South Dakota (O. J. Larimer, w, Huron)
Wisconsin, flood inundation study (C. L. Lawrence, w, Madison)
Flood investigations:
United States (D. M. Thomas, w, W)
States:
Arizona, flood hydrology (B. N. Aldridge, w, Tucson)
Arkansas (M. S. Hines, w, Little Rock)
California, flood-plain mapping (A. O. Waananen, w, M)
Florida:
Flood investigations, Alafia basin (L. H. Motz, w, Tampa)
Flood investigations, Marion County (W. Anderson, w, Ocala)
Georgia, Atlanta, flood characteristics (H. G. Golden, w, Atlanta)
Hawaii, flood gaging (R. Nakahara, w, Honolulu)
Illinois, flood-depth frequency (J. D. Camp, w, Champaign)
Indiana, flood frequency (L. G. Davis, w, Indianapolis)
Iowa:
Flood profiles, Dry Run Creek (O. G. Lara, w, Iowa City)
Flood profiles, statewide (O. G. Lara, w, Iowa City)
Flood profiles and flood-plain information, Cedar Rapids (O. G. Lara, w, Iowa City)
Flood profiles and flood-plain information, Linn County (O. G. Lara, w, Iowa City)
Kansas, statewide (H. R. Hejl, w, Lawrence)
Maryland, floods of June 1972 (K. R. Taylor, w, Parkville)
Minnesota, flood-plain studies (L. C. Guetzkow, w, St. Paul)
Nebraska, magnitude and frequency of floods (E. W. Beckman, w, Lincoln)
New York:
Floods of June 1972 (K. I. Darmer, w, Albany)
Peak discharge of ungaged streams (B. Dunn, w, Albany)
Oklahoma, statewide flood-frequency report (V. B. Sauer, w, Oklahoma City)
Pennsylvania, floods of June 1972 (L. V. Page, w, Harrisburg)
South Dakota, Rapid City area floods, June 1972 (O. J. Larimer, w, Huron)
Tennessee, Nashville-Davidson County metropolitan area (L. G. Conn, w, Nashville)

Geologic mapping—Continued

Map scale smaller than 1 inch to 1 mile—Continued

States—Continued

Colorado:

Denver 2-degree quadrangle (B. Bryant, D)
Geologic map (O. L. Tweto, D)
Leadville 2-degree quadrangle (O. L. Tweto, D)
Montrose 2-degree quadrangle (W. J. Hail, Jr., D)
Oil-shale investigations (D. C. Duncan, W)
Pueblo 2-degree quadrangle (G. R. Scott, D)
Sterling 2-degree quadrangle (J. A. Sharps, D)

Idaho:

Challis Volcanics (D. H. McIntyre, D)
Dubois 2-degree quadrangle (D. L. Schleicher, D)
Idaho Falls 2-degree quadrangle (D. L. Schleicher, D)
Preston 2-degree quadrangle (S. S. Oriel, D)
Snake River plain, central part, volcanic petrology (H. E. Malde, D)
Snake River plain region, eastern part (S. S. Oriel, D)
Spokane-Wallace region (A. B. Griggs, M)

Montana:

Butte 2-degree quadrangle (M. R. Klepper, W)
Spokane-Wallace region (A. B. Griggs, M)

Nevada:

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:

Socorro 2-degree quadrangle (G. O. Bachman, D)
West half of Santa Fe 2-degree quadrangle (R. B. Johnson, D)

North Carolina, Winston-Salem 2-degree quadrangle (D. W. Rankin, G. H. Espenshade, W)

Oregon (G. W. Walker, M)

Pennsylvania, Greater Pittsburgh region geology (W. R. Wagner, Carnegie)

Tennessee, Winston-Salem 2-degree quadrangle (D. W. Rankin, G. H. Espenshade, W)

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)

Virginia, Winston-Salem 2-degree quadrangle (D. W. Rankin, G. H. Espenshade, W)

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 inch to 1 mile, and larger:

States and territories:

Alaska:

Anchorage area (E. Dobrovolny, D)
Bering River coal field (A. A. Wanek, c, Anchorage)
Cape Beaufort-Corwin Bluffs coal field (A. A. Wanek, c, Anchorage)
Juneau area (R. D. Miller, D)
Kukpowruk River coal field (A. A. Wanek, c, Anchorage)
Nelchina area Mesozoic investigations (A. Grantz, M)
Nenana coal investigations (C. Wahrhaftig, M)
Nome area (C. L. Hummel, M)

Arizona:

Bowie zeolite area (L. H. Godwin, c, Carlsbad, N. Mex.)
Cochise County, southern part (P. T. Hayes, D)
Cummings Mesa quadrangle (F. Peterson, c, D)

Geologic mapping—Continued

Map scale 1 inch to 1 mile, and larger—Continued

Arizona—Continued

Garnet Mountain quadrangle (P. M. Blacet, M)
Gunsight Butte SW quadrangle (F. Peterson, c, D)
Mt. Wrightson quadrangle (H. Drewes, D)
Ray district, porphyry copper (H. R. Cornwall, M)

California:

Big Maria Mountains (W. B. Hamilton, D)
Bucks Lake quadrangle (A. Hietanen-Makela, M)
Clear Lake-Geysers area (B. C. Hearn, Jr., W)
Coast Range, ultramafic rocks (E. H. Bailey, M)
Condrey Mountain-Hornbrook quadrangle (P. E. Hotz, M)
Klamath Mountains, southern part (W. P. Irwin, M)
Malibu Beach and Topanga quadrangles (R. F. Yerkes, M)
Merced Peak quadrangle (D. L. Peck, W)
Palo Alto, San Mateo, and Montara Mountain quadrangles (E. H. Pampeyan, M)
Point Dume and Triunfo Pass quadrangles (R. H. Campbell, M)
Ryan quadrangle (J. F. McAllister, M)
Sacramento Valley, northwest part (R. D. Brown, Jr., M)
Searles Lake area (G. I. Smith, M)
Sierra Nevada batholith (P. C. Bateman, M)

Colorado:

Aspen 15-minute quadrangle (B. Bryant, D)
Barcus Creek quadrangle (W. J. Hail, D)
Barcus Creek SE quadrangle (W. J. Hail, D)
Bonanza quadrangle (R. E. Van Alstine, W)
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)
Kremmling quadrangle (G. A. Izett, c, 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)
Platoro caldera and related volcanic rocks, southeastern San Juan Mountains (P. W. Lipman, D)
Poncha Springs quadrangle (R. E. Van Alstine, W)
Rangely NE quadrangle (H. L. Cullins, c, Metairie, La)
Rough Gulch quadrangle (W. J. Hail, D)
San Juan mining area (R. G. Luedke, W)
Savery quadrangle (C. S. V. Barclay, c, D)
Smizer Gulch quadrangle (W. J. Hail, D)
Squaw Pass and Evergreen quadrangles (D. M. Sheridan, D)
Strasburg NW and SW quadrangles (P. E. Soister, c, D)
Ward and Gold Hill quadrangles (D. J. Gable, D)
Washboard Rock quadrangle (R. G. Dickinson, c, D)
Watkins and Watkins SE quadrangles (P. E. Soister, c, D)

Connecticut:

Cooperative mapping program (L. R. Page, Boston, Mass.)
Taconic sequence (E-an Zen, W)

Florida, Attapulgus-Thomasville area, fuller's earth deposits (S. H. Patterson, Beltsville, Md.)

