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GEOLOGICAL SURVEY RESEARCH 1974

GEOLOGICAL SURVEY PROFESSIONAL PAPER 900

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 900

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

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UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

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FOREWORD

"Geological Survey Research 1974" is the 15th annual review highlighting and summarizing U.S. Geological Survey programs and their results. From 1960 to 1972 comparable reviews constituted the first or A chapters of multichaptered series. The short scientific and technical papers, counterparts of those previously presented in the other chapters, have been published since January 1973 in the bimonthly subscription periodical "Journal of Research of the U.S. Geological Survey."

The Geological Survey continues to direct its research activities toward solving 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 expanding and diversifying to respond to urgent needs for better information about resources; 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.

This volume provides a synoptic review of many of these undertakings.

V. E. McKelvey,
Director.

CONTENTS

ILLUSTRATIONS

ABBREVIATIONS

AEC --- Atomic Energy Commission
AID --- Agency for International Development, U.S. Department of State
AIDJEX --- Arctic Ice Dynamics Joint Experiment
AIME --- American Institute of Mining, Metallurgical, and Petroleum Engineers
atm --- atmosphere
BOD --- biochemical oxygen demand
B.P. --- before present
b.y. --- billion year
cal --- calorie
CHS --- Canadian Hydrographic Ship
CIPW --- Cross, Iddings, Pirsson, and Washington
CIRES --- Cooperative Institute for Research in Environmental Sciences
COD --- chemical oxygen demand
CRIB --- Computerized Resources Information Bank
CRREL --- Cold Regions Research and Engineering Laboratory
d --- day
dc --- mean diurnal temperature
d-c --- direct-current
DCP --- Data Collection Platform
DCS --- Data Collection System
DDD --- dichloro-diphenyl-dichloroethane
DDE --- dichloro-diphenyl-dichloroethylene
DO --- dissolved oxygen
DOD --- Department of Defense
DSDP --- Deep Sea Drilling Project
dyn --- dyne
ECAFE --- Economic Commission for Asia and the Far East
emu --- electromagnetic unit
EPA --- Environmental Protection Agency
EROS --- Earth Resources Observation Systems
ERTS --- Earth Resources Technology Satellite (now Landsat)
ESIAC --- Electronic Satellite Image Analysis Console
ESMR --- electronically scanning microwave radiometer
eU --- equivalent uranium
FRUC --- Front Range urban corridor
h --- hour
HUD --- Housing and Urban Development
Hz --- hertz (cycle per second)
IGC --- International Geological Congress
IGU --- International Geographical Union
IHD --- International Hydrological Decade
IUGS --- International Union of Geological Sciences
J --- joule
JPL --- Jet Propulsion Laboratory
JTU --- Jackson turbidity unit
K --- kelvin
kcal --- kilocalorie
KREEP --- potassium, rare-earth elements, phosphorus
LARSYS --- Laboratory for Applications of Remote Sensing (computer) System
lat --- latitude
loc. --- locality
long --- longitude
mb --- millibar
MBAS --- methylene blue active substance
mg/l --- milligram per litre, or ppm
mGal --- milligal
MeV --- megaelectronvolt
min --- minute
mo --- month
mol --- mole
MSS --- multispectral scanner
m.y. --- million year
μg/g --- microgram per gram, or ppm
μg/l --- microgram per liter, or ppb
μg/ml --- microgram per millilitre, or ppm
μmho --- micromho
NASA --- National Aeronautics and Space Administration
NATO --- North Atlantic Treaty Organization
NAWDEX --- National Water Data Exchange
NOAA --- National Oceanic and Atmospheric Administration
NPS --- National Park Service
NSF --- National Science Foundation
ohm-m --- ohm-metre
PDB --- Peedee belemnite
pCi --- picocurie
pH --- measure of hydrogen ion activity
ppb --- part per billion
ppm --- part per million
ppt --- part per thousand
RALI --- Resource and Land Information
RBV --- return beam vidicon
rms --- root mean square
s --- second
SCS --- Soil Conservation Service
SP --- self potential
U.N. --- United Nations
UNESCO --- United Nations Educational, Scientific, and Cultural Organization
USBM --- U.S. Bureau of Mines
USCG --- U.S. Coast Guard
USGS --- U.S. Geological Survey
USPHS --- U.S. Public Health Service
UTM --- Universal Transverse Mercator
yr --- year

METRIC-ENGLISH EQUIVALENTS

Metric unit			English equivalent
Length			
nanometre (nm)	=	10	angstroms (A)
micrometre (μm)	=	10,000	angstroms
centimetre (cm)	=	.3937	inch (in.)
metre (m)	=	3.281	feet (ft)
kilometre (km)	=	.6214	mile (mi)
Area			
square centimetre (cm^2)	=	0.1550	square inch (in^2)
square metre (m^2)	=	10.76	square feet (ft^2)
hectare (ha) or square hectometre (hm^2)	=	2.471	acres
hectare	=	.003861	square mile (mi^2)
square kilometre (km^2)	=	.3861	square mile
Volume			
cubic centimetre (cm^3)	=	0.0610	cubic inch (in^3)
cubic centimetre	=	.00003531	cubic foot (ft^3)
litre (l)	=	61.03	cubic inches
litre	=	.2642	gallon (gal)
litre	=	.006290	barrel (bbl) (1 bbl=42 gal)
cubic metre (m^3)	=	35.31	cubic feet
Volume—Continued			
cubic metre	=	.0008107	acre-foot (acre-ft)
cubic metre	=	.0002642	million gallons (10^6 gal or Mgal)
cubic metre, or kilolitre (kl)	=	6.290	barrels
cubic hectometre (hm^3)	=	810.7	acre-feet
cubic kilometre (km^3)	=	810,700	acre-feet
cubic kilometre	=	.2399	cubic mile (mi^3)
cubic kilometre	=	264,200	million gallons
Weight			
gram (g)	=	0.03215	troy ounce (troy oz)
gram	=	.03527	ounce, avoirdupois (oz avdp)
gram	=	.002205	pound, avoirdupois (lb avdp)
tonne (t)	=	1.102	tons, short or U.S. (2,000 lb)
tonne	=	.9842	ton, long (2,240 lb)
Specific combinations			
metre per kilometre (m/km)	=	5.280	feet per mile (ft/mi)
millimetre per hour (mm/h)	=	.03937	inch per hour (in./h)

Metric unit		English equivalent	
Specific combinations—Continued			
metre per second (m/s)	=	3.281	feet per second (ft/s)
metre per second	=	2.237	miles per hour (mi/h)
metre per day (m/d)	=	3.281	feet per day (ft/d) (hydraulic conductivity)
kilometre per hour (km/h)	=	.9113	foot per second
kilometre per hour	=	.6214	mile per hour
metre squared per day (m^2/d)	=	10.764	feet squared per day (ft^2/d) (transmissivity)
cubic metre per cubic kilometre (m^3/km^3)	=	147.2	cubic feet per cubic mile (ft^3/mi^3)
cubic metre (or kilolitre) per cubic kilometre (m^3/km^3 or kl/km^3)	=	26.22	barrels per cubic mile (bbl/mi^3)
cubic metre per second (m^3/s)	=	35.31	cubic feet per second (ft^3/s)
cubic metre per second	=	22.82	million gallons per day
cubic metre per minute (m^3/min)	=	264.2	gallons per minute (gal/min)
litre per second (l/s)	=	.03531	cubic foot per second
litre per second, or cubic decimetre per second (dm^3/s)	=	.02283	million gallons per day
litre per second	=	15.85	gallons per minute
litre per second per metre ($l\ s^{-1}\ m^{-1}$)	=	4.831	gallons per minute per foot ($gal\ min^{-1}\ ft^{-1}$)
cubic metre per second per square kilometre ($m^3\ s^{-1}\ km^{-2}$)	=	91.47	cubic feet per second per square mile ($ft^3\ s^{-1}\ mi^{-2}$)
cubic metre per square kilometre per year ($m^3\ km^{-2}\ yr^{-1}$)	=	91.47	cubic feet per square mile per year ($ft^3\ mi^{-2}\ yr^{-1}$)
tonne per kilometre (t/km)	=	1.774	tons (short) per mile (ton/mi)
tonne per square kilometre (t/km^2)	=	2.855	tons (short) per square mile (ton/mi^2)
gram per cubic centimetre (g/cm^3)	=	62.43	pounds per cubic foot (lb/ft^3)
tonne per cubic hectometre (t/hm^3)	=	.002697	ton (short) per cubic foot per second-day ($ton\ ft^{-3}\ s\text{-}d^{-1}$)
litre per tonne (l/t)	=	.2397	gallon per ton (short) (gal/ton)
gram per square centimetre (g/cm^2)	=	.01422	pound per square inch (lb/in^2)
gram per square centimetre	=	2.048	pounds per square foot (lb/ft^2)
kilogram force per square centimetre (kgf/cm^2)	=	14.22	pounds per square inch
newton per square metre (N/m^2)	=	.0001450	pounds per square inch
joule per gram times degrees Celsius ($J/g\times°C$)	=	.0002390	British thermal units per pound times degrees Fahrenheit ($BTU/lb\times°F$)
Temperature			
degree Celsius (°C)	=	1.8	degrees Fahrenheit (°F)
degrees Celsius (temperature)	=	[(1.8×°C)+32]	degrees Fahrenheit

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GEOLOGICAL SURVEY RESEARCH 1974

MINERAL-RESOURCE AND MINERAL-FUELS INVESTIGATIONS

BASE, FERROUS, AND PRECIOUS METALS

Lithospheric plates, thermal plumes, and mineralization

In his continuing analysis of the distribution of metallogenic provinces, P. W. Guild (unpub. data, 1974) concluded that some types of ore deposits which occur within continental parts of plates and which have no relationship to subduction may also be accounted for in global tectonic terms. Crustal uplift, fracturing, and the initiation of plate separation along rifts have been attributed to thermal plumes rising from deep within the mantle (Wilson and Burke, 1973; Dewey and Burke, 1973); other fractures not suitably oriented for rifting are loci of transcurrent stress, increased geothermal gradient, and minor magmatic activity which may be episodic and repeated (Macintyre, 1973).

Guild proposed that heat from plumes rising under sialic (continental) plate interiors can provide the energy to mobilize elements dispersed in rocks and fluids and concentrate them into ore deposits. Prime examples of deposits that may owe their genesis to this cause are the various ores of the Mississippi Valley type that occur on or around low domes transected by extensive lineaments marked by, among other features, cryptoexplosion structures, alkalic to alkalic-mafic intrusions, diatremes, and kimberlites (Snyder, 1970; Heyl, 1972). The presence of carbonate-platform cover rocks over older basement rocks favors the genesis of these telethermal deposits, but other deposits that seem to have a more direct relationship to magmatic activity may also be due primarily to energy from thermal plumes.

Hydrothermal biotite, fluid inclusions, and sericitic alteration at porphyry copper deposit in Utah

W. J. Moore and J. T. Nash (1974) have determined from studies of many samples from the porphyry copper ore body at Bingham, Utah, that the distribution limits for hydrothermal biotite and high-salinity fluid inclusions generally follow the crudely triangular form of the disseminated copper ore zone. Extensive sericitic alteration of plagioclase is confined to rocks in the northern one-third of the Bingham stock; the generalized southern limit of sericitic alteration trends northeasterly and nearly bisects the copper ore zone. Moore and Nash believe that hydrothermal mineralization and alteration were accompanied by repeated boiling of fluids in the temperature range from 600°C to 400°C. Sericitic alteration was apparently superimposed on the earlier assemblage as the hydrothermal system cooled; cooling was promoted by progressive introduction of meteoric waters along a broad zone of northeast-trending fractures.

Fluid inclusion petrography of quartz from a porphyry copper zone in Puerto Rico

Through a study of thin sections, J. T. Nash and D. P. Cox reported that a zone of halite-bearing fluid inclusions in quartz coincides with areas of higher grade disseminated copper mineralization at Sapo Alegre, Puerto Rico. The halite-bearing inclusions are most abundant in a biotite-chlorite zone of alteration in quartz diorite porphyry. Lateritic weathering hampers recognition of the original lithology and hydrothermal alteration in most areas, but fluid inclusions can be readily studied in residual quartz in soils. In Puerto Rico, a study of residual quartz may lead to recognition of disseminated copper ore bodies not detectable at the surface by standard geologic and geochemical methods.

Environment of ore deposition and geochronology of mineralization

P. M. Bethke and P. B. Barton, Jr., in collaboration with R. O. Rye have completed reconnaissance studies of light stable isotopes in base-metal deposits at Creede, Colo. The sulfur isotopic compositions of both sulfide minerals and barite are ambiguous with respect to the origin of the sulfur. The sulfide data show little variation even though the oxidation state of the ore fluid fluctuated rapidly over a range of at least five orders of magnitude. This suggests that equilibrium between aqueous sulfide and sulfate species did not obtain.

M. A. Lanphere, Bethke, and Barton have dated the mineralization at Creede at 24.8±0.6 m.y. B.P. Vein-filling adularia formed early in the mineralization history yielded an age of 24.4±0.6 m.y., as determined by K-Ar methods. Three samples of sericite produced by wall-rock alteration during the later stages of mineralization yielded ages of 25.0, 24.8, and 24.6 m.y., all ±0.6 m.y. Lanphere, Bethke, and Barton's age determination is consistent with the geologic relations previously determined by T. A. Steven and J. C. Ratte, supported by K-Ar determinations by H. H. Mehnert and J. D. Obradovich.

Mineralogic interpretations of the lead-silver ores, Wood River district, Idaho

The Wood River lead-silver deposits, near Bellevue in southcentral Idaho, occur as veins in sheared zones in contact-metamorphic siliceous and limey argillites of Devonian age, near contacts with quartz diorite. W. E. Hall and G. K. Czamanske (1972) reported that galena in purified mineral separates from these ores contained from 2,100 to 5,000 ppm Ag and from 3,100 to 4,700 ppm Sb (atomic proportions of silver and antimony are approximately 1:1). Electron-probe analyses show that slightly less than one-half of the antimony and silver are in solid solution in the galena. The remainder is present in minute inclusions of five distinct compositions, all rich in both silver and antimony. The Wood River ores are thought to have been deposited over a temperature range from greater than 350°C in the early stages to less than 280°C during the late stages.

Geochemical anomalies in the Edna Mountain area, Nevada

Detailed geologic and geochemical mapping by R. L. Erickson and S. P. Marsh (1974 a, b, c, d, e), in the Brooks Spring 7½-min quadrangle, Humboldt County, Nev., has revealed numerous areas that contain anomalous amounts of a variety of metals. Copper-molybdenum-bismuth-silver anomalies occur in and along the contacts with a quartz monzonite intrusive which cuts the rocks of the Havallah Formation in the upper plate of the Golconda thrust fault. Rocks throughout the area are altered, and abundant secondary copper minerals occur along faults and fractures. The main mass of the intrusive is covered by gravels.

A lead-silver-bismuth anomaly occurs peripheral to the copper-molybdenum-bismuth-silver anomaly and is especially pronounced in an area of silicified upper plate rocks west of the intrusive.

A gold anomaly, apparently only in narrow north-northwest-striking silicified shear zones and quartz veins, occurs on the southwestern flank of Buffalo Mountain and is associated with mercury, arsenic, antimony, and tungsten anomalies. This suite of volatile elements was probably emplaced by hot-spring activity. The area is faulted on the southeast by a northeast-trending Basin and Range fault.

Hemlock Formation exploration area extended

Geologic mapping and geophysical surveys in the Witch Lake 15-min quadrangle, Michigan, by W. F. Cannon has extended the known areal extent of the Hemlock Formation by direct tracing of the unit and by inferences from ground-magnetic traverses. The Hemlock Formation, consisting mostly of mafic flows with some intermediate and felsic flows and pyroclastic rocks, is now known to be at the surface but mostly beneath thick drift cover in a belt encircling the Smith Creek uplift (northeast of the Amasa uplift) where it crops out sporadically. Because of its distinct magnetic pattern, it is inferred to encircle the Wilson Creek uplift (north of the Amasa uplift) which is devoid of outcrops.

During the past few years, exploration interest for metallic sulfide deposits in the Hemlock Formation has increased sharply. The extension of its known outcrop belt increases the target area for exploration for sulfides.

Gold in the Black Hills, South Dakota

On the basis of a review of existing reports bearing on gold in the Black Hills, J. J. Norton (1974) suggested that exploration for deposits concealed in the subsurface in that area is likely to be fruitful. Most of the gold is in metamorphosed iron-formation such as occurs in the famous Homestake mine at Lead which produced about 91 percent of the almost 1 million kg of gold obtained in the Black Hills. Gold production has also been from replacement deposits in the Deadwood Formation of Late Cambrian age and in the igneous intrusions of Tertiary age within 8 km of Lead. Other deposits of various kinds have been minor sources.

Isotope studies by D. M. Rye (Yale Univ.) and R. O. Rye (USGS) (1974) have indicated that the gold at Homestake was an original constituent of the iron-formation and was concentrated into the ore bodies during Precambrian metamorphism. Placer gold in basal conglomerate of the Deadwood Formation is an indirect sign that gold is from nearby Precambrian rocks. Replacement deposits in Paleozoic and Tertiary rocks are a consequence of Tertiary hydrothermal activity. The gold of Tertiary hydrothermal deposits is most plausibly interpreted as having been transported from underlying Precambrian concentrations.

Indications from the literature suggest that suitable target areas to search for buried Precambrian gold deposits are 6 km or more north-northwest of Lead, 6 km southwest of Lead, and near Rockerville in the southern Black Hills.

Gold and copper in fault zones in the Albany quadrangle, Wyoming

Several fault zones containing copper and gold have been mapped by M. E. McCallum in the western portion of the Albany quadrangle in the Medicine Bow Mountains, Wyo. Most of the mineralized faults trend northwest and are comparable to those in the adjacent Keystone quadrangle. Host rocks are predominantly quartzofeldspathic and biotite-rich metasediments and foliated phases of the Keystone quartz diorite pluton. Metal concentrations are generally low, although locally several percent copper and up to 100 ppm Au have been detected. Gold is apparently present in pyrrhotite and to a lesser extent in pyrite. Copper occurs predominantly as chalcopyrite and in numerous secondary minerals. Studies of polished sections and X-ray analyses have been used to identify the mineral components and the following general paragenetic sequence: pyrrhotite - pyrite-chalcopyrite - sphalerite (minor) - bornite (?) - covellite - malachite - chrysocolla - shattuckite-azurite-antlerite-chalcanthite.

Sampling for gold, bismuth, and arsenic in Catawba County, North Carolina

Two hundred and eighty samples of topsoil near the mine and of saprolite from the walls of the mine pit of the Shuford gold mine in Catawba County, N.C., were collected for geochemical analysis by J. W. Whitlow and J. F. Windolph, Jr. Only 2 samples of the saprolite and 26 samples of the topsoil contained detectable gold. The amounts found were low, ranging up to 350 ppb. Bismuth and arsenic were detected in only a few samples of the topsoil but were slightly more abundant in the saprolite.

Iron and rare-earth resources, Mineville, New York

Harry Klemic studied samples of iron ore containing rare-earth-bearing apatite from the deepest levels of a commercial iron mine at Mineville, Essex County, N.Y., and from holes drilled by the mining company into deep extensions of the Old Bed ore body. These studies indicate that the grade and mineralogy of the ore at depth are comparable to those of ore previously mined. The drilling also disclosed that a complex fold in the ore body mined in several levels of workings extended beyond the deepest production level. The trend of the ore body as determined in the mine was found to persist at greater depths.

Petroleum as a potential source of much vanadium

According to R. P. Fischer (1973), petroleum is a possible economic source of vanadium. Although present in only trace amounts in crude oils, vanadium accumulates in residual refinery products which are commonly used as fuel oils. In cases in which fuel oils are being processed for the removal of sulfur to reduce air pollution, it may be possible to recover vanadium profitably.

There is incentive to develop new sources of vanadium because the amount of that metal available in presently productive deposits is only about 91,000 t, whereas the expected cumulative domestic requirement for vanadium between the present and the year 2000 is in the range of 363,000 to 544,000 t.

Titaniferous iron-rich sands on Lake Superior beaches

In the course of geochemical sampling in the Michigan part of the Sault Ste. Marie 2° quadrangle, J. W. Whitlow and J. F. Windolph, Jr., found dark-gray to black sand in a bed or beds as thick as 30 cm. Samples of the sand contained as much as 11 percent titanium dioxide, 0.2 percent vanadium, and more than 20 percent iron.

Geochemically selected target area for zinc in southwestern Wisconsin

Geochemical data obtained from analyses of stream sediments collected in the Hurricane quadrangle, Wisconsin, have been interpreted by W. S. West as indicating a promising area for prospecting for zinc and lead. The area defined by West is in secs. 28, 29, 32, and 33, T. 4 N., R. 4 W., and overlaps a favorable area for prospecting which De Geoffroy (1969) described on the basis of studies of the zinc content of spring waters. The zone of overlap is in the northeastern part of the area enclosed by the 0.30 ppm zinc-isopleth contour as drawn by De Geoffroy.

Two-stage dolomite in East Tennessee zinc district

Much of the coarse-grained recrystalline dolomite (altered limestone) of the upper part of the Kings-port Formation in the East Tennessee zinc districts was formed in two stages. Petrographic studies of selected mine samples by Helmuth Wedow, Jr., showed that many of the coarse dolomite rhombs have cloudy cores and clear, oriented overgrowths. The cloudy cores include a part of the original insoluble fraction of the limestone and apparently formed by dolomitization of part of the primary carbonate in the original permeable rock. The clear, oriented overgrowths were precipitated later in pore space formed by solution of previously unreplaced limestone. These overgrowths thus are essentially of the same stage or stages of dolomite formation as the coarsely crystalline white dolomite gangue which fills the fractures of related crackle breccias and the authigenic dolomite which cements the graded, clastic, laminated breccia matrix lower in the ore structures. The volume of the overgrowth dolomite gives an estimate of the porosity of the rock in which the sphalerite of the zinc-bearing ores was precipitated.

LIGHT METALS AND INDUSTRIAL MINERALS

Increase in potential resources of alumina in Colombia

E. F. Overstreet and H. M. Nakagawa found that gibbsite ($Al_2O_3 \cdot 3\ H_2O$) and amorphous alumina in aluminous laterite near Cajibio, Colombia, extend well below the horizons that contain visible gibbsitic masses. X-ray and chemical analyses show that some of the material without visible gibbsite actually contains more gibbsite and alumina than does the material containing visible gibbsite. This discovery not only alters current ideas about the genesis of the material but increases the potential resources of alumina in Colombia.

New age determinations for clays in Georgia

Pollen studies by R. H. Tschudy on organic-rich peaty clay samples collected by S. H. Patterson have resulted in new age determinations for some sedimentary units in the kaolin belt of Georgia. Some deposits are now assigned a Late Cretaceous age, and others are as young as Claiborne (Eocene). Samples of material enclosed by sand units were found to be Paleocene in age. This first recognition of Paleocene beds in central Georgia will help in understanding the geology of the Atlantic Coastal Plain.

Fluorite study should aid search for new deposits

Study of the fluorite deposits of the United States by R. G. Worl, R. E. Van Alstine, and A. V. Heyl, Jr., should prove helpful in selecting new areas to search for commercial deposits of fluorspar. The study assigns deposits or districts to size categories on the basis of a combination of past production and estimated reserves. Deposits in the Illinois-Kentucky district have accounted for about 80 percent of the approximately 14 million t of domestic fluorspar shipments recorded between 1880 and 1974. This finished fluorspar represents more than 30 million t of crude fluorspar ore.

Of the more than 450 fluorite localities in the 48 conterminous States and Alaska, 100 have yielded significant quantities of commercial fluorspar for the steel, aluminum, chemical, and ceramic industries. About 83 percent of these productive deposits or districts are veins; 6 percent are mantos; 5 percent are stockworks or pipes; 5 percent are pegmatites or carbonatites; and 1 percent are skarns or greisens. No disseminated-fluorite deposit was of sufficient grade to have been profitably mined in the United States. As most of the larger and higher grade fluorspar veins apparently have already been discovered and worked, future efforts probably will be concentrated upon the search for fluorspar in deposits other than veins. Many of these types of deposits are larger, though lower in grade, than the veins worked.

Of the wallrocks at the 100 productive fluorite localities, about 30 percent are Paleozoic or Mesozoic limestones and dolomites; 30 percent are Precambrian, Mesozoic, or Tertiary silicic intrusive rocks; 20 percent are Tertiary volcanic rocks; 15 percent are Precambrian or Paleozoic metamorphic rocks; 3 percent are Paleozoic or Tertiary sandstones; and 2 percent are Paleozoic, Mesozoic, or Tertiary shales.

Sedimentary petrology helpful in prospecting for high-calcium limestone

H. A. Hubbard discovered that many economically important high-calcium limestones are calcarenites that were deposited in agitated water. Some calcarenites with sufficient impurities of fine-sand, silt, or clay size to make them unsuitable as high-calcium limestones were deposited in less turbulent water. Therefore, paleogeographic models of environmental reconstructions that distinguish areas of deposition in relatively turbulent water from areas of deposition in relatively quiet water can aid in prospecting for economic deposits of high-calcium limestone.

Self-sufficiency in lightweight aggregates

Most countries are faced with an energy shortage and need to place more emphasis on the use of energy-conservative natural materials, according to

A. L. Bush. In the fields of construction, heating, and cooling, wider use of expanded lightweight materials (argillaceous rocks, perlite, vermiculite, and others) provides very significant savings in energy consumption. Most countries have sufficient resources of at least one of two usable lightweight materials. The United States, for example, is totally self-sufficient in nearly all types, whereas some other countries may have to depend only on expanded clay. All countries apparently have some lightweight aggregates, but only a fraction of the benefits available from their wider use is generally realized.

Resources and geochemistry of peat deposits, eastern Maine

In Washington County, Maine, C. C. Cameron mapped a deposit estimated to contain 1,320,000 t of air-dried moss peat. The deposit covers 306 ha and is among the largest deposits in eastern Maine.

The use of peat-bog stratigraphy was found to be valuable for estimating the kind and amount of peat resources, for sampling and geochemical prospecting for peat, and for finding where and how elements concentrate in the bog. Study of the stratigraphic relationships of 29 elements in 39 peat deposits in Washington County shows that Cu, Zn, Pb, Mg, Ni, and B are not only most abundant in the convex upper moss layer, but their distribution roughly coincides with elevation contours; this suggests that these elements have been extracted from ground water by moss-type flora during the building of bog convexity. In contrast, molybdenum and gadolinium appear in greatest abundance beneath the bog dome in material deposited in marsh and pond environments. Vanadium and niobium are most abundant in the lowest part of the deposits where inorganic and water-borne organic sediments are most abundant. Tin and silver have wide distribution vertically through moss, marsh, and pond sediments of the peat deposits.

Origin of lithium pegmatites in the southern Black Hills, South Dakota

Investigation of the Harney Peak Granite by J. J. Norton and R. J. McLaughlin has caused doubt that it can be the parent of the lithium pegmatites of the southern Black Hills (U.S. Geol. Survey, 1973, p. 7). An alternative possibility is that partial melting of lithium-bearing schists gave rise to the magma that formed these pegmatites.

In a test of this view, reconnaissance sampling of diverse kinds of metamorphic rocks northeast of the granite has shown that their lithium content is approximately the same as that in the granite. Mica schists, which predominate in the area, contain the most lithium. In 16 samples of such schists, ranging from very micaceous to quartzose, the largest lithium content is 150 ppm; the average, 66 ppm, is similar to, or somewhat greater than, that in the granite and is in accord with analyses of clay minerals in unmetamorphosed argillaceous rocks (Tardy and others, 1972).

Samples from the garnet zone of metamorphism, collected from localities as much as 11 km apart in the granite, tend to have the lowest amounts of lithium, and samples taken through the staurolite zone and into the sillimanite zone adjacent to the granite show generally increasing amounts of lithium. Observations in New Hampshire by D. M. Shaw (1954) were similar.

The apparent metamorphic control over the abundance of lithium can mean that emanations from the granite carried lithium into the country rock or that somehow lithium migrated to higher grade rocks during metamorphism. In order to choose between these possibilities, sampling is required across the same metamorphic zone in an area remote from the granite. An area of very micaceous rocks west and northwest of the granite is now being tested. Near where these rocks cross the sillimanite isograd, there are several small lithium pegmatites. If some of the schist attains high concentrations of lithium, these rocks may well be the source of the lithium in the pegmatites.

NUCLEAR FUELS

Exploration guides in the Crooks Gap uranium district, Wyoming

Geologic mapping in and near the Crooks Gap uranium district, Wyoming, has permitted a clearer definition of the favored stratigraphic position of the uranium deposits and their localization relative to masses of altered rock, according to L. J. Schmitt, Jr. These relations should be useful guides in exploration. All known deposits in the area are in the upper half of the lower part of the Battle Spring Formation and below a sequence of conspicuous boulder-conglomerate beds in the upper part of the formation. Three types of alteration are recognized in the ore-bearing part of the formation: (1) bleaching or whitish reductive alteration, (2) yellow limonitic oxidative alteration, and (3) red hematitic oxidative alteration. The bleached rock contains pyrite and organic carbon below the zone of surficial oxidation and is believed to have acted as a reducing environment. Uranium deposits were localized where downward-moving uranium-bearing oxidizing solutions invaded the reducing environment. The ore-bearing solutions altered the rock by oxidation, leaving limonitic and hematitic stains.

Lenses of uranium-bearing beach sandstone bodies lack seaward continuity

Detailed correlation of members of the Whitsett Formation in Karnes and McMullen Counties, Tex., and study of its environments of deposition indicate to K. A. Dickinson that many of the sandstone bodies which form members of the Whitsett Formation are transgressive-regressive beach units that have a very limited extent, perhaps less than 2 km, downdip to the southeast. The beach sandstone bodies are long and narrow, having been confined to the ancient shoreline, but coincidence of the depositional and geologic strike gives the false impression that a unit may continue for great distances into the subsurface. In the offshore or downdip direction, the beach sandstone grades into shoreface sandstone that is finer grained and less permeable. In the updip or onshore direction, the deposits grade into swamp or lagoon mudstone. The beach units were deposited on mainland shores or on barrier islands, and lagoon or swamp deposits at the surface indicate a beach unit downdip in the subsurface. The previously accepted stratigraphic concept has been based on the continuity of these beds in a downdip direction. These misinterpretations may have led to exploratory errors in the search for uranium and petroleum or to misconceptions about the movement of ore-bearing solutions or petroleum.

Exploration guides to new uranium districts and belts

Uranium deposits in sandstone are widespread, and they occur in many different stratigraphic units and in areas having different geologic settings and histories. Nevertheless, significant geologic relations among the major districts and belts of uranium deposits were similar at the time of ore formation, and these relations may be useful as guides in selecting new areas and beds most likely to contain major uranium deposits, according to R. P. Fischer.

Host rocks favorable for large uranium deposits are sandstone lenses interbedded with mudstone; these mudstone beds or some overlying beds commonly contain volcanic ash. Sedimentation on a low-lying terrane with a high water table, yielding nonoxidizing conditions of water-saturated beds, is indicated by the presence of coalified plants in almost all host beds. During ore formation the host beds dipped gently because of initial stream gradient or slight tectonic tilting. The ore-forming solutions were ground waters that moved downward by gravity. The ore formed slowly under stable conditions, at shallow to moderate depths, in zones several kilometres to several tens of kilometres from the depositional or erosional edges of the host beds, at places where adequate reducing conditions were encountered. The reducing agents were obscure and perhaps varied. Roll-type deposits, like those in Wyoming, seem to have formed relatively late after the accumulation of the host beds, whereas tabular deposits, like those on the Colorado Plateau, may have formed relatively soon after sedimentation.

Low-grade disseminated uranium occurrences in igneous rocks

If adequate high-grade uranium deposits cannot be found to satisfy future requirements of nuclear reactors for generating electricity, considerable uranium might be obtainable from low-grade disseminated deposits in large masses of granitic rocks; such deposits may exist and a search for them should be made, according to F. C. Armstrong. Such deposits might be somewhat analogous to porphyry-type copper deposits.

In a crystallizing magma, uranium is concentrated in the late magmatic fluids. If it does not escape from the magma, uranium is found in the late differentiates, such as biotite quartz monzonite, alaskite, granite, and similar rocks and their associated granitic pegmatites. In these rocks, most of the uranium is occluded in rock-forming minerals or occurs in intergranular films or in its own minerals.

The Rössing deposit (vonBackström, 1970) in South-West Africa, which is in granitic rocks and is reported to be a large deposit of about 0.04 percent U_3O_8, might be an example of this type of deposit; it is currently under development. Other possible examples are: Charlebois Lake area, Saskatchewan, Canada (Mawdsley, 1952); Crocker's Well, South Australia, Australia (Campana and King, 1958); Bear Valley area, Valley County, Idaho (Mackin and Schmidt, 1956); and various places in northeastern Washington and the adajacent part of British Columbia.

Occurrence of disseminated uraninite in Wheeler Basin, Colorado

A small but interesting occurrence of disseminated uraninite has been found by E. J. Young and P. L. Hauff (1975) in Precambrian rocks in Wheeler Basin, Grand County, Colo. The host rocks are gneiss, migmatite, and pegmatite that contain scattered masses of biotite-rich rock, commonly about 1 m across. The uraninite occurs in minute grains and is most abundantly concentrated in the biotite-rich patches; one grab sample was analyzed as 0.73 percent U. The biotite-rich patches are composed of the following minerals, listed in decreasing order of abundance: biotite, sillimanite, quartz, pyrite, muscovite, monazite, hematite, uraninite, zircon, molybdenite, chalcopyrite, and fluorite.

Lead isotope studies by K. R. Ludwig on the uraninite indicate an age of 1390±60 m.y. This is also the approximate age of the Silver Plume Granite, which is common in this part of Colorado and a body of which lies within 120 m of this uraninite occurrence. Although this occurrence of uraninite is judged to have little or no resource significance, the contemporaneous age of the uraninite and its proximity to an intrusive body of this granite suggest that the uranium mineralization might be genetically related to the Silver Plume Granite, and that other occurrences of uranium might be found in other places of similar geologic setting.

Possible explanation for disequilibrium pattern between samples of uranium-bearing sandstone

In many uranium deposits in sandstone, the uranium (U or U_3O_8) content reported by chemical analyses is commonly higher than equivalent uranium (eU or eU_3O_8) reported by radiometric analyses for samples containing more than about 0.1 percent uranium, whereas chemical U (or U_3O_8) is commonly reported to be lower than eU (or eU_3O_8) in samples containing less than about 0.1 percent uranium. In order to determine if this pattern is real and not the result of faulty analytical techniques for one or both types of samples, a high-grade sample in which the chemical U (0.75 percent) was reported higher than eU (0.49 percent) was split into several samples. Each split was diluted with different amounts of barren sandstone so that the calculated grade of the splits ranged from 0.37 to 0.0015 percent U. Analysis showed that the chemical U was higher in each split than eU, and in about the same ratio as in the original sample, suggesting that the standard analytical techniques are not faulty. According to E. S. Santos, the most plausible explanation for this pattern of disequilibrium between high- and low-grade samples is to assume that the amount of daughter products lost is proportional to the grade of the uranium present, and that most or all of the daughter products is then redeposited uniformly in and near the deposit. There is thus a net gain of eU in low-grade material near the ore and a net loss in ore.

COAL

Reinhardt Thiessen collection established at Columbus, Ohio

Thin sections showing inherent microscopic characteristics of coal studied by Thiessen have been assembled at the USGS Coal Geology Laboratory in Columbus, Ohio. Thiessen began his coal studies with the Geological Survey in 1907 and continued his work with the USBM from 1912 until his death, late in 1937. These and subsequent studies have produced this series of unique reference preparations which represent virtually all important American commercial coal beds and which provide a detailed visual basis for examining the botanical composition of American coal. Some sections are from mined-out coal beds that were known to have unusual properties; others are from beds that have not been developed. Thin sections of western coal beds studied since 1950 at the Coal Geology Laboratory have been added to this collection, making a total of more than 13,000 thin sections. The collection is arranged by coal bed and geographic region for easy reference.

Coal bed discovered in New Mexico

A potentially commercial coal bed was located in the Raton coal field during field-checking operations by C. L. Pillmore. The bed, named Rattlesnake coal bed, is near the top of the Raton Formation and lies only 30 to 76 m below the crest of a high ridge between Spring and Gonzales Canyons, about 5 km northwest of Vermejo Park, N. Mex. It is 2.1 m thick and contains 1.4 m of coal in two main benches, 0.5 and 0.9 m thick, separated by a parting of carbonaceous shale.

Wyodak-Anderson coal bed in the Gillette area, Wyoming

A study by N. M. Denson and W. R. Keefer (1974) of sonic-density, gamma-ray, and electric logs from numerous oil and gas tests and from recent coal drill-hole data in the Powder River basin indicates that the Wyodak-Anderson coal bed in the vicinity of Gillette has a maximum thickness of about 38 m and occurs at depths of 61 m or less in a strip 72 m long and covering approximately 30,000 ha. On the basis of outcrop and drill-hole information, the Wyodak-Anderson coal bed in this area contains an estimated 6.4 billion t of coal resources. The coal is subbituminous in rank, and available analyses indicate that its sulfur content averages less than 1 percent, ash content averages 6.3 percent, and heat value averages 21 million J/kg.

Coal resources in the Nenana coal field, Alaska

An open-file report on coal resources in Nenana coal field (Wahrhaftig, 1973) indicates the presence of 3.75 billion t of coal resources with less than 305 m of overburden, nearly all in beds more than 1.5 m thick. An additional 1.7 billion t of coal resources occur in beds more than 1.5 m thick in measured, indicated, and inferred categories with 305 to 914 m of overburden.

OIL AND GAS

Significant petroleum accumulations possible beneath Atlantic Continental Shelf

In their regional geological and geophysical studies, R. Q. Foote, R. E. Mattick, and J. C. Behrendt (1974) have identified a considerably thicker section of sedimentary rocks (more than 10 km in the Baltimore Canyon area and 8 km on Georges Bank) than has been previously recognized beneath parts of the shelf. Two major deltaic sequences that are observed under the emerged Coastal Plain should extend under the shelf and should have marine sands associated with them. Also, carbonate rocks have been identified interfingering with clastic rocks. Potential hydrocarbon source beds are present along the coast in subsurface rocks of Cretaceous age. Potential reservoir sandstone beds are abundant in this sequence. For these reasons, it appears that beneath the Continental Shelf there are thick sedimentary sections and structural traps favorable for the accumulation of significant amounts of petroleum in Cretaceous and older strata.

Conodont color—a key to the thermal history of the host rock

A. G. Epstein, J. B. Epstein, and L. D. Harris are studying the use of the color of conodont elements as an index of the thermal maturity of the host rock. Collections of conodonts have been assembled from several traverses across the Appalachian basin and for several intervals of Paleozoic time. Only conodonts of similar age and, wherever possible, only elements of similar form and size are used for color comparison; five or six color groups have been distinguished.

Conodonts ranging in age from Ordovician through Devonian vary gradationally from pale amber, along the western edge of the Appalachian basin (Nashville dome to the Findlay arch), to dark brown or black, along the eastern edge of the Valley and Ridge province.

Conodont color changes generally follow trends of isocarbs based upon fixed-carbon ratios of Carboniferous plant material, so that conodonts are medium amber or lighter in areas where ratios are less than 60, medium to dark brown in areas where ratios are between 60 and 90, and black in areas with ratios greater than 90.

Long-term heating experiments are continuing. Colors of all conodonts observed in field collections have been duplicated in the laboratory but at rather elevated temperatures. Color changes of conodont elements are time dependent and temperature dependent so that changes achieved rapidly at elevated temperatures have also been reproduced over a period of several weeks at significantly lower temperatures. All heating experiments were made at 1 atm and under oxidizing conditions.

Sourwood Mountain anticline, southwestern Virginia

Geologic mapping in the Duty quadrangle, Virginia, by C. R. Meissner, Jr., indicates that the Sourwood Mountain anticline is a potential trap for oil and gas. The unique north-south orientation of this structure is in contrast to the northeasterly trend of the folded Appalachian Highlands. The anticline is 11 km long, 6 to 8 km wide, and has an amplitude of about 150 m.

Oil and gas possibilities in southeastern Kentucky

Paleozoic strata in a 155,000-ha area in southeastern Kentucky may be potential sources of economic quantities of oil and gas, according to an interpretation by A. J. Froelich (1973), who used data derived largely from geologic mapping by the USGS, in cooperation with the Kentucky Geological Survey. The area, which is in the Pine Mountain overthrust block, is underlain by more than 4,500 m of Paleozoic rocks. The attitudes of strata at the surface suggest a structural pattern that may reflect structural or paleogeomorphic alinements beneath the overthrust block.

Organic-rich zone defined by conodonts in Pilot Shale

An organic-rich zone comprising detrital clastic rocks that average more than 2 percent residual organic carbon has been found by C. A. Sandberg and F. G. Poole in the lower part of the Pilot Shale, of early Late Devonian (early Famennian) age, in western Utah and eastern Nevada. Its age has been defined by Sandberg on the basis of contained conodont faunas. In the Confusion Range, Utah, the zone is 93 m thick and ranges from the Lower *Palmatolepis crepida* or Upper *P. triangularis* Zone at the base, to the Lower *P. marginifera* Zone at the top. It thickens basinward to 133 m in the Red Hills, Nev., where the ages of the top and base are the same. The organic-rich zone abruptly changes facies in the South Burbank Hills, 35 km southwest of the Confusion Range, where the lower part, from the Upper *P. crepida* Zone downward, becomes the shallow-water West Range Limestone, whereas the upper part still tops in the Lower *P. marginifera* Zone but has reduced organic-carbon values that average about 1 percent. This finding suggests that deposition of possible petroleum source rocks occurred in a widespread, moderately deep marine environment that had an abrupt boundary with a less favorable shallower marine environment.

Petroleum source-rock studies, Permian System

Black shale beds in the Phosphoria Formation are probable source rocks of oil and gas and occur extensively in the States of Idaho, Montana, Utah, and Wyoming. These beds have long been known to be petroliferous and are low-grade oil shale locally in Montana, where they have yielded as much as 87.5 litres of oil per tonne of shale (Condit, 1919, p. 24, 25). The black shale beds are more than 100 m thick at localities in northern Utah and south-central Idaho, but eastward the strata thin and are absent in central Montana, central Wyoming, and easternmost Utah. Samples from these shale beds have been gathered from 25 localities in the 4 States and have been analyzed for organic-carbon content as an indicator of the degree of their original potential hydrocarbon yield. These shale beds commonly contain as much as 4 percent organic carbon although some beds analyzed contain more, and one bed contains 30 percent.

The Permian black-shale beds could have generated oil and gas for accumulation in natural reservoirs throughout the northern cordilleran region. Probably, not much oil has accumulated within this region because of extensive faulting and fracturing which would have allowed most oil to escape; however, eastward migration and accumulation in favorable reservoirs in eastern Montana, Wyoming, and Colorado has been postulated (Sheldon, 1967). By identifying preferred-migration routes from these source beds in the northern cordilleran region to favorable trapping beds, it may be possible to differentiate areas of greater potential and to assist in more efficient exploration.

Disconformities in Cenomanian and Turonian (Cretaceous) rocks, Wyoming and Colorado

Two major disconformities and a local disconformity have been traced by E. A. Merewether, G. A. Izett, and W. A. Cobban (1974) in rocks of Cenomanian and Turonian age across southern Wyoming and northern Colorado. The lower major disconformity is at the base of the Wall Creek Sandstone Member of the Frontier Formation. Its magnitude decreases from central Wyoming to northern Colorado. A local disconformity, representing part of latest Cenomanian and earliest Turonian time, is present locally in south-central Wyoming beneath the lower major disconformity. A second major, stratigraphically higher, disconformity at the base of the Niobrara Shale is now known to be more widespread across Wyoming and northern Colorado. Close faunal control above and below this second disconformity demonstrates that its magnitude increases from north-central Wyoming, where the Turonian succession is nearly complete, to northern Colorado, where as many as eight mollusk zones are absent beneath the disconformity. Understanding of the relationships of these disconformities may lead to delineation of possible stratigraphic traps for oil and gas.

Late Cretaceous delta-front sedimentation, central Wyoming

Upper Cretaceous rocks of the Mesaverde Formation, exposed between Hudson and Muskrat Creek on the south flank of the Wind River Basin, accumulated in an ascending succession of delta-front, tidal-flat, and delta-plain environments. M. W. Reynolds has traced rocks of the lower two environments from Alkali Butte eastward 15 km; they grade into rocks deposited in an offshore marine environment. Rocks of the delta-front facies are characterized by recurring sequences that grade from siltstone upward into sandstone beds; the lower sandstone beds of each sequence contain structures produced by slump and mass flow of sediments on the delta-front slope. The upper sandstone beds of each sequence accumulated in a variety of littoral-marine, beach-dune, and estuarine-channel environments. Deposition trends of sandstone units strike about N. 8° W. to N. 30° E. into the Wind River Basin, and Reynolds postulated that the beds may be reservoirs for petroleum on the downthrown (north) sides of east-trending faults in the basin.

Stratigraphic terminology of the Dakota Sandstone and Mancos Shale, west-central New Mexico

The generally transgressive rock sequence that constitutes the lower part of the Cretaceous System in west-central New Mexico—the intertongued Dakota Sandstone and Mancos Shale—has been divided into named formal and informal rock units of regional significance by E. R. Landis, C. H. Dane, and W. A. Cobban (1973). The formally named rock units are developed best in the Laguna area. They are, in descending order, the Twowells Sandstone Tongue of the Dakota Sandstone, the Whitewater Arroyo Shale Tongue of the Mancos Shale, the Paguate Sandstone Tongue (new) of the Dakota Sandstone, the Clay Mesa Shale Tongue (new) of the Mancos Shale, the Cubero Sandstone Tongue (new) of the Dakota Sandstone, and the Oak Canyon Member (new) of the Dakota Sandstone, which can be informally divided into distinctive upper and lower parts. Eastward and southward from Laguna, most of the sequence is mapped as the marine Mancos Shale. Westward and northwestward from Laguna, most of the sequence is mapped in the fluviatile and paralic Dakota Sandstone.

Geochemical anomalies in surface rocks may help find oil

Anomalous concentrations of manganese, vanadium, nickel, and iron as well as peculiar O^{18}/O^{16} ratios, have been found by T. J. Donovan (1974) in carbonate-cemented rocks overlying known petroleum deposits in the midcontinent and Rocky Mountain regions of the United States. The concentrations and ratios vary systematically and appear to coincide grossly with the subsurface structural pattern of the accumulations. Although the geologic and chemical processes behind these anomalies are not yet well understood, they appear to be related to the past movement of subsurface brines and hydrocarbons focused through anticlinal roofs. The anomalies may provide the basis for new geochemical tools for petroleum exploration.

Porosity studies, Pennsylvania sandstones in Wyoming

R. F. Mast studied porosity in Pennsylvanian sandstones in the Green River Basin, Wyo., using neutron, sonic, and density logs. Regression analysis of porosity and depth data showed a correlation coefficient of 0.70. Estimates of in-place permeability based on plots of core porosity and permeability indicate that natural or hydraulically induced fracturing may be required for commercial production of oil below 4,600 m.

Trace elements in crude oil

Published data for uranium, copper, vanadium, and nickel in crude oil have been evaluated in an attempt to correlate the occurrence of these elements with the strata that served as the source beds in which the oil formed. It was hoped that unusual concentrations of the elements could be related to their geochemistries in shales and limestones, the two most likely rock types in which petroleum will form. Preliminary evaluation has led to the conclusion that uranium is not a normal constituent of crude oil, and that distributions of vanadium and copper are not particularly significant. The content of nickel, however, is variable and may reflect the composition of various source beds. Vanadium-nickel ratios, when plotted for all oils without regard to sources or histories, seem to fall into two significant ranges of values that may be related to two types of source beds.

Transformation of algal sediment to oil shale

Motoaki Sato (USGS) and W. H. Bradley (Milbridge, Maine) have shown that the high oxygen content of algal sediment, such as the one found in Mud Lake, Fla., could be reduced to the level of the organic matter of oil shale by spontaneous decarbonation and dehydration. This finding has removed the difficulty Bradley (1966, 1970) pointed out in hypothesizing the algal origin of the rich oil shale in the Green River Formation. The study also indicated that the direct products of photosynthesis, such as carbohydrates, probably are the highest energy input in the process of separation of oxygen from carbon and hydrogen. Further oxygen separation to form hydrocarbons and other compounds richer in carbon or hydrogen would proceed spontaneously with evolution of some carbon dioxide and water, and with a fraction of the stored energy. Sato and Bradley concluded that the crucial factor for the formation of fossil fuels is the initial protection of the plant matter from aerobic oxidation. Blue-green algae provide such a protection themselves by the production of lauric acid which is a lethal inhibitor for aerobic bacteria, and also by mucilaginous sheaths which make the algae adhere and hinder aeration.

CHEMICAL RESOURCES

Potential shale-oil resources of units above the Mahogany zone, Green River Formation, Piceance Creek basin, Colorado

About 17 billion t of oil are contained in oil-shale units that average 45 to 76 l/t. According to J. K. Pitman and J. R. Donnell (1973), these units overlie the Mahogany zone, the uppermost rich oil-shale zone in the Piceance Creek basin, and heretofore had been considered overburden, probably to be wasted in a surface-mining operation. Some of these units underlie the prototype oil-shale lease tract C–a and could be stockpiled and later blended with the rich, stratigraphically lower oil shales in what is tentatively projected to be at least a 100,000-t/d open-pit operation.

Newly recognized marker beds in the Parachute Creek Member, Green River Formation

Stratigraphic studies by R. B. O'Sullivan along at least 16 km of outcrop in the eastern part of Piceance Creek basin, Colorado, revealed several key marker beds of dolomite in the Parachute Creek Member of the Green River Formation. The marker beds are very light tan and commonly form ledges in the generally smooth, gray slopes of the Parachute Creek Member. At many places, dark-brown solid hydrocarbons occur as very thin streaks or void fillings and give the marker beds a thinly banded or mottled appearance. Dawsonite ($NaAl(OH)_2CO_3$)

was detected in some of these beds by X-ray diffraction analysis. The marker beds are conspicuous and facilitate correlation of subdivisions of the Parachute Creek Member in the eastern part of the Piceance Creek basin.

Possible economic uses of trona-leonardite mixtures

Experiments by V. E. Swanson and T. G. Ging, Jr., (1972) indicated that the simple addition of water to mixtures of untreated trona and otherwise insoluble leonardite yields a rich, black, slightly alkaline solution of concentrated humic substances. Prices of both trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) from Wyoming and leonardite (naturally oxidized coal) from South Dakota and Wyoming are similar, ranging from $10 to $30 per tonne. The dissolved mixture could be used as a liquid soil conditioner, a leaf spray-micronutrient fertilizer (with the desired chelate elements added), or a leach solution for secondary recovery of ore metals or for capture of toxic metals from industrial wastes.

Processes of lithium concentration in sedimentary deposits

The compilation by J. D. Vine and E. B. Tourtelot of geological and geochemical data on the distribution of nonpegmatitic lithium deposits indicates an association with Basin and Range structure in the Southwest. The climate of this desert area favors concentration of lithium brines and salts by evaporation at or near the surface. The occurrence of lithium deposits in this region, however, probably has genetic significance for other reasons as well. For example, deep-seated faults may provide pathways for deep circulation of ground water; volcanic activity provides a source of heat to drive groundwater convection cells; and block faulting interrupts drainage, forming local basins that serve as hydrologic sinks from which the soluble constituents of surface and ground water cannot escape. Together, these processes serve to concentrate and trap lithium in near-surface sedimentary deposits where the lithium can most easily be discovered.

Zeolites and potassium feldspar of diagenetic origin in the Big Sandy Formation, Arizona

The Big Sandy Formation of Pliocene age covers an area of about 78 km^2 in southeastern Mohave County and consists chiefly of nearly flat lying lacustrine rocks that have a maximum exposed thickness of about 75 m. Lacustrine rocks are mainly mudstone with interbedded tuff and limestone. According to R. A. Sheppard and A. J. Gude, 3d (1973), tuffs make up about 2 or 3 percent of the exposed stratigraphic section, and they are from 0.01 to 1.02 m thick. All the originally vitric material in the tuffaceous rocks is completely altered. Zeolites, monoclinic potassium feldspar, clay minerals, and silica minerals now compose the altered tuffs. The zeolites are mainly analcime, clinoptilolite, erionite, and chabazite. Phillipsite, mordenite, and harmotome (a rare barium zeolite) are much less abundant. Monomineralic beds of zeolites and potassium feldspar were recognized, but most zeolitic tuff consists of two or more zeolites. Some beds of zeolite and potassium feldspar have economic potential. Analcime is associated with each of the other zeolites, and potassium feldspar is associated with analcime and most of the other zeolites. Textural evidence indicates that the zeolites, except analcime, formed directly from the silicic glass by a solution-precipitation mechanism. Neither analcime nor potassium feldspar seems to have formed directly from the silicic glass. Analcime formed from the early zeolite precursors, and potassium feldspar formed from analcime as well as from the other zeolites.

GEOTHERMAL RESOURCES

Determination of geothermal-reservoir temperature from chemical analysis of large-discharge warm springs

The waters of some high-discharge warm springs are mixtures of cold, dilute, near-surface ground water and hot more concentrated geothermal water that has ascended from depth. R. O. Fournier and A. H. Truesdell (1974) have devised a method of estimating the temperature and the proportion of the geothermal component. The method is based on the fact that the solubility of quartz in water is not linear with temperature, and it requires knowledge of the temperature and silica content of both the warm-spring water and the cold ground water of the region. This method may yield greatly improved estimates of subsurface temperatures in many geothermal areas and thus may prove to be an important exploration tool.

Long Valley, California

Geologic mapping by R. A. Bailey has confirmed that most of the thermal springs in the Long Valley caldera, Mono County, Calif., are located on or near north- to northwest-trending faults that are extensions of the Hilton Creek fault, one of the main active faults along the eastern margin of the Sierra Nevada. In addition, the thermal springs are generally distributed in an arcuate zone peripheral to the central resurgent complex of the caldera, suggesting that at depth the thermal waters are controlled by the caldera ring-fracture system or are localized in reservoirs in the thick sedimentary fill of the caldera moat zone. Control of thermal waters at depth by the caldera structures is also indicated by the apparent lack of any leakage of thermal waters along the Hilton Creek or other north-south faults outside the caldera even though the Hilton Creek fault is a deep and recently active structure.

Bipole-dipole techniques were used by W. D. Stanley, D. B. Jackson, and A. A. R. Zohdy (1973a, b) to produce an electrical resistivity map of the Long Valley caldera. The three major resistivity lows were discovered and then evaluated by 49 d-c resistivity soundings and 13 transient electromagnetic soundings. The resistivity low centered on the Cashbough Ranch, the largest in areal extent, is due primarily to a conductive layer as thick as 500 m, the top of which is at a depth of 50 to 300 m. A test hole 300 m deep showed this layer to consist of zeolitized rhyolitic tuffs and ashes at only 73° C. The second major resistivity low is due to a conductive zone at 600 to 1,400 m depth. It appears to be related to a splinter of the Hilton Creek fault and is coincident with a near-surface thermal anomaly. The third resistivity low is coincident with an aeromagnetic low at Casa Diablo Hot Springs and may be caused by extensive alteration of volcanic rocks to clays and zeolites.

The resistivity map and the sounding interpretations correlate with the geology and suggest that much of the hydrothermal activity has been confined to faults related to the Sierra frontal system, particularly the Hilton Creek fault. A geothermal reservoir probably exists only at depths greater than 1 km, and the most promising area for deep drilling appears to be at the intersection of two splinters of the Hilton Creek fault near Whitmore Hot Springs.

Using discharge measurements and chemical analyses of springs, R. E. Lewis calculated that the total surface discharge of geothermal water in Long Valley is about 250 l/s. Seventy-eight percent of this is discharged along a 2-km section of Hot Creek Gorge; 7 percent, by a group of springs in the vicinity of the fish hatchery; and 6 percent, by Whitmore Springs and the springs at the head of Little Hot Creek. Using the above discharge value and an estimated reservoir temperature of 180°C, the minimum heat flux from the Long Valley geothermal system is calculated to be 4.4×10^7 cal/s. This value is a minimum because it does not include conductive heat flow or heat accompanying unseen discharge of hot water below the ground surface.

Temperatures measured by A. H. Lachenbruch, R. E. Lewis, and J. H. Sass (1973) in 20 shallow holes (<30 m deep) in the Long Valley caldera indicate a variable pattern of the heat flow that can be attributed to movement of water within superficial sedimentary and volcanic rocks. Preliminary determination of conductive heat flow by Sass, Lachenbruch, and R. J. Munroe (1974) in granitic rocks north, south, and east of the caldera show no evidence of anomalous heat as little as 6 km from the rim. One measurement 3 km west of the caldera rim does, however, indicate excess heat. These heat-flow data suggest that the thermal anomaly of the Long Valley region is confined largely to the caldera. Although the caldera is likely to be underlain by a cooling pluton, the heat-flow data do not suggest appreciable volumes of molten material within 10 km of the surface.

A seismic-noise survey in Long Valley revealed a noise-amplitude anomaly with a predominant frequency of 2.5 Hz, which is 5 to 10 times higher than the regional background level. The noise anomaly is outside the region of surficial hydrothermal phenomena and may be due in part to amplification of regional background noise by the underlying 1 to 2 km of sediments. However, analysis of earthquakes recorded both on these sediments and on bedrock outside the area of anomalous noise shows that this is not the complete explanation.

The Geysers-Clear Lake area, California

Geologic mapping by R. J. McLaughlin in The Geysers steam field near Cloverdale, Calif., has delineated structural features in the complex Franciscan Formation of late Mesozoic age, that may have considerable bearing on interpretations of the geothermal system in that area. The dominant structural features in the Franciscan are a major system of northeast-dipping imbricate thrust faults cut by a system of nearly vertical northwest- to east-west-trending strike-slip faults that may be active. Thermal springs and zones of hydrothermal alteration along both of these fault systems indicate that the migration and localization of steam and thermal fluid is probably partly controlled by these features. Large serpentinite bodies and broad zones of pervasively sheared rock (mélange) along the northeast-dipping thrust faults form relatively impervious barriers along which lateral migration of steam might occur. The vertical movement of steam is partly controlled by high-angle faults that cut the thrust sheets and by related high-angle fracture zones in shattered rocks between the thrusts. Other structural features that could affect the localization of steam in The Geysers area are tight, southeast-plunging folds and probable broad, southeast-plunging regional warps.

Geologic mapping by B. C. Hearn, Jr., (USGS) and J. M. Donnelly (Univ. California, Berkeley), magnetic polarity determinations by C. S. Grommé, and K-Ar dates by Donnelly, G. B. Dalrymple, and M. A. Lanphere suggest that the central part of the Clear Lake volcanic field is younger than 0.5 m.y., whereas the southern part is older than 0.7 m.y. and thus overlaps part of the Sonoma Volcanics. Potassium-argon dates of less than 100,000 yr on obsidian from Borax Lake and olivine andesite from Mount Konocti suggest that the volcanic field is still active and may be underlain by a magma chamber.

Geothermal systems of Nevada

Studies by R. K. Hose have shown that most hot springs in Nevada occur along Basin and Range faults (late Miocene to Holocene) on the flanks of basins, but some occur within the basins. Spring temperatures range from slightly above ambient to boiling; some are superheated. Calculated minimum reservoir temperatures based on quartz solubility are mostly less than 190°C, although a few are higher (up to 252°C). Flows range from a trickle up to several hundred litres per minute.

The Nevada geothermal systems differ from the power-producing system at The Geysers and from those areas with a high potential for power production (for example, Jemez Mtns., N. Mex.; Long Valley, Calif.; Salton Sea, Calif.). These latter systems are associated with Quaternary felsic volcanic rocks, and probably derive their heat from cooling magma high in the crust. Northern Nevada, however, lacks felsic extrusive volcanic rocks younger than 10 m.y., and modern magmatic heat sources are therefore probably absent.

Northern Nevada is part of a large area of anomalously high heat flow and conductive geothermal gradients, probably resulting from a thin crust and a high-temperature upper mantle. Accordingly, Hose suggested that the geothermal systems in northern Nevada can be explained by deep circulation of meteoric waters along Basin and Range faults, without any reference to hidden bodies of magma.

Surveys by D. L. Peterson indicated that at least three hot-spring groups in Nevada are associated with intrabasin gravity highs. Gravity highs at Buffalo Valley and Leach Hot Springs are possibly caused by induration of basin sediments along fault zones. The gravity high at Hot Pot can be traced 8 km southward to an outcrop of Paleozoic sedimentary rock that is interpreted to reflect an uplifted Paleozoic block. Steep gravity gradients along the highs at Leach and Hot Pot probably reflect faults.

Geothermal systems of Idaho

A reconnaissance audiofrequency magnetotelluric (AMT) survey by D. B. Hoover outlined a major electrical-resistivity anomaly over more than 135 km^2 of the Grandview area of Owyhee County, Idaho. Subsequent d-c electrical-resistivity soundings were made by D. B. Jackson to determine the true resistivities and extent of the conductive zone at depths greater than those reached in the AMT survey. The soundings confirmed a conductive layer with a resistivity of about 5 ohm-m and a thickness of about 1.6 km in the area of the main AMT anomaly. The anomaly extends with reduced thickness at least as far east as Hammet.

Many hot springs and artesian wells throughout the area of the anomaly suggest that the conductive layer is related to hot formation water and associated hydrothermal alteration. H. W. Young and R. L. Whitehead estimated that ground-water temperatures at depth, based on several geochemical thermometers, are at least 150°C. Salinities of spring and well waters range from 181 to 1,100 mg/l. The elevated temperatures, good water quality, and immense indicated reservoir size suggest strongly that the Grandview area should be considered as a site for an experimental low-temperature geothermal powerplant.

Two areas near Weiser, Idaho, also are considered to have significant geothermal potential. H. W. Young and R. L. Whitehead reported that minimum reservoir temperatures based on geochemical thermometers are 150°C for Weiser Hot Springs and 170°C for Crane Creek Hot Springs. Estimated temperatures at depth, assuming that the sampled waters are a mixture of geothermal water and shallow ground water (Fournier and Truesdell, 1974), range from 200°C to 248°C for Weiser Hot Springs and from 212°C to 270°C for the Crane Creek area. A preliminary AMT survey by D. B. Hoover shows conductive zones at depth in both areas.

EXPLORATION TECHNIQUES

AREAL GEOCHEMICAL STUDIES

Gold Basin-Lost Basin district, Arizona

Analyses by J. C. Antweiler and E. L. Mosier of gold concentrates from more than 100 small quartz veins and prospects in the Gold Basin-Lost Basin area, Mohave County, Ariz., suggest the possibility of a mineralized zone containing disseminated molybdenum. Molybdenum is present in many gold samples, and tin and tungsten are present in a few.

Silver and copper are found in widely divergent concentrations in all samples. Lead, bismuth, and mercury are found in most samples; zinc, tellurium, and antimony are present in a few samples. Spectrographic analyses by J. C. Hamilton of the rock and ore samples that were hosts for the gold detected many of the same elements but in generally lower concentrations than those found in the corresponding gold concentrates. The analyses suggest a mineralized zone that may contain a disseminated molybdenum and (or) copper deposit.

Mineral Butte district, Arizona

A geobotanical survey made by M. A. Chaffee and C. W. Gale III, in the vicinity of the Mineral Butte porphyry copper deposit in Pinal County, Ariz., revealed a very close correlation between the areal extent and density of specimens of the California poppy (*Eschscholtzia mexicana*) and the areal extent of the copper in the residual-soil anomaly associated with the known copper deposit. This relationship between poppy populations and copper deposits has been noted by many workers in other parts of Arizona. Unfortunately, this poppy does not seem to grow around all Arizona copper deposits; consequently, its value as a geobotanical indicator plant is limited.

Montezuma district, Colorado

In their investigation of the Montezuma mining district, G. J. Neuerburg, Theodore Botinelly, and J. R. Watterson have found that this part of the Colorado mineral belt is defined by an assemblage of certain rock and alteration types and ore-mineral species, all of which originated during the venting of a Tertiary batholith through weak structures in Precambrian host rocks. The ore consists of silver-lead-zinc veins clustered on the propylitic fringe of a geometrically complex system of altered rocks, which are located at the intersection of the Oligocene Montezuma stock with the Montezuma shear zone of Precambrian ancestry. The alteration pattern conforms to the standard porphyry-metal model, but the pattern is developed around several small intrusives strung out along the shear zone and is therefore not expressed as the usual thick concentric zones centered on one large plug. The distribution of trace amounts of molybdenum suggests the possibility of molybdenum deposits in the district, but the alteration pattern suggests that any deposits would probably be small, scattered, and very deep. Disseminated molybdenite is essentially coextensive with altered rock and increases slightly in quantity toward the inner alteration zones. Two areas of vein molybdenite are associated with phyllic and potassic alteration and represent possible diffuse halos of molybdenite deposits. One group of veins resembles the Climax and Henderson deposits; however, this veining is only present in a small and isolated group of outcrops. The second group of molybdenite veins is in a bismuth-rich part of the Montezuma stock and underlies an area of bismuth veins; this group records the passage of contact-metasomatic ore fluids. Another bismuth-rich area is in the southeast corner of the stock in a region of bismuth veins and may indicate a third group of molybdenite veins.

Coeur d'Alene district, Idaho

Recent evaluation by G. B. Gott, J. M. Botbol, and J. B. Cathrall of geochemical data pertaining to the part of the Coeur d'Alene district adjacent to the Gem and Dago Peak monzonite stocks has resulted in the following conclusions:

1. Dispersion halos of lead, lead-zinc, copper-zinc, and tellurium-silver suggest that the known and exploited mineral belts in the northern part of the district extend northwest into a 30 km^2 area occupied by the syncline between the Dobson Pass and Carpenter Gulch faults. A thick sequence of Belt Supergroup rocks, some of which have been proved to be hospitable to the formation of lead-zinc-silver replacement veins, fill the syncline. The geochemical halos listed above appear to define the extension of the mineral belts.
2. Monzonite intrusive stocks in this area are truncated and offset by the Dobson Pass fault. Heat derived from the intrusive rocks has apparently remobilized and redistributed sulfur, tellurium, and cadmium relative to zinc to form halos of these volatile elements concentrically around the monzonite stocks. These halos are offset by the Dobson Pass fault in a manner similar to that of the intrusive rocks. The sulfur, tellurium, and cadmium halos are arranged normal to the trend of the mineral belts. This relation between the most volatile elements and the mineral belts containing lead-zinc-silver deposits suggests that the intrusives were at an elevated temperature after the mineral belts were formed.

Robinson district and vicinity, Nevada

In the Robinson mining district and Rowe Canyon area of White Pine County, Nev., Keith Robinson, G. B. Gott, A. E. Hubert, and G. L. Crenshaw have found that thallium and indium exhibit zoning patterns and geochemical distribution halos similar to those of other metals that are present, such as lead, zinc, and silver. All of these elements form aureoles or halos around the central copper- and iron-rich core. The distributions of thallium or indium do not appear to be related to the lithology of the Paleozoic or Tertiary host rocks. In the zone of hydrothermal alteration anomalies of both elements cluster adjacent to the intrusive Cretaceous stocks and to the major fault zones. Thus, it appears that the intrusive stocks are responsible for the introduction of thallium and indium into the surrounding host rocks, with the faults serving as conduits. On the basis of its wider areal distribution, thallium is apparently more mobile than indium. A correlation analysis indicates no relationship between the distribution of the two elements. A cluster analysis involving all elements suggests that the distribution of thallium is closely associated with that of the volatile elements, cobalt and mercury, and the distribution of indium is associated with the distribution of gallium and tin. Using the exposed Robinson mining district as a model, the restricted distribution of thallium in the Rowe Canyon area and the almost complete absence of detectable indium suggest that mineralization may occur at depth with only the tip of the geochemical halo being exposed at the surface. Thus, the potential of thallium, in conjunction with indium, for use as a sensitive indication of economic mineral deposits is considerably enhanced, particularly in the search for concealed mineralization.

Hillsboro district, New Mexico

According to T. G. Lovering, representative samples of supergene jasperoid from a large area of silicified Paleozoic carbonate rocks about 3 km east of Hillsboro, N. Mex. contain >10 percent Pb, 70 to 100 ppm Ag, 300 ppm Cu, 30 ppm Mo, 70 ppm Sn, and 0.1 to 0.2 percent Zn. There are no mines in this area, which is south of the gold-mining district and immediately south of the outcrop area of a small quartz monzonite stock containing copper minerals.

The samples, collected by A. V. Heyl, Jr., and C. H. Maxwell, consist of silicified gossan containing cerrusite and descloizite. They are very similar in minor-element content to supergene jasperoid samples from the Leadville district in Colorado. The silicified area represented by these samples is at least 100 m wide and 0.5 km long at the surface and is adjacent to a highway at its northern end. Field relations suggest that the copper-bearing quartz monzonite stock may underlie the silicified carbonate rocks here at shallow depth.

Hamme district, North Carolina

In the Hamme tungsten district, North Carolina, J. E. Gair and J. F. Windolph, Jr., have found that semiquantitative spectrographic data from soil samples indicate a favorable but limited method of search for tungsten occurrences in geologically favorable areas in the Piedmont, specifically in the border zones of granitic plutons. Soil samples taken above, or within several hundred metres downslope from, known huebnerite-bearing quartz veins commonly contain from 50 ppm (lower limit of detection) to several hundred parts per million tungsten, whereas samples that are not near veins generally contain less than detectable concentrations of tungsten. Near veins, tungsten values are distributed sporadically, with the highest values not necessarily directly over a vein. Huebnerite is not very soluble during weathering; thus, tungsten probably is irregularly dispersed in the soil in particles of huebnerite. Therefore, tungsten concentrations of 50 ppm or more in soil, derived from huebnerite or other members of the wolframite series, are likely to be found only where normally lenticular mineralized veins are near enough to the surface to be subject to mechanical weathering and where vein-quartz float is present.

Keg Mountain district, Utah

R-mode factor analysis was used by D. A. Lindsey to develop and test a model relating mineralogy to trace-element content of water-laid tuff in the Keg Mountains of Utah. Interpretation of the factor analysis indicates that five processes are responsible for a major part of the observed variation in mineralogy and trace-element content. These processes are: (1) local concentration of major detrital minerals, including iron oxides, (2) concentration of accessory detrital sphene and zircon in the eastern part of the Keg Mountains, (3) zeolitization of volcanic glass, (4) feldspathization, and (5) slight concentration of lead, gallium, and beryllium in the parent rhyolite magma.

The concentration of detrital minerals derived from older volcanic rocks has a strong effect on the distribution of trace elements in the unmineralized water-laid tuff. The elements Ba, Fe, Cu, Mn, Ti, and V are associated with the concentrations of major detrital minerals. The elements lanthanum, niobium, yttrium, and zirconium are associated with the concentration of sphene and zircon. It is evident that any geochemical exploration for heavy metals or rare earths that utilizes trace elements in clastic deposits most consider the effects of sedimentation on trace-element variation.

TOPICAL GEOCHEMICAL STUDIES

Thallium and indium in manganese nodules

Thallium concentrations ranging into the hundreds of parts per million have been detected by Keith Robinson, G. L. Crenshaw, and A. E. Hubert in both marine and nonmarine manganese nodules. Indium concentrations are generally very low or below the limits of detection. These observations, together with the fact that there are anomalous thallium concentrations in mineralized areas, particularly those rich in the base metals, suggest that thallium analyses of secondary manganese oxides could be used effectively in mineral exploration programs.

Scavenging of silver by manganese oxides

A number of heavy metals can be scavenged by the hydrous manganese and iron oxides in sediments and soils in the weathering zone. One additional metal, silver, has been found by T. T. Chao and B. J. Anderson to be strongly scavenged by manganese oxides. Stream sediments containing anomalous amounts of silver were collected near Montezuma and Ouray, Colo. These samples were immersed in nitric acid of different molarities (1–10 *M*). Silver, manganese, and iron that simultaneously dissolved at each acid concentration were determined by atomic absorption. The relationship between silver dissolution and the dissolution of manganese and (or) iron was evaluated by linear and multiple-regression analyses. The results indicate that manganese oxides, rather than iron oxides, are the major control on the scavenging of silver in these stream sediments.

Luminescence properties of selected natural materials

Previous success with a prototype Fraunhofer Line Discriminator (FLD), an optical-mechanical device for the detection of solar-stimulated luminescence, indicates that an FLD could prove to be a very useful instrument in many types of remote sensing surveys. In order to determine the required sensitivity and optimum Fraunhofer lines for operation of a FLD of an advanced design, measurements of luminescence as a function of wavelength were made of selected materials (with rhodamine WT as a standard), using a Perkin-Elmer MPF–3 fluorescence spectrometer with a correction attachment that adjusts for variation with wavelength of the detector sensitivity and source intensity (Watson and others, 1973). Resulting spectra were also corrected for the wavelength dependence of the intensity of direct sunlight and diffuse skylight. The luminescence spectra of 56 petroleum samples demonstrate that crude oil luminesces at the 518.4-nm Fraunhofer line at intensities equivalent to as high as 1,600 μg/l rhodamine WT, while refined oils luminesce at the 486.1-nm Fraunhofer line with intensities as high as 8,000 μg/l. Similar measurements on nine effluent samples collected from surface drainage adjacent to phosphate processing plants in central Florida confirm that luminescence at the 486.1-nm Fraunhofer line with an equivalent intensity as high as 80 μg/l rhodamine WT dye. The luminescence of needles of *Pinus ponderosa* growing in a copper-rich soil near the Malachite mine, Jefferson County, Colo., was compared with the luminescence of needles from trees growing in soil of background copper content. Results indicate that the luminescence of anomalous and background trees at the 656.3 Fraunhofer line ranges between rhodamine WT dye equivalent intensities of 5 μg/l and 19 μg/l. There does appear to be a short-term diurnal effect, however, with the maximum difference between background and anomalous trees occurring in the early afternoon. It should be noted that luminescence measured in the laboratory was found to be from 43 to 48 times more intense than would be measured with an FLD because of a difference in measurement techniques. Even with this correction, resulting luminescence intensities appear to be within the sensitivity limits of an advanced FLD currently being developed. These findings suggest that luminescence surveys of forested areas with an airborne FLD might possibly be useful in mineral exploration. In addition to suggesting the use of the FLD for the detection of the materials discussed above, these data represent the first effort to quantify and compare luminescence of materials in terms of a standard, rhodamine WT, the luminescence properties of which are well known.

NEW ANALYTICAL TECHNIQUES

Fluorimetric determination of selenium

A sensitive and rapid method for the determination of selenium occurring in geologic materials in concentrations less than crustal abundances has been developed by G. L. Crenshaw and H. W. Lakin (1974). The method involves the formation of 4,5-benzopiazelenol for the fluorimetric estimation of selenium with a lower detection limit for a 0.5-g sample of 0.04 ppm Se.

Gas detector for mercury and radon

An experimental instrument ensemble developed by W. W. Vaughn will allow simultaneous quantitative measurements of mercury and radon in the volume of gas to a level of sensitivity below the crustal abundance for both gases. Reliable and reproducible determinations of these constituents in soil gases should be useful in mineral exploration surveys and in environmental studies.

RESOURCE ANALYSIS

Resource data bases

Interest in the Computerized Resource Information Bank (CRIB) of the USGS (described by Calkins, Kays, and Keefer, 1973) increased markedly during 1973 as CRIB activities moved from a principal emphasis on development to one focusing on operations, data management, and extended applications, such as map plots, which expanded the utility and availability of CRIB to a larger user community. The file tripled in size during 1973 (to 32,000 records). A major part of the addition was approximately 10,000 records on mineral deposits and occurrences in Alaska. The CRIB file is presently being actively used, and contributed to, by the Tennessee Valley Authority, the Bureau of Land Management, the National Museum, Geological Surveys of Alabama and Idaho, and personnel within the USGS.

Parallel with the growing interest in CRIB, there was an increasing interest, domestically and internationally, in the creation of other geologically related data files: geothermal resources, coal resources, uranium and thorium resources, and isotope data.

J. M. Botbol and R. W. Bowen have developed a Geologic Retrieval and Storage Program (GRASP) for interactive processing of oil- and gas-pool data which has (1) complete system portability, (2) immediate data access, (3) simplicity of operation, and (4) a geoscience orientation. The GRASP system has been specifically applied to the Oil and Gas Data Bank at the University of Oklahoma, where there are 400 variables for each pool and also a graphics file containing each pool's boundary sectors. The textral file and graphics file for each pool are linked by a unique identification number. The interactive nature of GRASP, coupled with the ease of operation, provides the user with immediate access to large amounts of data for purposes of selective retrievals, data manipulation, and graphical display.

The Office of Resource Analysis of the USGS has recently purchased the MANIFILE (Laznicka, 1973) from the University of Manitoba. The file contains just under 4,000 records, each record being a distinct mineral deposit or area. Associated with each record are 132 items, the most important being assured content, estimated content, and grade of Au, Ag, Cu, Zn, Pb, Cr, W, Mo, Sb, and Hg. Some of the other items associated with each deposit include references, geological ages, geotectonic information, ore-body shape, and minerals. A part of the file is interactively retrievable with the GRASP system. On the basis of selected conditions, rapid retrieval of any part of the file can be obtained.

Resource estimates

N. J Page and J. C. Dohrenwend (1973) reported that the Stillwater Complex contains the largest potential chromite and platinum metal resources and the second largest potential nickel resource in the United States. The ultramafic zone has produced about 900,000 t of chromite concentrate and contains unmined potential resources of 8,200,000 t of Cr_2O_3. Nickel and copper sulfide minerals that occur in the basal zone and adjacent metasedimentary rocks represent one of the largest potentials of nickel in the United States—a known reserve of 165 million t of 0.25 percent Ni, 0.25 percent Cu, and a potential resource of 2 to 10 times as much. The complex has been estimated to contain the largest potential source of platinum metals in the United States—possibly over 4.2 million kg. In addition, the anorthosites in the Banded and Upper zones represent alumina resource of about 16.9 billion t. An iron-formation also is present in the adjacent Precambrian metasedimentary rocks, and a coal bed is present in the nearby Eagle Sandstone, of Cretaceous age, which contains about 33.5 million t of B and C bituminous coal at 50-percent recovery. The eventual utilization of these resources depends on the availability of large quantities of energy, and for this reason, they may not be recovered unless new sources of energy or new recovery techniques are developed.

Resource model studies

L. J. Drew (1974a, b) used a simulation model and statistical-analysis technique in two studies to analyze the process of exploring for petroleum deposits in the Powder River Basin. In the first study, a simulation model was used to determine the effects of resource-base exhaustion upon various scales of exploration activity. The exhaustion of the resource base of petroleum deposits was shown to force the larger exploration operators out of the basin early in the exhaustion sequence. Smaller operators were found to be able to make an acceptable rate of return even when 75 percent of the resource base was exhausted. This result from the model study correlates closely with the actual behavior of the exploration companies that were active in the study area. Another result obtained from the model study was the indication that a large deposit which remained undiscovered until 1969 would have almost certainly been discovered much earlier if a random-drilling strategy had been employed.

The second study involved analysis of the effectiveness of exploring for deposits during periods when exploration plays were active (cyclical wildcat drilling), as compared with the effectiveness of exploring for deposits on the basis of long-range regional-exploration data (ambient wildcat drilling). The efficiency factor for exploring during ambient phases of the exploration process was shown to be 2.8 times greater than that for exploring during the cyclical phases. During the 1950–71 period, 3,691 wildcat wells were drilled in the basin. Of this total, 1,146 wells were drilled during ambient phases, resulting in the discovery of 40 deposits. The average wildcat well drilled during ambient periods discovered 43,380 t of petroleum. During the cyclical phases of exploration of the basin, 2,545 wildcat wells were drilled, and 120 deposits were discovered. The average wildcat well drilled during cyclical periods discovered 15,726 t of petroleum.

Although the average quantity of petroleum discovered per wildcat well was nearly three times lower during periods when exploration plays were active, the practice of following exploration plays rather than drilling regional prospects was not without its reward. The risk of failure was found to be substantially higher during the ambient phase, with only 3½ chances of success per 100 wildcat wells drilled. During the cyclical periods, the chance of success rose to 5 wells per 100 drilled. The acceptance of a nearly three to one reduction in expected returns in order to reduce the risk of failure by about 43 percent shows that the average operator in the basin has an aversion to risk. This aversion is so strong that it forced the average operator to accept and drill prospects during exploration plays which returned on the average only about 51 percent of that which was gained by drilling prospects based upon long-range regional evaluations.

Another result of this study was the construction of a statistical model that was used successfully to predict the magnitude and duration of exploration plays in various parts of the Powder River Basin. This model was based only upon the size and depth of the suite of deposits discovered during the duration of the various plays which developed within the time period studied.

MINERAL INVESTIGATIONS RELATED TO THE WILDERNESS ACT

The Wilderness Act of 1964 directs the Secretary of Agriculture and the Secretary of the Interior to review the suitability of lands being considered for inclusion in the National Wilderness Preservation System. To aid in evaluating suitability for wilderness inclusion, the USGS and USBM 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 2.9 million ha. Reports on 31 of the areas have been published as USGS bulletins, and reports on the remaining 3 were placed in open file during 1973; they will be printed during 1974 and 1975. The primitive-area report that was published in fiscal year 1974 is summarized as follows:

Idaho Primitive Area, Lemhi and Valley Counties, Idaho

The primitive area is underlain by rocks ranging in age from Precambrian to Cenozoic. Older Precambrian rocks are intensively metamorphosed schist and gneiss that crop out mostly in the northwestern part of the area.

Younger Precambrian rocks are slightly metamorphosed sediments that have been intruded by complex bodies of gabbro and syenite of late Precambrian age; these rocks are exposed mainly in a belt across the central part of the area. Granitic rocks of the Idaho batholith of Cretaceous age underlie much of the northern part and some of the southern part of the area. A thick pile of Eocene volcanic rocks covers much of the central part of the primitive area, and these volcanic rocks have been intruded by a small granitic batholith, also of Eocene age. All the rocks have been subjected to several periods of deformation.

The mineral survey of the primitive area and vicinity by F. W. Cater, D. M. Pinckney, W. B. Hamilton, and R. L. Parker (USGS), and R. D. Weldin, T. J. Close, and N. T. Zilka (USBM) included the originally designated primitive area of about 4,960 km^2 and adjoining areas that aggregate about 705 km^2.

The study area is surrounded by highly mineralized terrain. Mining districts within and contiguous to the primitive area have yielded more than $95 million worth of Au, Ag, Cu, Pb, Zn, W, Sb, Co, Ni, and Hg ore, of which about $1,671,500 worth of

Au, Ag, Cu, Pb, Zn, and W ore has been extracted from deposits inside the study area. County records show that about 5,400 mining claims have been located in the area.

The appraisal of the mineral-resource potential of the study area involved reconnaissance geologic mapping, extensive sampling of rocks and stream sediments, and studies of all known mineral occurrences and areas considered favorable for mineral deposits. An aeromagnetic survey of the area was also made to help evaluate geologic environments favorable for ore deposits.

The area is informally divided into 11 districts; the 4 adjacent areas are designated as additions. Six districts and one addition have a record of mineral production, and they have a small-to-modest mineral resource potential. These districts and the additions are along the west and south sides of the primitive area. The Thunder Mountain district, judging from its past production and potential resources, is the most important gold-silver district in the primitive area. It has produced more than $500,000 in gold and silver, mostly from two mines, the Dewey and the Sunnyside. Reserves blocked out by mine workings and drilling total a few million tonnes of mineralized rock of marginal grade. The geology of the area of these and three other mines indicate a potential for additional resources of moderate tonnage of low-grade mineralized rock. Many thermal springs are in the primitive area, especially in the southern part, but data on the geology indicates they have a moderately low potential for geothermal energy. (See F. W. Cater and others, 1973.)

WILDERNESS AREAS

Mineral surveys have been completed on 13 of the 54 wilderness areas that were established before or by the Wilderness Act of 1964. A report on the Chiricahua Wilderness was published during 1973, and four others may be printed during 1974. A report on the Pasayten Wilderness Area, Washington, which was established after 1964, was published in 1971.

Chiricahua Wilderness, Cochise County, Arizona

The Chiricahua Wilderness encompasses about 72 km^2 of the rugged central part of the Chiricahua Mountains near the southeast corner of Arizona. The mountains are a fault block typical of many ranges in southeastern Arizona. The rocks in the wilderness are mainly weakly deformed middle Tertiary volcanic and intrusive rocks—chiefly rhyolite and monzonite—and shale and sandstone of Cretaceous age.

The mineral survey was conducted by Harold Drewes (USGS) and F. E. Williams (USBM), and they found the wilderness area to have a low mineral potential. The area is mostly covered by volcanic rocks younger than the period of major mineralization in the region, which is Late Cretaceous or early Tertiary in age. Furthermore, Cretaceous and older rocks exposed within a few kilometres of the wilderness are only weakly mineralized. One area, about 9 km to the north, is moderately mineralized. Thus, although the occurrence of similarly mineralized rock beneath a thick cover of unmineralized volcanic rocks is conceivable, finding such deposits would be difficult, and recovering the metals in them would not be economically attractive. (See Harold Drewes and F. E. Williams, 1973.)

Bob Marshall Wilderness Area, Lewis and Clark and Flathead Counties, Montana

Geologic mapping by M. R. Mudge and R. L. Earhart in the Bob Marshall Wilderness and adjacent areas, northwestern Montana, has demonstrated that the Lewis thrust fault at Glacier Park extends approximately 125 km farther south than had been previously supposed. The southern extension of the Lewis fault was called the West Fork thrust zone by Mudge (1966, 1972) in the western part of the Sun River area. Prior to the present investigation, the fault was known to extend only 21 km south of Glacier Park. Earlier investigators, lacking detailed geologic maps, disagreed on the southern extension of the Lewis fault.

The Lewis fault is the westernmost and youngest thrust fault in the disturbed belt in north and central parts of the area, whereas a thrust fault slightly younger than the Lewis is mapped a short distance west of the Lewis in the southern part. The average strike of the Lewis trace is about N. 15° W., and the dip of the fault plane ranges from 17° to 43° W.; dips of 17° to 20° are most common. In places, the Lewis thrust overrides related but slightly older thrust plates to the east. At the south end of Glacier Park, the fault trace can be observed for about 19.3 km in an east-west section. Here, Precambrian Y rocks of the Belt Supergroup are in thrust contact on thrust-faulted and folded Cretaceous rocks.

In the northern part of the study area, Belt rocks of Precambrian Y age are thrust over Mississippian rocks and, in places, Cretaceous rocks. At Glacier Park, the horizontal displacement on the fault is probably more than 38 km, and the amount of displacement diminishes southward to a hinge point that appears to be in Dearborn Canyon, about 125 km south of the park. In the upper part of Dearborn Canyon, the Lewis fault has thrust Mississippian rocks over Mississippian rocks.

Galiuro Wilderness, Graham County, Arizona

The Galiuro Wilderness Area covers about 260 km², but the study area necessary for an adequate mineral evaluation covers at least 520 km². The Copper Creek mining district, which in 1972 contained one operating copper mine and where two extensive programs of porphyry copper exploration were underway, is contiguous to the northwestern corner of the wilderness area.

The geologic setting of the porphyry copper deposits comprises a basement of Laramide and older potential host rocks overlain by postore Tertiary andesites and ash-flow tuffs. Geologic mapping of fresh and altered rocks in the vicinity of Copper Creek along the boundary of the wilderness area has revealed that older rocks favorable for porphyry deposits lie within the wilderness area beneath the Tertiary volcanics. Some claims have been staked within the wilderness area, but recent drilling so far has been outside the wilderness boundary.

South Warner Wilderness, Modoc County, California

The South Warner Wilderness encompasses about 280 km² of rugged terrain in the Warner Mountains of northeast California. The crest of this north-trending range bisects the area and reaches a maximum elevation of nearly 3,050 m. According to studies by W. A. Duffield, the Warner Mountains are a fault-bounded block of the Basin and Range province that has been upfaulted between 1,500 and 3,000 m. The bedrock in this horst consists of 1,700 m of coarse clastic sedimentary rocks of Oligocene age that are overlain by about 1,700 m of rhyolitic, andesitic, and basaltic volcanic rocks of Miocene age. Mafic sills are common in the Oligocene section, and abundant, steeply dipping mafic dikes penetrate the top of the range. The entire bedrock section is conformable and dips about 25° to the west. Uplift and tilting began no sooner than about 13 m.y. ago, which is the K-Ar age of the uppermost rocks.

Jarbidge Wilderness, Elko County, Nevada

R. R. Coats, R. C. Greene, and L. D. Cress, evaluating the mineral resources of the Jarbidge Wilderness and adjacent areas, found numerous barite occurrences, some of which were previously known. One deposit in the adjacent study area is estimated by L. Y. Marks (USBM) to contain about 80 billion t of barite accessible by surface mining. Most larger occurrences are vein deposits in Ordovician limestone and chert, or in upper Paleozoic limestones and quartzite. Minor occurrences are known in lower or middle Tertiary volcanic rocks. Most of the veins fill steeply dipping fractures.

STUDY AREAS

Mineral surveys of 54 of the 291 areas being studied by the Forest Service for the Wilderness System have been completed. Investigations of 13 of the completed study areas are included in reports on primitive and wilderness areas. Nineteen areas are discussed in 11 open-file reports. Results from some of the areas are given below.

Granite Fiords area, Alaska

Fieldwork for the mineral-resource evaluation of the Granite Fiords study area was completed during the summer of 1973, by H. C. Berg, R. L. Elliott, J. G. Smith, and Andrew Griscom (USGS), and T. L. Pitman and A. L. Kimball (USBM). The 2,600-km² area is in the remote and unpopulated Coast Mountains near the southern tip of the southeastern Alaska panhandle.

The area is underlain by Mesozoic and Cenozoic plutonic and metamorphic rocks collectively known as the Coast Range batholithic complex. Preliminary K-Ar dating studies show that several of the less foliated plutons are about 45 to 50 m.y. old, and that a gabbro just south of the area is about 23 m.y. old.

A zone postulated to be one of large-scale overthrusting was discovered in the northeastern part of the area. This is the first thrust fault to be mapped in the region, and it offsets the rock units that contain the most significant mineral deposits.

Indian Peaks study area, Boulder and Grand Counties, Colorado

Geologic mapping by R. C. Pearson, in connection with the mineral-resource study of the area, has revealed that the Arapaho Pass route, long proposed for a highway across the Continental Divide, has serious geologic problems. A large fault extends through Arapaho Pass and Caribou Pass and parallels the best highway route for several miles. The amount of deformed rock along the fault is comparable to that of the Berthoud Pass fault, to the south, which has caused many engineering problems in highway and tunnel construction.

Cougar Lakes-Mount Aix study area, Yakima and Lewis Counties, Washington

Reconnaissance geologic mapping conducted during the mineral survey of the study area by G. C. Simmons and A. P. Pierce has confirmed much of unpublished work of A. T. Abbott and added new data pertinent to the geologic history of this little known area east of Mount Rainier National Park.

The oldest rocks are argillite, graywacke, and metabasalt that were folded, slightly metamorphosed, and eroded prior to the deposition of the Puget Group of Eocene and Oligocene rocks. The Puget Group consists of shale, arkose, and carbonaceous shale which interfingers with the upper part of the Ohanapecosh Formation of Oligocene age. The Ohanapecosh consists of tuff, breccia, and flows of andesitic composition. All rocks were slightly folded and successively intruded by granitic rocks and rhyodacite. Slight mineralization accompanied the intrusions.

After a period of erosion, dikes, and sills of andesite porphyry were intruded. The rocks are considered to be hypabyssal equivalents of the Fifes Peak Formation, an Oligocene or Miocene unit which unconformably overlies the older rocks.

During the Miocene, while the Yakima Basalt was overlapping the Fifes Peak Formation to the east, the Fifes Peak was eroded. Andesite flows were extruded from several centers, probably during the Pliocene. After the present drainage was well developed, basalt of probable Pleistocene age accumulated along the crest of the Cascade Range and flowed into adjacent valleys. The glaciated basalt plateau is capped by an unglaciated Holocene basalt cinder cone.

Tracy Arm-Fords Terror study area, Alaska

Reconnaissance geologic mapping and extensive geochemical sampling in the Tracy Arm-Fords Terror study area, in southeastern Alaska, has been concentrated along a transect at the southwestern and southern boundaries. Low-grade metavolcanic, metacarbonate, and metadetrital clastic rocks of late Paleozoic and early Mesozoic(?) age have complex structures and lie to the southwest of higher grade metavolcanic rocks that are adjacent to gneiss and a Tertiary(?) granitic intrusive complex of the high part of the Coast Range. The studies by D. A. Brew, Béla Csejtey, Jr., A. B. Ford, and D. A. Grybeck indicate a varied petrogenetic history for the gneiss in the complex and suggest that there was emplacement of a much greater volume of Tertiary(?) granitic rocks than was hitherto suspected.

Laramie Peak study area, Wyoming

Mineral-resource studies in the Laramie Peak area, southeastern Wyoming, by Kenneth Segerstrom, noted that the highest part of the granitic Laramie uplift appears to be a northeast-striking horst about 30 km long and 5 to 10 km wide. The horst is bounded on the southeast side by a shear zone with minor copper and nickel mineralization, and on the northwest side by a broad fracture zone in which a swarm of mafic dikes has been emplaced. The dikes of Precambrian age are commonly sheared at their borders and, less commonly, throughout their entire width. Most, if not all, of the shearing and fault-block displacement probably took place in post-White River (Oligocene) and pre-Ogallala (Miocene) time.

OFFICE OF MINERALS EXPLORATION

MINERALS DISCOVERY LOAN PROGRAM

The USGS, through its Office of Minerals Exploration (OME) under Public Law 85–701, approved August 21, 1958, 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. An approved application must indicate a reasonable geologic probability that a significant discovery of ore may be made on a property by the proposed exploration work. Contracts for exploration work are prepared for approved applications. 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 based on favorable results of work on completion of a contract, the obligation for royalty payments on production 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, the following 27 minerals or metals are eligible for Government participation at 50 percent of the allowable costs of exploration:

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)	

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

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

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

Activity on the OME program in calendar year 1973 and totals for the program through December 31, 1973, were as follows:

	Calendar year 1973	*Program totals, 1958 through 1973*
Applications:		
In process of review Jan. 1, 1973	13 (revised)	
Received	18	[1] 940
Denied	2	386
Withdrawn or inactive	16	337
Approved	3	207
In process of review December 31, 1973	10	
Contracts:		
Executed	3	207
Total value	[2] $110,306	$13,067,746
Government share	[2] $82,729	$7,548,733
Contracts—Continued		
Disbursements	$156,249	$4,636,284
Repaid to Government through royalties on production	$8,010	$404,937
Estimated recoverable value of reserves at metal prices as of mid-July 1973	$2 million	$163 million

[1] Revised total. Total estimated cost of proposed exploration—$89.7 million.

[2] Includes value added to existing contract by amendment.