Geologic mapping—Continued

Map scale 1 inch to 1 mile, and larger—Continued

Idaho:

Alpine quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Bayhorse area (S. W. Hobbs, D)
Boulder Mountains (C. M. Tschanz, D)
Goat Mountain quadrangle (M. H. Staatz, D)
Grouse quadrangle (B. A. Skipp, D)
Hawley Mountain quadrangle (W. J. Mapel, D)
Henrys Lake area (I. J. Witkind, D)
Malad southeast quadrangle (S. S. Oriel, D)
Montour quadrangle (H. E. Malde, D)
Mt. Spokane quadrangle (A. E. Weissenborn, Spokane, Wash.)
Palisades Dam quadrangle (D. A. Jobin, c, D)
Patterson quadrangle (E. T. Ruppel, D)
Poker Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Upper and Lower Red Rock Lakes quadrangles (I. J. Witkind, D)
Washington Peak quadrangle (D. A. Seeland, D)
Wood River district (W. E. Hall, M)
Yandell Springs quadrangle (D. E. Trimble, D)
Yellow Pine quadrangle (B. F. Leonard, D)

Indiana:

Ohio River Quaternary (M. P. Weiss, DeKalb, Ill.)
Ohio River valley, Quaternary geology (L. L. Ray, W)

Kentucky, cooperative mapping program (D. W. Olive, Lexington)

Maine:

Blue Hill quadrangle (D. B. Stewart, W)
Castine quadrangle (D. B. Stewart, W)
Chain Lakes area (E. L. Boudette, Hanover, N.H.)
Orland quadrangle (D. R. Wones, W)
Rumford quadrangle (R. H. Moench, D)
The Forks quadrangle (F. C. Canney, D)

Maryland, Delmarva Peninsula (J. P. Owens, Beltsville)

Massachusetts:

Boston and vicinity (C. A. Kaye, Boston)
Cooperative mapping program (L. R. Page, Boston)
Taconic sequence (E-an Zen, W)

Michigan:

Gogebic Range, eastern (V. A. Trent, W)
Gogebic Range, western part (R. G. Schmidt, W)
Isle Royale National Park (N. K. Huber, M)
Wakefield quadrangle (W. C. Prinz, W)
Western Negaunee quadrangle (G. C. Simmons, D)

Montana:

Absaroka volcanic field (H. W. Smedes, H. J. Prostka, D)
Bearpaw Mountains, petrology (B. C. Hearn, Jr., W)
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, W)
Crazy Mountains Basin (B. A. Skipp, D)
Decker quadrangle (B. E. Law, c, Casper, Wyo.)
Diamond City No. 3 quadrangle (W. B. Myers, D)
Diatremes, Missouri River Breaks (B. C. Hearn, Jr., W)
Elk Park quadrangle (H. W. Smedes, D)
Hardy quadrangle (K. S. Soward, c, Casper, Wyo.)
Henrys Lake area (I. J. Witkind, D)
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, W)
Pearl School quadrangle (G. L. Galyardt, c, Casper, Wyo.)
Ranchester quadrangle (B. E. Barnum, c, D)

Geologic mapping—Continued

Map scale 1 inch to 1 mile, and larger—Continued

Montana—Continued

Rocky Reef quadrangle (K. S. Soward, c, Casper, Wyo.)
Wickiup Creek quadrangle (H. W. Smedes, D)
Wolf Creek area, petrology (R. G. Schmidt, W)

Nevada:

Austin quadrangle (E. H. McKee, M)
Bellevue Peak quadrangle (T. B. Nolan, W)
Carlin region (J. F. Smith, Jr., D)
Jordan Meadow and Disaster Peak quadrangles (R. C. Greene, M)
Kobeh Valley (T. B. Nolan, W; C. W. Merriam, M)
Lida Wash quadrangle (K. B. Krauskopf, M)
Midas-Jarbidge area (R. R. Coats, M)
Pinto Summit quadrangle (T. B. Nolan, W)
Spruce Mountain 4 quadrangle (G. D. Fraser, c, D)

New Hampshire:

Cooperative mapping program, surficial (C. Koteff, Boston, Mass.)
Milford 15-minute quadrangle, surficial (C. Koteff, Boston, Mass.)

New Jersey, Delaware River basin, lower part (J. P. Owens, Beltsville, Md.)

New Mexico:

Acoma area (C. H. Maxwell, D)
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, W)

New York:

Pope Mills and Richville quadrangles (C. E. Brown, W)
Taconic sequence (E-an Zen, W)

North Carolina:

Central Piedmont (A. A. Stromquist, D)
Northern slate belt, North Carolina-Virginia (V. M. Seiders, Beltsville, Md.)

North Dakota:

Clark Butte 15-minute quadrangle (G. D. Mowat, c, Billings, Mont.)
Dengate quadrangle (C. S. V. Barclay, c, D)
Glen Ullin quadrangle (C. S. V. Barclay, c, D)
Heart Butte and Heart Butte NW quadrangles (E. V. Stephens, c, M)
New Salem quadrangle (H. L. Smith, c, D)
North Almont quadrangle (H. L. Smith, c, D)
White Butte 15-minute quadrangle (K. S. Soward, c, Casper, Wyo.)

Pennsylvania:

Allentown 15-minute quadrangle (A. A. Drake, Jr., W)
Claysville-Avella area (S. P. Schweinfurth, W)
Northern anthracite field (M. J. Bergin, W)
Southern anthracite field (G. H. Wood, Jr., W)
Western Middle anthracite field (H. Arndt, W)
Wind Gap and adjacent quadrangles (J. B. Epstein, Beltsville, Md.)