Silver and gold exploration projects accounted for about 66 percent of the total value of contacts conducted on the program from 1958 through 1973 as shown:

Commodity	*Number of contracts*	*Total value of contracts*	*Percentage of total value*
Silver	73	$5,472,000	42
Gold	64	3,145,000	24
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	1
Beryllium	3	127,000	1
All others (cobalt, fluorspar, mica, nickel, platinum, uranium	12	550,000	4
Total (15 commodities)	207	$13,068,000	100

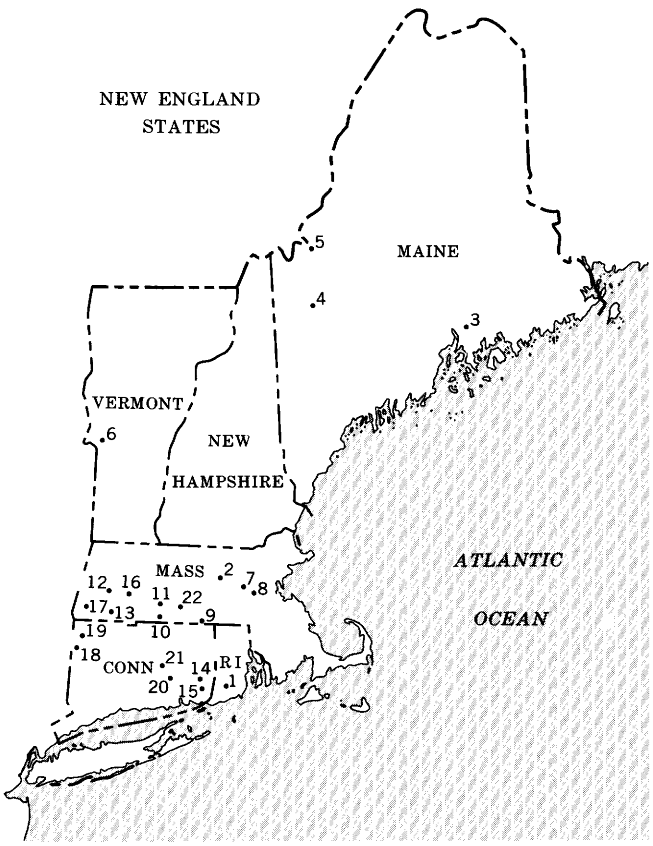
GEOLOGICAL, GEOPHYSICAL, AND MINERAL-RESOURCE INVESTIGATIONS

NEW ENGLAND

USE OF REMOTE-SENSING DATA IN GEOLOGIC MAPPING

Seismic surveys show saturated deposits in Rhode Island

The Rhode Island Board of Water Resources has outlined three potential ground-water reservoirs in Washington County, R.I. (loc. 1, index map). Seismic-refraction surveys conducted by C. R. Tuttle and J. H. Peck within the broadly defined limits of the three areas confirm that large volumes of water-saturated surficial deposits occupy what are probably pre-Pleistocene valleys in the bedrock surface. Seismic velocity of the saturated material in all three basins is nearly uniform, averaging 1.62 km/sec. Although the texture and hydrologic characteristics of the water-bearing deposits cannot be determined by seismic methods, the remarkably uniform velocity seems to indicate that the materials do not have wide variations in geologic character and probably range in size from silt to fine gravel. Of 127 seismic shot points which were fairly unevenly distributed among the 3 basins, 68 (53 percent) had calculated thicknesses of water-saturated material of more than 15 m. Twenty-eight percent of the points had more than 30 m of saturated sediments. Test borings and pumping tests are required to fully evaluate the reservoir characteristics, but all three basins appear to have a good potential for development of large supplies of ground water for municipal or commercial use.



Magnetic anomaly in Sterling, Massachusetts

A positive magnetic anomaly in the town of Sterling, Mass. (loc. 2), is a prominent feature on the west side of the aeromagnetic map of the Clinton quadrangle (U.S. Geol. Survey, 1970). Geologic mapping of the area by J. H. Peck and study of the surface rocks show that there is no magnetite-bearing rock at the surface which could cause the anomaly. Analysis of the anomaly indicates a depth to the top of the magnetic rock of about 76 m below ground surface. The anomaly is interpreted to be caused by a small (about $328\times1,830$ m) gabbroic plug that has a thin (probably less than 33 m wide) basic dike trending northeasterly away from the plug. The anomaly is similar in intensity to those recorded over Triassic diabase dikes in central Massachusetts. It seems probable, therefore, that the plug is Triassic in age and is a feeder for a small diabase dike in the subsurface.

STRUCTURAL AND STRATIGRAPHIC STUDIES

Ordovician igneous activity in south-central Maine

Muscovite- and garnet-bearing granitic plutons have been recognized by D. R. Wones in south-central Maine (loc. 3). Preliminary Pb^{207}/Pb^{206} dating of zircon by R. E. Zartman yields an age of about 430 m.y. These plutons comprise part of a migmatized terrane known as the Passagassawakeag Gneiss. [The Passagassawakeag Gneiss of Bickel (1971) is herein adopted for usage by the USGS.] The gneiss contains evidence of three deformations prior to the Ordovician intrusions and is most probably of Precambrian age. The geologic block containing these Ordovician intrusions is bounded to the northwest by a N. 55° E.-trending strike-slip fault and to the southeast by a steeply dipping fault of unknown motion. The motion of the fault on the southeast is pre-Middle Devonian, but the fault on the northwest was active after Middle Devonian plutonism.

Dating of metamorphic and tectonic overprinting in western Maine

Previous bedrock mapping by R. H. Moench (1971) and by C. T. Hildreth and Moench in western Maine (loc. 4) 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 intense superposed deformation and high-grade metamorphism. These superposed features evidently are directly related to the emplacement of subhorizontal sheetlike bodies of granitic magmas at depths in the crust of about 13 km. The exposed part of the Mooselookmeguntic pluton appears to be the broadly arched part of one great sheet that extends beneath a cover of metamorphic rocks. To the northeast, it is interpreted to join a subhorizontal sheetlike extension of the Lexington pluton, inferred by Kane and Bromery (1968) from gravity data. Cupolas and isolated granitic bodies above the principal sheet (or sheets) form the smaller plutons in the region. Samples from the Mooselookmeguntic pluton and related bodies have yielded a 379±6 m.y. isochron age (9 points, rubidium-strontium whole-rock method, by R. E. Zartman). Samples of pegmatite obtained from drill cores show some scatter from the isochron but yield an average age, assuming the same initial Sr^{87}/Sr^{86} ratio, that is consistent with the 379±6 m.y. isochron age (Moench and Zartman, 1974). This radiometric age effectively dates the youngest high-grade metamorphism and superposed deformation in western Maine.

Relict obduction and hinge zones in central western Maine

Rocks in central western Maine are assigned by E. L. Boudette to four major tectono-stratigraphic successions: (I) A Precambrian sialic basement massif that has an isotope age between 955 and 1,510 m.y.; (II) Upper Cambrian(?) to Lower Ordovician(?) coupled ophiolite and flysch sequences; (III) Middle Ordovician(?) flysch; and (IV) Silurian-Devonian molasse grading to flysch.

A hinge zone and a probable Late Cambrian or Early Ordovician obduction zone comprise the fundamental tectonic boundaries in the region. Both zones trend northeast on regional strike. The hinge zone is defined in space and time by the unconformable northwestward transgression of rocks of IV over older rocks near the end of the Late Cambrian or Early Ordovician orogeny. The obduction zone separates rocks of I and II and is probably a Late Cambrian or Early Ordovician synkinematic relict. The transition between ultramafic plutonic rocks at the base of the ophiolite sequence (II) and rocks in the upper part of the Chain Lakes massif (I) can be observed in classic exposures in the Jim Pond quadrangle (loc. 5). Here, rocks of I have been contact metamorphosed, and cataclastic features have been found in succession I rocks and in the base of succession II. These criteria indicate northwestward thrust dislocation of hot oceanic crust against the Precambrian.

The ophiolite sequence (II) is relatively thin (3 km thick), and a sheeted dike zone is not found associated with it. Apparently this ophiolite represents an emplacement that was distal to a spreading zone probably in close proximity to a continental rise or island-arc trench floored by succession I rocks.

Origin of the slaty cleavage in the Taconic allochthon and age of metamorphism

In a recent work, Powell (1973) proposed that the slaty cleavage in the slate belt of western Vermont, part of the Taconic allochthon, resulted initially from dewatering according to the hypothesis of Maxwell (1962), and Powell cited conformable clastic dikes in these rocks from Doran quarry near Castleton, Vt., (loc. 6) as evidence. According to E-an Zen, some of these clastic dikes, upon close examination, prove to be tectonically transposed silty beds. Others appear to be real clastic dikes, but some of these intersect the slaty cleavage at right angles, and therefore their genetic relation seems doubtful. Thin-section study of one dike illustrated by Powell shows that it had been fractured, and the fracture healed by a metamorphic mineral assemblage; superimposed on the assemblage is the slaty cleavage. The observable slaty cleavage apparently is postmetamorphic, probably Taconic, as an age of 416±4 m.y. was obtained from another nearby quarry in the same rock and same structure by M. A. Lanphere by the argon-fusion method; if there was an earlier soft-rock slaty cleavage, it is not now observable.

Characteristics and probable extensions of the Bloody Bluff fault, eastern Massachusetts

The Bloody Bluff fault, which crosses the Concord, Framingham, and Marlborough quadrangles (loc. 7), is one of the principal faults in eastern Massachusetts, according to A. E. Nelson. It appears to be the principal fault on the northwest side of a cataclastic rock zone that is locally 1.2 km wide. This zone of cataclastic rocks extends a minimum of 27 km in eastern Massachusetts. Intensity of deformation within the zone is variable; in some places, the rocks are only slightly deformed, whereas in exposures near the fault the rocks are completely crushed and milled to mylonites and ultramylonites. Other exposures have crystallized to blastomylonites. Some of the rocks are polycataclastic. Generally, the intensity of deformation gradually diminishes away from the trace of the Bloody Bluff fault.

The Lake Char-Honey Hill fault system in Connecticut, which probably joins the Bloody Bluff fault (Skehan, 1967), also has a wide zone of cataclastic rock associated with it (Lundgren and Ebblin, 1972). The Fundy cataclastic zone (Ruitenberg and others, 1973) in New Brunswick, Canada, is also on strike, across the Gulf of Maine, with the projection of the Bloody Bluff fault. If the Fundy, Bloody Bluff, and Honey Hill cataclastic zones are part of the same fault, it represents, in New England and New Brunswick, a structural feature that is of the same magnitude as the Brevard zone in the Southeastern United States.

New Precambrian to early Paleozoic? nomenclature in eastern Massachusetts

Three formations have been defined by A. E. Nelson in a 3,500-m-thick section of sedimentary and volcanic rocks of Precambrian to early Paleozoic(?) age in the Natick quadrangle, Massachusetts (loc. 8). In ascending order, they are the Rice Gneiss and the Cherry Brook and Claypit Hill Formations. These, along with other formations, are tentatively correlated with formations of the Blackstone Series in Rhode Island and with the Plainfield, Quinebaug, and Mamacoke Formations in Connecticut.

Right-lateral movement in southeastern New England

Analysis of mapping in the southwest portion of the Webster quadrangle, Massachusetts-Connecticut (loc. 9), by P. J. Barosh indicates an apparent right-lateral offset of 5.6 km along the northeast-trending Eastford fault. The southeast side of the Eastford fault in the Eastford quadrangle (Pease, 1972) is formed of the Eastford Gneiss bordered to the east and west by the Hebron Formation. A similar intrusive gneiss flanked by the Hebron Formation occurs on the other side of the fault to the northeast in the Webster quadrangle and indicates the amount of apparent displacement.

This evidence together with indications of one to several kilometres of right-lateral displacement along a number of northeast-trending faults and probable faults not yet mapped in detail in eastern Massachusetts and Rhode Island suggest a general right-lateral displacement across southeastern New England.

Silurian and Devonian rocks exposed in the Hampden quadrangle, Massachusetts-Connecticut

Rocks in the vicinity of the contact between the Silurian-Devonian and the Ordovician are well exposed at several localities in the Ludlow and Hampden quadrangles, Massachusetts and Connecticut, south of U.S. Route 20. J. D. Peper reported that the rock sequence of probable Silurian and Devonian age in the Hampden quadrangle (loc. 10) can be interpreted as follows:

1. The thick sequence of gray quartz-plagioclase-biotite granulite and muscovite schist is best correlated with the Erving Formation (Thompson and others, 1968) rather than with the Littleton Formation.
2. Two discontinuous lenses of felsic and mafic metavolcanic gneiss, 45 to 60 m thick, occur near and locally at the base of the Erving. The northernmost lens overlies 3 to 6 m of gray granofels that forms the base of the Erving. The southern lens extends for a distance of at least 6 km and variously overlies gray granofels at the base of the Erving, amphibolite of the Ammonoosuc Volcanics, and quartzite. According to Peter Robinson (Univ. of Massachusetts) and G. W. Leo (USGS) (oral commun., 1973), similar conclusions were drawn from observations in the adjoining Ludlow quadrangle (loc. 11).

Radiometric age determination for Precambrian and Cambrian rocks on the east edge of the Berkshire massif

Preliminary rubidium-strontium whole-rock isochron work by D. G. Brookins and S. A. Norton indicate that the rocks which are intercalated along the Middlefield thrust zone in the Becket quadrangle, Massachusetts (loc. 12), at the east edge of the Berkshire massif are Lower Cambrian schists (Hoosac Formation) and Precambrian gneisses (approximately 1,000 m.y.). According to R. W. Schnabel, however, studies resulting from mapping in the Tolland Center, Otis, and West Granville quadrangles, Massachusetts and Connecticut (loc. 13), suggest that continuous deposition may have occurred in a sequence of rocks that have been described as ranging in age from Precambrian to Cambrian. Preliminary age determinations on rocks called Precambrian indicate these rocks may be very young Precambrian. A sequence of samples across these rocks on the east flank of the Berkshire massif has been collected for zircon age determinations that may lend more insight to this problem.

Petrography and cataclasis in the Jewett City quadrangle, Connecticut

Preliminary petrographic examinations of the rocks of the Jewett City quadrangle, Connecticut (loc. 14), by H. R. Dixon indicate a zone of felsic rocks overlying the Preston Gabbro. The rocks are composed of quartz, a very sodic plagioclase (An 10–20), and minor amounts of biotite or hornblende. They are compositionally similar to the trondhjemite dikes that cut the gabbro and the adjacent Quinebaug Formation as described by Sclar (1958), and to the oligoclase granite of Loughlin (1912). The felsic rocks are not well exposed and may not be continuous across the top of the gabbro. Where best exposed, they have a maximum width of about 150 m. All samples observed have a cataclastic fabric, but where least cataclastically deformed, the rocks are massive and unfoliated, are clearly related to the gabbro, and are not a part of the older, metamorphic rock sequence.

Also, detailed surficial mapping in the Jewett City quadrangle by B. D. Stone has revealed a previously unreported outcrop of cataclastic rock along the eastern edge of Pachaug Pond. This outcrop conclusively establishes the trace of the Lake Char thrust zone in that area.

Lake Char and Honey Hill faults near the Preston Gabbro, Connecticut

A zone containing northwest-dipping mylonite has been mapped by Richard Goldsmith along the southeast side of the composite Preston Gabbro in the Old Mystic quadrangle, New London County, Conn. (loc. 15). The zone is continuous with a zone of mylonite marking the easternmost strand of the Lake Char fault mapped by H. R. Dixon in the adjacent Jewett City quadrangle to the north. In the Old Mystic quadrangle, the zone truncates at a small angle northwest-dipping rocks of the Quinebaug and Plainfield Formations and granitic gneiss of the Sterling Plutonic Group lying to the south. Northwest of the zone, gabbro and related rocks, as well as rocks of the host Quinebaug Formation, are greatly contorted and differentially sheared. The discontinuous and almost chaotic distribution of rock types in the upper plate contrasts greatly with the fairly uniform distribution of rock types in the lower plate. Some of this irregularity is attributed to the predeformation intrusion of the Preston Gabbro, but narrow zones of mylonite and sheared rock of differing orientations are found over a wide area in the upper plate for at least the width of the composite gabbro mass. Near the south end of the gabbro, the zone appears to split around a southwestern mass of coarse-grained gabbro; the northern strand trending northwestward, although highly contorted, and the southern strand trending south-southwestward to Sclar's (1959) classic mylonite locality on Connecticut Route 2, north of Lantern Hill. The southern strand then appears to travel westward and northwestward to tie in with the southern strand of the Honey Hill fault. The connection of the northern strand with the Honey Hill fault is more complex. It appears to intersect the northern strand of the Honey Hill fault which trends northeastward through or west of the composite gabbro mass. An imbricate pattern is thus indicated. Northwest-trending tear faults complicate the pattern west of the gabbro.

The mylonites and upper- and lower-plate rocks are offset by a zone of north-south-trending high-angle faults. The Lantern Hill silexite mass and several small silexite masses to the north and northeast of it lie in this zone. Relative displacement in this zone appears to be up to the east or left lateral. This is in contrast to displacements along similar high-angle faults to the east which have an opposite sense.

PLEISTOCENE GEOLOGY

The morphologic-sequence concept as applied to southern New England

The morphologic-sequence concept has been classified by Carl Koteff into eight basic types of chronologic groups of forms composed mostly of melt-water deposits. Sequences are distinguished according to differences in depositional environment such as fluvial, lacustrine, or marine, and by the presence or absence of an ice-contact head of outwash. The construction of profiles to show depositional gradients enhances the mapping and interpretation of sequences.

Because of the relative absence of morainal features in southern New England, the distribution of morphologic sequences provides the best means of recognizing retreat positions of the last ice sheet. The distribution and physical features of sequences strongly support the view that ice recession was characterized by stagnation-zone retreat, influenced strongly by topography. The width of the stagnant zone, crudely measured by length of eskers or ice-channel fillings, was at least 2.5 km. The major source of melt-water deposits that make up the morphologic sequences is suggested as having been a shear zone at the interface between live ice and stagnant ice. Debris from this area was carried by melt water from the surface of the live ice and deposited as outwash in, but chiefly beyond, the stagnant zone. Blocks of stagnant ice appear to have contributed only minor sediments to the mass of melt-water deposits in southern New England.

Moraines record additional deglaciation stages in the Triassic lowland border, Massachusetts

In mapping the southern part of the Westhampton quadrangle, Massachusetts (loc. 16), C. R. Warren has found evidence for an even more complex deglaciation history than the 18 stages he had already recognized (U.S. Geol. Survey, 1973, p. 33). He now subdivides the events of the Wisconsin deglaciation into 25 numbered stages, of which several are known to be multiple, although most of the evidence lies beyond the area he has studied. Several of the stages are recorded by small lateral moraines marginal to the Connecticut Valley ice tongue.

Abundant potter's clay in Housatonic River Lowlands

Further investigation by W. S. Newman of Falls Village proglacial lake (Holmes and Newman, 1971) confirms that it extended north from Great Falls in Connecticut for about 30 km to the village of Housatonic, near Great Barrington, Mass. As much as about 33 m of clayey silt underlie the Housatonic River lowlands along this reach of the valley, and this material is currently being used locally in the making of pottery (loc. 17). Considerable reserves of the lacustrine clayey silt are found at shallow depths in this area of southwestern Massachusetts and northwestern Connecticut.

Oldest postglacial date yet obtained from northwestern Connecticut

A sample collected for palynological study from a fen in the Housatonic Highlands in the west-central part of the Ellsworth quadrangle, Connecticut (loc. 18), yielded a radiocarbon date of 12,750± 230 yr B.P. The dated sample was collected at a depth of approximately 6 m and consisted of partly decomposed peat material immediately overlying 1.5 m of organic-rich lacustrine silts and clays. Analysis of pollen extracted from the underlying lacustrine deposits indicates a significant but undetermined time duration of postglacial, cool-climate deposition. Analysis of pollen in the overlying peaty materials indicates vegetation and climatic changes commensurate with changes reported for other areas in western Conecticut.

According to W. S. Newman, this is the oldest postglacial date yet obtained from northwestern Connecticut. The pollen from this site and from three other sites in the Sharon and South Canaan quadrangles, Connecticut (loc. 19), are boreal pollen at the base of the sections. By extrapolation, it is assumed that the area was probably free of glaciers by 13,000 radiocarbon years B.P.

Glacial deposits in the Colchester quadrangle, Connecticut

Further work in the Colchester quadrangle, Connecticut (loc. 20), by R. M. Barker has delineated the sequence of deglaciation in detail. Three consecutive south-trending sequences of stratified drift were deposited in the Lake Hayward-Nelkin Brook valley before a lower outlet opened toward the west via Meadow Brook and the southwest-flowing Jeremy-Salmon River system. Additional northward retreat of ice over the high ground west-northwest of the town of Colchester terminated deposition of these sequences, and younger sequences of stratified drift in the northwest quadrant of the area were graded westward toward the south-flowing Jeremy River.

The east half of the Colchester quadrangle followed a different deglaciation pattern. There, melt-water sequences graded to a glacial lake in the Gardner Lake area while the ice retreated north a considerable distance. Later sequences were independently graded to tributaries of the east-flowing Yantic River. Outwash bodies are generally smaller and coarser grained in the east half of the quadrangle than in the west because the eastern topography is more uneven and the eastern valleys are mostly narrow, fingertip tributary valleys.

Outwash from the Triassic in the Marlborough quadrangle, Connecticut

Pink outwash, derived from Triassic source rocks, has been traced by D. W. O'Leary in kame terraces in Connecticut from the mouth of the Salmon River in the Deep River quadrangle, north through the Moodus quadrangle, and into the Marlborough quadrangle. This pink outwash is located east of the Great Hill drainage divide; hence its presence in the Moodus and Marlborough quadrangles is anomalous according to ordinary stream-flow mechanisms. In the Marlborough quadrangle (loc. 21), the pink outwash is sparse and is more mixed with local components than it is farther south. It thus seems unlikely that pink sediment was transported by melt water originating from gaps west of the divide. Large terraces of pink sand and gravel high on the west slope of the divide in the Marlborough quadrangle are unrelated to drainage east of the divide, although friable till derived from Triassic components is also present on the west slope. This suggests that the source material for the pink outwash in the Moodus and Marlborough quadrangles was brought over the divide by moving ice, was subsequently sorted and transported by melt-water streams, and was deposited some distance to the south. In the Marlborough quadrangle, the lower till contains a noticeable volume of Triassic detritus; it is possible that some of the outwash of Triassic material may have been derived from erosion of lower till.

Use of geologic and derivative maps in land planning

J. S. Pomeroy reported that geologic and derivative maps for the Warren quadrangle (loc. 22) have been in demand by various local and regional organizations in Massachusetts. The Conservation Commission and Planning Board of Warren plan to use the information in preparing an Earth materials inventory and establishing local land-use policy. The Central Massachusetts Regional Planning Commission (Worcester) is formulating a master plan for this area and has used the open file and miscellaneous field studies maps (Pomeroy, 1973a–c; Londquist, 1973) already released. The Southern Worcester County Conservation District (SCS) at Holden anticipates that maps showing unconsolidated materials and outcrops of thin drift will be useful not only in a soils mapping program for the town of Warren but also in the preparation of Natural Resource Inventory reports by the SCS for adjacent towns in the Quaboag Valley. Further use of the maps can be expected if HUD grants a loan guarantee to a developer for a proposed mini-city of 20,000 which would be completely contained within the quadrangle.

APPALACHIAN HIGHLANDS

APPALACHIAN PLATEAU

Sources and petrography of the "Pittsburgh Sandstone"

J. B. Roen reported that the sandstone above the Pittsburgh coal bed occurs in at least three separate, major, north- to northwest-trending deltaic-fluvial systems. Owing to erosion, the interrelationship of these systems is unknown up the paleoslope to the south and southeast. Whether they represent one river system draining the same source, or three systems originating from separate sources, cannot be inferred from the distribution patterns. Preliminary results from petrographic studies, however, suggest that more than one source is represented. On the basis of the relatively higher amounts of plagioclase, the detritus forming a sandstone lobe in Belmont County, Ohio, may have been derived from a different source than that which supplied the material for two lobes in southwestern Pennsylvania. A more significant compositional variation within the study area is that of fluvial sandstone that forms isolated and discontinuous bodies in western Maryland and nearby areas. Relative to other lobes, this sandstone contains considerably more monocrystalline quartz, is much cleaner, and contains little if any feldspar. These compositional variations suggest the possibility of perhaps three sources for the sandstone lobes overlying the Pittsburgh coal bed.

The petrography suggests that there may be a direct relationship between the occurrence of siderite and pyrite. In most thin sections in which siderite was detected, pyrite also occurred in relatively significant amounts. The lack of siderite, attributable to either its absence or nondetection, does not preclude the presence of pyrite although the latter appears to be more prevalent. Undoubtedly, some pyrite may be detrital rather than authigenic in origin. The pyrite occurs as subhedral to euhedral cubes, octahedrons, and pyritohedrons, or as anhedral masses. The small crystals and clusters range from 0.004 mm to 0.1 mm in diameter and generally occur in close proximity to the carbonate. In one section, the pyrite has partially to completely replaced small spheres of siderite. The evidence is not conclusive, but it does suggest that the presence of pyrite in the "Pittsburgh Sandstone" (of former and local usage) could be controlled by the occurrence of siderite.

TRIASSIC BASINS

Triassic and related rocks in the Culpeper basin, northern Virginia

The Culpeper basin of northern Virginia is a wedge-shaped trough bordering the eastern front of the Appalachian Mountains and filled chiefly with Triassic clastic sediments derived from adjoining highlands. K. Y. Lee reported that volcanic rocks occur in the upper part of the sedimentary sequences that were deposited in fluvial and lacustrine environments. Following deposition of these rocks, the basin was uplifted in the north and downwarped in the south. This movement was accompanied by border faulting in the southwest and in part of the west, and by large-scale intrusion of diabase, by block faulting, and by westerly and northwesterly tilting of Triassic strata within the basin. In the north, the volcanic rocks associated with red beds have since been removed by erosion. The Triassic rocks were extensively metamorphosed into hornfels. During cooling of the diabase, pegmatites and coarser diabase were formed by magmatic differentiation, followed by hydrothermal sulfide mineralization and zeolitization in fracture zones of host rocks.

BLUE RIDGE AND PIEDMONT

Glauconite-related aeroradiometric anomalies

North-trending linear aeromagnetic anomalies over the Coastal Plain in the eastern part of the Stafford quadrangle, Stafford County, northeastern Virginia, are apparently related to glauconite-rich and locally muscovitic sediments. Ground-checking with the aid of a Mount Sopris scintillometer by Louis Pavlides and K. A. Sylvester (Pavlides and others, 1974) indicates that the glauconitic Aquia Formation is the unit primarily responsible for these anomalies. According to R. B. Mixon (U.S. Geol. Survey, 1970, p. A28–A29), glauconite is more abundant in that part of the Aquia Formation deposited farther offshore than in the part deposited closer to the shore. The absence of any radiometric anomalies over patches of Aquia Formation near the Coastal Plain-Piedmont contact may reflect this facies distribution of glauconite.

Geochemical anomalies northwest of the Haile gold mine

Northwest of the Haile gold mine in southern Lancaster County, S.C., areas anomalous in gold, copper, and tin have been found by Henry Bell III, using heavy-mineral concentrates and fine-grained alluvium. The geochemical anomalies occur where magnetic data from ground and airborne surveys and geologic mapping show abundant Triassic diabase dikes intruded into a possible shear zone. A small positive gravity anomaly in this same area may be caused by a porphyritic diorite body known only from float and saprolite.

ATLANTIC COASTAL PLAIN

Geology of Coastal Plain is partial indicator of geology of Continental Shelf sediment wedge

New information on the possible great thickness of the sediment wedge beneath the Continental Shelf from Cape Hatteras to Georges Bank and on the complex structures apparently present there enhances the value of detailed geologic mapping in the emerged Coastal Plain, the most readily accessible and best known part of the province. Recent studies by J. P. Minard suggest the presence of broad structures in many areas of the Coastal Plain. Detailed lithologic studies in the emerged plain make it easier to predict the lithologies that probably are present under the shelf. The knowledge that there are structures under the shelf gives more importance to the structures in the emerged plain and, until drill holes are put down in the shelf, allows more confidence in projecting shore features seaward.

Age dating of Coastal Plain sediments

According to R. B. Mixon, uranium-series dating on shells by B. J. Szabo from the Cape Charles, Va., part of the Delmarva Peninsula, indicates that two barrier-back barrier sequences are present: the older (90 to 120,000 yr) is the higher in elevation (about 12 m) and the younger (about 60,000 yr) is near sea level. Only the higher sequence is present north of Chincoteague, Va., suggesting removal of the lower sequence by a still younger marginal-marine sequence.

CENTRAL REGION AND GREAT PLAINS

Trace elements useful in distinguishing certain rock types

On the basis of preliminary whole-rock trace-element analyses by J. L. Harris, A. V. Heyl reported that alkalic ultramafic igneous rocks, which intrude the craton between New York and Kansas, contain several elements in anomalous amounts that aid in distinguishing these rocks from Alpine ultramafic intrusive rocks and from cryptoexplosion breccias of unknown genesis such as those from Serpent Mound, Ohio, and Kentland, Ind.

Lanthanum in amounts of 50 to 500 ppm, niobium in amounts of 5 to 100 ppm, and scandium in amounts of 5 to 20 ppm were found in all alkalic ultramafic igneous rocks. Molybdenum was present in 13 of 19 samples in amounts of 3 to 30 ppm; cerium, in 14 of 19 samples in amounts of 200 to 500 ppm. Scandium was the only one of these elements found in the Alpine ultramafics, and none were found in the cryptoexplosion breccias with the exception of molybdenum, of which 15 ppm was reported in 1 (Decaturville, Mo.) of 6 samples analyzed.

ARKANSAS

Basal contact of Atoka Formation in northern Arkansas previously misidentified

As part of a cooperative program between the Arkansas Geological Commission and the USGS, D.

STATES IN CENTRAL REGION
AND GREAT PLAINS

L. Zachry and B. R. Haley (1973) (Univ. of Arkansas and USGS, respectively) have traced the basal contact of the Atoka Formation (Pennsylvanian) across northern Arkansas (loc. 1, index map). Haley observed that the contact, as shown on the geologic map of Arkansas (Arkansas Geol. Survey, 1929), is incorrectly located in an area extending over a distance of more than 200 km between Washington County and the Mississippi embayment in White County. In this area, earlier workers had placed the contact at the base of a massively bedded continuous sandstone above the Brentwood Limestone Member of the Bloyd Shale (Pennsylvanian) and as a result had included the upper part of the Bloyd in the Atoka Formation. Presumably, because they did not find fossils typical of the upper Bloyd above the sandstone, the early workers assumed that the upper Bloyd strata were missing owing to erosion, and they postulated a major regional unconformity at the base of the sandstone. Investigations by Zachry and Haley failed to find lithologic evidence to indicate an unconformity at the true contact between the Bloyd and Atoka; therefore, the postulation of an unconformity at the base of the Atoka seems untenable.

ILLINOIS AND KENTUCKY

Potential sites of ore occurrence in the Illinois-Kentucky fluorspar district

A regional geologic map of the Illinois-Kentucky fluorspar district (loc. 2) compiled by D. M. Pinckney shows the major structures of the district to be a broad arch and numerous grabens. The arch trends northwesterly and terminates at Hicks dome at the southern margin of the Illinois basin. Eleven major northeasterly to easterly trending grabens as much as 65 km long and 5 km wide are defined. Mineralization, chiefly of fluorspar, zinc, and lead, tends to be localized where certain strata are intersected by fissures. These strata are exposed in an area of about 1,500 km^2 at the crest and on the flanks of the arch; they are extensive over an equivalent area in the subsurface at depths less than 500 m. Most known mineral deposits have been discovered by near-surface exploration. By extending exploration to greater depths, the target area for mineralization and the potential for discovery of new ore bodies would be greatly increased.

KENTUCKY

Geologic mapping of State

A cooperative project with Kentucky, begun in 1960, was more than 80 percent completed by May 1, 1974, when 471 geologic maps had been printed (fig. 1), another 51 maps had been approved for publication, and an additional 50 were undergoing editorial review. Geologic mapping was in progress in more than 80 quadrangles. About 710 maps will be published to cover the 763 7½-min quadrangles that are wholly or partly within the State. The geologic maps are printed on recent editions of topographic base maps of quadrangles, at 1:24,000 scale, and are published in the geologic quadrangle map series.

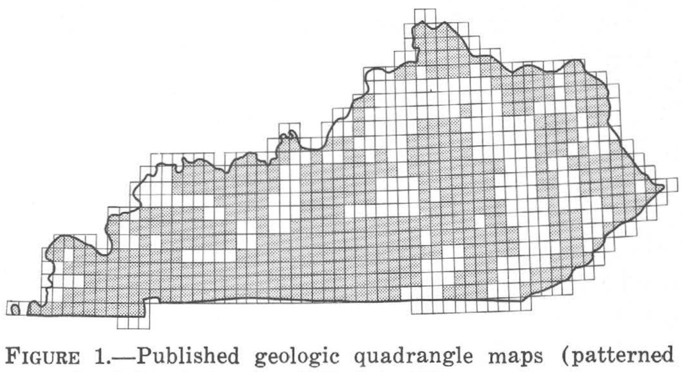


FIGURE 1.—Published geologic quadrangle maps (patterned area) of Kentucky as of May 1, 1974; small squares are 7½-minute quadrangles.

MICHIGAN

Archean greenstones, Wakefield area, Michigan

W. C. Prinz has succeeded in splitting out several mappable units in the Archean (Precambrian W) greenstone belt of the Wakefield 7½-min quadrangle, Gogebic County (loc. 3). The oldest exposed unit consists of metamorphosed tuff, graywacke, and volcanic breccia. It is overlain by three flow units, each 300 m to 750 m thick, composed of metamorphosed basalt, andesite, and dacite that commonly show amygdaloidal and ellipsoidal structures. These are separated by thin and poorly exposed rhyolite units. The Archean rocks form a gently warped, steeply south-dipping monocline, as opposed to the north-dipping monocline formed by the overlying iron-bearing rocks of Precambrian X age. Tops of strata in the Archean rocks face south, whereas those in the Precambrian X rocks face north. The Archean rocks, therefore, must have been overturned to the north when the Precambrian X rocks were deposited and must have been subsequently rotated back to their present right-side-up position when the Precambrian X rocks were tilted to the north.

MINNESOTA

Faulting during early Precambrian in northeastern Minnesota

Three regional steeply inclined fault sets, hitherto unrecognized, have been delineated in the Vermilion District (loc. 4) by P. K. Sims (USGS) and J. C. Green, G. B. Morey, and R. W. Ojakangas (Minnesota Geological Survey). The faults are younger than the granitic rocks of early Precambrian (W) age that intrude a folded eastward-striking sequence of interbedded volcanic and sedimentary rocks, also of early Precambrian (W) age. Fault traces are marked by topographic and aeromagnetic lineaments and by mylonitized rock.

The oldest faults are dip-slip faults of diverse trends that formed at the margins of large plutons of granitic rocks as a result of buoyant uplift of the granite relative to the denser volcanic and sedimentary sequence. Differences in assemblages of metamorphic minerals in rocks on opposite sides of one of the faults suggest a vertical displacement of at least 3,000 m. Strike-slip faults with northeasterly trends, transverse or diagonal to the trend of the volcanic and sedimentary strata, and with left-lateral displacements of as much as 6.5 km, are abundant in the central part of the district. They formed contemporaneously with, or perhaps prior to, eastward-trending longitudinal strike-slip faults. The principal longitudinal strike-slip fault, the combined Vermilion-Wolf Lake-North Kawishiwi fault, has a right-lateral displacement of about 22 km. It and subsidiary right-lateral faults have superposed a shingled effect on the mass of volcanic and sedimentary rocks, converting the shape of this mass from an east-trending thick lens to a northeast-trending tenuous body.

SOUTH DAKOTA

Erosional features in Badlands National Monument area related to structure

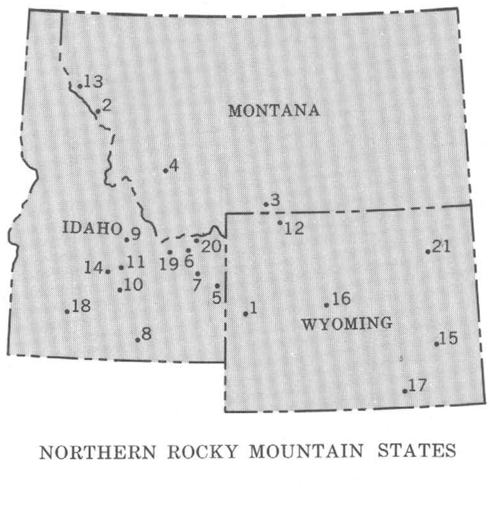
Geologic mapping of the Badlands National Monument area (loc. 5) by R. U. King and W. H. Raymond reveals that the most striking erosional features are related to subtle post-Oligocene folding and faulting that trend northwesterly in the vicinity of the "Badland land wall" in the northeastern part of the area. Exposed formations include marine shale of Late Cretaceous age and continental deposits of sand and bentonitic clay of Oligocene and Miocene age. These older rocks are partly covered by alluvial and eolian deposits.

NORTHERN ROCKY MOUNTAINS

MINERAL-RESOURCE STUDIES

Copper, silver, and zinc in the Nugget Sandstone and older Triassic red beds, Wyoming

According to J. D. Love, copper, silver, and zinc occur in a bleached zone at or near the top of the normally pink Nugget Sandstone (Triassic? and Jurassic?) along a 105-km-long segment of the thrust belt of western Wyoming (loc. 1, index map). Copper also occurs in a bleached zone at the base of the normally pink Crow Mountain Sandstone of the Chugwater Group (Triassic) 120 km east of the thrust belt, on the Circle Ridge dome in west-central Wyoming. Maximum values for elements in the Nugget Sandstone, in ppm, are: Cu, 67,000; Ag, 1,200; Zn, 32,000; As, 7,000; Ba, 5,000; Pb, 5,000; Co, 700; Mo, 150; and Zr, 1,000. In contrast, the Crow Mountain Sandstone contains a maximum of only 4,400 ppm Cu, 87 ppm Zn, and normal amounts of the other elements. Preliminary data on some of these localities have been described by J. D. Love and J. C. Antweiler (1973).



NORTHERN ROCKY MOUNTAIN STATES

At the 10 study areas in the Nugget Sandstone, there is oil staining, either in the mineralized sandstone or directly above it in Jurassic rocks. The Crow Mountain Sandstone is likewise stained by oil, possibly from underlying Permian rocks. If copper and other elements are genetically related to oil at these localities, as they seem to be, the different patterns of concentration in these two rock sequences of different ages, in areas 120 km apart, may have been governed by the original trace-element content of the oils, one Permian and the other Jurassic. Evidence, admittedly incomplete, suggests that oil can be both a source and a mechanism for concentrating minerals in some bleached red-bed host rocks. Bleaching and oil staining of red-beds may thus suggest exploration sites for Cu, Ag, Zn, Co, Mo, Pb, and possibly other mineral deposits.

Another place to look for Belt stratabound copper?

J. E. Harrison's reconnaissance geologic mapping of Belt Supergroup rocks near the Idaho-Montana line southwest of Superior, Mont. (loc. 2), has identified a series of previously unmapped thrust sheets that bring up lower Belt rocks in an area that had previously been mapped as middle Belt carbonate (Wallace Formation). Rocks of the middle Belt carbonate have been poor in anomalous copper throughout the Belt basin, whereas some rocks in the thrust sheets (Ravalli Group) have been relatively rich in anomalous copper. The presence of Ravalli rocks in an area previously thought to be all Wallace Formation provides a new place to search for stratabound copper.

Ages of intrusives and ore deposits

Ages were determined for several mineral separates from rocks collected by J. E. Elliott near Cooke City, Mont. (loc. 3). Fission-track ages were measured on zircon and sphene by C. W. Naeser, and K-Ar ages were determined on biotite and adularia by C. E. Hedge. The results indicate two major periods of igneous activity and two ages of mineralization. In the northern part of the area, near Goose Lake, intrusion and mineralization of Late Cretaceous age is indicated. An age of 84.6 ± 11.2 m.y. is assigned to a syenite stock. Potassium alteration associated with copper mineralization in the syenite stock has an age of 73.6 ± 0.9 m.y. In the central part of the area, igneous activity occurred from late Paleocene to late Eocene or early Oligocene. An equigranular diorite stock has been dated at 55.3 ± 0.7 m.y. Two radiometric ages from dacite porphyry bodies are 44.0 ± 4.1 m.y. and 40.6 ± 3.5 m.y. Further intrusion produced breccias and postmineral dikes. A major phase of alteration and mineralization occurred after the 40.6-m.y.-old dacite porphyry.

Paleozoic stratigraphy near the Hecla mining area

Mapping by E-an Zen of Paleozoic sedimentary rocks south of Hecla, Mont. (loc. 4), has strongly revised local stratigraphy and structure. A dome, possibly expressing a cupola of the Pioneer batholith, caused local metamorphism and mineralization in Cambrian and Devonian dolostones. Rocks to the south, previously mapped as Cambrian and in a north-facing sequence, are now recognized as the Madison Group (Mississippian) in a south-facing and nearly vertical sequence. Because the Madison of the Pioneer Mountains is barren of mineralization, this discovery could guide future prospecting. Contact metamorphism led to extremely coarse grained marbles (about 8×20 cm, possibly as large as several metres across) and large crystals of skarn minerals: early grossularite, diopside, epidote, hornblende, tremolite, and late serpentine.

IGNEOUS ROCKS

Swan Valley graben and basaltic vent chain

Swan Valley, in southeastern Idaho (loc. 5), is part of a long, narrow complex graben that extends from Palisades Reservoir northwest to the Snake River Plain, where it disappears beneath young basalts. Studies by H. J. Prostka show that ash-flow tuffs dated at 4.5 m.y. that lap high onto the flanks of the Caribou and Snake River Ranges, are dropped more than 300 m into the graben. Younger basalts, sediments, and an ash-flow tuff that partially fill the graben have been extensively warped and faulted by renewed movements. Continuing deformation is suggested by drainage anomalies and abundant seismicity in the area.

The basalts erupted within the graben are part of a chain of basaltic volcanoes that extends more than 100 km northwestward across the Snake River Plain. The chain indicates the presence of a major rift zone, similar to the Great Rift near Craters of the Moon. Three of the five major geothermal features in the northeasternmost part of the plain are along this zone: Heise Hot Springs, Lidy Hot Springs, and Warm Springs Creek.

Linear concentrations of basaltic vents, Snake River Plain

G. T. Stone (Univ. of Oklahoma) and P. J. Iagmin (USGS), working north of Prostka, also found that the Great Rift is not the only fissure zone that produced episodic, basaltic volcanism during the Pleistocene in the eastern Snake River Plain. Almost as spectacular is a concentration of nearly 100 eruptive centers in a zone approximately 48 km long and 11 km wide. It lies in the northeastern part of the plain from the Island Park caldera westward to an area just south of Spencer, Idaho (loc. 6). Lineations are expressed by fissures and associated spatter ramparts, alinement of various eruptive centers, and minor faulting. Prominent tensional cracks like those of the Great Rift have not been found.

Two older and narrower belts of fissures extend southeastward to the central axis of the Snake River Plain from extensions of range-front faults of the Lost River and Lemhi Ranges. Both belts seem to end at young basaltic vents, one near the east side of Big Southern Butte and the other at Hell's Half Acre lava field west of Idaho Falls. These narrow volcanic zones, thought to lie along rifts, are all perpendicular to the central axis of the plain, where volcanic activity was concentrated during Pliocene and Pleistocene time.

Ash-flow tuffs of eastern Snake River Plain

A sequence of five ash flows is exposed on the eastern Snake River Plain, near Hiese Hot Springs (loc. 7). H. J. Prostka and P. L. Williams reported that some of these sheets have been traced in reconnaissance throughout the eastern Snake River Plain, and their approximate age and distribution are now known.

The uppermost sheet (informally, Willow Creek A) is the distal facies of the Huckleberry Ridge Tuff, 2 m.y. old, erupted from the Yellowstone Park area. This welded tuff caps much of the Rexburg and Willow Creek Benches. The tuff crossed the Big Hole and Snake River Ranges from the south end of Teton Valley into Swan Valley, where it now forms part of the deformed graben fill along with interlayered basalts and fine-grained sediments of the Pine Creek Bench sequence and conglomerates of the Long Spring Formation of Merritt (1956).

The next oldest tuff (informally, Heise C) is a thick, compound-cooling unit that is lithologically very distinctive and extremely widespread. It is the thick unit in which Teton Canyon is incised, and it correlates with the tuff of Boone Creek east and west of the Teton Range (R. L. Christiansen, oral commun., 1973). It is present in the Juniper Hills in the center of the Snake River Plain; it flanks the southern margin of the western Centennial Range and Beaverhead Range; and it may correlate with the Edie School Rhyolites of Scholten and others (1955). It caps much of the northwestern end of the Caribou Range and Willow Creek Bench as far southwest as the Blackfoot Range. A sample of this tuff from the quarry near Ammon has been dated at 4.5 m.y. (R. L. Armstrong, written commun., 1972). In Swan Valley, it is present as far southeast as Palisades Dam, where it overlies a sequence of vitric tuffs and terrigenous sediments of the Salt Lake or Teewinot Formation. The Palisades Dam Andesite of Savage (1961) is a thick lava flow interlayered with the upper part of this tuffaceous sequence.

The next two oldest tuffs (informally, Heise B and Nave tuff) were found only in the Rexburg Bench-Willow Creek area. The lowermost tuff (informally, Heise A) is very widespread along the southern margin of the Snake River Plain from Heise to the Blackfoot Mountains and south to the Caribou Range. The age of this tuff is unknown. It rests mainly on a surface of prevolcanic rocks with high relief; hence its thickness is variable.

All of the sheets except the youngest are interbedded with a variety of air-fall and water-laid tuffs, and in the Kelly Mountains are associated with rhyolite flows. The relations of these sheets to those in the Yellowstone-Island Park area are now reasonably well known, but their relations to those in the Blackfoot-Pocatello area have not yet been established.

Potassium-argon dating of intrusive rocks in the Pioneer batholith

Three pairs of coexisting hornblende and biotite samples and two single biotite samples from five petrographically and geographically distinct intrusive rocks collected by E-an Zen (loc. 4) were analyzed for their radiogenic Ar^{40} by R. F. Marvin and H. H. Mehnert. The rocks are (1) a quartz diorite, (2) a porphyritic granodiorite, (3) a granite (petrographically equivalent to the Butte Quartz Monzonite of the Boulder batholith), (4) a tonalite, and (5) another porphyritic granodiorite. Cross-cutting relations show that 1 is older than 2, and 3 is the youngest. The calculated ages range from 68.0 to 71.0 m.y., except for a hornblende from 1, which is 76.5 m.y. and could mean an original age for this rock whose biotite age was modified by later intrusions. The initial Ar^{40} plot shows an average isochron age of about 70.0 m.y., and the scatter is small even though both hornblende and biotite are plotted. Either the initial Ar^{40} content is negligible, or its isotopic composition is essentially modern. Two high-grade metamorphic gneisses from the area of samples also have 70-m.y.-old biotite megacrysts. These ages are about the same or slightly younger than those of similar rocks in the Boulder batholith and the Philipsburg batholith.

The five intrusive rocks from the Pioneer batholith (loc. 4) submitted for K-Ar dating were studied petrographically by E-an Zen, and were chemically analyzed. Each rock is distinct in texture or in mineralogy. Compared with the Boulder batholith, they are termed "sodic" in the sense of R. I. Tilling (1973) in plots involving K_2O against SiO_2; in a Na_2O-SiO_2 plot, they conform to his so-called "main series." In chemistry and mineralogy, the rocks seem to be intermediate between the two series proposed by Tilling and resemble the Burton Park pluton in the Boulder batholith.

GEOLOGIC AND STRATIGRAPHIC STUDIES

Analysis of fans relates hot well to fault

Studies by K. L. Pierce and P. W. Schmidt (Williams and others, 1974) of the surficial geology of the Raft River geothermal area (loc. 8) show that an important geothermal well there lies on the trend of a Pleistocene fault. The fault cuts fan gravels deposited about six pluvial episodes ago (middle(?) Pleistocene) but does not cut adjacent fans deposited about three pluvial episodes ago (late? Pleistocene). The Bridge hot well is on the projected trace of this fault; young fan gravels conceal the fault in the area of the well.

The time of fault movement was determined by comparing the amount of loess mantle and soil development on the successively older fans. Fan gravels of the last pluvial (latest Pleistocene) are mantled by loess about 0.5 m thick bearing a weakly developed soil, as are the roughly correlative gravel deposits of the last glaciation and of pluvial Lake Bonneville. Gravel deposits of increasingly older pluvial episodes are mantled by increasingly thicker loess containing buried soils every half metre or so.

Rocks resembling Roberts Mountains Formation in central Idaho

The lower part of the Silurian section in the Lone Pine Peak 15-min quadrangle (loc. 9), south of Challis, Idaho, consists of roughly 800 m of dark, mainly slabby, impure dolomite and limestone, according to W. H. Hays. It overlies the Saturday Mountain Formation of Ordovician and Silurian(?) (Llandoverian?) age and underlies light-gray, nonfossiliferous sugary Laketown(?) Dolomite of probable younger Silurian age. Its lithology resembles much of the Roberts Mountains Formation (Silurian and Lower Devonian) of central Nevada, and it indicates that during part of Silurian time, the Roberts Mountains depositional environment extended from Nevada far north into central Idaho.