Puerto Rico (J. M. Aaron, San Juan)

Geologic mapping—Continued
Map scale 1 inch to 1 mile, and larger—Continued
South Dakota:
Black Hills Precambrian (J. A. Redden, Hill City)
Keystone Pegmatite area (J. J. Norton, W)
Northern Black Hills (R. W. Bayley, M)
Rapid City area (J. M. Cattermole, D)
Tennessee, Midway belt, western part of State (W. S. Parks, w, Nashville)
Texas: Coastal plain, geophysical and geological studies (D. H. Eargle, Austin)
Tilden-Loma Alta area (K. A. Dickinson, D)
Utah:
Basin Canyon quadrangle (F. Peterson, c, D)
Big Hollow Wash quadrangle (F. Peterson, c, D)
Blackburn Canyon quadrangle (F. Peterson, c, D)
Butler Valley quadrangle (W. E. Bowers, c, D)
Canaan Creek quadrangle (H. D. Zeller, c, D)
Canaan Peak quadrangle (W. E. Bowers, c, D)
Carcass Canyon quadrangle (H. D. Zeller, c, D)
Coal-mine bumps, 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)
Cummings Mesa NE and SE quadrangles (F. Peterson, c, D)
Dave Canyon quadrangle (H. D. Zeller, c, D)
Death Ridge quadrangle (H. D. Zeller, c, D)
East-of-the-Navajo quadrangle (F. Peterson, c, D)
Fourmile Bench quadrangle (W. E. Bowers, c, D)
Griffin Point quadrangle (W. E. Bowers, c, D)
Gunsight Butte SW ¼ quadrangle (F. Peterson, c, D)
Henrieville quadrangle (W. E. Bowers, c, D)
Horse Mountain quadrangle (W. E. Bowers, c, D)
Iron Springs district (P. D. Rowley, 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)
Pine Lake quadrangle (W. E. Bowers, c, D)
Raft River Mountains (R. R. Compton, Stanford, Calif.)
Salt Lake City and vicinity (R. Van Horn, D)
San Francisco district (D. M. Lemmon, M)
Seep Flat quadrangle (E. V. Stephens, c, M)
Sheeprock Mountains, West Tintic district (H. T. Morris, M)
Ship Mountain Point quadrangle (H. D. Zeller, c, D)
Skutumpah Creek-Bold Knoll quadrangles (H. D. Goode, Salt Lake City)
Sooner Bench quadrangle (F. Peterson, c, D)
Sunset Flat quadrangle (F. Peterson, c, D)
Upper Valley quadrangle (W. E. Bowers, c, D)
Vernal phosphate area (E. M. Schell, c, Casper, Wyo.)
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:
Delmarva Peninsula (J. P. Owens, Beltsville, Md.)
Northern slate belt, North Carolina-Virginia (V. M. Seiders, Beltsville, Md.)
Rapidan-Rappahannock (L. Pavlides, Beltsville, Md.)
Washington:
Chewelah No. 4 quadrangle (F. K. Miller, M)
Glacier Park area (F. W. Cater, D)
Loomis quadrangle (C. D. Rinehart, M)

Geologic mapping—Continued
Map scale 1 inch to 1 mile, and larger—Continued
Washington—Continued
Mt. St. Helens and Spirit Lake quadrangles (C. A. Hopson, Santa Barbara, Calif.)
Mt. Spokane quadrangle (A. E. Weissenborn, Spokane)
Newport 30-minute quadrangle (F. K. Miller, M)
Olympic Peninsula, eastern part (W. M. Cady, D)
Olympic Peninsula, northwestern part (P. D. Snavely, Jr., M)
Puget Sound Basin (D. R. Mullineaux, D)
Stevens County (R. G. Yates, M)
Twin Lakes quadrangle (G. E. Becraft, W)
Wisconsin:
Black River Falls and Hatfield quadrangles (H. Klemic, W)
Lead-zinc district (W. S. West, Platteville)
Wyoming:
Absaroka volcanic field (H. W. Smedes, H. J. Prostka, D)
Albany and Keystone quadrangles (M. E. McCallum, Fort Collins, Colo.)
Alkali Butte quadrangle (M. W. Reynolds, D)
Alpine quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Badwater Creek (R. E. Thaden, D)
Bailey Lake quadrangle (M. L. Schroeder, c, D)
Browns Hill quadrangle (C. S. V. Barclay, c, D)
Bull Creek quadrangle (M. L. Schroeder, c, D)
Cache Creek quadrangle (D. A. Jobin, c, D)
Camp Davis quadrangle (D. A. Jobin, c, D)
Clause Peak quadrangle (M. L. Schroeder, c, D)
Cottonwood Rim quadrangle (C. S. V. Barclay, c, D)
Crawford Mountains (W. C. Gere, c, M)
Creston Junction quadrangle (R. B. Sanders, c, D)
Deer Creek quadrangle (D. A. Jobin, c, D)
Devils Tooth quadrangle (W. G. Pierce, M)
Ferry Peak quadrangle (D. A. Jobin, c, D)
Gas Hills uranium district (F. C. Armstrong, Spokane, Wash.)
Gillette Coal Field (W. L. Rohrer, c, Casper)
Grieve Reservoir quadrangle (C. S. V. Barclay, c, D)
Hoback Peak quadrangle (D. A. Jobin, c, D)
Hulett Creek (C. H. Maxwell, D)
Ketchum Buttes quadrangle (C. S. V. Barclay, c, D)
Lander area phosphate reserve (W. L. Rohrer, c, Casper)
Monarch quadrangle (B. E. Barnum, c, D)
Observation Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Oil Mountain quadrangle (W. H. Laraway, c, Casper)
Pickle Pass quadrangle (D. A. Jobin, c, D)
Pine Creek quadrangle (D. A. Jobin, c, D)
Poison Spider quadrangle (W. H. Laraway, c, Casper)
Ranchester quadrangle (B. E. Barnum, c, D)
Reid Canyon quadrangle (W. H. Laraway, c, Casper)
Riner quadrangle (R. B. Sanders, c, D)
Savery quadrangle (C. S. V. Barclay, c, D)
Sheridan Pass quadrangle (W. L. Rohrer, c, Casper)
Ship Mountain Point quadrangle (H. D. Zeller, c, D)
Square Top Butte quadrangle (W. H. Laraway, c, Casper)
Stewart Peak quadrangle (D. A. Jobin, c, D)
Sweetwater County, Green River Formation (W. C. Culbertson, D)
Taylor Mountain quadrangle (M. L. Schroeder, c, D)
Tullis quadrangle (C. S. V. Barclay, c, D)
Wapiti quadrangle (W. G. Pierce, M)
Wind River Basin, regional stratigraphy (W. R. Keefer, D)
Geomorphology:
Morphology, provenance, and movement of desert sand (E. D. McKee, D)
Ohio River Quaternary (M. P. Weiss, DeKalb, Ill.)