Antler flysch in central Idaho

Flysch deposits of Mississippian and possibly Devonian age were studied by F. G. Poole (unpub. data, 1974) in the Pioneer Mountains and Lost River Range (loc. 10), Custer, Blaine, and Butte Counties, central Idaho. These strata represent a northward extension of the Antler flysch sequence of Nevada and western Utah. As much as 4,500 m of well-bedded neritic and bathyal marine, flyschlike mudstone, siltstone, sandstone, conglomerate, and subordinate impure limestone was deposited in a subsiding, elongate foreland basin on the continental shelf (cordilleran miogeosyncline) east of the Antler orogenic belt and west of the cratonic platform. The major source of siliceous flysch sediments in the foreland trough was terrigenous detritus derived from a rising cordillera to the west, composed of strongly deformed Devonian and older rocks. In latest Devonian time, during the Antler orogeny of Late Devonian and Mississippian age, these rocks were deformed and subsequently thrust eastward as the Roberts Mountains allochthon onto the outer carbonate shelf. Most of the flysch sediment within the foreland basin was deposited in a relatively deep-water trough by sediment gravity flows originating in relatively shallow water. Proximal and distal turbidites, debris-flow deposits, and hemipelagic deposits are recognized in the Antler flysch; these facies and their associations in the flysch trough indicate a complex system of submarine environments including slope, fan, and basin floor. Much of the fine-grained flysch is organic rich and may have been important in late Paleozoic petroleum generation.

Copper Basin allochthon in central Idaho

Mapping by B. A. Skipp in the southern Pioneer Mountains (loc. 10), central Idaho, indicates that the Copper Basin Formation of Carboniferous age is a gently folded and faulted allochthon approximately 19 km wide. The sequence, faulted at both the base and top, consists of more than 4,900 m of interbedded argillite, conglomerate, sandstone, and impure limestone and is thought to be a part of the siliceous Antler Flysch of F. G. Poole (1974). The allochthon overrides Devonian and older carbonate rocks of both miogeosynclinal and transitional facies near Fish Creek Reservoir (Skipp and Sandberg, 1972) along its western margin, and miogeosynclinal limestone, shale, and siltstone of Late Mississippian age along its eastern margin in exposures north of Craters of the Moon National Monument. To the west, the Copper Basin allochthon is overridden by rocks of the Wood River Formation (Permian and

Pennsylvanian) along a folded and faulted thrust at Fish Creek Reservoir. Present traces of the thrusts both above and below the Copper Basin Formation trend generally north-northwest into the central Pioneer Mountains.

Trilobites in type section of Copper Basin Group

B. A. Skipp found two partial trilobites in the heretofore nonfossiliferous type section of the Iron Bog Creek Formation of Paull and others (1972) near the top of the Copper Basin Group, as used by Paull and others (1972), at Brockie Lake in the Muldoon Canyon quadrangle (loc. 11). A. R. Ormiston (Amoco Research Center) identified them as *Archegonus* (*Phillibole*) (Richter and Richter, 1937). Ormiston reported that the subgenus has a range of Famennian (Late Devonian) through Visean (Late Mississippian). The Idaho forms most closely resemble a species from the Lower Mississippian of Kentucky and Tennessee. The trilobites were found in dark, fine-grained quartzite 60 to 90 m above the base of the Iron Bog Creek Formation, and about 4,900 m above the lowest exposed beds of the Copper Basin Group. The Iron Bog Creek Formation was considered by Paull and others (1972) to be of Pennsylvanian age on indirect evidence.

Clastic dikes furnish rock emplacement data

Some 30 localities in the upper Clarks' Fork of the Yellowstone River area in northwest Wyoming (loc. 12) have been found where clastic carbonate dikes composed of Heart Mountain fault breccia have been injected as much as 15 m into the volcanic rocks immediately overlying the fault. Pieces of fragmented, but not brecciated, carbonized wood found in one of them by W. G. Pierce indicate that the fault breccia lay exposed on the fault surface at the time the wood was introduced. The fault breccia and wood fragments were injected in dikes apparently as the weight of about 60 m of volcanic rocks shifted, causing lateral flow along the base of the volcanic rocks toward the dikes. In some of the dikes, the lowermost volcanic rock also apparently flowed laterally toward the dike and then moved upward along with the flow of carbonate dike material.

Paleontologic dating of shale-siltstone sequence at the base of the Paleozoic rocks

A unit of about 100 m of interbedded quartzose siltstone, calcareous siltstone, dark quartzose shale, and iron-rich, banded siltstone—below massive dolostone of the Hasmark Formation of Cambrian age and above a thick sequence of sandstone and conglomerate of uncertain age—provided fossils on the north slope of Sheep Mountain in the northwest part of Vipond Park quadrangle (loc. 4). The fossils, collected by E-an Zen and J. T. Dutro, Jr., consist mainly of trace fossils but include echinoderm fragments. The unit is definitely early Paleozoic—probably Cambrian and possibly Middle Cambrian; it thus correlates with the Silver Hill Formation of the Philipsburg area and the Wolsey Shale of the platform sequence. Dating of this unit is important because of the possible paraconformable relation with the underlying clastic sequence and because the shale is locally deformed and metamorphosed enough to suggest a Precambrian age. The fossils are the first of their kind in this unit in the Pioneer Mountains.

STRUCTURAL STUDIES

Large fold near Hope fault, northwest Montana

Mapping by A. B. Griggs in the western half of the Wallace 2° quadrangle (loc. 13) outlined a third large overturned fold just north of the Lewis and Clark line. Like the other two folds, it trends north, is overturned to the east, and has the western limb thrust over the eastern one. The eastern limb is exposed for almost 12 km along Prospect Creek, which empties into the Clark Fork at Thompson Falls, Mont. There, rocks extending from the lower Prichard Formation into the lower part of the Snowslip Formation (nearly 10,000 m of section) have dips ranging from near vertical to overturned as much as 45° to the west. This section represents much of the Belt Supergroup of Precambrian metasedimentary rocks exposed in this area. Unlike the other two folds, this fold lies just west, rather than just east, of the Hope fault system. The eastern side of this fold ends abruptly against the most westerly strand of the Hope fault system, which here trends northwest. The eastern limbs of the other two folds also end abruptly against northerly trending, steep-dipping faults. Right-lateral displacement of many kilometres along the Osburn fault (within the Lewis and Clark line) has been fairly well demonstrated just to the west in the Coeur d'Alene district. These sharp overturned folds give the same sense of eastern translation in the upper crustal rocks in the block north of the Osburn fault.

Thrust faulting in south-central Idaho

W. E. Hall and J. N. Batchelder recognized at least four thrust sheets near Hailey, Idaho (loc. 14). Thrusting is from southwest to northeast and juxtaposes deep-water oceanic, transitional, and miogeosynclinal facies. The Paleozoic formations there, the Wood River and Milligen Formations, are both allochthonous. The thrusts were traced for at least 90 km from north of Ketchum, Idaho, southeast to the Fish Creek Reservoir, where they were first recognized and mapped by B. A. Skipp.

Neogene block faulting in Laramie uplift

According to Kenneth Segerstrom, the highest part of the granitic Laramie uplift, southeastern Wyoming, appears to be a northeast-striking horst about 30 km long and 5 to 10 km wide. The horst (loc. 15) is bounded on the southeast side by a shear zone with minor copper and nickel mineralization, and on the northwest side by a broad fracture zone intruded by a swarm of mafic Precambrian dikes. The dikes are commonly sheared at their borders with less shearing throughout. Most, if not all, of the shearing and faulting probably took place in post-White River (Oligocene) and pre-Ogallala (Pliocene) time.

Recurrent Laramide structural movements, south flank of the Wind River Basin

Recurrent movement during Late Cretaceous and early Tertiary time on the northern extension of the Emigrant Trail thrust fault in the Wind River Basin was documented by M. W. Reynolds from mapping in the Sand Draw and Alkali Butte areas, Wyoming (loc. 16). Unconformities of Campanian and Maestrichtian (Late Cretaceous) age, two unconformities of Paleocene age, and another of Eocene age truncate older rocks along or near the trace of the fault. Facies of lower Eocene rocks east of the fault are dominantly piedmont, whereas those west of the fault are dominantly flood-plain and lacustrine. Rocks as young as late Eocene are folded and displaced along the fault trace. Thus, the history of movement of the fault in the Wind River Basin corroborates the history of the fault as deduced from structural and stratigraphic relations along the northern margin of the Great Divide basin (M. W. Reynolds, 1966; unpub. data, 1974). Erosion accompanying successive episodes of movement in the Wind River Basin destroyed potential reservoirs for petroleum in Upper Cretaceous and Paleocene rocks from Alkali Butte to Muskrat Creek.

Postconsolidation tilting of Lake Owens mafic complex, Wyoming

Studies of the magnetic properties of the Lake Owens mafic complex of the southeastern Medicine Bow Mountains of Wyoming (loc. 17) by P. N. Shive and J. A. Morel (Univ. of Wyoming) support a conclusion based on geologic study by R. S. Houston (USGS) that this complex has been tilted some 60° northeast after consolidation. The initial geomagnetic pole for the body in its present attitude does not fall near any established Precambrian pole from North America. If the igneous foliations are rotated into an approximately horizontal position, however, the virtual geomagnetic pole (lat 20° N., long 145° W.) plots near the trend in the equatorial Pacific established for North American rocks of this approximate age (Larson and others, 1973, and Spall, 1971). The Stillwater Complex of Montana, located some 600 km northwest of the Lake Owens complex, also shows a north to northeast tilt, but Jones and others (1960) suggested that only 35° of the tilt could have been Precambrian. Whether tilting of these complexes is local or regional is not known, but it should be considered in interpretations that suggest Precambrian ancestry for Laramide structure.

GEOPHYSICAL STUDIES

Gravity and magnetic anomalies in western Snake River Plain

D. R. Mabey and D. L. Peterson reported that large gravity and magnetic highs occur over the western Snake River Plain, Idaho, (loc. 18) and extend over extensive exposures of Columbia River Basalt. At the northwest end of the plain, major features of the gravity and magnetic anomalies suggest that the plain is underlain by a thick layer of material that is more dense and more magnetic than the enclosing rocks. The geophysical data are interpreted as suggesting that the western half of the Snake River Plain is underlain by a layer of basalt 1 to 3 km below the surface and 2 to 4 km thick. Depressions on the surface of the basalt layer are filled with lower density sedimentary rock and silicic volcanic rock.

ENVIRONMENTAL-GEOLOGIC STUDIES

Environmental aspects of southern Beaverhead Range, Idaho

The absence of reported epicenters during this century and, apparently, of geomorphically fresh fault scarps suggests that the east flank of the Beaverhead Range and adjoining Crooked Creek Valley, Idaho (loc. 19), are now seismically quiet. D. L. Schleicher reported that range-front faults along the east flank of the range are mantled by welded tuffs interbedded with cemented tuffaceous fan gravels (correlatives of the Salt Lake Formation?), suggesting that the faults there are at least a few million years old. The area has geothermal potential that is developed at Lidy Hot Springs, undeveloped at the springs feeding Warm Creek, and only implied near a hitherto-unrecognized intrusive plug at the south tip of the range. Silty soils in at least two drainages may be arable, especially if water can be found in adjacent alluvial-fan gravels.

Centennial fault, Idaho-Montana

Southwestern Montana and the adjacent parts of southeastern Idaho are dominated by northwest-trending basin-and-range structures. The east-trending Centennial Range-Centennial Valley structural pair cuts sharply across this northwest-trending structural pattern. The valley is downthrown along the high-angle Centennial fault, which dips valleyward (northward) and, for the most part, delineates the north face of the range.

The Centennial Range (centered at loc. 20) forms a major part of the northern margin of the easternmost Snake River Plain, and sedimentary units that make up the range dip southward and probably pass below the mafic and felsic volcanic rocks that floor the plain.

Current field mapping by I. J. Witkind has concentrated on the Centennial fault. Its length is unknown, but it extends at least 64 km from its apparent western end near Monida, Mont., to its apparent eastern end near Henrys Lake, Idaho.

The fault can be divided into three parts. In the western sector which is about 43 km long, the fault appears mostly as an impressive north-facing scarp. The scarp ranges in height from 11 to 12 m, and can be traced for about 27 km. For the most part, Lower Cretaceous strata (Aspen? Formation) on the upthrown block are juxtaposed against surficial deposits on the downthrown block. In at least three places along the fault, stratigraphic units on the downthrown block are similar to comparable units on the upthrown block, suggesting vertical displacement of several thousand metres. Although many old alluvial fans are offset by the fault, it is partly concealed by younger small alluvial fans and earthflows.

The central 11 km of the fault cuts bedrock. Here, the fault apparently has split to form a 6-km-wide zone of northwest-trending en echelon breaks offset to the north.

The eastern segment of the fault reaches at least into the western end of the Henrys Lake basin, but how much farther east it extends is not known. The fault here is essentially a single break largely concealed by surficial deposits. In one locality, however, it offsets a moraine of Pinedale age.

Local residents report that their homes are shaken repeatedly by minor earth tremors. This is yet another example of continuing movement along a large fault in the intermountain seismic belt.

Resource and land information applied to environmental protection in the Gillette area, Wyoming

Geologic, hydrologic, and related studies in the Gillette area of central Campbell County, Wyo. (loc. 21), contain estimates of the potential effects of surface mining the thick coal deposits of the area (N. M. Denson, W. R. Keefer, and G. H. Horn, 1973; W. R. Keefer and P. W. Schmidt, 1973; L. M. Shown, 1973; U.S. Geol. Survey, 1973). W. R. Keefer reported that detailed geologic mapping by USGS geologists, supplemented by drill data, has delineated 6 billion t of low-sulfur, subbituminous coal within 60 m of the ground surface in a belt 75 km long and 3 to 5 km wide. The thickness of the strippable coal (Wyodak-Anderson bed) averages from 15 to 30 m in large sections of this belt. A study of the ground-water conditions in the area shows that the extraction of the coal would markedly disrupt the shallow ground-water aquifer system, which might, however, be partially restored by reclamation of the land surface.

SOUTHERN ROCKY MOUNTAINS

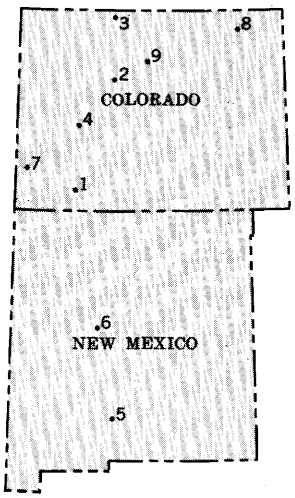
MINERAL-RESOURCE STUDIES

Multiple ages of mineralization in the western San Juan Mountains, Colorado

Most of the economic mineralization in the western San Juan Mountains is localized by structures of the Silverton caldera (and the related San Juan and Uncompahgre calderas) previously thought to have formed during the waning stages of this caldera cycle about 28 m.y. ago. However, recent studies in the Lake City area (loc. 1, index map) by P. W. Lipman demonstrated several distinct periods of mineralization, extending over about 15 m.y. in late Tertiary time.

In the Lake City area, scattered mineralization, thus far of limited economic significance, occurs in the intrusive cores of intermediate-composition stratovolcanoes that were active about 35 to 30 m.y. ago, before the occurrence of any of the ash-flow eruptions which resulted in caldera collapses. Significant vein and disseminated mineralization occurred in the northern parts of the Uncompahgre caldera after it collapsed about 28 m.y. ago but before the Lake City caldera collapsed during eruption of the Sunshine Peak Tuff 22.5 m.y. ago, since fragments of mineralized rock occur in landslide debris in adjacent parts of the Lake City caldera fill. Additional vein and disseminated mineralization occurs in and near the Lake City caldera and is therefore younger than 22.5 m.y. old.

Major veins, which follow faults of the Eureka



SOUTHERN ROCKY MOUNTAIN
STATES

graben between the Lake City and Silverton calderas, also seem to have formed after collapse of the Lake City caldera, even though the graben faults existed as pre-Lake City structures. The following field relations suggest this: (1) Altered rocks and vein quartz seem to be absent in landslide breccias within adjacent parts of the Lake City caldera, although the Eureka graben veins and mineralized rocks extend to the structural margin of the caldera. (2) At Engineer Pass on the northwest side of the Eureka graben, silicic quartz porphyry intrusions, which cut the Sunshine Peak Tuff erupted from Lake City caldera, occur at a focal area where alteration zones converge with a silicified breccia pipe and mineralized veins. These silicic quartz porphyry intrusives are part of a well-defined northeast-trending belt, which extends about 40 km from northwest of Silverton to north of Lake City and ranges in composition from quartz latite to silicic rhyolite and granite. They are petrologically distinct from dated intrusions of the main ash-flow caldera-forming cycle at about 28 m.y., but they have distinct petrographic affinities to magmas of the 22.5-m.y. Lake City cycle and are tentatively considered to be similar in age.

A similar association of intense alteration and breccia-pipe mineralization with silicic quartz porphyry intrusions in the productive Red Mountain district, on the west side of the Silverton caldera, suggests that mineralization in this area may also be younger than 22.5 m.y. The age of the major vein systems southeast and northwest of the Silverton caldera is even less certain, but at least some of the major veins southeast of Silverton cut quartz porphyry intrusions similar to those in the Engineer Pass and Red Mountain areas. Thus, at least some of the productive mineralization structurally associated with the Silverton caldera appears to be 6 to 10 m.y. younger than the formation of the caldera 28 m.y. ago. The caldera appears to have acted mainly as a structural control as much of the mineralization is genetically associated with quartz porphyry intrusions that are petrologically distinct from rocks erupted during the caldera-forming process.

Geologic mapping in the Leadville 2° quadrangle

Compilation of detailed geologic mapping and widespread field reconnaissance in the eastern quarter of the Leadville 2° sheet, Colorado (loc. 2), by Ogden Tweto has provided an up-to-date geologic framework of one of the most important segments of the Colorado mineral belt, including the major mining districts of Breckenridge, Fairplay, Gilman, Climax, and Leadville. Although the geology of each of these districts had been studied in detail, no modern geologic overview of the entire region existed. This mapping provides a basis for analyzing the influence of Precambrian, Laramide, and post-Laramide tectonics and Laramide and post-Laramide igneous activity on ore deposition. Reconnaissance mapping of about 1,500 km^2 of previously unstudied Precambrian rocks in the northern Sawatch Range by J. C. Reed, Jr., and R. H. Moench has established the general structure of the Precambrian terrane and the distribution of 1.4- and 1.8-b.y.-old granitic rocks.

Distribution of lead and zinc

C. S. Bromfield and R. B. Hall have studied the geographic and geologic distribution of lead and zinc production in the Southern Rocky Mountains, using regional mining-district production. Approximately 90 percent of the production has come from the Colorado mineral belt; about 65 percent from its central part, 30 percent from its southwest part, and only a few percent from its northeast part. Ten districts have produced nearly 90 percent of the total, and two districts, Leadville and Gilman (loc. 2), have produced over half.

In the Southern Rocky Mountains, lead and zinc were deposited in four metallogenetic epochs—Precambrian, Laramide, middle Tertiary, and late Tertiary. About 65 percent of production comes from Laramide deposits, 30 percent from middle Tertiary deposits, 5 percent from Precambrian deposits, and very little from upper Tertiary deposits.

Replacements, chiefly in carbonate rocks, are the most important deposits and have yielded about 60 percent of the total production; 25 percent from veins in volcanic rocks, 8 percent from veins in other rocks, and 5 percent from massive sulfide deposits in Precambrian rocks.

IGNEOUS ROCKS

Calderas in the San Juan Mountains of Colorado

Studies by T. A. Steven and P. W. Lipman have shown that the late Oligocene calderas in the San Juan volcanic field (loc. 1) in southwestern Colorado formed in response to recurrent large-volume ash-flow eruptions. Eighteen major ash-flow sheets have been identified; 14 calderas are known, 3 are postulated, and another possibly remains to be discovered.

Development of the calderas is believed to chronicle the emplacement of successive segments of an underlying shallow batholith whose presence is also indicated by a major gravity low. Early calderas (30 to 29 m.y. old) formed in areas of clustered andesitic volcanoes and are not clearly associated with the main gravity low. These probably formed above local high-level magma chambers before the rise of the main body of the batholith. Five calderas in a western caldera complex formed between 29 and 27 m.y. ago in an area of clustered andesitic volcanoes. These are above the western part of the batholith indicated by gravity data and indicate final upward movement of magma in the underlying segment. A central San Juan caldera complex formed between 28 and 26 m.y. ago. During this period, eight major ash-flow sheets were deposited, and at least seven calderas formed. The calderas are above the main eastern segment of the gravity low, and they are believed to mark the culminating magmatic activity in this part of the batholith. Contrasting lithologies of sequential ash-flow sheets derived from overlapping caldera sources in both the central and western complexes require rapid development of successive cupolas above the batholith, and of provincial differentiation within each cupola.

New Colorado magnetic gabbros and peridotites

A previously unmapped mafic and ultramafic Precambrian intrusive body covering an entire 7½-min quadrangle has been discovered by G. L. Snyder in the northern Park Range of Colorado (loc. 3) just south of the Wyoming line. Most of the body is a uniform medium-grained diabasic gabbro, but a variant exposed over several square kilometres in the northeastern part of the body consists of coarse-grained coronaed-olivine gabbro and norite with inclusions of harzburgite and amphibole lherzolite. Anomalous platinum-group elements occur in the more mafic phases of the body. 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 of the west side of the Park Range shows a positive anomaly of more than 500 gammas over the gabbro body and indicates as much gabbro westward beneath Tertiary cover as is presently exposed. A previous aeromagnetic survey had mislocated this anomaly by more than 8 km, and the anomaly was thought to be caused solely by intrusive Tertiary rocks.

Volcanic and intrusive rocks in West Elk Mountains, Colorado

South and west of the West Elk Wilderness Area (loc 4), D. L. Gaskill reported that the volcanic rocks are dominantly high-angle, near-vent, cone facies. The volcanic rocks are cut by a west-trending zone of faults and dikes, associated with areas of argillized, propylitized rock and explosion breccias, along the northern perimeter of the volcanic field.

Some 24 asymmetrical to cylindrical, granodioritic laccoliths and many sills are emplaced at various horizons throughout a 2,400-m-thick sequence of Jurassic, Cretaceous, and Tertiary strata. No clear evidence was found of laccolithic bodies intruding the volcanic rocks. At least two bysmalithic bodies bulged in Jurassic rocks at or near the Precambrian contact. Most of the laccoliths are in the Mancos Shale, but the largest are floored in the Mesaverde Formation and younger strata.

Several small rhyolite plugs and altered rhyolitic sills are exposed in and adjacent to the volcanic rocks.

GEOLOGIC AND STRATIGRAPHIC STUDIES

Devonian Brachiopoda of New Mexico

The geologic history of the Devonian of New Mexico was developed by G. A. Cooper (Smithsonian Institution) and J. T. Dutro, Jr., (USGS) from analysis of the strata and fossils. Devonian rocks are widespread in the south-central and southwestern parts of the State (loc. 5), especially in the Sacramento, San Andres, Franklin, and Caballo Mountains. Detailed stratigraphic sections and biostratigraphic data clarify correlations, facies distributions, and paleogeographic patterns. A faunal zonation, based primarily on brachiopods, is supplemented by the distributions of conodonts, corals, and cephalopods.

The Onate Formation is late Middle Devonian in age and lies unconformably on Silurian and Ordovician strata. The overlying Sly Gap Formation is entirely of Frasnian Age (early Late Devonian). [The Onate and Sly Gap Formations of Stevenson (1945) are hereby adopted as redefined by Flower (1965) for usage by the USGS.] The Percha Shale is of early and middle Famennian Age (late Late Devonian) and is everywhere younger than the Sly Gap. A sandy facies of the lower Percha rests on the Sly Gap in the San Andres Mountains. The so-called Percha of southeastern New Mexico is a southern facies of the Onate Formation. The Devonian sequence is overlain unconformably by either Mississippian or Pennsylvanian rocks.

Pediment surfaces in central Rio Grande trough

The relation of basalt flows and Cenozoic faulting to pediment surfaces in the Rio Grande Valley between Albuquerque and Socorro, N. Mex. (loc. 6), was studied by G. O. Bachman. Pedogenic caliche deposits that cap some of these surfaces are prominent markers and valid map units. Caliche began to accumulate on the oldest of these surfaces, the Llano de Albuquerque, soon after the Los Lunas basaltic volcano became dormant. R. F. Marvin, H. H. Mehnert, and V. M. Merritt suggest a tentative age of 1.0 ± 0.1 m.y. for the Los Lunas basalt. This indicates a maximum age for the Llano de Albuquerque surface.

Rico Formation in the southeast end of Gypsum Valley anticline, Colorado

The Rico Formation exposed in steeply dipping beds in the southeastern end of the Gypsum Valley anticline in the Dawson Draw quadrangle (loc. 7) is 568 m thick. It is underlain conformably by the limestone-bearing upper member of the Hermosa Formation and is overlain unconformably by formations ranging from the Chinle (Triassic) to the Summerville (Jurassic). D. E. Ward described the Rico as reddish-brown siltstone and shale; massive lenticular beds of sandstone that are feldspathic to arkosic, micaceous, and conglomeratic; and sparse, comparatively thin limestone and calcareous shale beds that are persistent and fossiliferous. Eighteen of these calcareous units occur scattered through the formation. Fossils—mostly mollusks, brachiopods, and gastropods—from three beds in the upper third of the formation were assigned a late Pennsylvanian age by E. L. Yochelson.

Uncommon deposit beneath Rocky Flats Alluvium

Approximately 8 km north of Sterling, Colo. (loc. 8), J. A. Sharps found that the Rocky Flats Alluvium is underlain by silt (probably wind deposited), in contrast to other areas of Colorado where the Rocky Flats is generally underlain by bedrock. The silt deposit is of interest because it may contain fossils by which the maximum age of the overlying Rocky Flats Alluvium might be determined.

GEOPHYSICAL AND STRUCTURAL STUDIES

Crustal structure of the Southern Rocky Mountains

Claus Prodehl (Geophysicalisches Institut der Universitat Fridericiana, Karlsruhe, West Germany) and L. C. Pakiser, Jr., (USGS) completed an interpretation of a seismic study of the crustal structure of the Southern Rocky Mountains. The results indicate that the crust is about 45 km thick along a north-trending line extending across the San Juan Mountains (loc. 1), the Sawatch Range, the Park Range (loc. 3), and the Sierra Madre Mountains, and 52 to 54 km thick in the Front Range. Along the San Juan Mountains-Sierra Madre Mountains line, the crust includes a low-velocity zone in the upper 20 km and is not distinctly layered, but in the Front Range, it is distinctly layered. The transition from lower crust to upper mantle is gradual throughout the Southern Rocky Mountains, and the upper-mantle velocity, not well determined, is in the range 7.7 to 7.9 km/s.

Precambrian folding in the Ward area

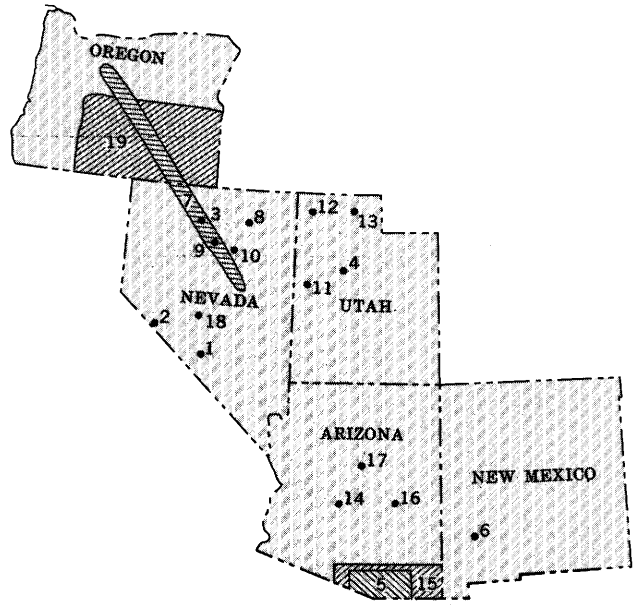
D. J. Gable found that large northeast-trending folds dominate the structure of the Ward 7½-min quadrangle (loc. 9) and have the same trend as folds mapped near Central City, 16 km to the south. The largest fold, an anticline, extends across the southern half of the Ward quadrangle from the adjoining Nederland quadrangle; a large syncline extends into the northwest corner of the Ward quadrangle from the Monarch Lake quadrangle. Earlier and smaller northwest-trending folds occur on the east limb of the large northeast-trending anticline.

BASIN AND RANGE REGION

MINERAL-RESOURCE STUDIES

Occurrences and composition of alunite at Goldfield, Nevada

R. P. Ashley and W. J. Keith (1973) found that alunite shows at least five distinctly different modes of occurrence in hydrothermally altered rocks and ores in the Goldfield mining district (loc. 1, index map), Esmeralda and Nye Counties, Nev. Hypogene alunite shows four modes of occurrence; it replaces constituents of silicified volcanic rocks, is intergrown with quartz near the margins of ore-bearing veins,



STATES IN BASIN AND
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forms veins in unoxidized silicified rocks, and forms coarse-grained breccia fillings in silicified zones along with jarosite. Supergene alunite forms fine-grained veins that cut across both silicified and argillized rocks in the zone of oxidation. Standard semiquantitative spectrographic analyses and additional spectrographic and X-ray fluorescence data for lithium, cesium, rubidium, and strontium are not notably different for the various types of hypogene alunite, or for hypogene versus supergene alunite, although some hypogene alunite samples are relatively enriched in lead. Flame-photometric sodium and potassium analyses, when compared with X-ray diffraction data, show that many alunite samples, regardless of mode of occurrence, consist of at least two phases: one relatively potassium rich, and one relatively sodium rich. The two phases are not distinguishable optically; comparison of the compositions of coexisting alunites indicates that they are not solvus phases. Relations between coexisting phases are not yet understood, and the possibility that individual alunite crystals are zoned is being investigated. Alunite samples apparently containing both potassium and sodium alunites occur in other districts with alunitic alteration; for example, Marysvale, Utah, and the Comstock Lode, Nev.

Precious-metal placer deposits

Under the direction of F. J. Kleinhampl, reconnaissance investigations in northern Mono Basin, Calif. and Nev., by geologists and geophysicists of the USGS and the California Division of Mines and Geology, indicate an area of possible precious-metal placer deposits northwest of Aurora (loc. 2), Mineral County, Nev., buried beneath Quaternary gravels. The deposits are localized along a structural lineament believed to have channeled major stream drainage out of Aurora. The best potential site for placer deposits lies at the junction of the lineament with an inferred presently buried topographic high of volcanic rocks that could have acted as a barrier to the stream flow.

Cambrian bedded sulfides in north-central Nevada

F. G. Poole and R. L. Erickson recognized sparse laminae of pyrite intercalated with bedded barite and mudstone in the Preble Formation (Cambrian) north of Golconda Summit (loc. 3) in southeastern Humboldt County, Nev. Both the pyrite laminae and associated high-grade barite beds are believed to be sedimentary in origin. Coexistent sedimentary barite and sulfides occur in eugeosynclinal strata in many parts of the world, but this occurrence in Nevada is the first reported in the Basin and Range province. The discovery of bedded pyrite in Nevada suggests that high-grade sedimentary sulfide deposits may occur in eugeosynclinal strata in the Western United States.

East-west patterns of Tertiary volcanism and mineral deposits, Nevada and Utah

Outcrops of calc-alkaline andesite and dacite and associated intrusive rocks define two broad east-west belts of major Tertiary volcanism in Nevada and Utah. A synthesis by J. H. Stewart and W. J. Moore indicates that the northern belt, which contains rocks generally ranging in age from 30 to 40 m.y., extends from near the Wasatch Mountains between about lat 3°30′ and 40°40′ N. in Utah westward and a little south to central western Nevada. In parts of Nevada, this northern belt is poorly defined and is difficult to separate from a major region of calc-alkaline volcanic rocks in northeastern Nevada. The southern belt, which contains rocks generally ranging in age from 20 to 30 m.y., is well defined and extends from the High Plateaus of Utah westward to the Tonopah-Goldfield area of western Nevada. In westernmost Nevada, the two belts merge in an area of extensive early to middle Miocene (about 10–20 m.y., time scale of Berggren, 1972) calc-alkaline volcanic rocks along the northwest trend of the Walker Lane. Voluminous andesitic volcanism in the Reno-Carson City region within the Walker Lane is on line with the northern belt and may indicate a recurrence of volcanic activity along the same structural trend as the northern belt.

Mineral deposits in Utah are clearly related to these east-west volcanic belts, and over 95 percent of the production of Cu, Pb, Ag, Au, and Zn has come from three east-west mineral belts lying within the broad volcanic belts described here. In Nevada the relationship is less clear, but many ore deposits occur within the volcanic belts, and most of the large Tertiary epithermal gold-silver deposits, for example, Goldfield, Tonopah, Aurora, and the Comstock, are located within andesitic volcanic fields in the Walker Lane region in line with the two volcanic belts described here. The ore deposits are contemporaneous or nearly so with their andesitic host rocks, implying a genetic relationship.

Possible buried caldera in west-central Utah

Detailed geologic mapping and volcano-stratigraphic studies by H. T. Morris (1973) in the south-central East Tintic Mountains, Utah (loc. 4), in conjunction with earlier geophysical and regional geologic studies by D. R. Mabey and H. T. Morris (1967), and diamond drilling by several mining companies, disclosed the possible presence of a buried caldera of large dimensions. This inferred caldera is centered on Buckhorn Peak 11.5 km south-southeast of Eureka, Utah. A circular, lava-filled area surrounded by scattered exposures of sedimentary rocks, and a magnetic anomaly essentially coincident with it, indicate a diameter of about 13.6 km. Data from a number of diamond drill holes in its northwestern quadrant indicate a depth of more than 900 m. Areas where the northern wall of the caldera is cut by mineralized veins may be underlain by concealed ore bodies.

Potential for copper, Nogales 2° quadrangle, Arizona

Southeast Arizona is one of the world's richest copper provinces, and it currently faces mounting confrontations involving industrial and mining growth, urbanization, and environmental considerations. As part of the USGS effort to provide State and local planners with understandable and factual data to be used in making decisions related to land use, a map was prepared by a USGS team under the direction of T. G. Theodore and S. C. Creasey (U.S. Geol. Survey, 1973) showing the potential for copper deposits in the eastern three-fourths of the Nogales 2° quadrangle (loc. 5). About one-third of this quadrangle is underlain by rocks with a relatively high potential for hosting major copper deposits. One of these high-potential areas includes five producing mines that together yielded about one-sixth of the nation's primary copper in 1973. But most importantly, the study revealed broad zones where the alluvial deposits are less than about 300 m thick in the areas of high potential.

These alluvial deposits may cover some major undiscovered metal concentrations whose exploitation under strict environmental controls should be economically feasible with existing technology. Planners in future zoning decisions should carefully consider the metal potential of the undeveloped alluviated valleys because these are the areas most likely to be used for relief of population pressure.

Middle Tertiary mineralization in the Mimbres Range, New Mexico

Mapping by D. C. Hedlund in the Hillsboro and San Lorenzo 15-min quadrangles (loc. 6) along the Mimbres Range in Sierra and Grant Counties, N. Mex., indicates that the region is underlain by several thousand metres of Paleozoic sedimentary strata and Tertiary volcanic rocks. North- to north-northwest-trending high-angle extensional faults of Tertiary age tilt the section 15° to 35° eastward in the Hillsboro quadrangle, whereas in the San Lorenzo quadrangle and near the summit of the range, the faults tilt the section westward and have formed a graben along its western margin. The graben is separated from the Santa Rita horst, the western boundary of the mapped area, by the Mimbres fault which has a vertical displacement of more than 3,000 m. The fault is a possible source of geothermal energy since several hot springs are present along its projected trace.

There are essentially two types of target areas for mineral exploration in the region:

Tertiary intrusions of copper-bearing quartz monzonite and quartz diorite.—The quartz monzonite stock of Copper Flat in the Animas mining district has an outcrop area of 1 km^2 of which 0.25 km^2 is mineralized. Drill-hole data indicate that the stock expands with depth. The quartz monzonite stock of Warm Springs Canyon has a marginal facies of quartz monzodiorite which probably represents a slightly older magmatic differentiate that crystallized out along the limestone walls of the chamber. The quartz diorite of the Tank Canyon area intrudes El Paso Limestone; tactites are locally developed along the contacts. Anomalous concentrations of tungsten have been reported for stream sediments in the vicinity of the quartz diorite intrusion (H. V. Alminas and K. C. Watts, Jr., oral commun., 1973).

Major north-striking normal faults that have provided access for rhyolitic intrusions and associated silver-bearing ore fluid.—These faults are commonly loci for fissure veins of zinc, lead, and copper with trace amounts of silver. Approximately half of the 74 mineralized occurrences examined along or adjacent to faults were fissure veins localized in dolomite beds of the Fusselman and Montoya Dolomites. The remainder were localized along fault breccias or occur as bedding replacements in limestone.

Along the Pierce Canyon fault, the fissure veins in dolomite commonly have a talc alteration zone which is cut by sulfide-bearing quartz veins. In the Kingston district, replacement of dolomite by rhodochrosite and rhodonite occurs adjacent to faults and fractures that contain sphalerite, pyrite, galena, chalcopyrite, albandite, and argentite. Along the Grandview fault, San Lorenzo quadrangle, bedding replacement by sulfides is a common feature within the upper chert-bearing limestone beds of the El Paso Limestone. The chert-bearing limestone is locally thermally metamorphosed to scarn mineralogy, and the sulfide replacement bodies are nearly contemporaneous with the thermal metamorphic effects. Although no intrusive body is present in the immediate area of the principal mines (Royal John, Patsy, Columbia, and Grandview) rhyolite porphyry stocks are alined along the fault to the north of the mineralized area. Since these stocks predate the Kneeling Nun Tuff (33.4 ± 1.0 m.y., McDowell, 1971; Elston and others, 1973) and intrude the Rubio Peak Formation of Oligocene age, the mineralization appears to be of early to middle Tertiary age.

STRATIGRAPHIC AND STRUCTURAL STUDIES

Oregon-Nevada lineament

A belt of closely spaced, partly en echelon, faults (the Oregon-Nevada lineament) extending from near Mount Jefferson in north-central Oregon southeastward to Eureka in central Nevada (loc. 7) has been recognized by J. H. Stewart, G. H. Walker, and F. J. Kleinhampl. The lineament is 750 km long and generally 20 to 40 km wide. In addition to faults, the lineament is marked by centers of volcanic activity including voluminous upper Miocene lava flows in Nevada and by Miocene and younger volcanic rocks in Oregon. A conspicuous aeromagnetic anomaly is coextensive with the lineament in Nevada but is lacking in Oregon. The lineament is considered to be the surface expression of a deep-seated fracture zone in which some of the movement can be interpreted as right lateral.

Deep-sea origin of Ordovician pillow lavas and associated sedimentary rocks, north-central Nevada

Pillow basalts interlayered with chert and graptolitic argillaceous rocks of Ordovician age in the Independence Mountains, the northern Shoshone Range, and at Battle Mountain, Nev. (locs. 8, 9, and 10), have been investigated by C. T. Wrucke, Jr., and Michael Churkin, Jr., to determine environmental conditions at time of emplacement, particularly the depths of the ocean where these lavas accumulated. Measurements of the size and volume percent of vesicles in the pillows, using methods developed by Moore (1965) for modern submarine flows in Hawaii, indicate that most of the pillows accumulated at depths of 3 km or more. The Ordovician pillows, like their deep-water modern counterparts, have small, sparsely distributed vesicles and abundant varioles in their glassy rims. Pillows from a small area in the Shoshone Range, however, have relatively large and abundant vesicles, indicative of an origin at a depth of about 600 m. This suggests some type of local high-standing volcanic structure, perhaps a seamount.

The pillow basalts are from the Valmy Formation and its equivalents in the western part of a belt of graptolitic shale and chert of Ordovician age that extends from Nevada to Alaska. The Valmy Formation contains much more basalt and less shale than the Vinini Formation and its equivalents along the eastern side of the belt. The Vinini Formation grades eastward into limestone and shale that is transitional into carbonate rock and quartzite of the miogeosyncline. These facies changes indicate deposition in progressively deeper water from east to west, resembling facies transitions across modern continental margins. The Vinini Formation has current and gravity structures indicative of a turbidite origin on the continental slope. The scarcity of these structures in the Valmy Formation, the abundance of thin rhythmic beds, and the depth of water indicated by the pillow lavas suggests that the Valmy is a quiet-water pelagic deposit laid down partly on the continental rise near its distal end and partly on the abyssal ocean floor.

Stratigraphy and structure of the north end of the House and Fish Springs Ranges in Utah

Geologic mapping by L. F. Hintze (Brigham Young Univ.) has shown that dolomite and limestone, ranging from Cambrian through Middle Devonian, are exposed in the north end of the House Range and the Fish Springs Range fault blocks in Juab and Millard Counties, Utah (loc. 11). The major normal fault in the House Range is on the west side of the range, whereas that of the Fish Springs Range is on the east. These faults nearly come together at Sand Pass. Neither range exhibits much folding, but strata in the Fish Springs Range have been tectonically reduced in thickness in a rather random pattern along the strike of the beds. The adjacent House Range shows no such tectonic thinning. Alteration is localized along vertical fractures, affecting areas several metres on either side of the fractures, and is probably related to fluids generated during emplacement of Tertiary volcanic rocks found in adjacent areas.

Tertiary tectonics in northwestern Utah

Geologic mapping in the Matlin Mountains, Box Elder County, Utah (loc. 12), by V. R. Todd has shown that outcrops previously believed to be bedrock and an unbroken part of the suprastructure are a series of thin rootless glide plates which have moved across, and are intercalated with, fanglomerates and tuffaceous sandstones of middle to late Miocene ($\cong$ 11 m.y.) age (time scale of Berggren, 1972). Sheets less than 150 m thick of very steeply dipping brecciated upper Paleozoic carbonate rocks rest on Tertiary rocks for a distance of 19 km from north to south along strike in the area. Ages of rocks in the upper plates appear to reflect gradual stripping, by thrusting or gravity gliding, of the western metamorphic terrane. A compressive, rather than extensional, tectonic regime is suggested by the presence in both hanging-wall and footwall rocks of north-northeast-trending folds that are truncated by the faults. The sheets of upper Paleozoic and Tertiary rocks were folded together on north-northeast axes subsequent to emplacement. This is the axial trend of late- and post-metamorphic folds in the nearby metamorphic terrane.

Type section of Brigham Quartzite deciphered

Stratigraphic and structural studies by M. D. Crittenden, Jr., and M. L. Sorensen reveal that rocks exposed in Box Elder Canyon, immediately east of Brigham City, Box Elder County, Utah (loc. 13), the type locality for the Brigham Quartzite, include units as much as 3,000 m below the base of the fossiliferous Cambrian. Beginning at the east end of the canyon (stratigraphic top), the following units of Huntsville and Pocatello sequences are recognized:

Unit	*Thickness (Metres)*
Geertsen Canyon Quartzite	1,300
Browns Hole Formation (terra cotta quartzite member) Bedding fault (inferred stratigraphic separation, 1,500 m)	60
Caddy Canyon Quartzite (partial section)	200
Papoose Creek Formation	70
Kelley Canyon Formation (only top exposed)	100

The upper three dominantly quartzitic units, together with rocks cut out by faulting, constitute the Brigham Group as now defined. A hornblende K-Ar date of 570±7 m.y. was obtained by M. A. Lanphere on volcanics of the Browns Hole Formation, indicating that a large part of this section is of Precambrian Z age (570 to 800 m.y.). The Kelley Canyon is the oldest unit exposed in Box Elder Canyon itself, but older units are exposed to the west in highway cuts in the outskirts of Brigham City.

Stratigraphy of the iron-formation in the Pikes Peak area, Arizona

Recent mapping by P. M. Blacet of Precambrian metamorphic rocks exposed in the Hieroglyphic Mountains (loc. 14), Maricopa and Yavapai Counties, Ariz., 35 km northwest of Phoenix, indicates large-scale isoclinal folding of a thick stratigraphic section of mafic volcanic and volcaniclastic rocks overlain by a monotonous sequence of graywacke exhibiting well-preserved graded bedding. A major iron resource, the iron-formation in the Pikes Peak area, occupies a distinctive stratigraphic zone at the top of the volcanic unit where steeply dipping lenses of ferruginous metachert and hematitic schist are exposed along strike for about 6 km. An extensive cover of Tertiary rocks conceals this ferruginous zone in the vicinity of Lake Pleasant, but the persistence of this zone and the scale of folding are indicated by the discovery of an exposure of massive iron-formation precisely on strike 16 km to the northeast. A striking similarity exists between the Precambrian sequence in the Pikes Peak area and that marking the stratigraphic break between the lower and upper units of the Spud Mountain Volcanics in the Townsend Butte area 35 km to the north-northeast (Anderson and Blacet, 1972). Photogeologic reconnaissance along the intervening schist belt in Black Canyon supports the interpretation that the schists in the Pikes Peak area are equivalent to the middle part of the well-dated (1,775±10 m.y.) Big Bug Group of the Yavapai Series (Anderson and others, 1971). The Pikes Peak deposits constitute a large undeveloped iron resource which lies at the edge of the Phoenix metropolitan area, thus having important economic and environmental implications.

Synthesis of Laramide tectonics of southeastern Arizona

A tectonic synthesis of parts of southeastern Arizona in Cochise, Pima, and Santa Cruz Counties (loc. 15), led H. D. Drewes (1974) to conclude that most of the thrust faults were formed during the late Late Cretaceous and represent a link in the

Laramide fault system that extends northward from central western Arizona at least to Canada and southward from El Paso, Tex., into Mexico.

The allochthonous terrane in southeastern Arizona forms two northeastward-transported lobes, each of which is broken into two major thrust plates. The lobes are distinguished by differences in trend of the allochthonous front, combined with differences in their internal style of deformation. The distal margin of the southeastern lobe strikes east and is continuous with the distal margin of a thrust fault identified by Corbitt and Woodward (1973) in southern New Mexico. The distal margin of the northwestern lobe trends north toward Superior, Ariz., where it appears to swing more westerly to Phoenix and Wickenburg, an area in which postorogenic cover is extensive. Near Tucson, the allochthon of the northwestern lobe differs from that of the southeastern one in that it contains larger sheets of Precambrian rocks, its lower plate is widely metamorphose, and it is associated with probable underthrusting.

The northeast-trending tear fault that probably separated these lobes and permitted them to develop independently is largely concealed by younger deposits. Segments of the tear fault are probably also intruded by late Laramide (Paleocene) stocks and are offset along northwest-trending left-lateral strike-slip faults and related minor thrust faults. Other segments are concealed beneath middle Tertiary glide plates or are obscured by middle Tertiary low-angle normal faults.

Late Pleistocene or Holocene structural movement in east-central Arizona

Mapping by M. E. Cooley of the Salt River channel and its terraces in Gila County, Ariz. (loc. 16), using low-altitude aerial photographs (black-and-white infrared film filtered with Wratten No. 25 filter, approximate scale 1:12,000), has shown that terrace-gravel deposits are transected by numerous large joints and that a few deposits are offset slightly by normal faults. Faulted terrace-gravel deposits were recognized in at least four places along the Salt River between the area of confluence of the Black and White Rivers and Theodore Roosevelt Lake. The deposits displaced by faults are within 20 m of river level. The low terraces probably are of late Pleistocene age, as are similar terraces along nearby streams; therefore, the structural movements are late Pleistocene or Holocene in age.

Late Quaternary structure determined from ERTS–1 imagery

According to M. E. Cooley, the distribution of alluvium and alluvial fans constitutes an aid in the interpretation of late Cenozoic structure in Arizona. The alluvial deposits can be easily identified and mapped on ERTS–1 imagery and, coupled with available ground data, a map at a scale of 1:1,000,000 showing these alluvial features has been prepared for Arizona. The upper Cenozoic alluvium covers large areas in the broad Phoenix basin in south-central Arizona and in the southwestern part of the State in the Gulf of California embayment. In other areas, the alluvium is present only in the central parts of valleys or in narrow bands along streams.