Hydrology, ground-water–Continued
New York:
Long Island, prediction of movement in zone of aeration (R. C. Prill, w, Mineola)
South Carolina, capacity use study (A. L. Zack, w, Columbia)
Washington, Pullman (H. H. Tanaka, w, Tacoma)
Wisconsin, a study of ground-water pollution in the Niagara dolomite of Door County, Wis. (M. G. Sherrill, w, Madison)
Hydrology, surface-water:
Hydrology of estuaries (D. W. Hubbell, w, Bay St. Louis, Miss.)
Lakes and reservoirs:
Compilation of hydrologic data on lakes and reservoirs of Oregon (R. B. Sanderson, w, Portland)
California, flood hazard study (M. W. Busby, w, Garden Grove)
Florida, statewide, lake studies (G. H. Hughes, w, Tallahassee)
Missouri, small lakes (J. H. Barks, w, Rolla)
Oregon, hydrologic inventory of Malheur Lake (L. L. Hubbard, w, Portland)
Washington, lakes of Washington (G. C. Bortleson, w, Tacoma)
See also Evaporation; Limnology.
Modeling principles (J. P. Bennett, w, Bay St. Louis, Miss.)
Open channel experiments (F. A. Kilpatrick, w, Bay St. Louis, Miss.)
Hydrology, surface water
Operation models (M. E. Jennings, w, Bay St. Louis, Miss.)
Physical modeling (V. R. Schneider, w, Bay St. Louis, Miss.)
Streams:
Hawaii, Oahu, hydrology and sedimentation in Moanalua Valley (C. J. Ewart, w, Honolulu)
Illinois, Big Creek basin, effects of land-surface disposal of sewage effluent on streamflow, sedimentation, temperature, and specific conductance (C. R. Sieber, w, Champaign)
Mississippi, Pearl River boatway studies (J. K. Arthur, w, Jackson)
Missouri:
Flood studies–small areas (L. D. Hauth, w, Rolla)
Storage requirements to control flood flows (J. Skelton, w, Rolla)
Stream and spring characteristics (J. Skelton, w, Rolla)
Nevada, small drainage areas, floods (L. Harmsen, w, Carson City)
New York, influx to Lake Ontario (E. C. Rhodehamel, w, Albany)
Oregon, Alsea River basin, effects of logging on streamflow, sedimentation, and temperature (D. D. Harris, w, Portland)
Pennsylvania, Philadelphia area (R. A. Miller, w, Harrisburg)
Wisconsin, hydrologic effects of a small reservoir, Nederlo Creek basin (P. A. Kammerer, w, Madison)
States:
Arkansas, time-of-travel studies of Arkansas streams (T. E. Lamb, w, Little Rock)
California, flood hydrology Butte Basin (R. G. Simpson, w, Sacramento)
Florida, Loxahatchee River (H. G. Rodis, w, Miami)
Idaho, special studies (C. A. Thomas, w, Boise)
Kansas:
Channel geometry (E. R. Hedman, w, Lawrence)
Streamflow models (P. R. Jordan, w, Lawrence)
Ohio, time-of-travel studies of Ohio streams (A. O. Westfall, w, Columbus)
South Carolina, low flow characteristics (W. M. Bloxham, w, Columbia)

Hydrology, surface water–Continued
Texas, Trinity River time-of-travel studies (R. H. Ollman, w, Fort Worth)
Washington, low flow (M. R. Collings, w, Tacoma)
See also Evapotranspiration; Flood investigations, areal; Marine hydrology; Plant ecology; Urbanization, hydrologic effects.
Industrial minerals. *See* specific minerals.
Iron:
Resource studies, United States (H. Klemic, W)
Michigan:
Gogebic County, western part (R. G. Schmidt, W)
Gogebic Range, eastern (V. A. Trent, W)
Negaunee and Palmer quadrangles (J. E. Gair, D)
Western Negaunee quadrangle (L. D. Clark, M)
South Dakota, northern Black Hills (R. W. Bayley, M)
Wisconsin, Black River Falls (H. Klemic, W)
Isotope and nuclear studies:
Instrument development (F. J. Jurceka, D)
Isotope ratios in rocks and minerals (I. Friedman, D)
Isotopes in hydrology (C. T. Rightmire, w, Arlington, Va.)
Isotopic hydrology (F. J. Pearson, w, W)
Lead isotopes and ore deposits (R. E. Zartman, D)
Mass spectrometry and isotopic measurements (J. Stacey, D)
Nuclear irradiation (G. M. Bunker, D)
Nuclear reactor facility (C. P. Kraker, w, D)
Radioisotope dilution (L. P. Greenland, W)
Stable isotopes and ore genesis (R. O. Rye, D)
Upper mantle studies (M. Tatsumoto, D)
See also Geochronological investigations; Geochemistry, water; Radioactive-waste disposal.
Land resources analysis:
Idaho, eastern Snake River Plain region (S. S. Oriel, D)
Tennessee, Knox County (L. D. Harris, w, Knoxville)
Land subsidence, California, San Joaquin Valley (J. F. Poland, w, Sacramento)
Lead, zinc, and silver:
Lead resources of United States (C. S. Bromfield, D)
Silver resources of United States (A. V. Heyl, Jr., D)
Zinc resources of United States (H. Wedow, Jr., Knoxville, Tenn.)
Zoning, epithermal deposits (R. G. Worl, D)
States:
Arizona, Lochiel and Nogales quadrangles (F. S. Simons, D)
Colorado:
Rico district (E. T. McKnight, W)
San Juan Mountains, eastern, reconnaissance (W. N. Sharp, D)
San Juan Mountains, northwestern (F. S. Fisher, D)
Montana, Wickes district (W. B. Myers, D)
Nevada:
Comstock district (D. H. Whitebread, M)
Silver Peak Range (R. P. Ashley, M)
Utah, Park City district (C. S. Bromfield, D)
Wisconsin, lead-zinc (W. S. West, Platteville)
Limnology:
Big Bear Lake water quality (G. A. Irwin, w, M)
Interrelations of aquatic ecology and water quality (K. V. Slack, w, M)
Microbial ecology of ground water (G. G. Ehrlich, w, M)
Modeling ground-water flow near lakes (S. P. Larson, w, St. Paul, Minn.)
Oxygen cycle in streams (R. E. Rathbun, w, Bay St. Louis, Miss.)
Thermal and biological characteristics of lakes (R. G. Lipscomb, w, St. Louis, Mo.)
See also Contamination, water; Quality of water.

Urban geology–Continued
- Colorado–Continued
  - Engineering geology mapping research, Denver region (H. E. Simpson, D)
- Connecticut Valley urban area study (F. R. Pessl, Middletown, Conn.)
- Maryland, Baltimore-Washington urban area study (J. T. Hack, W)
- Massachusetts, Boston and vicinity (C. A. Kaye, Boston)
- New Mexico, geology of urban development (H. E. Malde, D)
- Pennsylvania, Greater Pittsburgh regional studies (R. P. Briggs, Carnegie)
- South Dakota, Rapid City area (J. M. Cattermole, D)
- Tennessee:
  - Memphis area (W. S. Parks, w, Nashville)
  - Knox County (L. D. Harris, Knoxville)
- Utah, Salt Lake City and vicinity (R. Van Horn, D)
- Washington:
  - Puget Sound Basin (D. R. Mullineaux, D)
  - Puget Sound urban area study (F. Hidaka, w, Tacoma)