Alluvial fans are concentrated along the flanks of the Phoenix basin in the area south of Gila River in southwestern Arizona and along a trough occupied by Bouse and Centennial Washes. Alluvial fans are not common near the Colorado River because in Arizona the river was downcutting during most of late Quaternary time. Apparently the Phoenix basin and Gulf of California embayment were subsiding during late Quaternary time, which caused a partial filling of alluvium; these are the thickest deposits of upper Quaternary alluvium in the State. The distribution of the alluvium and alluvial fans suggests that an axis of subsidence trended northwestward across the central part of the State in a line from near Tucson northwestward through Casa Grande, Maricopa, and Laveen, and along Centennial and Bouse Washes in the Harquahala-Ranegras Plain area toward the Colorado River.

Evolution of Verde Valley

Detailed mapping (1:6,000 and 1:62,500) in the Hackberry Mountain area (loc. 17), Coconino and Yavapai Counties, Ariz. (southeast Verde Valley), by D. P. Elston and G. R. Scott has revealed the existence of a thick (about 800-m) sequence of interstratified basalt flows, dacitic flows and tuffs, and associated sedimentary strata. Potassium-argon age dating by E. H. McKee indicates that the sequence was deposited about 13 m.y. to 3 m.y. ago. Following deposition of basalt flows of Hickey age (about 10 to 14.5 m.y. ago), dacitic volcanic rocks erupted in the Hackberry Mountain area; they are interstratified with broadly contemporaneous basalt flows that issued from nearby fissure systems. Normal faulting along the Verde fault appears to have occurred about the time of the beginning of dacitic volcanism, initially defining the northeast flank of the Black Hills and the southwest side of the Verde Valley. Faulting recurred about 6.5 m.y. ago, marked by subsidence and the deposition of lake beds of the Verde Formation of late Pliocene age in the Verde Valley, north of the Hackberry Mountain Volcanic center. Basaltic eruptions along the margin of the Colorado Plateau northeast of the Verde Valley and sporadic dacitic eruptions in the Hackberry Mountains area at the south end of the valley continued to about 3 m.y. ago, forming a volcanic ramp and a dam that at least temporarily impounded drainage from the valley.

GEOCHEMICAL AND GEOCHRONOLOGIC STUDIES

Age and origin of the Darrough Felsite, Toiyabe Range, Nevada

Reconnaissance mapping by R. C. Speed and E. H. McKee in and near the Darrough Felsite, a large body of rhyolite in the southern part of the Toiyabe Range (loc. 18), Nye County, Nev., indicates that the rock unit consists of a thick pile of rhyolite ash-flow tuffs and some lava flows. The unit probably accumulated around and within a caldera formed at the site of eruption. Potassium-argon dates suggest a middle Tertiary age, although the unit has previously been considered to be Permian and to be a large intrusive body (Ferguson and Cathcart, 1954).

Metamorphic ages of Cambrian phyllite in south-central Nevada

E. H. McKee determined two isotopic ages on Cambrian phyllite collected by F. G. Poole from thrust plates in Wall Canyon in southern Toiyabe Range, northern Nye County, Nev. (loc. 18) The autochthonous lower plate phyllite (Upper Cambrian unit) yielded a whole-rock K-Ar age of 73 m.y. and corresponds to Cretaceous plutonic events in the southern Toiyabe Range. The allochthonous upper plate phyllite (Lower Cambrian unit) yielded a muscovite K-Ar age of 338 m.y. and corresponds to Mississippian orogenic events during the Antler orogeny.

Progressive age of late Cenozoic silicic volcanism in southeastern Oregon and its implications for geothermal exploration

A geographic age progression of silicic volcanism in southeastern (loc. 9) Oregon suggested by G. W. Walker has been confirmed by additional field studies and K-Ar age determinations in a joint effort by G. W. Walker, N. S. MacLeod, and E. H. McKee (1974). Silicic domes, flows, and ash-flow tuffs occur along two northwest-trending belts. The northern belt extends from near Duck Butte, southeast of Harney Basin, to Newberry Volcano; the southern belt extends from Beatys Butte at least as far as the Cougar Peak-McComb Butte area northwest of Lakeview. At Duck Butte and Beatys Butte, K-Ar ages of silicic volcanic rocks are 10 m.y.; silicic domes in the middle parts of the belts at Horse Mountain, Drews Range, Cougar Peak, Thomas Peak, Thomas Creek, Tucker Hill, and McComb, Owen, Palomino, and Burns Buttes are 6 to 8 m.y.; and domes at the northwestern end are 5 m.y. at Glass Buttes, 4 m.y. at Frederick Butte and Cougar Mountain, and 1 m.y. and younger at Quartz Mountain, East Butte, and China Hat. Newberry Volcano at the northwestern end of the northern belt and South Sister along a further projection of this belt have silicic volcanic rocks that are less than several thousand years old. The southern belt projects toward Crater Lake where silicic volcanism occurred about 6,500 to 7,000 years ago. These age data suggest that shallow silicic intrusive bodies young enough to have retained sufficient magmatic heat to be exploitable for geothermal energy are most likely to occur at the northwest ends of these two belts in the area near and between Newberry Volcano, South Sister, and Crater Lake.

PACIFIC COAST REGION

CALIFORNIA

Lower Paleozoic(?) sedimentary rocks in eastern Klamath Mountains

Geologic mapping by P. E. Hotz in Yreka and the eastern parts of Fort Jones and Etna quadrangles, eastern Klamath Mountains, California, has shown that retention of the Duzel Formation, defined by Wells and others (1959) is no longer tenable. More detailed mapping of terrane previously considered to be dominantly phyllitic graywacke characteristic of the Duzel Formation demonstrated that there are six lithologic units instead of one. The boundaries of most units are thrust faults. Fossiliferous strata have not been found so far in these rocks, and fossiliferous Ordovician limestones in eastern Etna quadrangle are beneath a thrust plate of rocks previously considered to be part of the Duzel (Wells and others, 1959). Since the Duzel is no longer a valid formational unit, it is proposed to abandon the name and establish new lithologic subdivisions (P. E. Hotz, unpub. data, 1974). The stratigraphic succession and age are uncertain, so the new units have been given informal designations. In northern Yreka and eastern Fort Jones and northeastern Etna quadrangles, these rocks are faulted (thrust?) against amphibolite, adjacent to a belt of serpentinite. M. A. Lanphere (personal commun., 1973) obtained ages of 328 m.y. (Mississippian) and 391 m.y. (Devonian) on two samples from this belt.

Cucamonga fault zone

Youthful appearing fault features are common in the easternmost 20 km of the Cucamonga fault zone, along the base of the eastern San Gabriel Mountains. Mapping by D. M. Morton of this segment of the fault zone has documented a number of fault scarps cutting alluvium, as well as occurrences of basement rock thrust over alluvium and Pliocene-Pleistocene(?) sediments. Most of the recent fault features are restricted to a zone 0.5 to 1.5 km wide along the mountain front in a still largely undeveloped area. The most youthful appearing scarp is 5 km in length and as much as 7 m in height. If this scarp originated during a single event, comparison of this scarp's height with those documented for shallow onshore thrust faults suggests the associated earthquake could have been as great as M 8 (Morton and Yerkes, 1974). Planning for future development in the general area should consider both the width over which faulting has occurred and the probable magnitude of credible future earthquakes.

Tertiary granitic rocks

Pelona Schist of the San Gabriel Mountains and Orocopia Schist (of Miller, 1944) of the Chocolate Mountains, both of unknown age, have long been considered as probable equivalents, offset by the San Andreas fault. Detailed mapping by D. M. Morton in the San Gabriel Mountains and by F. K. Miller in the Chocolate Mountains has revealed granitic plutons intrusive into both the Orocopia and Pelona Schists. Potassium-argon dates from coexisting hornblende and biotite from quartz monzonite, intruding Orocopia Schist, are 21.4 and 21.0 m.y., respectively (Miller and Morton, 1974); a nearby related intrusive gave hornblende ages of 23.8 and 21.8 m.y. and biotite ages of 23.8 and 23.5 m.y. Biotite from a granodiorite pluton intrusive into the Pelona Schist gave ages of 14.2, 14.5, and 14.6 m.y.; these are apparently the youngest plutonic rock ages recorded in southern California.

Early Tertiary history of San Andreas fault

The Butano Sandstone of the Santa Cruz Mountains and the Point of Rocks Sandstone Member of the Kreyenhagen Formation of the Temblor Range formed a large deep-sea fan deposited during Eocene time in a continental borderland basin. The fan was subsequently offset by right-lateral movements on the San Andreas fault totaling about 320 km. Reconstruction of the displaced fan segments provides a well-documented offset that is similar to offsets determined for Oligocene and lower Miocene strata, indicating that the San Andreas fault underwent two stages of active right-lateral slip, one in the Late Cretaceous to early Tertiary and the other from early Miocene to present (Clarke and Nilsen, 1973). From at least Eocene to early Miocene time, the fault was not active. This history is corroborated by studies of the history of plate movements in the eastern Pacific ocean floor by Atwater (1970).

Geology and movements on the Calaveras and Hayward faults

Geologic mapping by T. W. Dibblee, Jr., (1974) east of the San Andreas fault indicates that the Hayward fault is continuous southeastward from Milpitas as a recently inactive imbrication of faults along the foothills east of San Jose and eventually terminates against the Calaveras fault north of Morgan Hill. Southeastward, the Calaveras fault extends nearly continuously and is locally recently active through and far beyond Hollister. Sedimentary formations along both faults and between them are intensely deformed into tight folds with axes that trend slightly more westward than do the faults, suggesting that movements on the faults were primarily right lateral, in accordance with indications from recent movements.

Chronology of tectonic events in the western Sierra Nevada, California

A framework for establishing the major tectonic events during the Jurassic and Triassic in the Mother Lode country of the Sierra Nevada, Calif., was set up as a result of recent geological mapping by B. A. Morgan III, and with the help of new K-Ar ages from hornblendes determined by M. A. Lanphere. Hornblende from a wehrlite in a large ultramafic complex gives a K-Ar age of 200 ± 6 m.y. Garnet amphibolite blocks in a melange near the base of the complex also give a K-Ar age of 200 ± 6 m.y. These older, deep-seated, high-grade rocks were probably exhumed during a period of later thrusting. The ultramafic rocks are overlain by a thick unit of andesite flows and breccias and then by slates and graywackes; sparse fossils indicate that these rocks are Oxfordian to Kimmeridgian (Late Jurassic) in age. Deposition of all rocks was brought to a close by a period of rapid and multiple underthrusting to the east along the continental margin. The ultramafic complex was incorporated within a series of chaotic slabs of serpentinized peridotite, volcanics, and slates. Transgression of the thrust zones by Sierra Nevada plutons dating since 136 m.y. indicates a westward migration of tectonic activity toward the Great Valley and the California Coast Ranges.

Origin of potassium-poor magmas

It has been recognized for some time that the potassium content in the Cretaceous plutonic rocks and Cenozoic volcanic rocks in the cordillera increases toward the continent. This has been related by Dickinson (1970), to the depth of a magma chamber above a subducting oceanic plate. However, in the Feather River area, A. M. Hietanen has shown that potassium content in the Paleozoic magmas increased notably with time. Similar increase in potassium content has been recently recognized in many island arcs, where first sodium-rich and later potassium-rich andesitic magmas have erupted. In the Feather River area, a similar change in chemistry took place during the Devonian to Permian volcanism. A possible explanation is the difference in the stabilities of biotite and hornblende. According to a recent experimental work by Allen and others (1972), hornblende decomposes at lower pressures than biotite. Therefore, it is possible that the early magmas were formed in the island-arc environment at shallow depths, where biotite was still stable. Potassium from the biotite was released only later, after thickening of the crust of the continental plate above the magma chamber by deposition and deformation, as was suggested for the Permian by Hietanen (1973).

Complex structural succession established; stress orientation of last folding constant over large area

Field mapping at 1:6,000 scale has been completed in the Ritter Range pendant, Sierra Nevada, Calif., by R. S. Fiske and O. T. Tobisch. Suites of specimens of the metavolcanic rock have been collected for radiometric age dating by Rb-Sr and Pb-U methods to establish firmly the age of the lower nonfossiliferous part of the volcanic section. Structural analysis of the rocks indicates three periods of deformation in the Paleozoic sequence and two periods of deformation (plus penecontemporaneous slumping) in the Lower Jurassic sequence. The last period of deformation, found in both rock sequences in the Ritter Range (and part of the Foothill belt to the west), is characterized by a conjugate fold system from which the regional stresses may be determined. The analysis suggests that the regional stress regime was statistically constant over a large part of the central Sierra Nevada during the last period of deformation.

Nature of rocks underlying the Sierra Nevada batholith, California

Alkaline basaltic to andesitic volcanic pipes at several localities in the western Sierra Nevada, Calif., 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 gneisses, and garnet amphibolites. Gabbroic and granulitic gneiss 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 subbatholith 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.

Root of the Sierra Nevada

L. C. Pakiser, Jr., has reconciled the conflicting interpretations of Dean Carder and J. P. Eaton on the root of the Sierra Nevada. His analysis supports Eaton's conclusions that there is a deep root of high-velocity material in the lower crust, and that the total crustal thickness of the Sierra is more than 50 km. The conflict between Carder's and Eaton's interpretations disappears on recognition that Carder mapped the upper surface of the high-velocity root of the Sierra rather than the Mohorovičić discontinuity.

Regional gravity anomalies, Bakersfield 1° by 2° quadrangle

Complete Bouguer gravity data compiled by W. F. Hanna, H. W. Oliver, R. F. Sikora, and S. L. Robbins (unpub. data, 1974) for the Bakersfield 1° by 2° quadrangle, California, indicate that gravity gradients across the Sierra Nevada and Tehachapi Mountains, negative eastward, are caused by an eastward thickening of the Earth's crust at the expense of underlying higher density and by an eastward volume increase of granitic rocks relative to heavier metamorphic rocks within the crust. A northwest-trending string of negative closures in the Sierra Nevada foothills is generally caused by local thickenings of sediments overlying faulted basement rocks, although one closure is attributable to a westward subsurface extension of low-density granitic rocks forming a lobe of unfaulted basement. The broad positive anomaly along the eastern side of the San Joaquin Valley, which noses southwestward along the Bakersfield arch to the Elk Hills Naval Petroleum Reserve, is probably caused by mafic basement rocks which also generate a positive magnetic anomaly. Gravity lows at the southern and western margins of the valley are produced by thick accumulations of sediments. Numerous gravity highs over the Temblor and Caliente Ranges are associated with marine Cretaceous rocks having higher densities than the Tertiary and Quaternary sediments of the adjacent San Joaquin Valley and Carrizo Plain.

WASHINGTON

Contact of lower and middle Yakima Basalt in southeast Washington

D. A. Swanson and T. L. Wright mapped the contact of the lower and middle Yakima Basalt, as defined by Wright and others (1973), along the Snake River between Walker and Almota, Wash., a distance of about 80 km. They also traced the contact high into the Blue Mountains south of Dayton. The contact, which separates flows of Yakima chemical type (below) from overlying flows of different chemistry (generally Frenchman Springs Member), is recognized in the field by the presence of a reddish saprolite a few centimetres to several metres in thickness. The saprolite was apparently formed during a lull in volcanic activity on the Columbia Plateau. This lull marks the time at which one of the most profound changes in Columbia River magma composition took place. Middle Yakima flows, primarily belonging to the Frenchman Springs Member, pinch out to the east against the saprolite, indicating that basining of the Columbia Plateau began at least as early as the end of early Yakima time.

High-angle faults in the Swauk Formation of the central Cascade Range, Washington

What appear to be large-scale, chevron-form folds in the Alpine Lakes study area are inferred to be high-angle faults. Although dips in flanking Swauk beds persist into the axial areas and characteristic fault features such as shear planes, slickensided surfaces, or fault breccia are not evident, J. L. Gaultieri and G. C. Simmons early in their study deduced that the structures might be faults. The Swauk in the Alpine Lakes study area is a homogenous, competent rock—95-percent thick- to massive-bedded sandstone—a rock unlikely to be deformed into chevron-form folds. Subsequent mapping along projections of the axial trends revealed the existence of offsets of the Swauk with older and younger formations and (or) the presence of igneous dikes emplaced on or near the projected axes.

Oligocene continental slope beneath Juan de Fuca

Geologic studies by P. D. Snavely, Jr., and N. S. MacLeod in the northwestern part of the Olympic Peninsula, Wash., and along southern Vancouver Island, were conducted jointly with D. L. Tiffin and Jan Muller (Geological Survey of Canada). Results of these studies indicated that the Oligocene sedimentary rocks exposed north and south of the Strait of Juan de Fuca were deposited in markedly different depositional environments. On Vancouver, about 500 m of Oligocene siltstone and sandstone, which overlie pre-Tertiary metamorphic and igneous rocks west of Port San Juan, contain molluscan and foraminiferal faunas indicative of a neritic environment. In contrast, in the northwestern part of the Olympic Peninsula, more than 2,500 m of Oligocene siltstone and interbedded units of turbidite sandstone contain a foraminiferal fauna indicative of bathyal or abyssal depths.

A pronounced southward-dipping linear gravity gradient along the central part of the strait and parallel to it probably results from a change in crustal thickness across the strait. This gravity gradient and the changes in the thickness and depositional environments of Oligocene sediments suggest that the western strait may be the site of a former steep Oligocene continental slope that separated shelf deposition to the north from deep marginal basin deposition to the south. Thick and extensive zones of penecontemporaneously deformed sedimentary rocks occur in the deep-water Oligocene sequence. These deposits may have resulted from downslope slumping of sediments triggered by tectonic activity.

Knowledge of the regional distribution of Oligocene shelf and deep-water-facies sedimentary rocks may provide a key to unraveling the tectonic evolution of the Olympic Peninsula. Also, the Oligocene shelf facies is an important target for oil and gas exploration because encouraging shows have been encountered in test wells drilled in the northeastern part of the Olympic Peninsula where it onlaps middle Eocene basalt highs. The deep-water Oligocene deposits may also have petroleum potential, as oil and gas seeps occur in this sequence in the northeastern part of the Olympic Peninsula, and some turbidite sandstones are petroliferous.

Seamounts and subduction in the Olympic Peninsula, Washington

Field mapping, plus petrologic and structural analysis by W. M. Cady and R. W. Tabor, in the Olympic Peninsula, Wash., reveal that lower and middle Eocene submarine basalt, chiefly tholeiite of oceanic-ridge composition, forms two centers of accumulation, which were perhaps originally seamounts. They were first involved in thrusting (probably with subduction of adjacent sea floor to the west), which climaxed in the late Oligocene, and were then involved in complex doming and (or) oroclinal bending in the middle to late Miocene. A large accumulation of basalt, 15 km thick, is near the eastern and southeastern periphery of the peninsula, and a smaller accumulation, 5 km thick, is near the northern periphery. The presently curving and outward-dipping volcanic piles each have strike lengths of about 75 km, which suggests the minimium diameters of the seamounts. The basalts stratigraphically overlie and interfinger laterally with Eocene to middle Miocene clastic marine sedimentary rocks. These peripheral volcanic and sedimentary rocks are thrust faulted against Eocene to Miocene marine shales, turbidites, and minor basalts within the core of the Olympic Mountains; the rocks in the latter group are penetratively sheared and metamorphosed, and form fault-bounded, northwest-trending arcuate packets. The originally east-dipping and low-angle thrust faults, shear zones, and rock packets now dip steeply in the complex dome or orocline. Large clasts eroded from the early Tertiary and older continent to the east are found in the pyrogenic matrix of the Eocene tholeiites and in the turbidites. These clasts indicate that the suggested seamounts were close to, or overlapped from the sea floor onto, the North American plate. Continuing eastward spreading at the sea floor and westward advance of the continental plate were responsible for the low-angle thrusts and shears that apparently mark a subduction zone in the Olympic Peninsula.

Comparison of Anarchist and Covada Groups of north-central Washington

Separated by about 100 km of volcanic and plutonic terrane, the Anarchist (west) and Covada (east) Groups occupy discrete outcrop areas. Both have been considered to be approximate correlatives of the Cache Group of southern British Columbia, exposed about 300 km to the northwest, because of similar eugeosynclinal lithologies, and because the age of fossils found in Cache Creek (Mississippian(?), Pennsylvanian, and Permian) overlaps that of the Anarchist (Upper(?) Permian) and Covada (Pennsylvanian(?)). However, detailed study of the Anarchist, coupled with field reconnaissance of the Covada by F. K. Fox, Jr., and C. D. Rinehart, indicates that significant lithologic differences exist between the Anarchist and Covada, and, judging from published descriptions of the latter, also between these groups and the Cache Creek.

Rocks of all three groups are composed mainly of variably metamorphosed, complexly interfingering deposits of argillite, siltstone, graywacke, limestone, and lava. The Cache Creek and Anarchist also contain sharpstone conglomerate and pyroclastic deposits, and, in addition, the Cache Creek contains bedded chert. The most significant difference between the three groups is in the composition of the coarser grained clastic deposits—graywacke, sandstone, arkose, and conglomerate. Coarser clastics in the Anarchist and Cache Creek are mainly from a volcanic provenance, whereas otherwise comparable rocks of the Covada are, surprisingly, from a granitic provenance. For example, judging from 11 thin-sectioned specimens collected from widely spaced outcrops along the Columbia River between Kettle Falls and Hunters, Wash., the graywacke of the Covada Group contains angular to poorly rounded grains of quartz, sodic plagioclase, potassium feldspar, mica, orthoquartzite, and, rarely, granitic rock. In contrast, the coarser grained clastic rocks of the Anarchist typically contain detrital quartz, chert, slate, siltstone, volcanic rocks, and plagioclase. However, in the upper part of the Anarchist in outcrops nearest to the Covada, clastic rocks typical of the Anarchist apparently intertongue with weakly metamorphosed, typical Covada lithologies of graywacke, arkose, and orthoquartzite; the latter composed of detrital quartz, plagioclase, and potassium feldspar.

These circumstances suggest that the upper Paleozoic clastic rocks comprise two facies—a southern and eastern (Covada) facies from a granitic provenance, and a northern and western (Cache Creek) facies from a volcanic or eugeosynclinal provenance. The Anarchist Group includes elements of the Cache Creek facies on the north and of the Covada facies on the south, and thus apparently straddles the intertonguing contact of the two facies.

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 six subdivisions corresponding to six major geographic regions.

NORTHERN ALASKA

Northern Alaskan-Canadian boundary reconnaissance

During July 1973, a geologic reconnaissance both east and west of the northernmost portion of the Alaskan-Canadian boundary was completed by D. K. Norris (Geological Survey of Canada) and H. N. Reiser (USGS). This work resulted in the extension into Canada of the major fault separating the belt of mafic-volcanic and carbonate rocks of Cambrian age from the underlying rocks to the north. Previously, this contact was regarded as an unconformity along its eastern portion. Onsite comparisons were made of the Upper and Lower Cretaceous, Jurassic, and Triassic sections over a distance in excess of 300 km. These confirmed the legitimacy of assigning the formation names of Shublik and Kingak to at least portions of these respective Triassic and Jurassic sections in Canada. Coarse conglomerates mapped as Upper Cretaceous (Moose Channel equivalent) on lower Trail River in Canada are lithologically very similar to an exotic, thick sequence of unfossiliferous rocks occurring 80 km west of the boundary on the Jago River, but here these rocks are regarded as Lower Cretaceous, so the problem remains to be resolved.

Pennsylvanian beds in Lisburne Group, south-central Brooks Range

The southernmost exposures of the Lisburne Group in the central part of the Brooks Range are in a section about 300 m thick on the North Fork of the Koyukuk River in the Wiseman quadrangle. These exposures are about 50 km south of the Lisburne type area on the Anaktuvuk River where the group is about 900 m thick and comprises two formations, the Wachsmuth Limestone (Lower and Upper Mississippian; Osagean and Meramecian) and the Alapah Limestone (Upper Mississippian; Meramecian and Chesterian). Foraminifera recently collected by W. P. Brosgé, H. N. Reiser, and I. L. Tailleur from the upper 40 m of the Lisburne on the North Fork have been identified by A. K. Armstrong (USGS) and B. L. Mamet (Université de Montréal) as Lower Pennsylvanian (Morrowan; Mamet zone 20). The upper Lisburne on the North Fork is therefore younger than in the type area and is correlative with the Pennsylvanian (Morrowan and Atokan) Wahoo Limestone found typically in the upper Lisburne of the northeast Brooks Range.

Foraminifera from 11 m above the base of the Lisburne on the North Fork are Upper Mississippian (Meramecian; Mamet zones 12 or 13), according to Armstrong. The base of the Lisburne, therefore, is also probably younger than that of the type area and is about the same age as the basal Lisburne on the Marsh Fork of the Canning River in the northeast Brooks Range. As in the northeast Brooks Range, the Kayak Shale (Lower Mississippian) beneath the Lisburne on the North Fork of the Koyukuk rests unconformably on lower Paleozoic rocks.

The Lisburne on the North Fork is overlain locally by gray, partly calcareous siltstone, from which brachiopods of Early (?) Permian age have been identified by J. T. Dutro, Jr.; the siltstone is overlain by carbonaceous shale, siltstone, and limestone of the Shublik Formation, from which Late and possibly Middle Triassic pelecypods have been identified by N. J. Silbering. A north-dipping thrust fault along the valley of the North Fork separates this Mississippian to Triassic sequence from the typical central Brooks Range sequence of Upper Devonian to Upper Mississippian rocks (Endicott and Lisburne Group) to the north.

Western Brooks Range

I. L. Tailleur sampled two facies of the Mississippian part of the Lisburne Group from grossly superposed tectonic units in which A. K. Armstrong identified diagnostic fossils. One forms a thin layer of grainstone and wackestone sporadically exposed at the base of a folded broad allochthonous sheet on Cretaceous and older subthrust units. Although the limestone underlies the detritus-rich Utukok Formation, it lithogenetically resembles the Kogruk Formation gradationally above the Utukok. One sample locality lies at the foot of a ridge from which Armstrong (1970) described a 550-m section (62C–15) of Kogruk. Corals, foraminifers, and algae suggest a Meramecian age, possibly representing B. L. Mamet's endothyroid zones 14–15. Although the Kogruk has not been thoroughly zoned locally, the fossils seem no older than others from that formation. The thin layer would thus represent another broad thrust sheet instead of development of the Kogruk depositional environment before deposition of the Utukok Formation.

The other samples with diagnostic fossils represent the so-called black facies which comprise the structurally lowest exposures of the Lisburne Group in the region. Dark-colored packstone interbedded subordinately with lime mudstone contain Foraminifera and algae indicative of a Late Mississippian (zone 11–13) age. They are the first faunal evidence for the age of the facies across the headwaters of the Wulik River.

Further investigation of remnant mafic and ultramafic ophiolitelike complexes in the western Brooks Range was limited to a single landing near the apices of the large gravity and magnetic anomalies east of the lower Noatak River (Barnes and Tailleur, 1970). In addition to the serpentinite that had been observed in the vicinity in 1966, rubble consists of gabbroic and more mafic phases, as well as fragments of a very coarse grained black amphibole and white-feldspar pegmatitic phase. These lithologies confirm Barnes' inference that the anomalies reflect rocks denser than the shallow-scaled mafic rocks dominant in previous observations of the belt of igneous rocks across the west plunge of the Baird Mountains. That the bodies producing the anomalies could be ultramafic rock is suggested by a chromite claim in the vicinity, recorded in 1954, and the presence of similar rock types in ultramafic layers or sheets which rest synformally upon terrane of the shallow-seated phases in the Iyikrok Mountain, Avan River, Misheguk Mountain, and Siniktanneyak Mountain complexes in the southern De Long Mountains to the west, north, and east .

WEST-CENTRAL ALASKA

Reconnaissance geology of St. Matthew and Hall Islands

Reconnaissance investigations on St. Matthew and Hall Islands, by W. W. Patton, Jr., T. P. Miller, H. C. Berg, George Gryc, J. M. Hoare, and A. T. Ovenshine, show that these two central Bering Sea islands are made up almost entirely of calc-alkaline volcanic rocks that range in composition from rhyolite to high-alumina basalt. Along the northeast coast to St. Matthew, the volcanic rocks are locally intruded and thermally altered by small bodies of granodorite. The volcanic rocks are flat-lying to mildly deformed and are broken by north- and northeast-trending high-angle faults. Marine geophysical data and onshore mapping suggest that these volcanic rocks belong to a Late Cretaceous to early Tertiary arc that extends across the Bering Sea shelf from Anadyr Gulf in northeast Siberia to the Yukon Delta of southwest Alaska.

Newly discovered marine fauna of early Pleistocene age on Seward Peninsula

A richly fossiliferous marine deposit of so-called Anvilian (Aftonian, early Pleistocene) age was discovered on the York Terrace at California River, southwestern Seward Peninsula. The Anvilian transgression was previously known only from fossiliferous nearshore deposits encountered in mine shafts, now caved and inaccessible, near Nome. The new locality provides, for the first time, a place where the stratigraphic relationships of the Anvilian transgression can be examined in surface exposures. The presence of a few specimens of *Globorotalia pachyderma*, all right coiling, suggests that the California River fauna (and thus the Anvilian transgression) is older than 0.7 m.y. Fieldwork at California River was carried out by D. M. Hopkins and R. E. Nelson, and the paleontologic studies were conducted by R. W. Rowland (Molluska), R. J. Echols (Foraminifera) and P. C. Valentine, Jr., (Ostracoda).

Primitive mammoth found in weathered gravel on central Seward Peninsula

A primitive mammoth molar was discovered by D. M. Hopkins and R. E. Nelson in weathered gravel of early or middle Pleistocene age exposed on Kaveruk Creek, central Seward Peninsula. According to C. A. Repenning, the molar was similar to molars referred to the early Pleistocene *Archidiskodon* by A. V. Sher (Paleontological Inst., U.S.S.R.) who has studied the fossil mammals of northeastern Siberia. The find is of great importance because there are only a few fossil vertebrate finds older than late Pleistocene in Alaska.

Southeastern Seward Peninsula

Preliminary studies by T. P. Miller on the Darby pluton in southeastern Seward Peninsula suggest a possible above-average content of uranium and thorium (Miller and Grybeck, 1973). Three samples of quartz monzonite, selected on the basis of 35 modal analyses as representing the range in composition of the pluton, were analyzed by C. M. Bunker using gamma-ray spectrometric methods and showed a range of 9 to 15 ppm U and 49 to 65 ppm Th. These values are similar to published averages of 15 ppm U and 56 ppm Th for the uranium- and thorium-rich Conway Granite of New Hampshire. Studies are continuing on the distribution of uranium and thorium in the Darby pluton and adjoining bodies using a larger sample size to check this possible high uranium-thorium background.

New Tertiary basins in interior Alaska

Reconnaissance gravity surveys by D. F. Barnes are continuing to identify small Tertiary basins beneath alluvium-covered flats in the Alaska interior. Traverses along the upper portion of the Kuskokwim River drainage have shown a 30-mGal low with an areal extent of more than 500 km^2 near the village of Nikolai where a small outcrop of Tertiary sedimentary rocks has been reported. Most of the low lies southeast of the present Kuskokwim River drainage, so it was crossed primarily by traverses on tributary rivers, and additional data would be required to determine its true size.

Preliminary inspection of other data from lower portions of the Kuskokwim reveals at least one other gravity low of similar dimensions. Similar gravity lows were located along the Yukon and Tanana drainage systems, and all have magnitudes of 30 to 40 mGal, suggesting sedimentary sections of 8 to 10 km and fairly uniform rates of vertical deformation since the Tertiary.

Kanuti ultramafic belt

The recently mapped (W. W. Patton, Jr., and T. P. Miller, 1973; W. W. Patton, Jr., 1973) Kanuti ultramafic belt could provide valuable insight into the complex and as yet poorly understood tectonic history of western Alaska. This 125-km-long belt lies along the contact of two sharply contrasting geologic assemblages: on the northwest the Cretaceous-Tertiary volcanogenic deposits of the Yukon-Koyukuk provinces, and on the southeast the Precambrian(?)-Paleozoic platform deposits of the Ruby geanticline. Reconnaissance investigations and mapping of this belt were carried out in 1970 by W. W. Patton, Jr., and T. P. Miller and again in 1973 by Patton, M. A. Lanphere, and W. P. Brosgé in an effort to determine the age, structural setting, and mode of emplacement of the ultramafic-mafic complexes. The reconnaissance studies have served to outline six major ultramafic-mafic complexes ranging in size from less than 2 km^2 to 60 km^2, with a combined total area of about 150 km^2. The complexes occur as tabular masses as much as 1,000 m thick composed of partially serpentinized dunite-harzburgite in the lower part and gabbro in the upper part. They dip 10° to 60° northwestward beneath the Cretaceous and Tertiary volcanic and sedimentary deposits of the Yukon-Koyukuk province, and at the base they are thrust onto volcanic rocks of probable late Paleozoic age and pelitic schist and carbonate rocks of Precambrian(?) and early Paleozoic age. At present, the complexes cannot be dated more closely than post-Devonian to pre-middle Cretaceous.

EAST-CENTRAL ALASKA

Blue schist found in the Kukon-Tanana Upland

A single outcrop of schist containing abundant blue amphibole was found associated with a small body of serpentine in the Seventymile River area of the Eagle quadrangle by H. L. Foster. This is the first blue amphibole-bearing schist found in the Yukon-Tanana Upland and the first locality in the Tintina fault zone in Alaska.

Platinum found in an ultramafic rock from the Eagle quadrangle

Analyses for platinum-group metals were made of more than 80 samples of ultramafic rocks from the Eagle quadrangle. One sample from a biotite pyroxenite collected by H. L. Foster in the Eagle C–3 quadrangle contained 0.3 ppm Pt and 0.2 ppm Pd. The ultramafic rocks at this locality are not serpentinized and occur with coarse-grained hornblende-bearing intrusive rocks that range from hornblende gabbro to hornblende granodiorite.

Alpine-type peridotites recognized in the Eagle quadrangle

Study of the mineralogy of the rocks of more than 100 ultramafic bodies of the Eagle quadrangle by T. E. C. Keith and H. L. Foster indicates that the rocks can be divided into three groups on the basis of degree of serpentinization: group I, completely serpentinized; group II, partially serpentinized; and group III, not serpentinized. The rocks of groups I and II are considered to be alpine-type peridotites and may be part of a dismembered ophiolite. They include the Mount Sorenson and American Creek bodies.

Metamorphic rock sequence between Rampart and Tanana dated

The first collection of fossils from a 1,300-km^2 area of metamorphic rocks on the north side of the Yukon River between the villages of Rampart and Tanana was made in 1972 by R. M. Chapman. Colonial rugose corals were found in a thin limestone interbedded with schist and phyllite on Raven Ridge, about 37 km southwest of Rampart.

The corals are not well preserved, and the critical features are obscure in thin section. However, W. A. Oliver, Jr., C. W. Merriam, and A. K. Armstrong agree that the corals are post-Ordovician, could be Silurian to Permian, and have some resemblance to Devonian and Carboniferous genera.

Dark monazites in Alaska

Using optical and X-ray methods, Samuel Rosenblum identified gray-black monazite in Alaskan stream concentrates from the Tanana, Ruby, and Livengood quadrangles. Emission spectrographic analysis by E. L. Mosier shows that these Alaskan gray-black monazites have chemical compositions similar to those reported for gray monazites from Siberia, Taiwan, and France. This is apparently the first time that the gray-black variety of monazite has been reported in North America. The monazites are characterized by low thorium (0.4 to 1 percent) and high europium (0.3 to 0.7 percent) content.

Ultramafic complex at Pitka Fork may be a klippe

As a result of rapid reconnaissance of the Beaver quadrangle in 1971–72, a unit identified as eclogite and amphibolite was mapped in an area of 25 km^2 on the Pitka Fork by W. P. Brosgé, H. N. Reiser, and W. E. Yeend (1973). Two days' examination of the area by Brosgé, Reiser, and M. A. Lanphere in 1973 showed that the Pitka Fork complex consists largely of banded garnet amphibolite, foliated dunite and harzburgite with pronounced cleavage, gneissic leucogabbro, and only minor eclogite. These rocks are interlayered in a crude synform; most of the amphibolite is near the base, and most of the gneissic leucogabbro is at the axis. Massive nonfoliated gabbro cuts across the foliation of the ultramafic rocks. The synform lies within a large area of mafic volcanic rocks. The layers in the synform strike northwest, discordant with the contact with the volcanic rocks and with the apparent regional northeast strike of the volcanic rocks. At the only exposed contact that was found, the amphibolite rests on about 100 m of fine-grained pelitic and mafic schist of the amphibolite facies, which in turn rests on the volcanic rocks. Therefore, the Pitka Fork complex may be a klippe.

SOUTHWESTERN ALASKA

Pleistocene study, Amchitka Island

Tilted and faulted lower Pleistocene lake beds overlain by two interglacial marine deposits are recognized by L. M. Gard, Jr. as having been preserved by downfaulting in a graben at South Bight on Amchitka Island. During the early Pleistocene, trees grew on this presently treeless Aleutian Island, and the pollen assemblage suggests that the average July temperature was several degrees warmer than at present, according to E. B. Leopold.

The two marine deposits, named by Gard South Bight I and South Bight II, represent interglacial marine transgressions which carved broad terraces on Amchitka Island. The fossiliferous South Bight II deposit, previously dated by the uranium-series method at about 130,000 yr, is now calculated by B. J. Szabo to be 117,000 ± 5,000 yr.

Amchitka Island was covered by ice at least twice during the Pleistocene. The earlier glaciation, represented by well-indurated diamictite, appears to have occurred prior to the South Bight I marine transgression. The later glaciation, which is younger than the South Bight II transgression, probably covered the island in late Wisconsin time as soils and peat older than 10,000 yr have not been found. Several thin ice caps probably were present simultaneously during the Wisconsin, and distribution of distinctive erratics indicates that an ice cap at the east end of the island moved from east to west and had a source area that could have been no higher than 73 m above present sea level.

SOUTHERN ALASKA

Twenty million cubic metres of silt

Before the March 27, 1964, Alaska earthquake, Portage was a small roadside settlement at the head of Turnagain Arm, about 80 km southeast of Anchorage. Portage was abandoned after the earthquake because land subsidence amounting to at least 2.1 m occurred over an area of more than 18 km^2.

The earthquake dropped Portage into the intertidal zone of Turnagain Arm, a 72-km-long estuary nearly filled with sediment and subject to the second highest tides (10 m) in North America. Rapid sedimentation ensued. A. T. Ovenshine, D. E. Lawson, and S. R. Bartsch estimated that 20 million m^3 of silt have been swept into the Portage area since 1964. The new and still-forming tidal deposit is arborescent in plan because of the access to the depositional areas provided by the five streams that meet at tidewater in the Portage area. The thickness pattern of the deposit reflects the effects both of proximity to the source—the intertidal bars in Turnagain Arm—and the constraint on the floodtide of a highway embankment that follows the shoreline. Seaward of the highway, the thickness of the deposit averages 1.5 m; landward, 0.9 m.

The environmental consequences of inundation and sedimentation in the Portage area are more lasting and perhaps more serious than the direct effects of the earthquake. Habitations and businesses, most of which were only damaged by the earthquake, have been abandoned and partially buried, and a large area of beautiful forest and meadow was killed and covered by thick deposits of quicksilt that present the most severe foundation problems and may have taken the life of at least one unwary person.

History of movement on the Denali fault system

Two granodiorite plutons, which have nearly identical mineralogy and chemistry, are considered by B. L. Reed and M. A. Lanphere to be parts of a single igneous mass which has undergone a right-lateral displacement of about 38 km along the McKinley segment of the Denali fault system since this igneous mass crystallized about 38 m.y. ago. These offset plutons place severe constraints on the amount and rate of movement along the McKinley segment since the beginning of the Oligocene. The 38-km displacement indicates an average rate of 0.1 cm/yr if movement began immediately after crystallization in the early Oligocene, or an average rate of 0.4 cm/yr if movement began 10 m.y. ago in the Miocene. These rates, however, are considerably less than Holocene movement rates measured along the fault further to the east, which suggests that the Holocene displacement rate is greater than the pre-Holocene rate or that right-lateral movement along the fault may diminish to the west.

Plutonism and metamorphism, eastern Alaska Range

Regional mapping by D. H. Richter and radiometric dating by M. A. Lanphere on plutonic and metamorphic rocks indicate three principal plutonic events and two episodes of complex plutonic metamorphic activity in the eastern Alaska Range. The plutonic rocks, largely granodiorite and quartz monzonite, were emplaced in Late Pennsylvanian time (282 to 285 m.y.) and during two distinct intervals in Cretaceous time (105 to 117 m.y. and 89 to 94 m.y.). Development of a large plutonic-metamorphic complex, consisting of diorite and quartz diorite intimately associated with amphibolite-grade banded gneisses and other metamorphic rocks, apparently occurred during Late Triassic to Middle Jurassic time (163 to 199 m.y.). A smaller plutonic-metamorphic complex is Miocene in age (17 m.y.).

Ultramafic rocks in the schist at Willow Creek, southwestern Talkeetna Mountains

Detailed mapping of the enigmatic schist block at Willow Creek by Béla Csejtey, Jr., revealed several heretofore unrecognized serpentinite bodies within the schist. Preliminary petrographic studies of the schist suggest that it underwent two distinct periods of regional metamorphism. The present greenschist-facies metamorphism appears to have retrograded from a previous higher facies, probably amphibolite. The uniform petrography of the schist, the presence of serpentinized ultramafic bodies, and lack of similar rocks in adjacent regions suggest that the schist block is a tectonically emplaced fragment of a larger metamorphic terrane. Potassium-argon age determinations to decipher the complex geologic history of the Willow Creek schist are presently underway by J. G. Smith.

Isotopic age determinations in the Talkeetna Mountains batholithic complex

Reconnaissance investigations by Béla Csejtey, Jr., and M. A. Lanphere of the batholithic complex in the Talkeetna Mountains, approximately 6,500 km^2 in area, indicate that the bulk of the complex is made up by rocks of Late Cretaceous to early Tertiary age instead of Jurassic rocks as postulated by earlier workers. The batholithic complex is composite, mesozonal and epizonal in character, and ranges in composition from quartz diorite to granite. Jurassic ages, determined by the K-Ar and Pb-α methods, were obtained by Grantz and others (1963) for the Kosina pluton, which forms the easternmost part of the Talkeetna Mountains batholithic complex. In contrast, K-Ar age determinations on hornblende and biotite mineral-pair samples from scattered localities yielded Late Cretaceous to early Tertiary concordant ages. As most mineral deposits in southern Alaska are associated with plutons of Late Cretaceous to early Tertiary age (Reed and Lanphere, 1969), the new age determinations make the western two-thirds of the largely unexplored Talkeetna Mountains batholithic complex an attractive target area for mineral exploration.

Structural framework of the McCarthy quadrangle

Project work augmented by investigations in adjacent Nebesna and Bering Glacier quadrangles, respectively under the direction of D. H. Richter and George Plafker, have clarified the structural setting of the McCarthy quadrangle relative to regional tectonics. Except for its east-central and southwestern parts, the quadrangle is underlain by the Taku-Skolai terrane of Berg and others (1973). The oldest representative of the Taku-Skolai terrane in the quadrangle, the Skolai Group, is bounded on the north by the Denali fault (in the Nabesna quadrangle) and on the south by the Border Ranges fault. The southwestern part of the quadrangle, south of the Border Ranges fault, is underlain largely by upper Mesozoic flysch of the Valdez Group. A large area in the east-central part of the quadrangle is underlain by marble and amphibolite of the middle Paleozoic Kaskawulsh Group of Kindle (1952), a component of the Alexander terrane (Berg and others, 1973), which is best developed in southeastern Alaska. Although its contacts are incompletely mapped, the Kaskawulsh is largely separated from Skolai Group rocks by intervening granitic masses that include some syenite and monzonite; relationships between the two discrete terranes, the Alexander and the Taku-Skolai, are enigmatic. Possibly the granitic masses were emplaced along, and healed, major faults of regional significance, but there is scant evidence for this premise.

The tectonic history of the quadrangle can be summarized as follows:

1. Development of the Skolai Group as an island arc on oceanic crust during the late Paleozoic, and its subsequent accretion to the continent near the close of the Paleozoic or during the early Mesozoic.
2. The juxtaposition of the Skolai and Kaskawulsh Groups (Taku-Skolai and Alexander terranes) in the east-central part of the quadrangle by undetermined processes.
3. Development, probably during the late Mesozoic, of a zone of extensive south to north thrusting in the Taku-Skolai terrane that transcends the southern part of the quadrangle.
4. The evolvement of the Border Ranges fault, mainly a high-angle, north-dipping reverse fault, that separates the Taku-Skolai terrane from Mesozoic trench deposits, the flysch of the Valdez Group, to the south. The Border Ranges fault probably evolved during the late Mesozoic and culminated with the accretion of the Valdez Group to the continent, probably during the early Tertiary.
5. Development of steep faults during the Cenozoic. These faults generally lack major displacement and include the Totschunda and related northwest-striking faults in the northeast part of the quadrangle and faults with diverse strikes elsewhere.

Sedimentary and volcanic features of the Orca Group

Recent fieldwork in the vicinity of Cordova, Alaska, and subsequent laboratory studies by G. R. Winkler and George Plafker have added considerable new information about the sedimentary and volcanic features of the Orca Group, a thick highly deformed sequence of probable middle or late Paleocene age.

Collectively the sedimentary rocks may be characterized as a flysch and include thin pelitic intervals with pelagic Foraminifera. In a few places, coarse pebbly sandstone and conglomerate is interbedded with the more typical sandstone-siltstone turbidites. Paleocurrent measurements show general east-to-west sediment transport but are dispersed in a radial pattern. Probably the Orca sediments near Cordova were deposited on a complex, westward-sloping deep-sea fan.

The Orca sandstones are subquartzose—chiefly feldspathic or lithofeldspathic. Composition of lithic grains is widely variable, but volcanic and sedimentary clasts predominate. Pyriboles, epidote, and mica are the dominant heavy mineral grains; polycrystalline quartz comprises about 10 percent of total quartz. Orca detritus apparently was derived from a nearby tectonized terrane of sedimentary, metasedimentary, volcanic, and metavolcanic rocks.

Tabular bodies of greenstone are concordant on a large scale with the Orca sedimentary rocks. They constitute about 15 percent of the outcrop area of Hinchinbrook Island. The greenstones consist of pillowed and nonpillowed altered tholeiitic basalt flows, breccia, and tuffs, with subordinate interbedded sandstone and siltstone. Thin lenticular bioclastic limestone, chert, and red and green shale mantle upper surfaces of the volcanic rocks in many places and are supplanted upward by normal thick flyschoid sequences. Mafic volcanism during Orca time was thus active near enough to the continental margin for the effusive rocks to be intercalated within the rapidly forming prism of terrigenous sediment.

Spotty microfaunal evidence suggests a middle or late Paleocene age for the Orca Group on Hinchinbrook Island. The rocks were extensively folded and faulted, generally along trends parallel to the continental margin, and were regionally metamorphosed to the laumontite and prehnite-pumpellyite facies prior to, or concurrent with, intrusion of lower Eocene granitic plutons.

Radiometrically dated plutons in the Orca Group

The Orca Group is a thick, complexly deformed, and sparsely fossiliferous sequence of predominantly eugeosynclinal clastic and volcanic rocks that crops out over an area of roughly 15,540 km^2 of the Prince William Sound region and the Chugach Mountains, according to George Plafker. The group probably also underlies large parts of the Gulf of Alaska Tertiary province to the south of the outcrop belt and may extend southwestward at least as far as the Kodiak Archipelago.

Six new K-Ar dates by M. A. Lanphere from four granodiorite and quartz monzonite plutons intrusive into the Orca Group give closely concordant ages ranging from 49.2 to 52.2 m.y. These dates indicate that the Orca Group was deposited and deformed before emplacement of the plutons in early Eocene time, and they are compatible with meager paleontological data suggestive of a middle to late Paleocene age for the Orca Group sediments.

SOUTHEASTERN ALASKA

Glaciomarine formation replaces marine till near Juneau

R. D. Miller (1973) has redefined widespread till-like and shell-rich deposits near Juneau, Alaska, previously called marine till, into a composite glaciomarine deposit, the Gastineau Channel Formation. Such a redefinition incorporates into the origin of the deposits a fiord environment, free of valley-filling glaciers.

Valley glaciers in the immediate Juneau area are not believed to have reached tidal waters since more than 11,000 yr ago. Some of the coarse clasts in the formation are considered to have been carried into the Juneau area on icebergs floating from glaciers that reached the waters of the fiords elsewhere in this part of southeast Alaska and as debris on ice that seasonally built outward from shore. These clasts were dropped into finer grained fiord deposits before and during the land rebound (at least 230 m) that occurred in response to the retreat of the area's glaciers.

Extensive Tertiary granitic terrane in southeastern Alaska Coast Range batholithic complex

Continuing studies in the Juneau Icefield area show that granodiorite, quartz monzonite, and other phases of the approximately 50-m.y.-old informally named Turner Lake body are much more extensive than was originally surmised. D. A. Brew and A. B. Ford reported that over 1,650 km^2 of the unit have been mapped and studied to date and that the northwestern and southeastern limits are still unknown. The body contacts several country-rock units, including high-grade granitic gneisses to the southwest and medium-grade thermally metamorphosed volcanic rocks of probable original early Mesozoic age to the northeast. It appears that at least this part of the Coast Range complex consists mostly of Tertiary granitic rocks.

Vertebrate fossil discovered in southeastern Alaska

H. C. Berg discovered the first pre-Tertiary vertebrate fossil in southeastern Alaska. The occurrence is on the northern coast of Gravina Island, situated near the southern tip of the panhandle about 16 km from Ketchikan. The fossil, a reptile tentatively identified by C. A. Repenning as a mixosaurid ichthyosaur, is embedded in recrystallized Upper Triassic silty limestone. It consists of an approximately 38-cm-long segment of vertebral column, plus indefinite structures that might be ribs. In addition to the vertebrate remains, the enclosing beds also contain specimens of Late Triassic pelecypod *Halobia.*

A photograph of the vertebrate fossil, which is too fragile to remove from the outcrop, was submitted to Christopher McGowan of the Vertebrate Paleontology Department of the Royal Ontario Museum, Toronto. McGowan confirmed that the fossil is a mixosaurian, but the absence of forefins or skull precluded further identification. The locality information, however, will be useful in compiling data on global distribution of icthyosaurs.

PUERTO RICO

Stratigraphic and structural relations in the Sierra Bermeja area, southwestern Puerto Rico

Detailed field investigations by R. P. Volckmann in the San Germán, Parguera, and Puerto Real 7½-min quadrangles reveal that the bulk of the Sierra Bermeja—the prominent range of mountains in extreme southwestern Puerto Rico—is highly deformed chert in close physical association with an ophiolite-type complex of diorite, amphibolite, and serpentinite. The chert is bedded, with individual beds consisting of lenses 1 to 30 cm thick and 30 to 500 cm long. The lenses commonly are separated by a thin layer (2 to 5 mm) of siltstone or mudstone. In most places deformation has obscured the bedding, and the chert is generally recrystallized. The chert is estimated to be at least 800 m thick, but extensive faulting may have repeated or reduced the section.

The relationship of the chert and the mafic members of the ophiolite complex is not clear. The Sierra Bermeja is cut by many high-angle faults, most of which trend north to northeast, and the chert has only been observed in fault contact with the ophiolite-complex rocks. In places, serpentinite has been emplaced, probably diapirically, along the high-angle faults.

The northern border of the Sierra Bermeja appears to be an extensive, east-west trending, high-angle fault, dropped down to the north. A body of fine- to medium-grained quartz diorite has invaded the fault zone along much of its length and forms an intrusive contact with the chert. The age of the quartz diorite intrusive is unknown, but the body may correlate with other intrusive rocks north of the Lajas Valley in the San Germán quadrangle.

Stratigraphic relations of the Yauco, Lago Garzas, and Sabana Grande Formations in south-central Puerto Rico

Geologic mapping by R. D. Krushensky in the Yauco and Peñuelas quadrangles of south-central Puerto Rico indicates that the Yauco Mudstone of Late Cretaceous age (Campanian or early Maestrichtian) is interbedded over wide areas and throughout a thick sequence with the Lago Garzas Formation to the east and with the Sabana Grande Andesite of Mattson (1960) to the west. The Lago Garzas consists chiefly of volcanic breccia, lava, and subordinate epiclastic sandstone and conglomerate. To the east, the Lago Garzas correlates with the epiclastic rocks of the Coamo and Maravillas Formations of the Ponce and Coamo areas. The Sabana Grande Andesite in the Yauco quadrangle consists chiefly of volcaniclastic sandstone, breccia, and some rare lava flows interbedded with calcareous fine-grained siltstone, mudstone, and sandstone of the Yauco Mudstone. Widespread stocks of augite andesite that are mineralogically, chemically, and texturally identical with the volcanic rocks in the Lago Garzas-Coamo-Maravillas sequence crop out in the central part of the Peñuelas quadrangle and are believed to represent the local sources of the volcanic rocks in those formations. Similarly, stocks of andesite crop out widely over the Yauco quadrangle and are believed to have been sources for the volcanic rocks in the Sabana Grande Andesite.

Stocks in the Naguabo quadrangle

Field studies by J. W. M'Gonigle indicate that volcanic rocks in the Naguabo and Punta Puerca quadrangles in eastern Puerto Rico appear to represent the (Lower Cretaceous, Albian) Fajardo Formation and Figuera Lava or their equivalents. These rocks have been intruded by four previously unreported east-west trending stocks that range in composition from quartz keratophyre to hornblende diorite. The two southernmost stocks (granodiorite and hornblende diorite) lie along an east-west transcurrent fault zone and postdate the faulting. Many dikes associated with the granodiorite stock contain dipyramidal quartz crystals; these crystals are also found in parts of the youngest granodioritic unit in the San Lorenzo batholith to the south as well as in dikes emanating from it. The Naguabo and Punta Puerca intrusive rocks thus would appear to be about the same age as the younger parts of the San Lorenzo batholith.

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

The systematic description and mapping of rock units serve a major scientific objective by showing local and regional relationships, but most maps also serve more specific purposes. Some of the studies are for the purpose of extending geologic knowledge in areas of known economic interest; some are to gain detailed knowledge for engineering purposes, land-use 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 nearly four-fifths of the geologic-mapping program of the USGS. Such large-scale maps are available for about a quarter of the conterminous United States. Approximately half these maps have been produced by the USGS; most of the remaining maps have been produced by various State organizations and by educational institutions.

The USGS is carrying out large-scale geologic mapping projects in many parts of the country, with extensive cooperative programs underway in Connecticut, Kentucky, Massachusetts, and Puerto Rico. Other areas where mapping is underway include California, Maine, Maryland, Michigan, Nevada, New Hampshire, North Carolina, Pennsylvania, Tennessee, Virginia, Wisconsin, the Pacific Northwest, 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 they are also used as the basis for exploration of economic mineral deposits and for the preparation of reserve and resource estimates.

Many geologic maps are prepared in the search for a better understanding of the processes and mechanisms that affect the Earth's crust. Uses of these maps are growing in number and importance in the field of planning for more logical land use and for such large-scale engineering works as damsites, highway alinements, and subway routes. Actual construction is aided by locating vital construction materials and by providing the basis for site-preparation cost estimates. Another extremely valuable use of geologic maps is as an aid to avoiding hazards such as landslides and swelling clays, and to delineating 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 are compiled generally from available large-scale geologic maps and supplemented by reconnaissance geologic mapping at intermediate scales. Mapping at 1:250,000 has now expanded to constitute more than one-fifth of the geologic mapping program of the USGS. Many State geological surveys also have 1:250,000-scale geologic-mapping programs 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, although still largely a potential use at this time, is as a basis for a systematic inventory of land uses and resources throughout the Nation.

MAPS OF LARGE REGIONS

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

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

> Compilation of the new geologic map of the conterminous United States was completed in 1972 and the map is to be published late in 1974. The map legend, which comprises the third sheet, shows more than 150 map units arranged horizontally according to age and divided vertically into 6 general classes of rocks, including marine stratified deposits, continental deposits, eugeosynclinal deposits, volcanic rocks, plutonic and intrusive rocks, and metamorphic rocks. Correlation of Precambrian rocks and of the Phanerozoic plutonic and volcanic rocks is based on radiometric dating. An "Explanatory text to accompany the geologic map of the United States" was published separately (P. B. King and H. M. Beikman, 1974).

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

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

Geologic map of Arkansas, scale 1:500,000, revision by the Arkansas Geological Commisson, N. F. Williams, Director, and the USGS, B. R. Haley; assisted by E. E. Glick of the USGS and W. V. Bush,

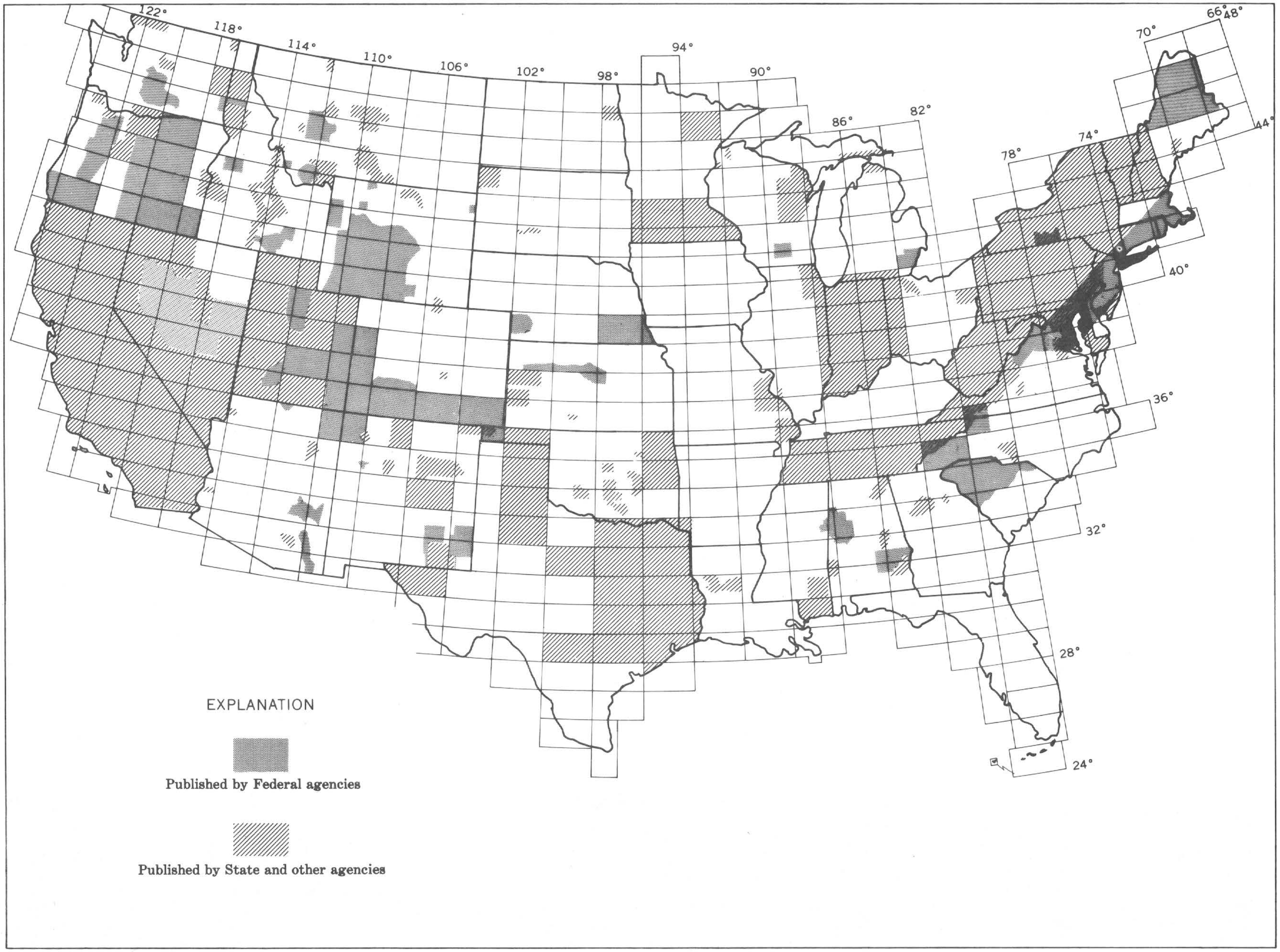


Figure 2.—Index map of the conterminous United States, showing 1:250,000-scale geologic maps published as of June 30, 1974.

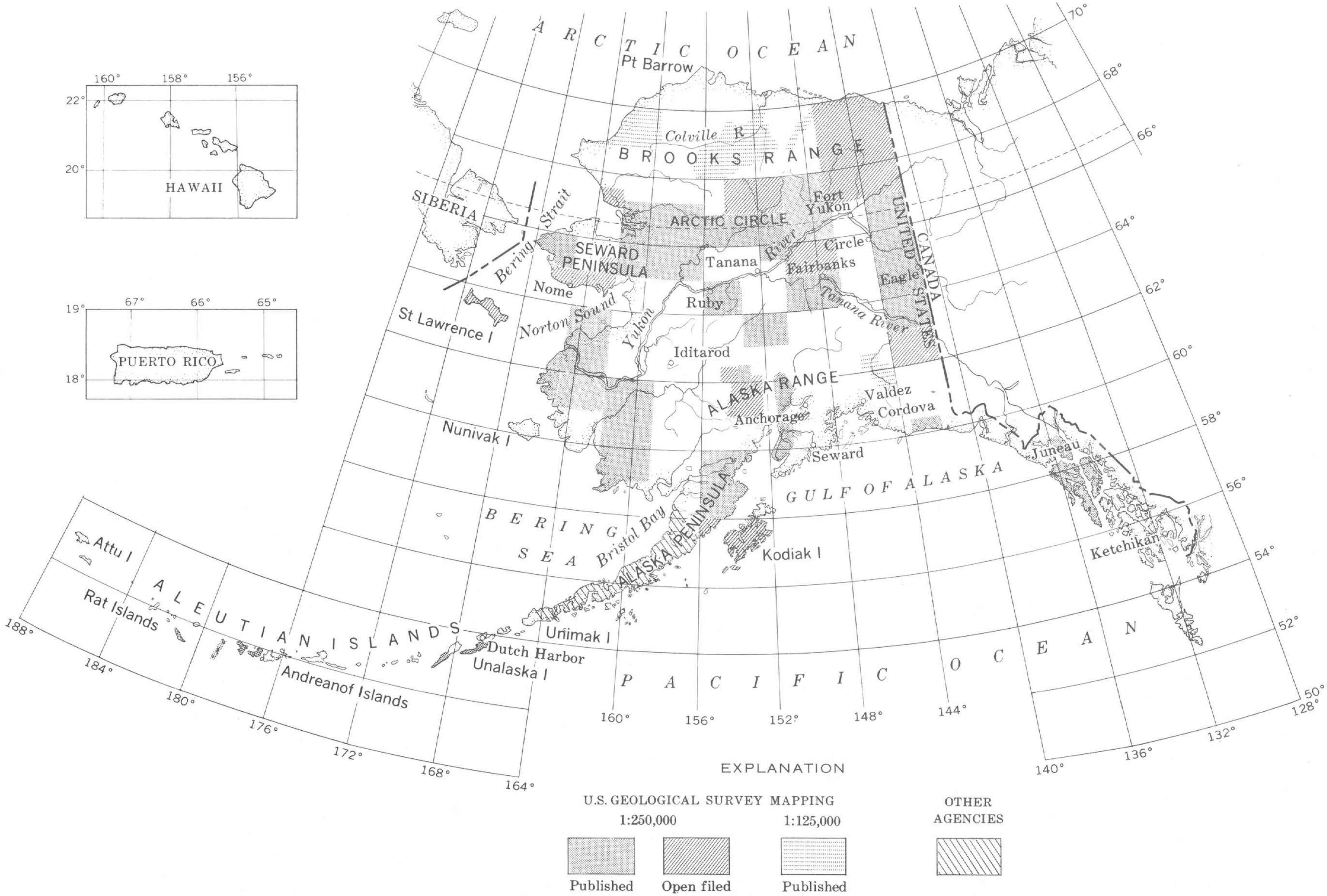


FIGURE 3.—Index map of Alaska, Hawaii, and Puerto Rico, showing geologic maps published or on open file as of June 30, 1974.

B. F. Clardy, C. G. Stone, M. B. Woodward, and D. L. Zachry 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, begun in 1971, will supersede the existing map published in 1935. The map, which is about 40 percent completed, will depict the vast increase in knowledge of the geology of Colorado during the last 40 years.

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

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

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

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

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

A new map is being compiled in cooperation with the Geological Survey of Wyoming. This map, which will replace the State map published 20 years ago, is based 75 percent on new data. Compilation is more than half completed.

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-suggested metamorphic-facies map explanation (Zwart and others, 1967). Progress includes preliminary compilation of regional metamorphic-facies maps at 1:1,000,000 scale for all of the State and coding of background metamorphic-mineral-locality information.

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

Both analyses are completed and include maps showing total thickness of rocks of the two systems, thickness and lithofacies of divisions of the systems, and distribution of rocks underlying and overlying the systems. In addition, interpretive maps show the transport direction of sediments, restored thicknesses, and tectonic development of the country during the two periods. Some maps show paleogeography and some show environments of deposition at selected times during the periods. The analysis of the Pennsylvanian System is in press (E. D. McKee, E. J. Crosby, and others, 1975), and the analysis of the Mississippian System is being prepared for publication.

World seismicity map, scale 1:39,000,000 at the Equator, prepared by the USGS from earthquake data of NOAA, A. C. Tarr, compiler.

This full-color map shows epicenters of earthquakes which occurred from July 1963 to December 1972, had body-wave magnitudes of 4.5 or greater on the Richter scale, and were observed at 10 or more stations. Also shown are the locations of earthquakes of surface-wave magnitude 8.0 or greater that took place from 1897 through 1972. Earthquake focal depths are divided into three depth-of-focus classes: 0 to 70 km, 71 to 300 km, and 301 to 700 km. The map (A. C. Tarr, 1974) also shows major physiographic features.

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 stream flow and time of travel under ice, mine acid drainage, overland flow, river basins, rivers, seepage, storm drainage, stratified flow, streamflow, stream classification, and water problems of the coal industry; (5) ground water—aquifers, artesian aquifers, artificial recharge, availability, carbonate-rock hydrology, connate water, core sampling, dispersion of contaminants, earthquake effects, electric-analog-model studies, flow, geochemistry, geochronology, geophysical logging, hot springs, hydraulics, hydrogeology, hydrologic properties, interpretations, investigations, levels, mapping, nuclear-explosion effects, nuclear-waste disposal, piezometric maps, pollution, pumping and pumpage rates, quality, quantity, radiocarbon dating, research, resistivity studies, saltwater intrusion, springs, subsidence of land, test-well drilling, thermal water, use of water, use of isotopes in investigations, waste disposal, and wells; (6) soil water—soil moisture, soil-water movement, and soil-water relationships; (7) lakes and reservoirs—biology and ecology, eutrophication, impoundments, lake levels, lake basins, limnology, ponds, and stratification; (8) water and plants—phreatophyte control, plant-water relationships, and tree rings; (9) erosion, sedimentation, and sediments—reservoir sedimentation, reservoir siltation, siltation, sediment control, and sediment transport; (10) quality of water—biological and ecological aspects of water chemistry, brine, chemical analysis, geochemistry, inorganic constituents, kinetics, radioactivity in water, salinity, solutes and solutions, and trace elements; (11) estuarine problems—biological and ecological problems, brackish water, distribution of sediments and wastes, tidal studies, transient flow, and upstream movement of saltwater; (12) water use—agricultural use, aluminum industry, copper industry, evaporation control, evapotranspiration control, hydroelectric use, industrial use, municipal use, petroleum industry, pulp and paper industry, rayon- and acetate-fiber industry, styrene-butadiene industry, surface- and ground- and waste-water use, synthetic-rubber industry, and water requirements; (13) agriculture, irrigation, and pesticides—movement in streams and ground water of pesticides, water requirements, and water spreading; (14) water management—flood control, management of ground- and surface-water resources, and use of models; (15) water-pollution effects, water-pollution sources, and water quality—agricultural sources of pollution, detergents in water, effect of pollutants on aquatic life, industrial wastes, movement of pesticides and other pollutants in streams and ground water, pesticides in water, pollutant identification, radioactive rainout, saline-water intrusion, source of pollutants, temperature, and thermal pollution; (16) waste disposal—radioactive-waste disposal and waste-water disposal; (17) planning and water-resources development—development of ground- and surface-water resources, flood forecasting, river-basin planning, water budgets, and water supply; (18) water law; (19) environments—antarctic regions, arctic regions, arid lands, deltas, deserts, karst terrain, swamps, urban areas, and wetlands; (20) water-resource studies—appraisals, computer applications in water research, data processing, evaluation, hydrologic data, infrared application, instrumentation for hydrologic studies and resources research, interpretations, investigations, mapping of ground water, model studies, processing, publication, remote sensing, reports, research, stochastic hydrology, techniques for hydrologic studies and resources research, and telemetry; (21) corrosion—well casings; and (22) water cycle.

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

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

During fiscal year 1974, 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 12,000 maps of flood-prone areas in all States and Puerto Rico have been completed to date, and about 1,600 pamphlets covering areas susceptible to flooding have been prepared. Studies of quality of surface water were expanded; there were approximately 5,100 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, phosphorus 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 850 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 are related to urban hydrology problems. Areal and research studies are being carried out in about 1,140 locations. Ground-water studies have been made or are currently in progress for about two-thirds of the Nation. In 1974, 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 1974. Records of about 265,000 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 55,000 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 1974, and a résumé of certain activities in the IHD program for 1974 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) noteworthy floods for each year.

Several factors have increased the urgency of obtaining and furnishing data on supply-versus-demand relationships of water in relatively small areas. The need to develop energy sources of various kinds in areas where industrial development has been nonexistent or minimal requires estimates of future water requirements in these areas and evalution of the adequacy of the water resources to meet the demand. Attention is being given to methods for expanding the scope and intensity of water-use investigations and improving methods for making these studies.

Investigations describing the occurrence of water as a natural resource are given in the following sections for the four regions of the United States (fig. 4) used since 1973 by the USGS for administering the water-resource program. These regions differ considerably from those used and illustrated in all USGS research summary volumes from 1963–72.

NORTHEASTERN REGION

Although the northeastern region experienced no spectacular hydrologic disasters in 1973 as it did in 1972—Tropical Storm Agnes and the Buffalo Creek, W. Va., flood—other storms and other floods kept USGS scientists busy collecting data in stricken areas. Torrential rains caused severe floods in late June and early July in much of New England and part of New York State. Peak flows of many streams in Vermont, where the most severe flooding occurred, were the greatest since the November 1927 flood, with discharges exceeding the 100-yr recurrence magnitude. The second most severely flooded State was New Hampshire. The Governors of both States declared emergencies. Record peak flows were recorded on small streams east of the Hudson River in New York. As much as 230 mm of rain fell in an 11-h period on August 1–2 in the Bound Brook-Plainfield area (lower Raritan River basin), New

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

Jersey, the Millburn area (upper Elizabeth and Rahway River drainage), and the Passaic River basin above Chatham, N.J. Severe flooding of these highly urbanized and industrialized areas resulted.

Throughout the region, emphasis continued on aquifer modeling and on studies of the effects of waste disposal on the quality of ground-water supplies. New modeling studies were undertaken in the Cape Cod and Indianapolis areas; model studies were continued for Long Island and for sections of Delaware, Indiana, Minnesota, New Jersey, Ohio, Virginia, and Wisconsin.

Studies of the effects of landfills on water quality were begun in the Indianapolis area and continued on Long Island and at a site near Catskill, N.Y. Studies of waste disposal by injection were continued at the Bay Park site on Long Island and at a site near Buffalo, N.Y.

Results of a reconnaissance analysis by digital simulation of the Coastal Plain aquifers, on the basis of available geohydrologic data, indicated that the aquifers within a radius of 48 km of Washington, D.C., are capable of sustaining a yield of 643,450 m^3/d. Pumpage from the aquifers within the radius is presently 227,100 m^3/d. Additional development, therefore, could supply an additional 416,350 m^3/d on a continuous basis—perhaps more if leakage through fine-grained confining beds proves to be significant.

INDIANA

Water-quality assessment of a national lakeshore

Results of water-quality investigations by L. D. Arihood indicated that the newly developed Indiana Dunes National Lakeshore area has both natural and disturbed-water environments. The parts of bogs in more natural areas are low in mineralization, with specific-conductance measurements ranging from 50 to 100 μmho. Other parts of bogs are much higher in mineralization, having conductance values from 400 to 1,380 μmho. Ponds exhibit a similar quality change, depending on their locations. This higher mineralization results from higher concentrations of constituents such as sodium, chloride, sulfate, calcium, and bicarbonate. Pinhook Bog, near a highway salt-storage area, shows sodium and chloride concentrations of 240 mg/l and 340 mg/l, respectively. An interdunal pond that once received fly-ash settling-pond overflow water had a sulfate concentration of 230 mg/l. In general, streams are more mineralized than bogs; yet both have the same water type—calcium bicarbonate.

Halfway through the 1-yr study, precipitation-quality samples have shown an average nitrate concentration of 0.76 mg/l. The average nitrate concentration for pond, bog, and lake sites is 0.04 mg/l; for watercourse sites, 0.54 mg/l.

MARYLAND

Extent and hydrologic nature of Ocean City-Manokin aquifer system near Ocean City

Five exploratory holes from 170 to 220 m deep were drilled in eastern Wicomico and Worcester Counties in the Maryland part of the Delmarva Peninsula. According to J. M. Weigle, most of the holes completely penetrated the freshwater zone. The Manokin aquifer underlies all of the area tested. However, geophysical logs of the test holes and cutting samples collected during the driling indicate that the Ocean City aquifer, which provides most of the public supply for Ocean City, continues as a potentially productive aquifer westward into Wicomico County but feathers out southward and loses its identity as a discrete hydrologic unit somewhere between Berlin and Snow Hill (probably near Newark, Md.). The geophysical logs and drill cuttings also indicate that in Ocean City and westward the Ocean City and Manokin aquifers very likely function hydraulically as one aquifer system. A layer of sand, sandy silt, and sandy clay occurs between the aquifers, but the clay in the layer is not persistent enough and the associated materials are generally not fine enough to permit the bed to function effectively as a confining layer.

Deep test well in southern Maryland

An exploratory well near La Plata in Charles County was drilled to a depth of 615 m (datum is 55 m above mean sea level). According to F. K. Mack, the well completely penetrated the unconsolidated Tertiary and Cretaceous deposits and extended more than 25 m into semiconsolidated sediments, probably Triassic in age. Previous drilling for water supplies in the area had generally been limited to 230 m. A freshwater aquifer between 345 and 410 m in depth may constitute a much needed source of additional water. The aquifer consists of several Lower Cretaceous fluvial sands with a cumulative transmissivity of about 2,100 m^2/d and a sand thickness of 35 m.

Ground-water resources of Harford County

Water in crystalline metamorphic and igneous rocks is unevenly distributed, and its availability is difficult to predict because of the extreme variability of the fracture system through which it is transmitted. Most of the newly developing suburban areas in Harford County utilize individual wells and septic tanks, and in many of these areas a substantial percentage of the wells drilled fail to yield an adequate quantity of water for domestic use.

According to L. J. Nutter, more than 80 percent of the well records available are of domestic wells. Many such wells were drilled on ridgetops or uplands, where the probability of high-yielding wells is low. Furthermore, few domestic wells were drilled for maximum yield. In contrast, wells drilled in valleys or along lineaments or fracture traces have substantially higher average yields than those determined from all available well records.

MASSACHUSETTS

Water resources, Connecticut River lowland, central Massachusetts

E. H. Walker, S. W. Wandle, Jr., and W. W. Caswell reported that three distinct aquifers occur within the Connecticut lowlands. The granitic and metamorphic rocks beneath the bordering hills yield adequate water supplies for domestic use. The sedimentary and volcanic rocks of Triassic age that underlie most of the lowlands may yield more than 6 l/s in favorable locations. Stratified deposits of glacial origin, which vary in character from fine-grained lakebeds to coarse, gravelly outwash, provide yields that range from 0.06 to 30 l/s.

Low-flow characteristics of minor streams are influenced by the amounts of stratified glacial deposits within their basins; other factors being equal, the larger the percentage of the area occupied by stratified glacial deposits, the higher is the streamflow in dry weather.

Water resources of the Nashua River basin

According to R. A. Brackley and B. P. Hansen, water use within the Nashua River basin is continuing to increase because of rising domestic and industrial needs.

High relief with small deposits of saturated stratified unconsolidated material in the western part of the basin gives way to gentle relief with more extensive deposits of saturated stratified material in the eastern part. As a result, most of the municipal water systems in the western part are supplied from reservoirs and those in the eastern part by wells. Preliminary evaluation indicates that use of ground water can be considerably expanded.

Except for within-basin cycling of water, the potential for additional development of South Branch Nashua River basin water resources is small, unless diversions to the basin are increased. During recent years, 5 to 10 percent of the runoff in this basin has contributed to Nashua River flow. The remainder has been diverted from the basin for municipal supplies.

Water resources of the Charles River basin

E. H. Walker, S. W. Wandle, Jr., and W. W. Caswell reported that water use in the Charles River basin is increasing because of increased population and higher per capita use in the area.

Most town wells in the basin yield 19 l/s or more water from sand and gravel aquifers averaging only about 14 m in thickness. Potential exists along the river and some of its tributaries for development of much more ground water by induced infiltration from the streams.

Sites exist in the urbanized lower part of the basin where hydrologic conditions would permit development of large supplies of ground water by induced infiltration, but certain constraints tend to deter such developments. For example, more pumping from aquifers near ponds would lower pond levels more than local interests would tolerate. Much of the water that might be developed by pumping wells near the Charles River would be diverted out of the basin by sewers, resulting in further depletion of the low flow of the river, already considered inadequate during many summers. Also, the dissolved-solids and chloride content of water in the Charles River and some other bodies of water in the urbanized area have risen substantially in recent years, making the water less desirable for public supply.

Coastal drainage basins of southeastern Massachusetts

Reconnaissance geologic mapping and analyses of well data by J. R. Williams and G. D. Tasker (1974a, b) showed that the principal aquifers in the area between Hingham and Kingston are localized in preglacial valleys cut in bedrock. The permeable materials consist of deltaic, ice-contact, and outwash deposits. Sands and gravel aquifers commonly lie beneath glacial till or glaciolacustrine deposits. The aquifers in the Plymouth-Wareham area are among the most extensive in the State and are 12 to 49 m thick; they consist of gravelly end moraines and extensive outwash plains that border the moraines. Discharge from these aquifers averages about 450,000 m^3/d. The principal ground-water-quality problems are saltwater intrusion along the shore and in estuaries, and salt contamination of some wells near heavily salted highways. Iron, manganese, and color exceeding suggested USPHS limits are common problems in both surface water and ground water. Studies show that the specific conductance of surface water seems to vary directly with population density.

MICHIGAN

Compilation of miscellaneous streamflow measurements

A report prepared by R. L. Knutilla is a compilation of all miscellaneous streamflow measurements made in Michigan through 1970. Approximately 10,000 discharge measurements, made at nearly 2,000 different sites, have been listed. The data are summarized in downstream order and are indexed by counties. Although most of the measurements have been published previously in the series of annual reports, this compilation of measurements presents the data in a form that may be easily used.

Ground water and geology of Marquette County

C. J. Doonan (USGS) and J. L. VanAlstine (Michigan Geological Survey) reported that ground-water resources of Marquette County are about evenly divided between bedrock aquifers and glacial-drift aquifers. In the northern and the extreme southern parts of the county, most wells are completed in bedrock at depths of less than 30 m. In central Marquette County, most wells are completed in glacial drift. Yields from wells finished in glacial drift are generally higher than those from wells finished in bedrock. Most ground water in the county is hard, and at some locations high concentrations of iron impair water quality.

Geology and hydrology for environmental planning in Delta County

A study of the geologic and hydrologic characteristics of Delta County has been made by W. B. Fleck and C. J. Doonan. Geologic and hydrologic information is being presented on a series of maps. These maps will aid planners and managers in evaluating land-use alternatives and in assessing their long-term environmental impact. Soil-infiltration rates, depth to bedrock, and yields of wells in glacial drift and bedrock deposits have been defined. The location of mineral deposits, distribution of swamp areas and surface waters, and other hydrologic information are being shown on the maps. Using the hydrologic data, the Michigan Geological Survey has prepared a map showing the relative suitability of areas for landfill operations. In general, areas in the southern and northern parts of the county seem to be more suitable for sanitary landfills.

Water resources of minor streams in southeastern Michigan

A study of the water resources of the minor stream basins draining into St. Clair River, Lake St. Clair, Detroit River, and Lake Erie was made by F. R. Twenter, R. L. Knutilla, and T. R. Cummings (1974). The study is the last in the series of eight water-resource studies of river basins in southeastern Michigan. Results of the investigation indicate that large parts of the areas drained by the streams are underlain by compact soils with low infiltration rates (25 to 50 mm/h) and by glacial deposits of low permeability. Because of these soil and rock characteristics, runoff is rapid after periods of rain or snowmelt. Conversely, during periods of base flow, many streams are either dry or they discharge less than 0.035 m^3/km^2. The dissolved-solids content of surface water ranges from 380 to 1,440 mg/l; about half have a dissolved-solids content of less than 500 mg/l.

Glacial deposits in the minor stream basins are mostly clay and fine-grained sediments that yield less than 0.6 l/s to wells. Water from glacial deposits usually contains less than 500 mg/l of dissolved solids. Bedrock is primarily sandstone, shale, limestone, and dolomite of Silurian, Devonian, or Mississippian age. Yields from wells in bedrock in the northern areas are generally less than 6.3 l/s. In the southern part, yields may be as much as 31 l/s. Water from bedrock is often highly mineralized and unsuitable for use as a water supply.

MINNESOTA

Ground water for irrigation near Alexandria

M. S. McBride investigated the availability of ground water for high-yield irrigation wells in the sand plains areas near Alexandria. Results of test drilling showed that two of five separate outwash plains within the study area are extensive enough to support major development.

A digital model of a 67-km^2 area east of Carlos is now operating, and adjustments on the input data are being made to fit the model to observed natural conditions. The input-data set for the second model, of a 204-km^2 area north and east of Parkers Prairie, is nearly complete.

Water in the surface outwash is of a calcium magnesium bicarbonate type. Specific conductivities of 14 samples ranged from 231 to 635 μmho/cm. The maximum boron concentration was 60 μg/l. The water thus seems to be of good to excellent quality for irrigation. Water from six wells had nitrate plus nitrite concentrations, expressed as N, of more than 1 mg/l, suggesting contamination from the surface.

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

J. O. Helgesen, G. F. Lindholm, and D. W. Ericson (1974) determined that nearly all water used in the

Lake of the Woods, Big Fork River, and Little Fork River watersheds is from ground-water sources. Ground-water quality, in part, depends on position in the regional flow system. Most water is of the calcium bicarbonate type. Dissolved-solids content generally increases downgradient, although hardness, in places, decreases by cation exchange, resulting in a sodium bicarbonate type water. Buried sand and gravel in the drift is the most favorable source for ground-water development. Many wells have been completed between the altitudes of 385 and 400 m in the southern part of the Big Fork River watershed.

The concentrations of dissolved solids in stream water at a given time depend upon the surficial geology; concentrations are larger in streams draining till areas than in streams draining peatlands. Water from peatlands is also typically higher in color and iron and lower in pH than water from areas of mineral soils. Streamflow in the Big Fork and Little Fork watersheds is sustained during periods of low flow by discharge from lakes and the ground-water system.

Ground water for irrigation near Appleton

Verification of one of two digital ground-water models to be used in the study of ground water for irrigation near Appleton has been completed by S. P. Larson. An 864-node uniform grid with 0.402-km nodal spacing was used to model the surficial sand and gravel aquifer. Saturated thickness in the aquifer ranges from 0 to nearly 30 m. Steady-state head distribution computed by the model is generally within 1 m of the observed field conditions. In addition, ground-water discharge into the Pomme de Terre River along a 28.2-km reach was computed to be 0.17 m^3/s. This compares favorably with base-flow increase in the same reach of 0.17 m^3/s and 0.15 m^3/s measured in 1964 and 1973, respectively.

Difficulties encountered in the modeling included determination of recharge and streambed-leakage rates. A uniform recharge rate of 4.0×10^{-9} m/s and a streambed-leakage factor (streambed hydraulic conductivity divided by streambed thickness) of 3.3×10^{-6} m s^{-1} m^{-1} were used to obtain the best results.

Effects of lowering the water table, Hennepin County

M. S. McBride reported that hydrogeologic data collection in the Ryan-Twin Lakes area in Hennepin County has been nearly completed. The 18.6-km^2 area studied was found to have a clean, well-sorted, medium-to-coarse gravel-outwash sand at the surface. A pumping test indicated a permeability of 122 m/d. The average thickness of the sand is 12 m; in places it is more than 21 m thick.

Over most of the area, the sand was underlain by sandy clay till derived from the Des Moines ice lobe. On the basis of studies of Des Moines-lobe till in other parts of Minnesota, the till was estimated to have a permeability of 0.0003 m/d.

While data were being collected, a simple (20 by 20 node) digital model of the area was constructed. This served as a guide for additional data collection and also indicated the magnitude of some of the input parameters for detailed modeling.

A more detailed (31 by 34 nodes) digital model is now in operation. It is being adjusted to conform to field conditions and will be used to predict environmental effects on lakes and marshes caused by dewatering of the outwash sand for highway construction.

Water resources of river basins in southwestern Minnesota

Studies in progress in 2 watersheds (Rock and Des Moines Rivers) in southwestern Minnesota by H. W. Anderson, Jr., show that all 38 municipal water systems in the 2 areas use ground water. Twenty-five percent use water from surficial sand and gravel outwash deposits; another 25 percent, from the Sioux Quartzite; and 50 percent, from sand and gravel lenses buried in the drift. Only one municipal system uses a Cretaceous sandstone aquifer as a source of supply.

Throughout most of the area, water levels in deep wells are lower than those in shallow wells, indicating downward water movement (ground-water recharge area). An exception to this is observed along the flanks of Precambrian Sioux Quartzite ridges, where water levels in the drift are higher due to greater recharge down the slope of the quartzite. On the relatively low ground adjacent to the quartzite ridges, local confining clay-till layers make conditions favorable for artesian wells.

Water budgets prepared by D. F. Farrell for the two watersheds show an increase in precipitation, runoff, and evapotranspiration from northwest to southeast across the area. A major divide is formed by the Bemis moraine. East of the moraine the drainage is poorly developed in a youthful topography, and west of the moraine the drainage is well established.

The ground water generally contains high concentrations of dissolved solids and sulfate. W. L. Broussard reported that dissolved-solids content in water from the drift ranges from 400 to 2,000 mg/l;

however, some surficial gravel may contain water with lower concentrations. Dissolved-solids content in water from Cretaceous aquifers generally ranges from 800 to 2,000 mg/l, and from 250 to 2,000 mg/l in Sioux Quartzite aquifers.

NEW HAMPSHIRE

Ground-water reconnaissance helps meet increasing New Hampshire water demands

Estimates place municipal water requirements for New Hampshire at 19,276 dm^3/s by the year 2020. This exceeds the capacity of present water systems by about 15,334 dm^3/s; this potential deficiency is more than five times the total municipal water use in 1970. J. E. Cotton reported that about 60 percent of the municipal systems currently rely at least in part on ground-water supplies. Twenty-eight of the 29 cities and towns with populations over 5,000 have municipal systems. Nineteen of these use ground water to meet at least part of the demand, including 5 of the 7 cities with populations greater than 20,000. Portsmouth, the fourth largest city, is seeking to double the capacity of its system to 438 dm^3/s solely through additional wells. Eleven ground-water-availability maps which cover the entire State are being prepared. Preliminary assessment of the principal aquifers, primarily saturated glaciofluvial sand and gravel deposits, will enable communities and their consultants to select efficient test-drilling programs and proper zoning.

NEW JERSEY

Digital model of the stratified-drift aquifer in western Essex and eastern Morris Counties

Harold Meisler is using a mathematical model to simulate the stratified-drift aquifer in western Essex and eastern Morris Counties. Significant ground-water withdrawals starting about the year 1900 and increasing steadily from 0.2 m^3/s in the period before 1930 to 1.1 m^3/s in 1970 have resulted in water-level declines of as much as 33 m. Calibration of the model is based upon comparison of computer-predicted and field-measured water-level declines at 12 observation wells for several time periods ranging from 3 to 13 yr. Preliminary results indicate that before the period of pumping, the primary source of water in the stratified-drift aquifer was the surrounding bedrock aquifer of the Brunswick Formation. After several years of pumping, this source of water was supplemented by induced leakage through the overlying glacial till from surface-water bodies.

1973 potentiometric surface of the Potomac-Raritan-Magothy aquifer system in New Jersey

Water-level measurements were made in November and December of 1973 in approximately 700 wells tapping the Potomac-Raritan-Magothy aquifer system. The preliminary contour map of the 1973 potentiometric surface prepared by G. M. Farlekas and J. E. Luzier, covering an eight-county area of approximately 9,065 km^2, shows that water levels are below sea level in much of the area. A large cone of depression extends northeastward in Salem, Gloucester, Camden, Burlington, and part of Ocean Counties. The greatest decline, more than 27 m below mean sea level, is in the north-central part of Camden County.

Another cone of depression extends from Middlesex into Monmouth and Ocean Counties; the lowest water level is more than 21 m below mean sea level in wells tapping the Farrington Sand Member of the Raritan Formation in Middlesex County. The highest levels were measured in wells tapping the Potomac-Raritan-Magothy aquifer system in Mercer County, the southern part of Middlesex County, and the southwestern part of Monmouth County. Water levels in this area were as much as 24 m above sea level. The water-level data will be used to calibrate mathematical models of the aquifer system.

NEW YORK

Quality of public water supplies of New York State

R. J. Archer (USGS) and Daniel E. Serrell (New York State Department of Health) reported that the results of the first 2 yr of a continuing program to examine public water supplies in the State of New York indicate that the chemical quality of drinking water is generally good. Approximately 450 supplies (about one-third of those in the State), serving more than 80 percent of the people using public supplies, were sampled 1 or more times. Each sample was analyzed for 53 parameters, including most parameters specified for State and Federal drinking-water standards. Twenty-five minor elements were determined by comprehensive emmission-spectrographic analyses. Pesticide concentrations were minimal or not detectable in the samples from approximately 100 supplies.

Almost no herbicides or pesticides in ground water of western Suffolk County

Although pesticides have been used for decades on crops, in parks, and on home lawns and gardens in western Suffolk County, Long Island, these substances generally have not been found in the ground water of the area, according to Julian Soren and J. E. Potorti. Minute traces to insignificant concentrations have been found in only a few places. Analyses of water samples from 50 wells, most of which were screened at depths of 3 to 9 m below the water table, were used in the study. Depths from the land surface to the water table at the well sites ranged from less than 1.5 m to more than 62 m.

Hydrogeologic conditions in Nassau County

All significant data on wells, subsurface geology, water levels, ground-water pumpage, and water quality are being stored in a computerized basic-data system by Chabot Kilburn to aid in a study of the hydrogeologic conditions in the town of North Hempstead in Nassau County. This basic-data system permits detailed and rapid interpretation of data for defining hydrologic or hydrochemical problems.

OHIO

Ground water in south-central Ohio

Four industrial plants and a public water-supply system, in fairly close proximity on a glacial-outwash terrace, pump a total of 30×10^3 m^3/d from wells screened in sand and gravel deposits above the shale bedrock. The wells are not close to the Scioto River, and recharge by induced infiltration is relatively small. A long-term water-level decline of 11 to 12 m has occurred near the center of pumping.

Results of studies by S. E. Norris, based in part on flow-net techniques, indicate that only 11 percent of the pumped water is from stream infiltration. Pumpage is largely sustained by a combination of regional underflow, direct precipitation, and steady depletion of aquifer storage. Improved understanding of the aquifer system resulting from the studies is expected to lead to better spacing of future wells and development of new and larger ground-water supplies in more favorable areas closer to the river.

Dayton aquifer model

A digital model of the glacial-outwash aquifers at Dayton has been developed by R. E. Fidler. The modeled area covers about 235 km^2 adjacent to the Great Miami River and its principal tributaries. Ground-water withdrawals for municipal and industrial supplies were about 5 m^3/s in 1958 and exceeded 6.5 m^3/s in 1972. The increased pumpage has resulted in continuing water-level declines in some parts of the area.

The model was made to simulate the aquifer as part artesian and part water table. The principal source of recharge to the unconfined part of the aquifer is from induced streambed leakage. Output from the model gives an areal distribution of the hydraulic head in the aquifer as a result of pumping. The model was verified using five pumping periods and water-table information for 1960.

The digital model was developed to provide a better understanding of the hydrologic properties of the aquifers in the Dayton area and to serve as a management tool.

PENNSYLVANIA

Well yields in the Cumberland Valley

Studies by A. E. Becher and W. S. Wetterhall show that the median 1-h specific capacity of 42 wells in the Martinsburg Formation (Ordovician) of the Cumberland Valley east of Shippensburg is 1.35×10^{-3} l/s per centimetre of drawdown. Wells in the Martinsburg Formation west of Carlisle have significantly higher specific capacities than wells east of Carlisle; medians of 1.76×10^{-3} l s^{-1} cm^{-1} versus 1.03×10^{-3} l s^{-1} cm^{-1}, respectively. Reconnaissance mapping indicates that this is the result of an abrupt change in structural character and lithology in the vicinity of Carlisle. Test drilling in carbonate rocks of the Cumberland Valley indicates that wells located on fracture traces have substantially greater yields than randomly located wells. Wells located on fracture traces, however, commonly intersect mud-filled cavities that may be difficult or impossible to clean out.

Ground water in tributary-valley systems in western Crawford County

Mapping of the thickness of glacial drift in western Crawford County by G. R. Schiner and J. T. Gallaher, using logs of about 3,000 wells, indicates a complicated Pleistocene drainage pattern, which consists of a main drainage system reflected by the present topography and a buried tributary system is incised as much as 60 m into the bedrock and crosses large upland areas in places. At least two periods of deposition are involved in the glacial history of the tributary valleys because drill holes frequently penetrate weathered glacial drift at depth. It is probable that the tributary-valley system was formed after the valleys of the main drainage system were partly filled. Water wells that penetrate the thick sections of the tributary-valley fill are generally at least 30 m deep; the shallower deposits consist of clayey gravel or cemented sand and gravel and yield little water to wells.

VIRGINIA AND NORTH CAROLINA

Hydrology of Dismal Swamp

Studies of the Dismal Swamp (Virginia and North Carolina) by W. F. Lichtler and P. N. Walker have led to a hypothesis concerning the hydrology of the swamp.

The studies, based largely on geologic work by Oaks and Coch (1973), pollen analysis by Whitehead (1972), and some field reconnaissance, show that a permeable sand facies of the Norfolk Formation (of local usage) underlies the swamp and crops out on the top of the Suffolk scarp west of the swamp. Movement of water through this sand was restricted in prehistoric times by a less permeable facies east of the swamp and by an overlying confining bed. Erosion breached the overlying confining bed about 9,000 yr ago and allowed upward seepage of water. This seepage, when combined with the abundant rainfall and naturally sluggish surface drainage, may have triggered the accumulation of peat, which started forming along stream valleys and gradually spread over the interfluve areas. The sand layer probably still plays an important role in the hydrology of the swamp. Manmade changes, which include ditching, pumping from shallow aquifers, and lockage for navigation in the Dismal Swamp Canal, have modified the swamp.

WEST VIRGINIA

Statistical tests relate specific capacity and water quality to geology, structure, and topography

Short-term specific-capacity tests were made and water samples were collected from wells at 62 selected sites in the Lost River and Little Cacapon River basins by W. A. Hobba, Jr. The wells tap shale and siltstone, sandstone, or limestone of Devonian age. Nonparametric statistical tests were used to test for significant differences in well productivities (specific capacity and height of static column of water in well) and relation of water quality to geology, geologic structure, fractures, and topography at the well site. At the 0.05 level of significance, the tests indicated that (1) well productivities of seven different aquifers were different, (2) productivities of wells located on fracture traces were better than those located on nonfracture areas, (3) the productivities of valley wells were better than those of hilltop or hillside wells, and (4) the productivities of wells on anticlines were no different from those of wells on synclines.