Urban hydrology:
- Geohydrology, urban planning (J. R. Ward, w, Lawrence, Kans.)
- Hydrogeology of landfills (H. H. Zehner, w, Louisville, Ky.)
- Investigation of urban hydrologic parameters (W. J. Schneider, w, W)
- Pollutional aspects of solid-waste disposal (D. A. Rickert, w, M)
- RALI southern Florida (T. J. Buchanan, w, Miami, Fla.)
- Storm runoff (W. J. Schneider, w, W)
- Urban areas reconnaissance (W. E. Hale, w, Albuquerque, N. Mex.)
- *States:*
- Arizona, Tucson-Phoenix urban area pilot study (E. S. Davidson, w, Tucson)
- California, San Francisco Bay area, urbanization (R. D. Brown, Jr., w, M)
- Colorado, Denver urban area pilot study, effects on water resources (E. R. Hampton, w, D)
- Massachusetts:
  - Connecticut River basin urban study (C. J. Londquist, w, Boston)
  - Waste water management feasibility study (J. E. Cotton, w, Boston)

Urbanization, hydrologic effects:
- Effect on flood flow:
  - Kansas, Wichita area (C. O. Geiger, w, Wichita)
  - Mississippi, Jackson area (K. V. Wilson, w, Jackson)
  - North Carolina, Charlotte area (A. L. Putnam, w, Raleigh)
  - Tennessee, Nashville-Davidson County metropolitan area (L. G. Conn, w, Nashville)
- Temperature patterns of selected east coast streams (E. J. Pluhowski, w, W)
- *States:*
- Arkansas, effect of urban development on thermal springs in Hot Springs National Park (M. S. Bedinger, w, Little Rock)
- California, Santa Ana River (M. W. Busby, w, Garden Grove)
- Florida:
  - Urban hydrology:
    - Bay Lake (J. O. Kimrey, w, Winter Park)
    - Englewood area (H. Sutcliffe, w, Sarasota)
    - Venice area (H. Sutcliffe, w, Sarasota)
- Maryland, sedimentation and hydrology in Rock Creek and Anacostia River basins (T. H. Yorke, w, College Park)
- Washington, metropolitan Seattle-Tacoma area (F. T. Hidaka, B. L. Foxworthy, w, Tacoma)

Vegetation:
- Elements in organic-rich material (F. N. Ward, D)
- *See also* Plant ecology.

Volcanic-terrane hydrology. *See* Artificial recharge.

Volcanology:
- Absaroka volcanic field, stratigraphy, structure, petrology, and mode of deposition (H. W. Smedes, H. J. Prostka, D)
- Cascade volcanoes, geodimeter studies (D. A. Swanson, M)
- Cauldron and ash-flow studies (R. L. Smith, W)
- Columbia River basalt (D. A. Swanson, M)
- Regional volcanology (R. L. Smith, W)
- Volcanic ash chronology (R. E. Wilcox, D)
- Volcanic hazards in the Cascades Range, California and Washington (D. R. Crandell, D)
- *States:*
- Arizona, San Francisco volcanic field (J. F. McCauley, M)
- Hawaii:
  - Hawaiian Volcano Observatory (D. W. Peterson, Hawaii National Park)
  - Submarine volcanic rocks (J. G. Moore, M)
  - Volcanic hazards, Island of Hawaii (D. R. Mullineaux, D)
- Idaho:
  - Central Snake River Plain, volcanic petrology (H. E. Malde, petrology (H. E. Malde, D)
  - Eastern Snake River plain region (P. L. Williams, H. J. Prostka, D)
  - Snake River basalt (P. L. Williams, H. J. Prostka, D)
- Montana, Wolf Creek area, petrology (R. G. Schmidt, W)
- New Mexico, Valles Mountains, petrology (R. L. Smith, W)
- Oregon, Bend area, volcanics (L. C. Rowan, Flagstaff, Ariz.)
- Washington, Mount St. Helens and Spirit Lake quadrangles (C. A. Hopson, Santa Barbara, Calif.)
- Wyoming, deposition of volcanic ash in the Mowry Shale and Frontier Formation (G. P. Eaton, D)

Water resources:
- Applications of operations research tools (D. R. Dawdy, w, M)
- Delmarva Peninsula, Md.-Va.-Del., hydrology (E. M. Cushing, w, Parkville, Md.)
- Foreign countries:
  - Brazil, surface water, national program (W. W. Evett, w, Rio de Janeiro)
  - Ethiopia, ground water, national program (H. E. Gill, w, Addis Ababa)
  - India, ground-water investigations in states of Madhya Pradesh, Gujarat, Maharashtra and Mysore (J. R. Jones, w, New Delhi)
  - Kenya, hydrogeology of eastern Kenya (W. V. Swarzenski, w, Nairobi)
  - Nepal, hydrogeology off Terai region (G. C. Tibbitts, Jr., w, Kathmandu)
  - Pakistan, Hydrologic investigations related to waterlogging and salinity control in the Punjab region (P. R. Seaber, w, Lahore)
- General hydrologic research (R. L. Nace, w, Raleigh, N. C.)
- Great Lakes, hydrology of cold-water streams (G. E. Hendrickson, w, Lansing, Mich.)
- Ground water, Regional ground-water study of the Upper Mississippi River basin (R. E. Bloyd, w, St. Louis, Mo.)
- Hazardous wastes study (E. G. Otton, w, Parkville, Md.)
- Intensive river quality assessment (D. A. Rickert, w, Portland, Oreg.)
- Lower Colorado River, ground-water return flows to (O. J. Loeltz, w, Yuma, Ariz.)
- National assessment (S. M. Lang, w, W)
- Plant ecology, hydrologic effects of conversion from pinyon-juniper woodland to grassland (J. R. Owen, w, D)
  - Dissolved solids yield related to vegetation and oils (F. N. Visher, w, D)