At the 0.06 level of significance, the tests indicated that (1) specific conductance of water from valley wells was higher than that of hillside or hilltop wells, (2) sulfate content of water from wells located on fracture traces was higher than that of water from wells located on nonfractures, and (3) sulfate content of water from wells located in valleys was higher than that of water from wells located on hillsides or hilltops.

Delineation of saltwater and freshwater

In order to facilitate the handling of a large volume of water data (35,000 wells) recorded on oil- and gas-well driller's logs, the information was coded and keypunched for computer manipulation. J. B. Foster used the USGS General Purpose Contouring Program to represent the altitude of the base of freshwater and the altitude of the top of saltwater on maps of 15-min-quadrangle size. In areas with an adequate distribution of data points the contouring program prepared reasonable contoured surfaces. Using the computer to manipulate data has proven to be the most feasible approach to preparing water-quality maps for over half the State of West Virginia.

WISCONSIN

Ground water in Walworth County

R. G. Borman reported that water of generally good quality is available from four aquifers in Walworth County in southeastern Wisconsin. Yields of over 31.5 l/s are available from glacial deposits in 80 percent of the county. Sandstones and dolomites of Cambrian and Ordovician age are capable of yielding 31.5 l/s over the entire county; wells with yields as high as 6.3 l/s can be developed in the Galena-Platteville aquifer of Ordovician age in the western part of the county and from the Silurian dolomite in the eastern part. Water from all aquifers is hard to very hard, and dissolved-solids content ranges from 100 to 500 mg/l.

SOUTHEASTERN REGION

Water-resource studies in the southeastern region are increasingly directed toward collection and analysis of hydrologic information necessary for sound water-management decisions. Considerable effort has been given to modeling techniques in response to demands for planning, development, and management needs. A planning model was designed in Puerto Rico to select the least-cost sets of water-supply projects and to sequence their construction. Digital and analog models of ground-water systems have been developed in Florida, Georgia, and Puerto Rico. New sources of ground water have been discovered in Alabama, Florida, Georgia, Mississippi, and Tennessee; and studies of known aquifers are continuing. Analyses of streamflow in North Carolina and South Carolina are providing a base for more efficient use of surface-water resources.

FLORIDA

New Florida water districts

The Florida Water Resources Act of 1972 will, by 1975, divide Florida into five water-management districts. The adequacy and applicability of existing water data to the functions and future programs of three of the districts, newly created by the act, are being assessed by K. E. Vanlier and others. Principal functions of the management districts requiring a base of water data are: (1) Authorizing consumptive water use, water wells, and water-management facilities, (2) declaring water shortages or emergencies, and consequently restricting water use, (3) formulating a water-use plan, and (4) constructing water-management works.

Shallow aquifers in northern Brevard County

As a result of a test-drilling program conducted by H. F. Grubb in northern Brevard County, three areas containing significant amounts of freshwater in an unconsolidated aquifer were identified. The areas containing freshwater are coincident with the Atlantic coastal ridge where land-surface elevations range from 9 to 21 m above sea level. Only two of these areas have the potential for supporting ground-water yields of 6 to 16 l/s per well on a sustained basis. A generally lower land surface and decreasing aquifer permeability northward limit ground-water withdrawals to less than 2 l/s in the northernmost area. Northwest of Titusville, in an area about 1 km wide and 5 km long, the city of Titusville has extensively developed the ground-water supply. The 45 producing wells in this area may be approaching the maximum development that is possible without problems of saltwater encroachment.

The third area in northern Brevard County, the only undeveloped area having a potentially large additional freshwater supply (6 to 16 l/s per well), is southwest of Titusville. This area is approximately 1 km wide and 3 km long and, like the area northwest of Titusville, is characterized by sand-dune topography and several closed-drainage depressions.

Man's impact on the southeastern Florida ecosystem

As part of the South Florida RALI report, B. F. McPherson, H. C. Mattraw, Jr., H. J. Freiberger, Z. S. Altschuler, and C. S. Zen (USGS), M. M. Sigel (Univ. of Miami), and H. J. Schmitz (Dade County Pollution Control Department) (1973) described man's impact on southeastern Florida's ecosystem. Major adverse impacts resulted from drainage, dredge and fill, and agricultural and urban development. The authors depicted gross changes in vegetation associated with changes in land use. The changes in land use have resulted in a reduction of wetland, major changes in the direction of water flow and duration of flooding, oxidation of peat soils, a deterioration of water quality, and adverse effects on some of the large animals of the area.

Hydrologic base for water management

J. E. Hull (1973) reported that a daily peak pumpage by the City of Miami reached 9,463 dm^3/s in April 1973, 175 dm^3/s less than in the drought year of 1971. However, officials of the Central and Southern Florida Flood Control District anticipated no curtailment of water use during 1973–74 because of above-normal rainfall and near-average water levels at the end of 1973.

Urban development changes streamflow characteristics

Results of an investigation by A. L. Putnam of the 111-km^2 Reedy Creek Improvement District, where the construction of Walt Disney World has continued since July 1966, indicate that the changes in land and water use have produced several slight changes in local hydrologic conditions. Since 1968, higher low-flows for both Reedy and Bonnet Creeks during the dry seasons indicate that surface-water discharge for portions of streams in the district are increasing because of development activity. Some of the increase is the result of nonrecurring activity such as the draining of Bay Lake and the initial seepage from the water table where canalization and stream-channel improvement incised the non-artesian aquifer more completely than before development activity. However, during the dry season, water pumped from the Floridan aquifer now maintains the water level in the lake and lagoon at a near-constant level, higher than the water table was when the lake level fluctuated with seasonal distribution of rainfall. Since 1970, this higher, less variable, lake level has maintained seepage into the streams during dry weather. As the pumpage, recharge to the aquifer, and seepage to stream channels stabilize and become more of a closed cycle, the increase in the base flow of the streams in the district should diminish somewhat and base-flow should stabilize at levels slightly higher than prior to development.

The variable effect of the progressive development precludes an accurate evaluation of the higher base flow. However, a comparison of flows for the driest month indicates that prior to the beginning of development in 1968, the monthly mean flows for April and May were less than 0.08 m^3/s, and since 1968 the monthly mean flows for April and May have been greater than 0.14 m^3/s. Also, prior to 1968, both streams had many days of zero flow but, since 1968, neither stream has had more than an occasional day of zero or near-zero flow. Streamflow data for other streams in the area indicate that this change in streamflow is not the result of more evenly distributed rainfall since 1968.

Water management for southern Dade County

In RALI program studies, Howard Klein (1973) showed that the availability of freshwater for southern Dade County could be increased through further reduction of storm-water discharge to the ocean. The reduction could be accompanied by (1) backpumping storm water to interior wetlands, (2) additional control structures in canals, (3) raising coastal ground-water levels through selected land filling, and (4) injecting storm water into the deep Floridan aquifer for later recovery. The quantity that could be salvaged by backpumping only 50 percent of the dry-year canal discharge in Dade County would nearly equal the quantity pumped for municipal purposes in the county in 1973. One stipulation is that the quality of the storm water must be high enough to minimize environmental degradation in the wetlands.

Forward pumping—a management practice to alleviate effects of drought in southeastern Florida

One of the water-management alternatives described by Howard Klein (1973) in the RALI studies in southern Dade County included the practice of forward (coastward) pumping as a method of retarding seawater intrusion and furnishing aquifer recharge in urban areas during prolonged drought. Water would be pumped from aquifer storage in interior areas and moved to the coast via canals, thereby maintaining coastal ground-water levels during the last weeks of dry seasons. The ensuing rainy seasons would provide annual replenishment. The pumping facilities used in the proposed backpumping plan for storing storm water in noncoastal areas also could be used in the forward-pumping plan.

Seminole County self-sufficient in terms of ground-water supply

C. H. Tibbals (1974) has determined that Seminole County is largely self-sufficient in terms of its ground-water supply. Approximately 2,850 l/s is recharged within the county and about 790 l/s flows in from neighboring Orange County via the Floridan aquifer. In addition, the county has, as a possible future source of water supply, the flow of several large springs that discharge a total of about 3,800 l/s of good-quality water into the Wekiva River, which forms most of the western boundary of the county.

Ground-water availability in Martin County

J. E. Earl reported that 14 test holes were drilled throughout Martin County to determine the shallow-aquifer characteristics in relation to water availability. Aquifer thickness ranged from 85 m in the southeastern part of the county to 43 m in the northwestern part of the county. Four wells were located in and around the Stuart well field for salinity observation. Twelve water-level recorders were installed at sites throughout the county to obtain ground-water levels on a continuous basis.

Geohydrologic investigations

An investigation by D. H. Boggess and T. M. Missimer of the ground-water resources in Lee County has revealed a large increase in the thickness of sediments comprising the Tamiami Formation of late Miocene age, along a synclinal fold in the south-central part of the county. In the center of the fold, the formation is about 150 m thick, whereas along the boundaries the thickness ranges from about 45 to 60 m. At least three separate confined aquifers occur within the thicker part of the formation.

Declines in ground-water levels north of Tampa result from heavy pumpage

A 2,600-km^2 area incorporating parts of Hillsborough, Pinellas, and Pasco Counties contains four well fields which supply the expanding urban centers of Pinellas County (St. Petersburg, Clearwater, and Tarpon Springs). C. B. Hutchinson reported that at times during 1973, total pumpage from the Floridan aquifer reached 4.4 m^3/s. To keep pace with demands for fresh ground-water supplies for Pinellas County and the city of Tampa, three additional well fields, each with a withdrawal capacity of 1.3 m^3/s, are under construction within this area. Contour maps show 4.5 to 9 m of drawdown in the potentiometric surface of the Floridan aquifer at the well fields. Regulatory levels imposed by the Southwest Florida Water Management District have limited drawdowns at the well fields so that the centers of the cones of depression are above sea level, thereby checking the threat of saltwater intrusion. The maps also show cones of depression developing in the water table of the surficial aquifer as a result of the increase in hydraulic head between the potentiometric surface and the water table. Levels of lakes, which have a direct hydraulic connection with the water-table aquifer, have dropped more rapidly near the well fields than have levels of lakes beyond the influence of the pumped areas.

Digital-model applications

A. F. Robertson successfully applied the USGS digital model for aquifer systems to simulate water-level history in several situations in west-central Florida. The model was calibrated utilizing results of several aquifer pumping tests in rapidly developing northwestern Hillsborough basin.

Supplementary aquifers defined within the unconsolidated materials in Osceola County

J. M. Frazee, Jr., has defined three aquifers in the unconsolidated sediments that overlie the Floridan aquifer in Osceola County. The major aquifer occurs in most of the southern part of the county at depths of 24 to 55 m below land surface. The water-bearing zone is composed of sand and shell which are interspersed with limey material at depth; it is overlain and underlain by thick clay beds. Most wells that tap this aquifer are screened at depths of 30 to 37 m.

In north-central Osceola County, owners of small citrus groves have developed sand-point wells to depths of 9 m in old dune deposits. Adequate quantities of water are pumped to support citrus units up to 8 ha in size.

West of Lake Tohopekaliga, an aquifer of unconsolidated material underlies an area of about 21 km^2. It occurs at a depth of about 13 m below land surface, is about 15 m thick, and is composed largely of very coarse sand. This area recharges the Floridan aquifer as there is a downward gradient and little retarding material in the overburden on the Floridan. The shallow aquifer is presently undeveloped because of the relative ease of developing large quantities of good-quality water from the Floridan.

Ground-water withdrawals in southwestern Hillsborough County

A. D. Duerr reported that continued urban and agricultural development resulted in greater ground-water withdrawals from the Floridan aquifer in southwestern Hillsborough County. Ground water of poor quality occurs along Tampa Bay, particularly near Gibsonton, where increased pumping has lowered the artesian head and saltwater has moved inland. A comparison of water quality in 1973 with that in 1955 showed higher chloride content in several wells in a densely farmed area about 1.6 km north of Ruskin.

A comparison of the potentiometric surface in May 1973 with that in May 1953 shows that water-level declines ranged from about 3 m at Apollo Beach to nearly 12 m near Wimauma. In May 1973, during the irrigation season, the zero potentiometric contour moved inland 22 km east of Tampa Bay. After the rainy season, in October 1973, water levels rose and the zero potentiometric contour moved westward into Tampa Bay.

Pumpage exceeds local canal infiltration

According to F. W. Meyer, infiltration from the Miami Canal to major well fields in the Miami Springs-Hialeah area is decreasing. Measurements of seepage losses from canals closest to the well fields during May 1973 indicated that only 50 percent of the average daily pumpage (4.5×10^5 m^3) was contributed by local infiltration. There are indications that the infiltration capability of this once important source of recharge is declining as a result of bottom-sediment buildup and drawdown beneath the canal system.

Frequency analysis of 1970-71 drought in southern Florida

M. A. Benson and R. A. Gardner analyzed precipitation data for southern Florida and found that frequency relations could be fitted satisfactorily to the data by using a log-Pearson type III distribution. This analysis indicates that the record-low dry-season precipitation recorded in southern Florida in 1970–71 can be expected to recur at intervals measured in centuries. This analysis was conducted as a part of the RALI project for southern Florida.

Evaluation of space-relayed hydrologic data in southern Florida

Using ERTS data, A. L. Higer, A. E. Coker, and E. H. Cordes (1974) and E. T. Wimberly developed a prototype operational hydrologic model for the Everglades Water Basin. The space-relayed data are being used by the U.S. Corps of Engineers and the National Park Service for their water-management activities.

Effect of control operations on water levels

Opening the salinity-control structures near the coast, after first building up a head for 24 h, gave sufficient data on water-level changes to permit an evaluation of the capability of existing drainage systems to drain newly developing inland areas. W. A. J. Pitt, Jr., used this method to determine the additional drainage required to provide flood protection from a 10-yr-frequency storm. He was further able to determine how far in advance the controls must be opened in order to lower ground-water levels sufficiently to prevent the water table from rising above ground elevation in the event of storms of different intensities.

Ground-water-quality mapping in DeSoto and Hardee Counties

W. E. Wilson III mapped water quality in the upper and lower parts of the Floridan aquifer in DeSoto and Hardee Counties. The maps show that ground water with the lowest mineral content occurs in the northwestern and northeastern parts of Hardee County, and that with the highest values generally occurs in southwestern DeSoto County. Mapped parameters include dissolved solids, hardness, temperature, sulfate, chloride, and fluoride. Concentrations are generally higher in the lower part of the aquifer than in the upper part. Fluoride content, however, is higher in the upper part, because fluorapatite is a common mineral in the upper part and is absent in the lower part. Throughout most of the counties, water from the Floridan aquifer is very hard, and in parts of the counties, concentrations of dissolved solids, sulfate, chloride, and fluoride exceed USPHS limits for drinking water.

Aquifer pumping tests

Data from an aquifer pumping test in southwestern DeSoto County were analyzed by A. F. Robertson. The aquifer conditions conformed reasonably well with the assumptions of the Theis model, and the analysis indicated a transmissivity of 1,430 m^2/d and a storage coefficient of 1.5×10^{-4}.

A second aquifer pumping test was conducted in a well field that supplies water to a large part of Pinellas County. Results of the test have not been completed, but preliminary analyses indicate that an isotropic condition exists. Data from 35 observation wells monitored during the test should provide detailed information about the aquifer.

Determination of flood profiles

A. F. Robertson has determined flood profiles for the nontidal reaches of the Alafia River in west-central Florida. The profile determinations were made using the USGS step-backwater digital-model program for flood magnitudes as great as the 200-yr recurrence interval. The Alafia basin is largely rural but is rapidly urbanizing owing to industrial and population expansions in the nearby cities of the Tampa Bay region.

Electric analog modeling

E. H. Cordes reported that the analog model of the hydrology of southern Florida was programed to determine the benefits of adding a secondary control structure to a major canal system. The model was also used to compute the change in storage and salvage of evapotranspiration losses by lowering the ground-water table through a program of ground-water pumping during periods of insufficient rainfall.

Test boring indicates permeable zones in the Biscayne aquifer

Results of recent test borings in the northwestern part of Hallandale and the North Rainbow Drive area of Hollywood show the Biscayne aquifer in those areas to be extremely permeable and capable of yielding large quantities of good-quality water, according to H. W. Bearden (1972). Permeable zones were tapped at depths of 9 to 16 m, 32 to 38 m, and 40 to 49 m in the Hallandale area, and 15 to 31 m, 32 to 35 m, and 43 to 46 m in the Hollywood area. In the Hallandale area, sandy limestone from 32 to 38 m and from 40 to 49 m would be most suitable for development; in the Hollywood area, sandy limestone and shell from 15 to 31 m would be most suitable for development.

Water resources of Broward County

Studies by C. B. Sherwood, Jr., and H. J. McCoy indicate that adequate public water supplies for the mushrooming population in Broward County can be developed despite problems caused by rapidly increasing water needs and contamination by seawater intrusions and manmade wastes. However, intensive regional and local water-management practices will be required to safeguard water resources.

Current studies are designed to determine the effects of sanitary landfills and urban runoff on the integrated ground- and surface-flow system and the effects of the injection of treated-sewage effluent on the deep artesian aquifers. Studies are also underway to determine the availability and quality of ground water in the shallow limestone aquifer in inland areas distant from the salt front.

Chloride concentration in an unconfined aquifer

Average background chloride concentration in the unconfined aquifer of the Peace River basin is estimated to be approximately 50 mg/l, according to J. J. Hickey. The easternmost part of the aquifer has chloride concentrations greater than the background concentrations. Probable causes of this condition are tidal inundation and contamination by flowing saline wells.

Belt of permeable limestone discovered by test drilling

A narrow belt of solution-riddled limestone, lying within an area of unconsolidated sandstone of lower permeability, was discovered by exploratory test drillings in Palm Beach County. H. G. Rodis, L. F. Land, and J. J. Schneider reported that the limestone belt is up to 3 km wide and ranges from 20 to 30 m in depth. The belt is 4 to 6 km from the coastline and offers a promising new source of water in an area where coastal well fields are threatened by saltwater intrusion. The investigation indicates that high-capacity wells tapping this belt will yield more than 63 l/s of fair-quality water. Wells in the adjacent sandstone generally yield less than 22 l/s of poor-quality water.

Potential recharge area to the Floridan aquifer

A potential recharge area to the Floridan aquifer in Volusia County has been verified in a study by J. O. Kimrey. The area of about 390 km^2 is part of the Talbot Terrace in the central part of the county, between the DeLand and Rima Ridges. Under present conditions, the ridges are prime recharge areas, but the intervening terrace area is waterlogged because the altitude of both the artesian pressure surface and the water table is at or near land surface most of the time.

D. D. Knochenmus previously reported that an apparently good hydraulic connection exists between the water table and Floridan aquifers in the Talbot Terrace area. This has been verified by a test-drilling program. A continuous core of the overburden (21–27 m) on the Floridan at 14 sites was obtained for visual estimates and laboratory determinations of vertical permeability. Geophysical logs were made for the coreholes and a number of preexisting supply wells in the area. The results of the study validate the good hydraulic connection between the aquifers, as postulated by Knochenmus. The most retarding materials, the clays, in the overburden are laterally discontinuous and usually thin; they are also relatively high in content of silt or coarser material. There is thus good potential for recharge to occur by induced downward leakage when well fields are developed in the area and the potentiometric surface of the Floridan is drawn down. Preliminary estimates are that such induced recharge could support a well-field yield as high as 4,380 l/s.

Digital modeling of coastal shallow aquifer

Preliminary information yielded by a digital model of the Lake Worth drainage district shows that lowering of water levels inland will have a minimal effect on saltwater intrusion at coastal well fields. The model under construction by L. F. Land covers an area of about 500 km^2 and will ultimately aid in water-resource management for the area.

GEORGIA

Availability of ground water for industry

An inventory by H. E. Blanchard, Jr., showed that well supplies of 13 to 220 l/s are being used by industries in one small part of Bartow County. The carbonate aquifer that furnishes water to these wells has proven to be widespread. Yields of similar quantity should be available in much of the industrial Cartersville area. The well water ranges from moderately hard to hard and is generally of good chemical quality.

Digital models of the principal artesian aquifer in the Brunswick and Savannah areas

Modeling of the principal artesian aquifer in the Brunswick and the Savannah areas has been used to answer ground-water management questions. H. B. Counts and R. E. Krause are using an iterative digital model developed by G. F. Pinder and modified by P. C. Trescott to simulate the hydrology of the aquifer in both areas. Good results have been attained, with the computed water levels closely matching the measured levels. Water-level data from the early 1940's to the present time are available for both locations. Comparison of the measured water-level configurations with the computed levels for selected years indicates a good areal match, and water-level trends in selected wells also match those computed. Several runs have been made in both models, predicting future water levels at current pumpage rates and by decentralizing pumpage from the areas of heavy withdrawal, and adding new pumpage of various amounts at selected sites.

Alternative sources of water for Glynn County

Aquifers of sand and sandy limestone of Miocene to Holocene age in Glynn County can yield as much as 31 l/s to well-point arrays. A compilation of data by E. A. Zimmerman indicates that these comparatively shallow aquifers can furnish ample water for current needs except for the major industries. Some of the aquifers have a transmissivity of almost 640 m^2/d. They normally produce water with a dissolved-solids concentration of less than 250 mg/l; locally the water contains sufficient dissolved iron to cause staining.

The aquifers have been eclipsed in importance by an underlying Eocene and Oligocene limestone aquifer capable of yields more than 10 times as great as the younger materials; nevertheless the shallow aquifers are a viable alternative to the heavily used limestone aquifer.

Areal distribution of Cretaceous aquifers

In a study of the Cretaceous of Georgia, R. C. Vorhis has defined the areal distribution of three aquifer units. The Providence and Cusseta Sands are restricted to the upper Coastal Plain in western Georgia and have limited ground-water potential. The aquifer composed of the Eutaw Formation and upper Tuscaloosa Formation is found throughout the Coastal Plain and is thought to contain freshwater in the study area. The deeper lower Tuscaloosa and Lower Cretaceous aquifer is also areally extensive, but it contains saltwater.

Solid-waste pollution of ground water

Recent dumping of solid waste into abandoned open-pit mines in Bartow County threatens to pollute the ground-water supply of the Cartersville area. Results of a preliminary study by C. W. Cressler indicate that the geologic settings of most of the pits make them unsuitable for solid-waste disposal.

KENTUCKY

Test wells unsuccessful on fracture traces

In an investigation of the water resources of north-central Kentucky, D. S. Mull mapped fracture traces from lineaments on black-and-white aerial photographs. Using the data from the photographs, Mull located two test sites in areas where few successful drilled wells exist. Two wells were drilled near the end of major lineaments because the areas of intersection of lineaments were inaccessible. The wells, 107 and 137 m deep, were drilled by the air-rotary method. The rocks penetrated were 76 to 107 m of essentially flat lying, thinly bedded limestone and shale underlain by thick beds of limestone with relatively little shale. Although the aerial photographs showed prominent lineaments, no evidence of fracture zones was observed during the drilling, and caliper logs showed no evidence of fractures that are usually common in wells located on fracture traces. Two explanations for these test wells not being more successful than other wells in the area are: (1) The wells may have missed the fracture zones, or (2) the sequence of shale in the upper part of the holes may be too impermeable for infiltration of ground water.

MISSISSIPPI

St. Louis Bay found to be fresh

Salinity surveys of St. Louis Bay and the estuarine Jourdan River showed that these bodies were fresh during ebb and flood tides in February 1974. D. E. Shattles reported that recent local flooding and high freshwater discharge into the Jourdan River Estuary and St. Louis Bay resulted in complete freshening with no saltwater wedge from Mississippi Sound detected during the survey. The maximum conductivity recorded was 500 μmho.

New ground-water supplies from Paleozoic rocks

E. H. Boswell and B. E. Wasson reported that test drilling for industrial water supplies in the Yellow Creek State Inland Port industrial area disclosed the presence of a high-yielding aquifer in an area where previous drilling had not been successful. The drilling was performed in 1973 at five sites, and two test wells were successful. One well is in chert of Mississippian age; the other is in Cretaceous gravel, which occurs either as a fill in a buried valley or in a downthrown structure. Water quality and water levels indicate that aquifers at the two sites are hydraulically connected.

Wells completed in the Paleozoic aquifer will be about 70 m deep and are expected to yield about 1.04 l s^{-1} m^{-1} of drawdown. The static water level is approximately at land surface. The water has a very low dissolved-solids content and is nearly free of iron. The pH is 5.5 and the temperature is 16°C.

NORTH CAROLINA

Saltwater flushing from Piedmont crystalline rocks

M. D. Winner, Jr., reported that ground-water circulation between the Piedmont crystalline rocks and the overlying Coastal Plain sediments in the Fall Zone area is controlled by the low transmissivity of the rocks, the depth and extent of the rock fractures, and somewhat by the type of sediments overlying the rocks. In Wilson County, located astride the Fall Zone in North Carolina, the limit of flushing of residual seawater from the crystalline rocks since the last incursion of the sea extends at least 19 to 24 km eastward of the westernmost scarp cut by the sea. Within the flushed bedrock area, a localized pocket of residual seawater has been found. This area, where salty water was pumped from a bedrock well at a depth of 107 m, is several kilometres north of the city of Wilson. Other wells in the immediate area to the east and southeast (in the direction of flushing) produce freshwater at depths of 152 to 183 m.

It is probable that this pocket of seawater is due to poorly connected bedrock fractures at depth, so that flushing would take place at a much slower rate than in surrounding areas. This situation north of Wilson may be related to the presence of two dissimilar rock types, an older Paleozoic slate and a younger Paleozoic granite; the fracture patterns of each (or lack of fractures) might serve to inhibit ground-water movement.

Vertical recharge in the North Carolina coastal plain

Maximum vertical-recharge rates for the two major artesian aquifers in northeastern North Carolina have been determined by analyzing the cones of depression that have developed around centers of heavy pumping in this area. T. M. Robison has estimated the maximum induced vertical recharge to the Castle Hayne aquifer at 820×10^3 l d^{-1} km^{-2} and the maximum rate for the Cretaceous aquifer at 48×10^3 l d^{-1} km^{-2}.

Regional draft-storage relations for North Carolina

To aid in site selection, planning, and managing the development of reservoirs in North Carolina, F. E. Arteaga and E. F. Hubbard, Jr., have developed allowable draft versus required storage relations for seven regions covering nearly all of the State. These relations, derived through analyses of streamflow data collected at 142 long-term gaging stations, enable the user to estimate the storage capacity that a planned or existing reservoir must have to furnish the draft he needs with a 2-, 5-, or 10-percent chance of failure within any one year.

The investigators have also provided relations to estimate the evaporation losses from reservoirs in each region and to estimate the sedimentation rate as a function of land practices in the basin.

PUERTO RICO

Water-resource planning models

E. R. Close and M. A. Lopez reported that the relative importance of hydrologic data in planning water-supply projects can be determined by evaluation of the sensitivity of water-resource planning variables within the framework of probable types, locations, and timing of future water-resource development. This information helps to establish more objective proposals for the investment of funds in the collection of hydrologic, economic, demographic, and other types of information used in the planning process.

The Puerto Rico water-resource planning model, described by D. W. Moody, E. D. Attanasi, E. R. Close, Thomas Maddock III, and M. A. Lopez (1973), was designed to select least cost sets of water-supply projects and sequence their construction over a given planning horizon. The resulting model is formulated as a mixed-integer program. A framework was suggested also for estimation analysis and for forecasting economic water demands. In particular, residential, commercial, and industrial water-demand models were proposed and tested.

Given a set of future water demands, the model selects and schedules the construction of proposed projects so that demands are met at minimum present cost. In addition to filling internal water demands, a given region may also export raw or treated water to meet demands in other regions.

To demonstrate the use of the model, the characteristics of 85 existing and proposed projects and estimates of water demands for each of 10 municipios (counties) were assembled from planning reports. The results indicated that the present cost of the system increased with water demand, but the sequence of project construction for the first three planning periods was about the same. These results suggest that ground water will be the dominant source of water in the region for about the next 15 yr. By using the model to select n "best" solutions, where n might be four or five integer solutions, the planner has reduced the extremely large number of possible project configurations to a manageable number for further study.

Artesian pressures in north-coast limestone

High artesian pressures in limestone aquifers on the northern coast of Puerto Rico were first discovered in 1968. Continuous development since then has helped to define the aquifers. The Lares Limestone and the lower part of the overlying Cibao Formation (Montebello Limestone Member) are the artesian aquifers. The Lares, though having the smallest hydraulic conductivities, is the thickest, and most deep wells penetrate this formation. The Montebello Limestone Member of the Cibao is areally more restricted but has a greater transmissivity. The Lares underlies 840 km^2; the Montebello, 390 km^2.

According to H. R. Anderson, pressures in these aquifers are from 60 to 90 m above land surface in the coastal areas. These pressures are sufficient to provide natural flows of 190 l/s.

Attempt to drain soils in Lajas Valley

Artesian pressures in the eastern end of Lajas Valley are the cause of hydraulic gradients that influence the flow of water into the soil zone, which in turn causes waterlogging of the soil. H. R. Anderson used a digital model of the area to investigate the possibility of reducing the pressure, thereby draining the soils. Thirty-five wells pumping a total 2,000 l/s, simulated on the model, resulted in lowering water levels as much as 5.3 m. Preliminary estimates using the model indicate a draft of 810 l/s will be sufficient to drain the soil in 1 ha.

SOUTH CAROLINA

Low flow of small streams

A preliminary study of Piedmont and Coastal Plain base-flow measurements of small streams by W. M. Bloxham indicates that the annual minimum 7-d mean flows range from 0 to 14 l s^{-1} km^{-2} at the 10-yr recurrence interval. Variations are attributed to differences in antecedent rainfall, limited permeability and capacity of Piedmont aquifers, and loss of streamflow in Coastal Plain sediments. The water is generally of excellent quality, low in dissolved-solids content, and, predictably, slightly acidic in the Coastal Plain.

Tests of Black Mingo Formation

C. A. Spiers reported that 20 observation wells were drilled in Berkeley County in July 1973. Pumping tests were conducted at selected wells and chemical samples were taken. Transmissivities for the Black Mingo Formation ranged from 81 to 1,100 m^2/d, and analyses of samples indicate possible mixing of surface and ground water in some wells.

Santee River studies

Lake Moultrie outflow that has been diverted into the Cooper River may be rediverted into the Santee River channel. F. A. Johnson made cross-sectional and longitudinal profiles of the Santee River which indicate that there is a large number of migrating dunes ranging from 1 to 3 m in height.

TENNESSEE

New water source for municipal and industrial use

C. R. Burchett reported that recent test drilling revealed the presence of a high-yielding aquifer in the southern Highland Rim. The aquifer is at least 80 km in extent and possibly much larger as evidenced by the analyses of data from test holes in Manchester and Tullahoma. Additional drilling for another project indicates the aquifer extends to southern Lincoln County.

The aquifer, named the Manchester aquifer, is within the Fort Payne Formation. The upper part of the aquifer consists of highly permeable chert rubble in the bottom of the weathered zone of the Fort Payne, and the lower part of the aquifer consists of solution openings in the uppermost few metres of the underlying bedrock. Test holes at three sites in the southern Highland Rim have penetrated 3 to 17 m of chert rubble yielding 13 to 19 l/s of freshwater. Most of these wells have also penetrated sizeable solution openings in the underlying bedrock which yields an additional 13 l/s or more freshwater.

This aquifer has great potential throughout its area of occurrence as a water source for municipal and industrial uses. The city of Manchester, as a direct result of the test drilling, has drilled two production wells which are to be tied into the municipal water system in 1974. These two wells will produce over 1,900 m^3 of water per day.

CENTRAL REGION

The hydrologic programs of the USGS in the central region are being focused on national issues and problems—energy, environment, and other water-related resource concerns. During the past year, significant revisions of programs, already underway, as well as development of new programs in Colorado, Montana, Utah, and Wyoming, have been achieved to respond to the water-supply problems and environmental effects of coal and oil-shale development. Three major program elements—basic-data collection, areal investigations, and supportive research studies—have been emphasized.

Regional appraisals of ground water in the Texas-Gulf region and the Arkansas-White-Red River region have been completed. These studies emphasize the significance of ground water in planning, developing, and managing water resources.

During the year, some USGS scientists concentrated on fluvial sediment problems in a Denver location.

Noteworthy activities in hydrologic research being conducted in the central region include the following: (1) Interdisciplinary investigations of artificial recharge of ground water, particularly at field sites near Lubbock, Tex., (2) application of hydraulic-fracturing techniques to measure regional distribution of tectonic stresses, (3) transport and interaction with rock materials of organic wastes injected into the subsurface, and (4) development of quantitative approaches to the application of geophysical-logging methods to a variety of hydrologic problems.

Water supplies from Madison Limestone in the Powder River structural basin, Montana and Wyoming

Results of a study of the Madison Limestone and other deep carbonate aquifers in the Powder River structural basin of Wyoming and Montana indicate that significant quantities of water can be made available for industrial development of the coal deposits of the area, according to F. A. Swenson. Wells yielding more than 570 l/s of excellent-quality water and wells exceeding 3,050 m in depth, yielding water of adequate quality for industrial use, have been developed. In parts of the area, water is of excellent quality at depths greater than 2,500 m. One well 2,560 m deep yields almost 3,800 l/min of water that contains only 860 mg/l total solids.

COLORADO

Potentiometric surface- and ground-water quality of the valley-fill aquifer, Wet Mountain Valley

The potentiometric surface of the valley-fill aquifer of the Wet Mountain Valley in the upper Arkansas River basin in Colorado indicates radial flow into the center of the valley. D. L. Bingham interpreted reported loss of streamflow in the upper reaches of Grape Creek and its tributaries to indicate recharge to the ground-water reservoir. The depth to the potentiometric surface is less than 3 m over a 91-km^2 area in the center of the valley, indicating areas of possible discharge to streams or evapotranspiration.

Samples were collected from 25 wells to define the water quality. The dissolved-solids concentration of the calcium bicarbonate water ranges from 94 to 431 mg/l. Water flowing through the unconsolidated sediments derived from the Wet Mountain volcanic rocks east of the area contains 17 to 41 mg/l of silica. Water flowing through the unconsolidated sediments derived from the metamorphic rocks of the Sangre de Cristo Mountains west of the area contains 10 to 15 mg/l of silica.

Lakes in the Front Range urban corridor

More than 160 lakes with surface areas greater than 2 ha are located in the Front Range urban corridor between lat 39°22′30″ and 40°00′00″ N. Forty-eight of these lakes have areas greater than 10 ha. The lakes were sampled during July and August 1973 by T. W. Danielson and T. G. Devenish. All but four lakes had specific-conductance readings of less than 750 μmho/cm. The upper and lower limits were 950 and 40 μmho/cm. Values of pH ranged from 5.5 to 10.0, but in 96 percent of the lakes sampled the pH ranged from 7.3 to 9.2. Transparency (Secchi disk) readings ranged between 0.2 and 5.5 m. Fourteen of the 48 lakes sampled had a transparency of less than 1.0 m. The largest lake in the area (Standley Lake) has a surface area of 492 ha and a perimeter of 12 km.

Ground-water quality, upper Arkansas River basin

As part of a reconnaissance study of the ground-water resources of the upper Arkansas River basin in Colorado, 200 water samples were collected to define the water quality. J. M. Klein reported that the water from the Quaternary glacial outwash and alluvial valley fill in the Salida-Leadville basin is generally a calcium bicarbonate type with a mean dissolved-solids concentration of 192 mg/l. Water from the Tertiary valley-fill deposits, which underlie the glacial and alluvial deposits, ranges from a calcium bicarbonate water near Leadville to an alkaline sodium carbonate or sodium bicarbonate water near Salida. The dissolved-solids concentration of water from the alluvial valley fill of the Arkansas River and its tributaries between Canon City and Pueblo increases from 500 to 1,500 mg/l.

Hot springs on the west side of the basin near Mount Princeton produce an alkaline sodium bicarbonate water with the following mean concentrations: Silica = 69 mg/l, fluoride = 13 mg/l, and magnesium = 0.2 mg/l. Probable precipitation of magnesium silicates accounts for the low-magnesium concentration and is the controlling factor maintaining the concentration of silica in solution. These hot waters compare chemically with warm water encountered in the Browns Canyon and Poncha Springs fluorspar deposits, and with the deep artesian waters from the San Luis Valley.

The Lower Cretaceous aquifers—the Dakota Sandstone and the Purgatoire Formation—yield water of varying quality near Pueblo. The quality is dependent primarily upon distance from the natural recharge areas where the formation crops out, and upon geologic controls and barriers such as faults which restrict flow or allow mixing of water from the Cretaceous aquifers with water from a deeper source. Calcium bicarbonate water with a dissolved-solids concentration of less than 500 mg/l predominates in wells drilled in the Dakota Sandstone where it outcrops southwest of Pueblo. In other localities near faults, the water may contain calcium, magnesium, and sulfate as the predominant ions. The Lower Cretaceous aquifers, where they are deeply buried and unaffected by structural controls, almost always contain a sodium bicarbonate water which grades to a sodium sulfate water northeast toward Pueblo.

Surface-water resources of Ute Indian Reservations

G. H. Leavesley reported that, in order to evaluate the surface-water resources of the Southern Ute and Ute Mountain Indian Reservations, determinations were made of the mean annual virgin flows and the present quality of the surface flows of the 10 major rivers of the upper San Juan drainage basin at their points of entry into the reservations. Mean annual historic streamflows for parts of the 10 basins were computed from available gaging-station records, extended where necessary to the time base of 1912 to 1971. Mean annual streamflow depletions above these gaging stations, resulting primarily from out-of-basin diversions and consumptive losses asociated with irrigation, were computed and added to the mean annual historic streamflows to give the mean annual virgin flows for these basins at the gaging-station points. Using these virgin flows and their respective basin areas, the relationship between mean annual precipitation and mean annual runoff then was developed and used to estimate the mean annual virgin flow contributions of those basin areas between the gaging stations and the reservation boundaries. The San Juan River, the major river in this region, is joined by nine important tributary river basins. The mean annual virgin flow of the San Juan River at its entry point to the Southern Ute Indian Reservation is 377 hm^3. At its entry point to the Ute Mountain Indian Reservation, after receiving the flow of the other nine rivers, its mean annual virgin flow is 2,483 hm^3.

Water samples collected from each river in the months of December 1972, and March, June, and August 1973, were analyzed for pesticide content, bacteria count, and chemical content. The water was well within the allowable limits for pesticide content for public and agricultural water supplies as set by the National Technical Advisory Committee on Water Quality Criteria. The Colorado bacteriological standard of not more than 1,000 fecal coliform groups per 100 ml was not exceeded by any of the samples from these rivers. Chemical analyses show seasonal variations because of dilution effects of the large spring-snowmelt runoff. During low-flow periods, dissolved solids and sulfate concentrations of the Mancos and lower San Juan Rivers were found to exceed the USPHS limits for drinking water. For irrigation purposes, all rivers were found to have a low sodium hazard, and all but the Mancos River were found to have a low-to-medium salinity hazard. The Mancos River is classed as a high-salinity-hazard river.

Prediction model developed for Arkansas River valley

A mathematical prediction model has been developed for the Arkansas River valley in Colorado, according to O. J. Taylor and R. R. Luckey (1974). The model utilizes current estimates of streamflow, precipitation, imported water, and initial reservoir storage. The supply is distributed among canals and wells according to the priority system of water rights and the availability in time and space. The interrelation between surface water and ground water is simulated with a technique using the stream-depletion factor. The model predicts the availability of canal water and well water to each irrigation company, the resulting streamflow and ground-water storage, reservoir content, and the streamflow available to Kansas at the Colorado-Kansas State line. The model is valuable to water managers for evaluating proposed changes in water use and to irrigators for planning purposes.

Hydrology of oil-shale lands

A study of the Piceance basin in northwestern Colorado is being made by J. B. Weeks, F. A. Welder, and G. H. Leavesley to determine the relationship of water resources to the development of an oil-shale industry. Hydrologic data from more than 50 wells have been used to develop a digital model of the aquifer system. The model is being used to estimate the pumping rates that will be required to dewater oil-shale mines, and the effects of dewatering on the hydrologic system. Preliminary estimates indicate that steady-state pumping rates of 141.6 and 283.2 l/s will be required to dewater mines 2.59 km^2 in area in Colorado tracts C-a and C-b, respectively.

Climatological, surface-water runoff, and diversion records are being compiled. The data will be used to develop a digital model of the surface-water system in Piceance Creek basin. A steady-state water budget has been developed for the 1,629-km^2 Piceance Creek basin. The mean annual budget indicates that of the 442 mm of rainfall, 431.8 mm is lost as evapotranspiration and 10.2 mm is discharged through Piceance Creek.

Water recreation along the Cache la Poudre River

The Cache la Poudre River, from Teds Place to Kinikinik, provides excellent opportunities for water recreation, according to D. A. Wentz. About 45 percent of this segment of the river is within the boundaries of Roosevelt National Forest, and the area is easily reached by a paved highway. Mostly, access to the stream is not limited by private-property owners or by adverse physical characteristics, such as dense vegetation or extreme bank slopes and heights. The stream is readily fished in the spring between icemelt and the start of snowmelt runoff, and after the return of low flows in early summer.

A reconnaissance of the stream and its major tributaries during low flow in April 1973 indicated that the chemical, physical, and biological water quality was good enough to sustain the local cold-water fishery, which has approximately equal numbers of wild-brown and rainbow trout.

IOWA

Ground water highly mineralized in south-central Iowa

Analyses of geohydrologic data collected in an 11-county area in south-central Iowa indicate that dependable, potable-water supplies are not readily available, according to J. W. Cagle, Jr. With the exception of water utilization by riparian users, the most pressing regional problem is that of highly mineralized ground water. Ground water is available in small to moderate amounts from at least three bedrock units, but the water in most of the region invariably contains dissolved solids in excess of 1,500 mg/l and usually in excess of 2,000 mg/l. Only the deep-lying Cambrian-Ordovician bedrock aquifer in the eastern three counties of the region yields moderate to large amounts of water containing less than 1,000 mg/l of dissolved solids. Moderate to large quantities of water containing less than 500 mg/l of dissolved solids are available from the principal streams and from the principal alluvial aquifers. The recently completed Rathbun flood-control reservoir, which has a storage capacity of 47.5 cm of runoff, is potentially the principal source of large amounts of good-quality water in the region. A four-county rural water district is implementing a regional plan to withdraw water from this reservoir.

KANSAS

Rate of water-level decline increases in Ogallala aquifer in northwestern Kansas

E. D. Jenkins and M. E. Pabst reported that the rate of water-level decline in the Ogallala aquifer is increasing in northwestern Kansas. Measurements in 315 wells indicate that water levels in the area declined at an average rate of 0.03 m/yr between 1950 and 1966. From 1966 to 1973, however, the average annual decline has been 0.2 m. The declines are attributed primarily to ground-water withdrawals for irrigation, which have increased 18 hm^3 in 1950, to 310 hm^3 in 1966, and to 620 hm^3 in 1972.

Numerical modeling of base flow

The Kansas Water Budget Model, a computer program developed by E. C. Pogge (Kansas Univ.) and his associates, was modified by P. R. Jordan (USGS) to provide a smoother transition between overland runoff and base flow, and to produce base-flow recession slopes that are more representative of conditions that exist from late fall through early spring. The modification introduces a storage volume representing bank storage, which interacts with the ground water and the stream as the levels rise and fall. Seasonal variation of base-flow recession slopes is accomplished by seasonal change in evapotranspiration from the bank storage.

Supplemental water for public and industrial use in central Kansas

Freshwater is in short supply in central Kansas except in the valleys of major streams. According to K. M. Keene and C. K. Bayne (Kansas Geological Survey), water to supplement existing public and industrial supplies probably can be obtained from wells in rocks of Early Cretaceous age. Most of the water is slightly to moderately saline (1,000 to 3,000 mg/l dissolved solids). The water, therefore, would require treatment or mixing with water of better quality before use. The cost of treating the water would be prohibitive for irrigation or single-unit domestic use.

Well yields are difficult to predict because of the lenticularity and irregular degree of cementation of the Lower Cretaceous sandstone units from which water is produced. The few existing wells tapping the Lower Cretaceous sandstone yield 3 to 19 l/s.

Large quantities of ground water available in Ford and Hodgeman Counties

D. H. Lobmeyer (USGS) and E. C. Weakly (Kansas Geological Survey) reported that wells yielding 140 l/s can be developed in channel sands of the Dakota Formation in Ford and Hodgeman Counties. In 1973, 59 irrigation wells pumped about 7.4 hm^3 of ground water to irrigate 2,000 ha. Hydraulic-head changes as a result of irrigation withdrawals have been as much as 12 m since 1968 in a part of the area where water in the Dakota Formation is confined. There has been little water-level change in those parts of the area where water in the formation is unconfined and where there are few wells.

LOUISIANA

Upland terrace aquifer an additional source of water for public-supply wells in Bossier and Webster Parishes

In southern Bossier and southwestern Webster Parishes, east of Bossier City and Shreveport, it has been difficult to find water-bearing sands in the Wilcox Group that will yield sufficient water for public supply wells. USGS scientists investigated the area and, according to J. L. Snider, found that sand and gravel of the upland terrace deposits are another source of water. These deposits form a water-table aquifer in parts of the area but had not been investigated as a source for public-supply wells. Tests indicate that the saturated sand and gravel, which ranges in thickness from 0 to 30 m and averages 13 m, could yield 750 l/min or more to wells. In Bossier Parish, water from the terrace deposits is high in iron content or in hardness or in both; in Webster Parish, water in some areas is low in hardness and iron content. Additional test drilling is necessary to determine the extent of the areas containing the good-quality water.

Water quality in the Mississippi River alluvial aquifer, southeastern Richland Parish

According to M. S. Whitfield, Jr., regional investigation of water quality in the Mississippi River alluvial aquifer in northeastern Louisiana has disclosed an area of approximately 260 km^2 in southeastern Richland Parish where water ranges from soft to moderately hard and has low concentrations of iron. This water would not require treatment for municipal use as is needed elsewhere for water from this aquifer in northeastern Louisiana.

MONTANA

Ground-water resources of the Fort Belknap Indian Reservation

R. D. Feltis reported that glacial till covers gravel deposits along at least 16 km of the preglacial channel of Little Peoples Creek, north of Hays. Water in the buried channel is under artesian pressure; one well reportedly flowed about 28.3 l/s, and other wells flow from 0.57 to 3.7 l/s. The water is hard to very hard; dissolved-solids content ranges from 580 to 2,300 mg/l. Sulfate is the dominant anion; concentrations increase downstream from 267 to 1,140 mg/l. Sodium, calcium, and magnesium are about equal in concentration at the upstream end of the area, but sodium predominates downstream where the sodium adsorption ratio has increased from 1.7 to 25.4. Water from the upstream reaches could be used for irrigation.

Hydrology of shallow aquifers in the northern Great Plains

According to W. R. Miller, hydrologic data from selected areas in coal-rich eastern Montana indicate that the Tongue River Member of the Fort Union Formation contains several aquifers. However, only the shallow aquifers less than 91.4 m deep have been developed, except along Otter Creek where flowing wells as deep as 366 m have been completed. Near Ashland these shallow aquifers are in the middle part of the Tongue River Member but are stratigraphically higher to the south.

Preliminary data indicate that the specific conductance of water from wells and springs ranges from 950 to more than 8,000 μmho/cm. Water from wells less than 61 m deep is a calcium sulfate to a sodium sulfate type; water from the deeper wells is a sodium bicarbonate type. Water from most springs is a magnesium sulfate type.

Ground-water quality in the Madison Group in eastern Montana

W. R. Miller reported that the dissolved-solids content of water samples from Madison Group carbonates ranges from less than 1,000 mg/l in extreme southeastern Montana, to about 5,000 mg/l south of lat 46°30′ N., to more than 300,000 mg/l northward in the Williston Basin. The water in southeastern Montana is mainly a calcium sulfate type but changes to a sodium chloride type in the Williston Basin. The area where water contains more than 100,000 mg/l of dissolved solids roughly coincides with the area of extensive salt deposits within the Madison Group in the Williston Basin.

NORTH DAKOTA

Buried glacial-valley aquifers in Morton County

D. J. Ackerman reported that test-hole logs, water-level measurements, and chemical analyses of water samples were used to make a preliminary assessment of the geohydrologic character of two buried glacial-valley aquifers in Morton County.