Water resources—Continued
Florida (w, Tallahassee, except as noted otherwise)—Continued
Duval County (G. W. Leve, Jacksonville)
East-central Florida (F. A. Watkins, Winter Park)
Everglades National Park (A. L. Higer, Miami)
Geohydrology, Cocoa well-field area (C. H. Tibbals, Winter Park)
Ground water:
Dade County, special studies (F. W. Meyer, Miami)
Fort Lauderdale area, special studies (H. J. McCoy, Miami)
Hallandale area, (H. W. Bearden, Miami)
Hollywood area (H. W. Bearden, Miami)
Palm Beach County flatlands (H. G. Rodis, w, Miami)
Peace and Alafia River basins (A. F. Robertson, Tampa)
Potentiometric St. Petersburg-Tampa (C. B. Hutchinson, w, Tampa)
Sarasota County, shallow aquifer (H. Sutcliffe, Sarasota)
Sewage effluent disposal, irrigation (L. J. Slack)
Southwestern Hillsborough County (J. W. Stewart, Tampa)
Hydrobiology, Conservation Area 3 (B. F. McPherson, Miami)
Hydrology:
Analog model, Biscayne aquifer (E. H. Cordes, Miami)
Aquifer modeling, Hillsborough, Pasco, Pinellas Counties (A. F. Robertson, Tampa)
Effects of canal controls (W. A. J. Pitt, Miami)
Infiltration, Miami Canal (F. W. Meyer, w, Miami)
Model study, Hillsborough River basin (J. F. Turner, Jr., Tampa)
Oklawaha Lakes (P. W. Bush, w, Miami)
Lee County (D. H. Boggess, Ft. Myers)
Osceola County (J. M. Frazee, w, Winter Park)
Palm Beach County (H. G. Rodis, Miami)
Seminole County (C. H. Tibbals, Winter Park)
Salt water, Citrus and Hernando (J. D. Hunn, w, Tampa)
South Florida ecological study (H. Klein, Miami)
Special studies, statewide (C. S. Conover, R. W. Pride)
Tampa Bay area (C. R. Goodman, Tampa)
Tampa Bypass Canal area (L. H. Motz, Tampa)
Unconfined aquifer, Charlotte (J. J. Hickey, w, Tampa)
Water atlas (A. A. Garrett)
Western Collier County (H. J. McCoy, Miami)
Georgia (w, Atlanta, except as noted otherwise)
Availability of water supplies in northwest Georgia (C. W. Cressler, w, Calhoun)
Hydrologic appraisal of the upper Cretaceous (R. C. Vorhis)
Information system (J. R. George)
Quality of ground water (R. G. Grantham)
Georgia, Florida, and South Carolina, study of the principal limestone aquifer, Suwannee Strait, in part (S. M. Herrick, w, Atlanta, Ga.)
Hawaii, ground water, Kekaha-Mana area, Kauai (D. A. Davis, w, Honolulu)
Idaho (w, Boise):
Ground water, Moscow Basin (E. G. Crosthwaite)
Hydrologic environment, White Clouds area (W. W. Emmett)
Hydrologic reconnaissance, Pahsimeroi River basin (H. W. Young)
Leakage from Blackfoot Reservoir (N. P. Dion)
Observation-well network, Kootenai Flats (N. P. Dion)
Recharge to Rathdrum Prairie (R. E. Hammond)
Test drilling, Snake River Plain (E. G. Crosthwaite)
Water quality, disposal wells (R. L. Whitehead)
Indiana (w, Indianapolis):
Ground water, Indianapolis hydrology (J. E. Heisel)
St. Joseph River basin (J. P. Reussow)

Water resources—Continued
Indiana (w, Indianapolis)—Continued
Water quality, river quality assessment (R. A. Pettijohn)
Iowa (w, Iowa City):
Mississippian aquifer appraisal (W. L. Steinhilber)
South-central (J. W. Cagle, Jr.)
Water availability, Muscatine Island, Muscatine County (R. E. Hansen)
Kansas (w, Lawrence, except as noted otherwise):
Ground water:
Ford and Hodgman Counties (E. D. Jenkins, Garden City)
Great Bend Prairie, south-central Kansas (S. W. Fader)
Greeley and Wichita Counties (E. D. Jenkins, Colby)
Nemaha County (J. R. Ward)
Northwestern part (E. D. Jenkins, Colby)
Scott and Lane Counties (E. D. Gutentag, Garden City)
Numerical modeling of Little Arkansas River basin, south-central Kansas (J. C. Halepaska, D. B. Richards)
Saline ground-water resources of Kansas (K. M. Keene)
Statistical analyses, ground water (W. M. Kastner)
Water supply in droughts (F. C. Foley)
Kentucky (w, Louisville):
Covington-Lexington-Louisville triangle (D. S. Mull)
Elizabethtown area (T. W. Lambert)
Ground water:
Alluvium of major Ohio River tributary streams (P. D. Ryder)
Hydrology, Princeton area (R. O. Plebuch)
Mammoth Cave area (R. V. Cushman)
Surface water, upper Kentucky River model (R. V. Swisshelm)
Louisiana (w, Baton Rouge, except as noted otherwise):
Baton Rouge area (C. D. Whiteman, Jr.)
New Orleans area (D. C. Dial)
Ground water:
Evangeline and Jasper aquifers (M. S. Whitfield)
Gramercy area (G. T. Cardwell)
Hydrology of the Red River Valley (A. H. Ludwig, Little Rock, Ark.)
Kisatchie Forest area (J. E. Rogers)
Morehouse Parish (T. H. Sanford)
Ruston area (T. H. Sanford)
Terrace aquifer, central Louisiana (T. H. Sanford)
Water quality in upper Mississippi River Delta alluvium (M. S. Whitfield)
Reports on special topics (M. F. Cook)
Site studies (R. L. Hosman)
Southwestern part (A. L. Zack)
Surface water:
Temperature of water in Louisiana streams (A. J. Calandro)
Velocity of Louisiana streams (A. J. Calandro)
Tangipahoa-Tchefuncte River basins (D. J. Nyman)
Water quality, Sabine Basin (F. C. Wells)
Maine (w, Augusta):
Ground water, Machias-Lubec area (G. C. Prescott)
Surface water, national eutrophication survey (G. S. Hayes)
Maryland (w, Parkville)
Baltimore-Washington urban hydrology (W. F. White)
Coastal Plain ground-water-quality data bank (W.E. Webb)
Ground water:
Aquifer modeling of coastal plain, feasibility and planning (E. G. Otton)
Aquifer studies in the Triassic rocks (L. J. Nutter)

Water resources—Continued
- Massachusetts (w, Boston):
  - Ground water:
    - Cape Cod National Seashore (J. E. Cotton)
    - Southeast coastal area (J. R. Williams)
  - Charles River basin (E. H. Walker)
  - Connecticut River lowlands (E. H. Walker)
  - Mathematical modeling of Ipswich River basin (I. James)
  - Nashua River basin (R. A. Brackley)
  - Neponset-Weymouth River basins (R. A. Brackley)
  - Northeastern coastal basins (F. B. Gay)
  - Southeastern coastal drainage (J. R. Williams)
  - Surface water, national eutrophication survey (J. R. Williams)
  - Water and related land resources for southeastern New England (M. H. Frimpter)
- Michigan (w, Lansing, except as noted otherwise):
  - Ground water:
    - Baraga County (G. E. Hendrickson)
    - Marquette County (G. E. Hendrickson)
  - Hydrology of river-based recreation (G. E. Hendrickson)
  - National eutrophication survey (P. C. Bent, w, Okemos)
  - River basins in southeastern Michigan (R. L. Knutilla)
  - Washtenaw County (F. R. Twenter)
- Minnesota (w, St. Paul):
  - Ground water for irrigation near Appleton (S. P. Larson)
  - Ground water for irrigation near Alexandria (M. S. McBride)
  - Rainy River watersheds (G. F. Lindholm)
  - Southern Minnesota watersheds (H. W. Anderson)
  - Upper Mississippi River watersheds (G. F. Lindholm)
  - Water budget:
    - Eagle Lake (R. J. Wolf)
    - Shagawa Lake (D. W. Ericson)
- Mississippi (w, Jackson):
  - Alcorn, Itawamba, Prentiss, and Tishomingo Counties (B. E. Wasson)
  - Benton, Lafayette, Marshall, Pontotoc, Tippah, and Union Counties (R. Newcome)
  - Calhoun, Chickasaw, Choctaw, Montgomery, Webster, and Yalobusha Counties (R. E. Taylor)
  - Ground water in north delta (G. J. Dalsin)
  - Ground water use (J. A. Callahan)
  - Jackson County (D. E. Shattles)
  - Surface water, low-flow analysis of Mississippi streams (E. J. Tharpe)
  - Water quality, Pascagoula estuary (D. E. Shattles)
- Missouri (w, Rolla):
  - Ground water resources - Springfield area (L. F. Emmett)
  - South-central Missouri (E. E. Gann)
- Montana (w, Helena, except as noted otherwise):
  - Ground water:
    - Central Powder River valley (W. R. Miller, w, Billings)
    - Clark Fork basin (A. W. Gosling)
    - Eastern Montana (W. B. Hopkins, w, Billings)
    - Fort Union Formation (W. B. Hopkins, w, Billings)
    - Helena valley (K. B. Wilke, D. L. Coffin)
    - Madison Group (W. R. Miller, w, Billings)
    - Missoula valley (A. J. Boettcher)
    - Northern Judith basin (R. D. Feltis, w, Billings)
    - Quality of water near Libby (A. J. Boettcher)
    - Southern Powder River valley (W. R. Miller)
    - Water supplies for national parks, monuments, and recreation areas (D. L. Coffin)
- Nebraska (w, Lincoln):
  - Determination of ground-water withdrawals in Hamilton, York, Seward, and Clay Counties (E. K. Steele)
  - Ground-water resources of Boyd County (C. F. Keech)

Water resources—Continued
- Nebraska (w, Lincoln)—Continued
  - Surface water, Salt Creek time-of-travel (L. R. Petri)
  - Water-quality investigations (R. A. Engberg)
  - Water in the Loup River basin (R. Bentall)
  - Pierce County (C. F. Keech)
  - Seward County (M. J. Ellis)
- Nevada (w, Carson City):
  - Ground water, Great Basin (T. E. Eakin)
  - Las Vegas Valley (J. R. Harrill)
  - Statewide reconnaissance (F. E. Rush)
  - Truckee River basin (A. S. Van Denburgh)
  - Smith Valley (F. E. Rush)
  - Water supply, mining districts (H. A. Shamberger)
- New Jersey (w, Trenton):
  - Coastal plain ground-water quality (D. Ellis)
  - Ground water:
    - Camden County, geology and ground-water resources (G. M. Farlekas)
    - Geohydrologic analysis of the Mount Laurel-Wenonah Formations (B. Nemickas)
    - Geohydrology, Potomac-Raritan-Magothy aquifer system—Trenton to Perth Amboy (G. M. Farlekas)
    - Geohydrology, Potomac-Raritan-Magothy aquifer system—Trenton to Salem (H. E. Gill, G. M. Farlekas)
  - Ground-water use inventory (W. Kam)
  - Water temperatures (M. G. McDonald)
- New Mexico (w, Albuquerque, except as noted otherwise):
  - Cimarron Basin analysis (E. D. Cobb)
  - Ground and surface water, Santa Fe County (W. A. Mourant)
  - Ground water:
    - Availability, White Sands Missile Range (T. E. Kelly)
    - Capitan Reef (W. L. Hiss)
    - Harding County (F. D. Trauger)
    - Malaga Bend area (C. C. Cranston, w, Carlsbad)
    - Mimbres basin (J. S. McLean)
    - Miscellaneous activities, State Engineer (J. B. Cooper)
    - Northern high plains (E. G. Lappala)
    - Rio Grande ground-water appraisal (W. L. Broadhurst)
    - Roswell basin, Chaves and Eddy Counties, quantitative analysis of the ground-water system (G. E. Welder)
    - Special problems (J. B. Cooper)
    - Taos-Cerro area (F. C. Koopman)
    - White Sands Missile Range, water levels and pumpage (J. A. Basler)
  - Hydrologic investigations:
    - Data bank (J. B. Peterson)
    - San Juan River valley (F. P. Lyford)
  - State water plan (J. B. Cooper)
  - Surface water, Rio Grande compact (E. D. Cobb)
- New York (w, Albany, except as noted otherwise):
  - Coastal plain ground-water-quality data bank (D. F. Vaupel, w, Mineola)
  - Ground water:
    - Long Island:
      - Bay Park, artificial recharge of treated sewage (J. Vecchioli, Mineola)
      - Nassau County, ground-water system study (N. M. Perlmutter, Mineola)
      - Suffolk County, geochemical aspects of pollution, Babylon-Islip (J. Soren, Mineola)
      - Suffolk County, hydrologic conditions (H. M. Jensen, Mineola)
      - Suffolk County, water-quality observation well program (J. Soren, Mineola)

Water resources—Continued

New York (w, Albany, except as noted otherwise)—Continued

Long Island:

Computer applications (D. E. Vaupel, Mineola)

Hydrologic modeling (G. T. Getzen, Mineola)

Preliminary evaluation of quality of water (C. A. Harr, Mineola)

Surface water, national eutrophication survey (G. E. Williams)

North Carolina (w, Raleigh):

Coastal plain ground-water-quality data bank (C. E. Simmons)

Ground water:

Cape Hatteras National Seashore (M. D. Winner)

Wilson County (M. D. Winner)

Northeastern part of State (K. L. Lindskov)

Public water supplies (N. M. Jackson)

Surface water:

Hydrology of estuaries (H. B. Wilder)

Low-flow and water-availability studies (W. L. Yonts)

Time-of-travel studies (W. G. Stamper)

North Dakota (w, Bismarck):

Ground water:

Bowman and Adams Counties (M. G. Croft)

Dunn County (R. L. Klausing)

Emmons County (C. A. Armstrong)

Grant and Sioux Counties (P. G. Randich)

Griggs and Steele Counties (C. A. Armstrong)

Ohio (w, Columbus):

Ground water:

Availability in Circleville area (R. E. Fidler)

Southeastern part, principal aquifers (A. C. Sedam)

Southwestern and central parts, principal aquifers (S. E. Norris)

Oklahoma (w, Oklahoma City):

Clinton quadrangle, west-central Oklahoma (J. E. Carr)

Enid quadrangle, north-central Oklahoma (R. H. Bingham)

Ground water:

Edmond-Guthrie area (J. D'Lugosz)

Hydrogeology of the Arbuckle Group in the Wichita Mountains area, southwestern Oklahoma (J. S. Havens)

Upper Red River basin, above Denison Dam, Oklahoma and Texas (M. V. Marcher)

Hydrology:

Oklahoma panhandle (D. L. Hart, Jr., G. L. Hoffman)

Platt National Park (D. L. Hart, Jr.)

Lawton quadrangle, southwestern Oklahoma (J. S. Havens)

Woodward quadrangle, northwest Oklahoma (R. B. Morton)

Oregon (w, Portland):

Ground water:

Coos Bay, dune aquifers (J. H. Robison)

Harrisburg-Halsey (F. J. Frank)

Lincoln County coast (F. J. Frank)

Northern Clackamas County (A. R. Leonard)

Sutherlin (J. H. Robison)

Surface water:

Velocity fluctuations in Columbia River (L. L. Hubbard)

Warm Springs Reservation (J. H. Robison)

Pennsylvania (w, Harrisburg, except as noted otherwise):

Anthracite Mine Drainage (J. R. Hollowell)

Coastal plain ground-water-quality data bank (C. R. Wood)

Geology and ground-water resources of Monroe County (L. D. Carswell, Philadelphia)

Ground water:

Clarion River, Redbank Creek basins (H. E. Koester)

Crawford County, western (G. R. Schiner)

Water resources—Continued

Pennsylvania (w, Harrisburg, except as noted otherwise)—Continued

Ground water—Continued

Cumberland Valley (A. E Becher)

Lackawanna County (J. R. Hollowell)

Summary report of the ground-water resources of each county in Pennsylvania (T. N. Newport)

York County, central and southern (O. B. Lloyd, Jr.)

Ground-water resources of the Williamsport Area (O. B. Lloyd)

Hydrology of anthracite coal mine area (H. R. Hollowell)

Limnology of streams in Chester County (B. W. Lium, West Chester)

Pilot study—Greater Pittsburgh (R. M. Beall, w, Pittsburgh)

Steamflow characteristics (L. V. Page)

Stormwater measurements (R. A. Miller)

Water-level monitoring, Matamoras area (W. C. Roth)

Water quality, highway construction, effects on streams (J. F. Truhlar)

Well data from drillers' cards (D. W. Speight, w, Philadelphia)

Puerto Rico (w, San Juan):

Ground water:

Guayama area (J. R. Díaz)

Lajas valley (H. R. Anderson)

San Juan area (H. R. Anderson)

South Coast alluvium analog model (G. D. Bennett)

Yabucoa area (T. M. Robinson, R. B. Anders)

Naunabo Valley (V. J. Latkovich)

Planning model (E. R. Close)

Rhode Island (w, Boston, Mass.):

Branch and Blackstone River basins (H. E. Johnston)

Providence-Warwick area (H. E. Johnston)

South Carolina (w, Columbia):

Coastal plain ground-water quality (P. W. Johnson)

Ground water, Coastal plain (P. W. Johnson)

Reconnaissance of estuaries (F. A. Johnson)

South Dakota (w, Huron, except as noted otherwise):

Brown County (N. C. Koch)

Cheyenne and Standing Rock Indian Reservations (L. W. Howells)

Deuel and Hamlin Counties (J. Kume, Vermillion)

Douglas and Charles Mix Counties (J. Kume, Vermillion)

Ground water:

Eastern part of State, basic research (E. F. LeRoux)

Hand and Hyde Counties (N. C. Koch)

Western Missouri River Basin (West) (E. F. LeRoux)

Marshall County (N. C. Koch)

McPherson, Edmunds, and Faulk Counties (L. J. Hamilton)

Tennessee (w, Nashville):

Caney Fork, Upper (G. K. Moore)

Duck River basin, upper (C. R. Burchett)

Memphis area (J. H. Criner, Jr.)

Texas (w, Austin, except as noted otherwise):

Ground water:

Analog model study of the Houston district (D. G. Jorgensen, w, Houston)

El Paso area, continuing quantitative studies (W. R. Meyer, w, El Paso)

Galveston County continuing quantitative studies (R. K. Gabrysch, w, El Paso)

Ground-water pollution study in vicinity of Toledo Bend Reservoir (E. T. Baker, Jr.)

Guadalupe Mountains National Park, water supply (E. R. Leggat)

Houston district, continuing quantitative studies (R. K. Gabrysch, w, Houston)

Waterpower classification–Continued
Colorado:
Colorado River between Dotsero and Orestod–review of withdrawals (R. Smith, c, D)
Dolores River Basin–review of withdrawals (R. Smith, c, D)
San Juan River upstream from Turley damsite–review of withdrawals (H. D. Tefft, Jr., c, D)
New Mexico:
Rio Chama River Basin–review of withdrawals (H. D. Tefft, Jr., c, D)
Rio Puerco Basin–review of withdrawals (G. A. Lutz, c, D)
San Juan River upstream from Turley damsite–review of withdrawals (H. D. Tefft, Jr., c, D)
Oregon (c, Portland):
Clackamas River Basin–review of withdrawals (L. O. Moe)
John Day River Basin–review of withdrawals (J. L. Colbert)
Mosby Creek damsites, Willamette River Basin (K. J. St. Mary)
Nestucca River Basin–review of withdrawals (K. J. St. Mary)
North Umpqua River Basin–review of withdrawals (J. L. Colbert)
Siuslaw River–waterpower resources (J. L. Colbert)
Walker Creek damsite, Nestucca River (K. J. St. Mary)
Wiley Creek damsite, Willamette River Basin (K. J. St. Mary)
Utah:
Duchesne River Basin–review of withdrawals (R. Smith, c, D)

Waterpower classification–Continued
Utah–Continued
Green River below Flaming Gorge Dam–review of withdrawals (H. D. Tefft, Jr., c, D)
Washington (c, Tacoma):
Blanca Lake and Troublesome Creek pumped-storage site, Skykomish River (J. B. Dugwyler, Jr.)
Coyote Creek and John Day pool pumped-storage site, Columbia River (J. B. Dugwyler, Jr.)
Naches River Basin–review of withdrawals (J. B. Dugwyler, Jr.)
Wood Plateau and John Day pool pumped-storage site, Columbia River (J. B. Dugwyler, Jr.)
Wyoming:
Greybull and Shoshone Rivers–review of withdrawals (G. A. Lutz, c, D)
Wind River Basin–review of withdrawals (J. D. Simpson, III, c, W)

Wilderness Program. *See* Primitive and Wilderness Areas *under* Mineral and fuel resources–compilations and topical studies, mineral-resources surveys.

Zeolites:
Bowie area, Arizona (L. H. Godwin, c, Carlsbad, N. Mex.)
Southeastern California (R. A. Sheppard, D)

Zinc. *See* Lead, zinc, and silver.

SUBJECT INDEX

[Some discussions cover more than one page, but only the number of the first page is given. See also "Investigations in Progress" (p. 324)]

INVESTIGATOR INDEX

See also "Investigations in Progress"

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