Aquifer materials consist of sand, ranging from 17 to 116 m thick, and as much as 27 m of gravel. The sand and gravel are interbedded with silt and clay. The aquifers are 0.8 to 1.6 km wide and as much as 152 m deep. Potential yields from the aquifers may be as much as 63.1 l/s. Dissolved-solids content of 40 water samples from the aquifers ranged from 465 to 3,230 mg/l.

Fox Hills and basal Hell Creek aquifer

Results of ground-water investigations in Adams and Bowman Counties by M. G. Croft indicate that five major aquifers occur within the rocks of Cretaceous and Tertiary age. The aquifers consist of fine-grained materials and have low transmissivities. Adams and Bowman Counties are recharge areas for aquifers that extend from the Little Missouri River to the Missouri River. Dissolved solids are concentrated in the upper aquifers by ionic sorption in fine-grained strata as water moves downward to the lower aquifers. Water is the lowest aquifer, the Fox Hills-basal Hell Creek, has a specific conductance of 1,600 to 2,000 μmho/cm and is free of organic color.

Availability of ground water in northeastern North Dakota

R. D. Hutchinson reported that test drilling revealed a major buried aquifer underlying about 285

km^2 of southern Ramsey County in northeastern North Dakota. The aquifer consists mostly of coarse sand and gravel, with an average thickness of about 24 m. Water from the aquifer generally contains 500 to 1,500 mg/l dissolved solids. Potential yield may exceed 63 l/s in some areas.

Relations between ground water and surface water in Grant and Sioux Counties

P. G. Randich reported that test drilling and low-flow stream measurements show that buried valley-fill aquifers of glacial origin underlie the Heart and Cannonball River channels in some localities. The buried valleys represent glacial ice-front streams and are filled with as much as 90 m of glaciofluvial deposits. The trend of these valleys is generally perpendicular to recent river valleys in Grant and Sioux Counties.

Low-flow measurements on the Heart River indicate that it is a gaining stream where a buried valley-fill aquifer underlies the present river channel. Flow measurements made on October 2, 1973, ranged from 0.24 m^3/s at the upstream end of the aquifer to 0.58 m^3/s near the downstream end. The increase in discharge is along a 16-km reach of the Heart River that coincides with the location of the buried-valley aquifer. Chemical analyses of water samples show a 10-percent increase in dissolved-solids content within this reach of the river.

Low-flow measurements made on the Cannonball River, where a part of this buried-valley aquifer underlies the river channel, indicate no measurable change in quantity or quality of the water. In this area, the upper sediments of the buried valley consist of till, clay, and silt which act as a confining bed between the buried glaciofluvial deposits and the recent river channel.

SOUTH DAKOTA

Aquifers in north-central South Dakota

Large-capacity wells yielding at least 1.1 l/s can be completed in glacial aquifers of outwash sand and gravel that underlies 2,150 km^2 of McPherson, Edmunds, and Faulk Counties, according to L. J. Hamilton (USGS) and C. N. Christensen (South Dakota Geol. Survey). Their study involves inventorying 2,000 wells and drilling 420 test holes. Shallow aquifers, less than 30 m deep, yield water that is high in calcium and magnesium, with an average hardness of 400 mg/l; deep glacial aquifers yield water that is high in sodium, with an average hardness of 220 mg/l.

Artesian wells in sandstone aquifers that are more than 300 m deep have pressures as high as 14 kg/cm^2. Locally, flows are reported to have exceeded 63 l/s. Dissolved-solids content of water from wells in the Dakota Sandstone averages 100 mg/l. Wells in deeper sandstone aquifers yield water with an average dissolved-solids content of 1,000 mg/l.

Buried channel of the ancient Bad River located

A buried glacial aquifer in the channel of the ancient Bad River has been located in western Hyde County. Results of a program of test drilling by N. C. Koch (USGS) and R. Halgerson (South Dakota Geological Survey) indicate that the aquifer consists of sand and gravel. A test hole 14 km north of Highmore penetrated 15 m of aquifer material between 52 and 110 m below land surface. By examining the surface topography, the ancient river channel was traced westward to the Missouri River. Chemical analysis of water from one well in the aquifer shows the water to be of a sodium bicarbonate type.

Thickest glacial drift in South Dakota contains several outwash aquifers

Preliminary test drilling in Deuel and Hamlin Counties, northeastern South Dakota, has totaled 12,200 m at 450 sites. Jack Kume reported that one result of the test drilling was the discovery of the thickest glacial drift in the State. In northwestern Deuel County in the Coteau Des Prairies region, 268 m of drift was penetrated. The thinnest known glacial drift in the two-county area is a section 56 m thick in northwestern Deuel County.

Several major outwash aquifers occur in the glacial drift. At one drill site, four outwash aquifers with a total thickness of 55 m of sand and gravel were discovered. Major gravel aquifers 23 m thick were found at two sites and seven layers of gravel 3 m or more in thickness were penetrated at another site.

UTAH

Large well yields from the Navajo Sandstone, southwestern Utah

Of all of the consolidated-rock units of southwestern Utah, the Navajo Sandstone (Triassic? and Jurassic) has the greatest water-yielding potential. Yields to large-diameter wells are most commonly in the range of 20 to 200 l/s, and in a large part of the area the possibility of obtaining yields in the upper half of the range is good, according to R. M. Cordova. The reason for the potentially large yield and easy availability is the combination of a high degree of fracturing and intergranular porosity.

Differences in aquifer characteristics in the Uinta Basin

J. W. Hood, F. K. Fields, and R. W. Cruff reported that the two most extensively used aquifers in the northern Uinta Basin are coarse-grained deposits of Quaternary age and the Duchesne River Formation of Tertiary age. The Quaternary deposits consist of boulders, gravel, and sand that fill stream valleys and cap broad terraces; however, the deposits only locally exceed about 15 m in thickness. Tentative results from an aquifer test made for these deposits indicate a transmissivity of about 600 m^2/d; the inferred hydraulic conductivity is 25 m/d.

The Duchesne River Formation, conversely, is widespread and thick, consisting of intercalated sandstone and shale. An aquifer test near Roosevelt yielded tentative figures of 300 to 500 m^2/d for transmissivity and 0.1 to 0.3 m/d for minimum hydraulic conductivity. The latter figure compares closely with laboratory determinations of 0.11 and 0.23 m/d for specimens of sandstone collected from nearby outcrops.

Laboratory determinations of hydraulic conductivity for sandstone specimens from elsewhere in the basin showed values ranging from 0.4 to as low as 0.17×10^{-4} m/d for the Duchesne River Formation, the Current Creek Formation, and the Navajo Sandstone. These figures indicate that most consolidated rocks in the northern Uinta Basin do not support large-yield wells. Moreover, the lower values for the Duchesne River Formation partly explain why the formation at depth in some areas yields water of poor quality. Where the hydraulic conductivity is low, ground water moves slowly and has greater opportunity to be in contact with, and dissolve larger quantities of, minerals from the formation.

Ground-water availability in Beaver Valley

Preliminary results of a study by R. W. Mower in Beaver Valley suggest that the ground-water reservoir consists of a lower unit (probably Tertiary) and an upper unit (probably Pleistocene). Both units consist mainly of deposits of gravel, sand, silt, and clay. The upper unit is more permeable; however, the thickness probably averages less than 50 m, whereas the thickness of the lower unit probably averages more than 100 m. At irrigation wells, the upper unit yields more than 2 $l\ s^{-1}\ m^{-1}$ of drawdown, but the lower unit usually yields less than 1 $l\ s^{-1}\ m^{-1}$ of drawdown.

The chemical quality of the water in both units is satisfactory for domestic and irrigation supplies in the upper reaches of Beaver Valley, but the quality of the water in both units is marginal to unsatisfactory for domestic and irrigation uses in some of the lower reaches.

Low runoff and sediment yield from pinyon and juniper woodlands on Green River Formation in northeastern Utah

Since 1970, J. R. Owen, Jr., has measured runoff and sediment yield in two small watersheds in the pinyon and juniper woodland area of the Uinta Basin. Precipitation for the study period has averaged 386 mm/yr, but runoff has averaged only 2 mm/yr or 0.6 percent of the precipitation for the same period. The low runoff is due primarily to the physical characteristics of the watersheds. Soils on the hillslopes are shallow, but the rocky, deeply weathered parent material, which is the Parachute Creek Member of the Green River Formation, allows a very high infiltration rate, resulting in low runoff. Sediment yield, determined from reservoir surveys, has averaged less than 47 $m^3\ km^{-2}\ yr^{-1}$.

The two watersheds are similar (in their topographic, geologic, and vegetational characteristics) to some areas that will be developed for oil shale in Colorado and Utah, and the runoff and sediment-yield relationships developed in this study should be usable for such lands.

WYOMING

Geohydrology of the Madison Limestone in the Powder River Basin in northeastern Wyoming

Data from records of 53 water wells, 166 oil- and gas-test holes, and 71 chemical analyses of water for the Madison Limestone of Mississippian age in the Powder River Basin have been collected and studied by W. G. Hodson. Depth to the top of the Madison exceeds 4,880 m in the deepest part of the basin. Recharge to the Madison is chiefly along the flank of the Bighorn Mountains, along the Black Hills, and at the north end of the Laramie Range. Movement of water is generally northward toward the Williston Basin of Montana and North Dakota. Upward leakage of water from the Madison occurs into the overlying rocks of Pennsylvanian age. Chemical quality-of-water data indicate that dissolved solids in water from the Madison are generally less than 3,000 mg/l in the Wyoming part of the Powder River Basin. Well yields of 3,800 l/min are common from cavernous parts of the formation in some parts of the basin.

Occurrence of ground water in the Gillette area

An appraisal by N. J. King (1974) of an area of about 2,800 km^2 in the vicinity of Gillette was made to determine general conditions of ground-water occurrence in shallow aquifers prior to the anticipated development of extensive coal resources in this area. Data from approximately 390 wells show that 91 percent of them are less than 91 m deep; in 94 percent of the wells, the depth to the water table is less than 61 m. Ground-water levels are highest in the southwestern part of the area, where the altitude of the land surface is highest, and the levels slope generally eastward and northward in the same direction as the slope of the land surface. Flowing wells can be obtained only in the bottom lands of the Belle Fourche River valley in the southeastern part of the area, and along Cottonwood Creek in the northeastern part of the area. Most wells yield water that is marginal or undesirable for human consumption but suitable for use by livestock. Surface mining of coal where the thickness of overburden is less than about 60 m may substantially lower the water levels in wells tapping shallow aquifers within about 6 km of individual mining operations.

WESTERN REGION

The western region continued its varied water-resource investigations programs. These included continuation of ongoing programs such as the San Francisco Bay region Environment and Resources Planning Study; collection and analyses of data on surface water, ground water, and water quality; research projects; and resource-appraisal studies. Also, major attention was given to the continuing need to obtain comprehensive hydrologic data related to possible construction of an oil pipeline from the North Slope of Alaska to Valdez on the southern coast. Detailed information on flow and channel characteristics of major streams to be crossed became of major concern, and specific studies of ground water and baseline biological conditions continued.

As the need to identify and develop new and environmentally acceptable energy resources continued to intensify, studies of the hydrologic effect of strip-mining coal in northeastern Arizona were made, and continuing attention was given to the location and hydrologic relationship of geothermal resources in California, Idaho, Nevada, and Oregon.

Ongoing water-resource investigations are increasingly oriented toward management of the hydrologic system and the collection and syntheses of hydrologic data. In response to water-management information needs, an increasing use of modeling techniques is made to simulate hydrologic systems and the effects of existing and projected development and management practices on the system.

ALASKA

Water-resource reconnaissance of Cordova

G. S. Anderson reported that the source of water supply for Cordova is small streams and ground water. Streams provide an adequate supply during the summer; however, discharge measurements made during the winter have indicated that the supply is inadequate to meet increasing demands. Under existing requirements, streamflow during winter is supplemented at times with ground water. Recent results of aquifer testing point out that additional ground water can be developed. However, a large increase in ground-water development will depend on inducing recharge from Eyak Lake.

Water-resource investigations of the Valdez-Copper Center area, south-central Alaska

According to C. E. Sloan, surface water and ground water of excellent quality are generally abundant in the relatively undeveloped area between Valdez and Copper Center. Some natural variations in both quality and quantity may, nevertheless, impose some temporal and spatial limitations on use. Water quality in glacial lakes and streams is affected during peak summer-flow periods by high turbidity. Low to moderate concentrations of bacteria occur in most surface water during late spring and early summer, but the concentrations decrease during winter-flow periods. DO concentrations are near saturation in surface water but approach zero under winter ice cover in shallow lakes such as Pippin and Willow. Although dissolved-solids concentrations in ground water are generally quite low throughout the area, high concentrations limit ground-water use in some areas such as the Copper Center area.

ARIZONA

Ground-water levels decline in the Dateland-Hyder area

According to D. W. Wilkins, a water-level decline of 18 m has occurred since 1965 in the principal aquifers of the area north of Hyder and east of Aztec Hills. No appreciable water-level changes have occurred in the flood plain of the Gila River that flows through the area. From 1942 to 1972, about 1,500 hm^3 of water was pumped from the aquifer, and 50 percent of this pumpage has occurred since 1967. It is estimated that the uppermost 30 m of saturated deposits contain about 6,200 hm^3 of water.

The chemical quality of the water varies greatly throughout the area but generally is good southeast of the Palomas Mountains. It is poorest in the flood plain of the Gila River. Dissolved-solids concentrations range from 480 to 18,600 mg/l; boron, from 0.32 to 26 mg/l; and fluoride, from 0.5 to 9.1 mg/l.

Six consecutive months of no flow recorded for the Santa Cruz River near Nogales

According to C. H. Benson, the Santa Cruz River near Nogales was dry during the 1973 water year for the longest consecutive period in 54 yr of record —1912–22 and 1929–73. No flow occurred near the gaging station for 6 mo. (In 1914, there were 4 mo of no flow.) Ground water usually sustains low flows at the Santa Cruz River near the Nogales gaging station; however, the municipal water supplies for Nogales, Ariz., and Nogales, Sonora, Mexico, are from wells drilled in the alluvium near the river, and, at times, the cone of influence of these wells intercepts and depletes the surface flow in the river.

CALIFORNIA

Selection of sites favorable for recharge near Indio

J. A. Moreland reported that nearly 150 drillers' logs of water wells were analyzed to determine the distribution of sediments in the upper 30 m of alluvial deposits in a 90-km^2 area northwest of Indio. Eleven test holes were augered to depths ranging from 20 to 33 m. Particle-size distributions determined for 19 grab samples collected from the test holes indicate that initial infiltration rates of 4.5 to 15 m/d can be expected in the more permeable areas, and that the sustained infiltration rate will be about 1 m/d. Depth-to-water maps indicate that from 15 to 60 m of unsaturated sediments overlie the ground-water body.

Hydrologic and salt balances for San Luis Rey ground-water basins

According to J. A. Moreland, hydrologic and salt balances were computed for the Pauma, Pala, Bonsall, and Mission ground-water basins of the San Luis River watershed. Hydrologic budgets were tested for compatibility with known hydrologic parameters by constructing and verifying near-steady-state and transient-state models. Near-steady-state inflow and outflow was calculated to be 3.67 hm^3/yr for Pauma basin, 3.11 hm^3/yr for Pala basin, 6.70 hm^3/yr for Bonsall basin, and 8.29 hm^3/yr for Mission basin. In 1972 annual net differences between inflow and outflow were —2.3 hm^3/yr for Pauma, —1.0 hm^3/yr for Pala, +0.3 hm^3/yr for Bonsall, and +1.6 hm^3/yr for Mission. Salt-balance calculations for 1972 indicate that salt inflow exceeded salt outflow by 1,990 t/yr in Pauma basin, 660 t/yr in Pala basin, 2,380 t/yr in Bonsall basin, and 3,850 t/yr in Mission basin.

Base and thickness defined for post-Eocene continental deposits, Sacramento Valley

The structure of the base of the post-Eocene deposits, according to R. W. Page (1973), is that of a large northward-trending syncline. The deposits themselves range in thickness from less than 1 m near the margin of the valley to about 10,500 m beneath the south-central part of the valley. The thickest sections occur along the axis of the syncline; however, around Sutter Buttes, a volcanic plug, the deposits are thinner than at any locale near the central part of the valley.

Ground-water resources in the Sacramento Valley

Using a digital model, R. M. Bloyd, Jr., defined natural ground-water conditions in the Sacramento Valley. Based upon ground-water levels and estimates of transmissivity, the model was used to compute flux values or average annual recharge. Natural conditions were defined and expressed in terms of a hydrologic budget. Estimated long-term average annual surface inflow to the valley is about 27 km^3/yr. This is by far the largest water-input component. Computed average annual ground-water recharge under natural conditions is 1.0 km^3/yr.

Estimated permeabilities of soils in the Sacramento Valley

G. L. Bertoldi (1973) applied several analytical techniques to engineering and hydrologic data contained in 15 studies covering various parts of the Sacramento Valley. The results show that 50 percent of the Sacramento Valley area has soils with permeabilities characterized by infiltration rates of less than 0.6 m/d. Consolidated barriers, such as hardpan, claypan, and durpan, that could impede the vertical flow of water were found in 30 percent of the area.

Economic and digital model studies aid efficient use of water

An economic analysis was coupled with a digital model of the ground-water hydrologic system to determine the most efficient balance of conjunctive use of local ground water and surface water. Specifically, the work was aimed at determining whether additional ground-water supplies can be developed in the Oak Glen area for local use and for export to the adjacent Yucaipa area, and at determining what the effects of imported water (to become available in 1980) will be.

According to W. R. Powers III and W. F. Hardt, the model predicted water-level changes from 1971 to 1980, using the maximum pumping capabilities of the wells under recharge conditions for average, wet, and dry periods. The predicted water-level changes were then used to calculate the average costs of pumping water during the period 1971–80. The economic evaluation suggests several practices that will allow optimum utilization of ground water and surface water within the framework of planned imports from outside the local basins.

Downstream flow of Mojave River predicted by model simulation

T. J. Durbin and W. F. Hardt developed a mathematical model that simulates the advance of streamflow down the initially dry channel of the Mojave River from Cedar Springs Dam to Barstow. For this 96-km reach, the model was used to evaluate the potential of the channel to move imported water downstream. The volume of imported water that can reach Barstow depends on the volume and duration of the antecedent flood, on the volume of imported water released from Silverwood Reservoir, and on the rate at which the water is released. A release of 24.6 hm^3 of imported water may produce at Barstow a maximum volume of imported water of 3.08, 9.86, or 13.6 hm^3 for a release rate of 14.2, 21.2, or 28.3 m^3/s.

HAWAII

Ground-water withdrawals for irrigation of coastal-plain canefields, Island of Kauai

Ground-water withdrawals at drilled wells and shafts tapping a basaltic aquifer for irrigation of sugarcane on the Kekaha-Mana plain of Kauai have increased from an annual average of about 16 hm^3 between 1940 and 1957, to more than 33.9 hm^3 between 1958 and 1968, and more than 98.6 hm^3 in 1972 and 1973, according to R. J. Burt and D. A. Davis.

Coastal-plain sediments of low permeability overlying the basaltic rock create artesian conditions in the part of the aquifer under the plain. Recharge to the basalt is in the adjacent highlands. Artesian heads in the basalt have declined from about 3.0 m above sea level in the early 1900's to about 1.5 m above sea level in recent years. Owing to seawater encroachment that accompanied increasing pumpage and declining heads, the chloride content of the water at drilled wells has increased from 100 to 400 mg/l in early years to more than 2,000 mg/l recently. The chloride content generally fluctuates erratically. Most of the wells drilled on the plain have been abandoned because of deteriorating quality of the water, and most pumpage is now at shafts and collection tunnels dug at the inland edge of the coastal plain.

The Schofield high-level water body investigated

Water levels in the Schofield high-level water body on Oahu are about 85 m above sea level, in contrast to water levels of about 8 m in adjacent basal-water bodies. On the basis of data from geophysical surveys and drilled wells, K. J. Takasaki and R. H. Dale estimated that the water body underlies a 104 km^2 area.

Estimated recharge by rainfall is 4.5×10^5 m^3/d. Pumpage from the water body is 1.9×10^4 m^3/d; thus slightly over 4.3×10^5 m^3/d of ground water is flowing to the adjacent basal-water reservoirs. On the basis of water-level maps and pumpage records for the adjacent basal-water bodies, it was concluded that most of the ground water flows in a southerly direction from the high-level water body to the adjacent Pearl Harbor basal-water body.

Because of a small temporal variation in water levels in the Schofield water body, it had been assumed that the outflow mode is by spilling over the top of an impermeable barrier rather than by flowing through a low-permeability barrier. A computer model was designed to simulate any possible combination of the two modes. The best solution obtained was for the case where approximately 70 percent of the flow was through the barrier and 30 percent was by spillover.

NEVADA

Water resources of Railroad Valley

Railroad Valley, a 7,123-km^2 basin 241 km north of Las Vegas, contains three large spring groups that yielded a total flow of about 0.62 m^3/s, according to A. S. Van Denburgh and F. E. Rush (1974). The valley also boasts the only oil production in Nevada at the small Eagle Springs field (about 100,000 barrels in 1972). During the Pleistocene epoch the basin contained a closed lake that covered as much as 1,115 km^2, to a maximum depth of from 52 to 61 m.

Railroad Valley's perennial ground-water yield may be about 92 hm^3/yr, of which less than 25 percent is consumed (mostly during irrigation). Brine that accompanies the oil, about 24,660 m^3 in 1972, may present a long-term localized contamination problem; elsewhere in the valley, much of the ground water is relatively dilute (specific conductance, 300–800 μmho), although hardness and fluoride are excessive in places.

OREGON

Valley alluvium most productive aquifer in Harrisburg-Halsey area

F. J. Frank reported that most of the high-yield wells in the Harrisburg-Halsey area produce water from sand and gravel aquifers that underlie the present flood plain of the Willamette River. In the broader, main part of the valley plain, the alluvial deposits are relatively thin and fine grained in contrast to deposits in other parts of the Willamette Valley. In much of the area these deposits are 30 m or less in thickness and consist largely of silt and other fine-grained material. The alluvial deposits are underlain by marine sandstone and siltstone that locally contain poor-quality water which, in places, may be too saline for most uses. In the foothills and upland areas adjacent to the valley, sedimentary and volcanic rocks generally yield small but adequate quantities of good-quality water for domestic use.

Inflow patterns defined for Malheur Lake

Preliminary evaluation of water-inventory data for Malheur Lake indicates an inflow pattern that varies from year to year. L. L. Hubbard observed that the source and pattern of inflow to the lake during the 1973 water year differed widely from that during the 1972 year. Inflow to Malheur Lake is largely from the Donner und Blitzen River on the south and the Silvies River on the north. During the 1972 water year, inflow to the lake was more than double the 1973 inflow. Records for a gaging station on Silvies River near Burns indicate that runoff in the area was 136 percent of the long-term mean in 1972, but only 31 percent of the mean in 1973. The Donner und Blitzen River provided more than one-half of the total inflow in both years, whereas the Silvies River provided about one-third of the total inflow for the high runoff year (1972) but less than one-twentieth of the total inflow for the drought year (1973). The smaller contribution from the Silvies River to the lake during the drought year occurred because most of the stream's flow was diverted for irrigation before reaching the lake. Other sources of inflow to the lake are from Sodhouse Spring and from precipitation falling directly on the lake. The flow of Sodhouse Spring varies inversely with the lake's level. As a result, inflow from the spring was about 10 percent greater during 1973, when the lake level was low, than in 1972. Ground-water inflow other than that provided by Sodhouse Spring apparently is not significant.

Data compiled for lakes of northwestern Oregon

Data compiled by M. V. Shulters for an inventory of 129 lakes and reservoirs in a 6-county area of northwestern Oregon indicate that lakes in this region generally are small and relatively shallow. Three-fourths of the lakes in Clatsop, Columbia, Tillamook, Lincoln, Benton, and Polk Counties have surface areas of less than 81,000 m^2, and more than half are less than 40,000 m^2 in size. Of the 33 lakes larger than 81,000 m^2, 19 are natural and 14 are artificial. More than half have average depths less than 1.5 m; only a few are more than 3 m deep.

The chemical character of the water showed considerable variation, although most of the lakes had a dissolved-solids content of less than 200 mg/l. Hardness generally was less than 120 mg/l, but it varied from a flow of 7 mg/l to a high of 190 mg/l. The pH also was quite variable, ranging generally from about 6.0 to 9.0; a coastal-dune lake in Clatsop County had the highest value, 10.1. All samples were collected during the dry season when lake levels were low; therefore, water-quality parameters probably were at the their highest seasonal values.

WASHINGTON

Lakes-reconnaissance evaluation

A technique for rapidly appraising the relative susceptibility of lakes to water-quality problems was developed by G. C. Bortleson and B. L. Foxworthy during an interdisciplinary study of the southern Hood Canal area. The investigation included 63 lakes as part of the Interior Department's RALI demonstration project in the Puget Sound basin.

On the basis of natural physical features of the lake basins and cultural sources of nutrient enrichment, more than 80 percent of the lakes were judged to have a high susceptibility to water-quality degradation. However, two-thirds of the lakes investigated had significant management opportunities available to local and State planners because of the largely undeveloped shorelands.

Test-drilling results demonstrate irrigation potential in parts of the Satus Creek basin

D. O. Gregg reported that test drilling in the lower Satus Creek basin has partially defined a highly permeable sand and gravel aquifer as thick as about 91 m. This aquifer is believed to be capable of supplying all local irrigation needs. Heavy withdrawal from the aquifer would alleviate a local waterlogging problem and would allow surface water to be applied elsewhere. Nitrogen in samples of ground water collected from 32 wells tapping valley-fill deposits averaged 100 mg/l (as nitrate); the highest concentration was 664 mg/l. Some concentration of salts has resulted from evapotranspiration, but overfertilization is suspected to be the greatest contributor of nitrates.

A 215-m-deep test well drilled in basalt in the heretofore unexplored Dry Creek syncline indicates that the basalt aquifer has a potential for moderate irrigation withdrawals. The success of the test well has sparked interest among landowners and leaseholders to develop irrigation wells in the area.

SPECIAL WATER-RESOURCE PROGRAMS

SALINE WATER

Saline water in the Little Arkansas River basin, Kansas

R. B. Leonard reported that ground water has formed a permeable zone at depths ranging from 100 to 170 m by dissolving salt from the truncated eastern edge of the Hutchinson Salt Member of the Wellington Formation. The saline water in this solution zone is separated from the overlying freshwater in the alluvial aquifer in the Little Arkansas River basin by about 30 m of shale. The zone was first detected by oil-well drillers who noted the excessive loss of drilling fluids when the zone was penetrated. Solution and removal of salt is apparently continuing, as indicated by an 8-km-wide band of active sinkholes and undrained depressions which trends southward along the western side of the McPherson Valley to the Little Arkansas River where the trend divides into southwest and southeast segments.

The potentiometric head in the solution zone is slightly lower than the top of the shale separating it from the alluvial aquifer and much lower than the water level in the alluvial aquifer. Chemical analyses of water from adjacent saltwater and freshwater supply wells suggest that the alluvial aquifer recharges the solution zone through fractures in the shale.

Migration of saline water from the zone is restricted by relatively impermeable boundaries to the east and west and by the greater hydraulic head in the alluvial aquifer. Southward migration is suggested by the high chloride concentrations in water from springs and flowing wells along the Arkansas River valley in Sumner County.

Remote sensing aids delineation of areas affected by saltwater in Florida

J. D. Hunn found that ERTS imagery of Citrus and Hernando Counties was helpful in locating the landward extent of salty ground water at shallow depths by detecting changes in vegetation. As vegetation changed landward from salt-marsh sawgrass to a mixed deciduous and evergreen forest in freshwater wetlands, there was a change in reflectance which is interpretable using ERTS data.

H. G. Rodis found that the health of cypress stands which are being killed by saltwater movement up the Loxahatchee River could be determined from color infrared photographs.

Rodis also reported that a minimum continuous flow of 1.4 m^3/s must be maintained to preserve the freshwater reach of the Loxahatchee River from upstream movement of salty, tidally affected water from the Atlantic Ocean. This flow can be maintained by preventing further decline in ground-water levels and augmenting flow by importing water during critical periods of the dry season, or by constructing a salinity barrier in the downstream reach of the river.

Saltwater intrusion in coastal aquifers of Florida

Results of continuing studies of seawater intrusion in Dade County by J. E. Hull and D. J. McKenzie (1973) indicate that the salt front was within 1.5 km of the city of Miami's well field in Miami Springs and within 300 m of the well field at Homestead Air Force Base.

A recently completed network of water-level and salinity observation wells in the coastal areas of Martin and Palm Beach Counties is being studied by J. E. Earle, L. F. Land, W. A. Long, H. G. Rodis, J. J. Schneider, and W. B. Scott. The most seriously threatened localities are the cities of Juno Beach and Tequesta; withdrawals are increasing at a rate of about 15 percent annually and future problems can be expected. Although the well field of the city of Stuart is on a peninsula surrounded by brackish water, it is not immediately threatened.

Since 1930, USGS scientists have been monitoring the quality of water from the Floridan aquifer at Jacksonville to detect saltwater intrusion. In general, the chloride content of water in the aquifer has remained below 40 mg/l until this year, when the first indications of the long-anticipated saltwater intrusion occurred in deep wells along the coast. According to G. W. Leve, the chloride content of water from a newly completed municipal well at Mayport was 600 mg/l, and the chloride content of water from other deep wells along the coast increased from about 35 to 100 mg/l within 8 mo.

Saltwater source may be Houston Ship Channel

In a study of the occurrence of ground water with higher than normal concentrations of chloride, D. J. Jorgensen has tentatively identified the Houston Ship Channel as the chloride source. Water samples from shallow wells near the ship channel show that salinity and artesian pressure decrease with depth. Trilinear plots of chemical analyses indicate that water from the tide-affected ship channel is mixing with the native water in the aquifer. Analyses for dissolved organic constituents of water from the ship channel and from a shallow observation well show unusual and similar compositions.

Before development of the shallow aquifer, water moved upward from the aquifer to the surface-water system. This situation has been reversed by heavy pumping, and water is now moving downward into the aquifer system. The extent of the area already contaminated and the rate of movement of the contaminants must be determined before an evaluation of the future deterioration of water quality in the aquifer can be made.

DATA COORDINATION, ACQUISITION, AND STORAGE

OFFICE OF WATER DATA COORDINATION

Water-data coordination activities continued during the year with special emphasis on field coordination of data-acquisition activities, development of recommended methods for water-data acquisition, and preparation of hydrologic-unit maps of the Nation. Closely related activities included implementation of river-quality assessment activities and the level I accounting network, and further work on the design of NAWDEX.

The ninth meeting of the non-Federal Advisory Committee on Water Data for Public Use was held May 21–23, 1974, in Sioux Falls, S. Dak. Members of the Federal Interagency Advisory Committee on Water Data, which had not met during fiscal year 1974, were invited to the Sioux Falls meeting and those attending served as observers for their committee.

The "Summary of Plans for Acquisition of Water Data by Federal Agencies, Fiscal Year 1975," released in June 1974, contains a digest of plans for water-data acquisition in each of the 21 regions designated by the Water Resources Council (WRC), and information on activities of national scope as reported by officials at headquarters level. Coverage during this field coordination cycle included Federal plans for gathering data on surface-water stage, flow, and quality, and on ground-water quality. The field coordination activity planned for fiscal year 1976 was initiated in April 1974 to cover the same activities and to update the "Catalog of Information on Water Data" (U.S. Geol. Survey, 1972). The format of the 1972 edition was revised in 1973 to present all water-data-acquisition activities for each of the 21 regions in separate volumes. Information in each volume reflected activities as of January 1, 1972, for those stations being operated for a period of 3 yr or more. Two sets of 1:1,000,000-scale maps accompanied the catalog and showed locations of streamflow and stage stations and of water-quality stations as of January 1, 1972. F. H. Pauszek (1973) summarized the information presented in the 1972 edition of the catalog by means of illustrations, tables, and a brief discussion of each major section.

The preliminary report of the Federal Interagency Work Group on Designation of Standards for Water-Data Acquisition (1972) recommends methods in the following areas: (1) surface-water stage and quantity, (2) ground water, (3) sediment, (4) biologic, bacteriologic, and chemical (organic) quality, (5) chemical (inorganic) and physical quality, and (6) automatic water-quality monitors. This handbook represented a first step toward the establishment of common methods for collecting water data. Revision and expansion of the handbook, which will give a better understanding of water in the entire hydrologic cycle, began in late fall 1973. The expanded handbook will include 10 technical chapters covering mensuration and collection of data on (1) surface water, (2) ground water, (3) sediment, (4) biologic and bacteriological quality of surface and ground water, (5) chemical (inorganic and organic) and physical quality of both surface and ground water, (6) soil moisture, (7) basin characteristics, (8) evaporation and transpiration, (9) snow and ice, and (10) hydrometeorological observations. The handbook will also contain conversion factors and useful tables for field and laboratory work and, in appropriate chapters, information on nomenclature, units of measurement, equipment, and quality control.

The Coordinating Council on Water-Data Acquisition Methods was established in 1974 with membership open to representatives of all Federal agencies wishing to participate. A. I. Johnson was appointed methods coordinator for development of recommended methods for water-data acquisition. Fifteen agencies have appointed representatives to the council to advise on the revision and updating of the handbook, and to make recommendations on its content, format, printing, and distribution.

The new series of USGS base maps entitled "State Hydrologic Unit Maps," being prepared by the Office of Water Data Coordination (OWDC) in cooperation with the WRC, has been reviewed by the regional sponsors of the WRC's 1975 assessment of the Nation's water resources, all designated river-basin commissions, all USGS Water Resources Division district offices, and many State agencies. The maps are currently being reviewed by the National Programs and Assessments Committee (NPA) of the WRC. The 1:500,000-scale maps, to be published and sold by the USGS, will show major regional and subregional boundaries for water-resource planning and for National Water Data Network accounting units and cataloging units. About 10 of the State maps are expected to be published late in 1974, and all are expected to be available for distribution early in 1975.

The comprehensive river-quality assessment of the Willamette River basin in Oregon continued with the assistance of the ad hoc Working Group on River Quality Assessment of the Advisory Committee on Water Data for Public Use. During the year, the Working Group (1) reviewed the progress of the Willamette River basin study, with emphasis on adherence to objectives and work plans; (2) developed criteria and outlined objectives for additional river-quality assessments; and (3) recommended additional river basins for future river-quality assessment studies by the USGS.

The USGS continued to implement the level I accounting element of the National Water Data Network, which is designed to account for quantity and quality of water discharged from each of approximately 330 accounting units. The accounting will provide a measure of water discharge and loads of selected quality-of-water parameters for about 90 percent of the water leaving a unit. For units discharging into the oceans, the Great Lakes, or across International boundaries, and where it is impractical to meet the 90-percent outflow goal with a reasonable number of stations, data acquired at the stations selected will serve as an index for estimating the outflow from the unit. For basins with interior drainage, only the principal flows originating in those basins are included. During fiscal year 1974, data collection for surface-water quality was initiated at 50 network stations, bringing the total to approximately 100 sites operated by the USGS. The network is being expanded so that there will be at least 1 station for each of the approximately 330 accounting units. The network-planning activity of OWDC, conducted by P. R. Seaber, is designing accounting, surveillance, and areal synthesis at information levels I, II, and III of the National Water Data Network.

The contract of the USGS with PRC Systems Sciences Co. of Los Angeles, Calif., completed in January 1974, recommended organizational and financial structures for NAWDEX as well as a plan for implementation. The survey of potential participants provided valuable information on the level of interest, anticipated user requirements, types of services required, and potential membership in NAWDEX. A second 1-yr NAWDEX contract has been issued (1) to aid in the design of a master water-data index and a water-data source catalog, (2) to define the responsibilities and benefits of NAWDEX membership, (3) to design or adapt formats to be used in storing and retrieving water data within NAWDEX, (4) to identify the software requirements and evaluate the existing software packages to meet those requirements, (5) to locate and identify sources of water-related data, define data formats, establish their availability, and describe the linkages required to access them, (6) to conduct a pilot project to test the data-handling requirements and procedures of the NAWDEX system, and (7) to prepare a preliminary operations manual for the system.

WATER-DATA STORAGE SYSTEM

The USGS uses a digital computer to process, store, retrieve, and display water-resource data. The computer is also used with water-resource studies that require capabilities in statistical and analytical techniques, graphical display and map presentation of data, and mathematical modeling of hydrologic systems. The computer system consists of a central computer located in Reston, Va., and remote terminal facilities located in 35 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 265,000 station yr of record. This covers more than 76 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 55,000 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 1974, the USGS continued its hydrologic investigations in the urban environment; A. F. Pendleton, Jr., reported that more than 350 USGS projects were either directly or indirectly related to urban water problems.

URBAN WATER-RESOURCE STUDIES

Alaska

G. S. Anderson reported that the water-resource investigation of the Kenai-Soldotna area of Alaska is continuing with emphasis on monitoring the long-term effects of ground-water development. The basic-data network includes 10 observation wells, 1 stream gage, yearly water-level measurements on 9 lakes, and a continuing inventory of major industrial and municipal ground-water withdrawals. Preliminary data analyses indicate that the effects of major ground-water withdrawals are observed only near the pumping centers; elsewhere, water-level fluctuations throughout the Kenai-Soldotna area are related to climatic conditions.

Ongoing studies by R. S. George of water availability in the Anchorage area include continued compilation and analyses of pumpage and water-consumption data. To meet the demand for future production wells, six sites for test drilling have been selected in the Anchorage area. An observation well to monitor potentiometric heads and water quality within the city well field has been drilled. Exploration for water has been extended to the Eagle River valley where one test hole was drilled to a depth of 136 m in unconsolidated sediments. Two potential aquifers were found; one is a shallow water-table aquifer in alluvial-fan deposits, and the other is a confined aquifer with a potentiometric head slightly above land surface.

Work accomplished in the continuing cooperative program with the Alaska Department of Natural Resources on water availability at various sites in Alaska included an administrative report on water availability at Seldovia. G. S. Anderson and D. R. Scully concluded that several sources of surface water are available for development and that their potential is probably more than adequate for the future needs of Seldovia. Ground water has not been developed but may be available in limited quantities. Development of ground water in conjunction with surface water would provide a dependable supply because the addition of the warmer ground water would reduce the probability of freezing in the distribution system during the winter months.

In response to a need for an expanded water system, G. O. Balding evaluated Salmon Creek Reservoir as a potential source of water for the city and borough of Juneau. Balding concluded that an adequate amount of water (storage capacity of 21.7 hm^3) is available and that the supply is of excellent quality. Because the city and borough cannot economically develop this supply, a 61-m test well may be drilled in glacial-outwash deposits in the northeastern part of Mendenhall Valley.

Colorado

R. K. Livingston reported that the use of a multiple-regression technique to relate precipitation to runoff will be valuable to city planners in Colorado Springs. The water supply in northwestern El Paso County consists of precipitation and imported water, most of which is consumed by evapotranspiration. The city of Colorado Springs obtains about 89 percent of its supply from surface-water sources and 11 percent from ground-water sources. About one-third of its supply comes from streams draining Pikes Peak.

A digital model of the Dawson aquifer was prepared because of expected development. A potentiometric map indicates that the principal natural recharge to the Dawson Formation is in the Black Forest, northeast of Colorado Springs. The ground water moves in a southerly direction, and it is discharged into Monument Creek or is lost through evapotranspiration. The interpretation of the ground-water hydrology by O. J. Taylor, D. L. Bingham, and J. M. Klein was supported by gain-and-loss studies along Monument Creek, by preparation of maps showing the distribution of dissolved-solids concentration in the aquifer, and by determination of the seasonal variations of sulfate concentration in Monument Creek.

Florida

Ft. Lauderdale's Prospect well field supplies water to users in central Broward County. According to H. J. McCoy and C. B. Sherwood, Jr., ground water west of the well field is available in sufficient quantities to increase the capacity of the well field from 1,750 to 4,800 l/s. This is one of Florida's many special studies on water availability in a rapidly expanding urban area.

Kansas

Geohydrologic studies related to land-use planning in the Kansas River valley between Topeka and

Kansas City have shown that the area contains mineral and water resources that will be materially affected by continued urban growth and changes in land use. According to H. G. O'Connor and J. R. Ward (Kansas Geological Survey), tax structures and land-use policies will be key elements in the orderly development of the resources. Factors that should be considered in resource development include planning for (1) mineral production (limestone, sand, and gravel) and sequential land use to maintain property values, (2) conservation of prime agricultural land, and (3) protection against contamination of ground- and surface-water resources.

Kentucky

M. C. Noger (Kentucky Geological Survey) and H. H. Zehner (USGS) are conducting an areal survey of Barren County to delineate suitable areas for sanitary-landfill sites. Maps of the county at a scale of 1:48,000 are being prepared. The maps will include slope zones, soils, residuum thickness, rock types, and flood-prone areas. Various areas were sampled at different depths to determine vertical permeability of clay residuum overlying the limestone that predominates in the county.

Minnesota

Maps of the water table in the Minneapolis-St. Paul metropolitan area were prepared by D. C. Larson. Topography, surficial geology, water levels in water-table wells, lake levels, and points where topographic contours cross perennial streams were used as guides in contouring. As a part of the study, 86 water-table observation wells were installed. About half of these wells are located in schoolyards for the following reasons: (1) Widespread distribution allowing for large selection of possible well sites, (2) ease of obtaining permission to auger, (3) ease of locating buried pipes and cables, and (4) potential educational value to faculty and students. Areas of major recharge to the main aquifer, the Prairie du Chien-Jordan, are being delineated.

Missouri

As part of a water-resource investigation of the Springfield area, water levels have been measured in wells completed in the deep Cambrian-Ordovician aquifer. A potentiometric map based on measurements made by L. F. Emmett and W. S. Oakes (USGS) and D. E. Miller (Missouri Geological Survey) shows an irregularly shaped cone of depression centered under downtown Springfield. The maximum depth to water in the center of the cone is 152 m below land surface. This represents a maximum decline of 91 m in the potentiometric surface over a 40-yr period.

North Carolina

Major fishkills in the Yadkin River during the late 1960's and early 1970's emphasized the need for information to evaluate the effects of treated effluent released by the city of Winston-Salem on downstream water quality. To obtain the necessary data, fluorescent dye was used to simulate the movement of water-borne wastes during four different flow conditions occurring from July 1971 to March 1973 over a 65.6-km reach, beginning at the sewage-treatment plant and ending on the Yadkin River at High Rock Lake at Salisbury. K. L. Lindskov developed relationships for predicting travel-times of the leading edge, peak, centroid, and the trailing edge of soluble substances for six selected subreaches. Total traveltime for the entire reach varied from about 28 hr during high flow to about 47 hr during low flow. Lindskov used the unit-concentration technique to develop a method for estimating the maximum-probable peak concentration of a conservative-soluble substance at any location downstream from a slug injection. The maximum-probable peak concentration is the product of the weight of soluble substance injected and the extreme-unit peak concentration divided by the discharge at the location in question. Also, lateral mixing of water-borne materials entering the Yadkin River from Muddy Creek was measured. Although the materials entering from Muddy Creek were found to disperse across the river within several kilometres during high-flow conditions, under low-flow conditions lateral dispersion was still incomplete more than 16 km downstream.

URBAN RUNOFF AND FLOODS

Nationwide studies

Areas inundated by the 100-yr flood are outlined on topographic maps as part of the National Program for Managing Flood Losses. According to E. J. Kennedy, the objective of this activity is to inform cities and towns quickly of the general extent of their potential flood problems. More than 12,000 such maps of flood-prone areas have been completed for all of the States, the District of Columbia, and Puerto Rico. The program has progressed in two phases. The first phase, beginning in 1969, was directed toward defining flood limits in populated areas where significant flood problems were known and flood information was urgently needed. The second phase, implemented during 1972, expanded coverage to include areas where future development is expected.

About 16 maps showing urban areas inundated by major floods, flood profiles, discharge-frequency relations, and stage-frequency relations were published during the past year as Hydrologic Investigations Atlases. These are described in the section, Floods, p. 200.

Alabama

A. L. Knight is conducting a study to determine the effects of urbanization on the magnitude and frequency of floods in Jefferson County (including Birmingham). A technique developed by R. W. Carter (1961) for estimating the magnitude and frequency of floods in suburban areas was modified and used. This technique utilizes relations between basin lag time, T, drainage area, A, a length-slope parameter, $L/\sqrt{S}$, and coefficient of impervious area, K. Data within a 96.6-km radius of Birmingham were used to define the parameters. The empirical relation (English units) for lag time in undeveloped drainage basins surrounding Birmingham was found to be: $T=5.19(L/\sqrt{S})^{0.69}$. The relation (English units) for the mean annual flood, $\overline{Q}$, was found to be: $\overline{Q}=294KA^{0.90}T^{-0.47}$. This relation has a standard error of —20 and +25 percent and compares favorably with one defined by Carter. A family of curves developed to use in determining T for various degrees of urban development was in turn used to estimate floods for recurrence intervals of 2.33 to 500 yr. A network of data-collection sites is being established. Data from these sites, which are equipped with instruments to record rainfall and/or stream-stage, will be used to evaluate and refine the relations developed to date.

Colorado

A map showing flood-prone areas along principal streams in the Boulder-Fort Collins-Greeley area of the Front Range urban corridor has been prepared. J. F. McCain and W. R. Hotchkiss reported that a total of 340 km², or about 7 percent of the study area, is subject to inundation by the 100-yr flood. The map will be useful for regional land-use planning; the list of references may serve as an index for more detailed flood-plain information.

New Jersey

S. J. Stankowski and A. J. Velnich (1974) reported that intense frontal rainfall caused flooding in four highly urbanized counties of north-central New Jersey on August 2, 1973. As much as 102 mm/h of rain fell in Plainfield. Maximum recorded precipitation was 210 mm in a 5-hr period at Watchung and peak flows were in excess of 21.8 $m^3\ s^{-1}\ km^{-2}$ in the upper Stony Brook basin near Watchung. New peaks of record in the area were established at three gaging stations, all of which had over 35 yr of record. The floods took 6 lives and caused an estimated $67 million in damage.

New York

A procedure for assessing the performance of storm-runoff basins and changes in natural and artificial ground-water recharge in the urbanized areas of Long Island has been developed by R. C. Prill and D. A. Aronson. Firehydrant water is applied to test plots to determine infiltration rate and the flow pattern in the unsaturated zone. Key measurements are water stage, rate of water application, water temperature, and pressure-head and moisture-content values in the unsaturated zone. This information can be used for several types of evaluations, including the suitability of a storm-runoff basin for supplemental recharge, appropriate procedures for increasing the infiltration capacity of a basin, and the best design for a new recharge system. Results obtained by applying the procedure to a particular basin excavated in glacial-outwash deposits show that: (1) The infiltration rate of the basin at low-water stage is about 46 cm/h; (2) flow through the unsaturated zone is almost vertical; (3) the infiltration rate is surface controlled; (4) if the water table is below the lower boundary of the controlling zone, it has little effect on infiltration rate; and (5) the infiltration capacity of the basin has not changed significantly during 18 yr of operation.

Oklahoma

On October 10–11, 1973, more than 250 mm of rain fell on an area of about 1,300 km² extending from Enid northeastward to the Kansas border. In an area of about 260 km², rainfall ranged from 380 mm to 510 mm. The maximum amount occurred in Enid, where about 510 mm of rain fell between 4:00 p.m. and 5:00 a.m. Indirect discharge measurements showed that runoff from small basins within the storm area reached a maximum of 18.1 $m^3\ s^{-1}\ km^{-2}$, according to R. H. Bingham, D. L. Bergman, and W. O. Thomas. Flooding was severe in Enid, where peak discharges ranged from about 1.75 to 3.0 times the discharge of the estimated 100-yr flood. The flood caused the loss of nine lives, and thousands of hectares of topsoil and winter-wheat crops were lost because of erosion. Highways, railroads, city streets, small businesses, and residential areas also were damaged considerably. Property damage caused by the October flood was $78 million, according to the Oklahoma Civil Defense Agency. The city of Enid and parts of Garfield, Grant, Kay, Kingfisher, and Noble Counties were declared disaster areas because of residential and agricultural damage, and parts of Osage and Pawnee Counties were declared disaster areas because of agricultural damage.

Virginia

The rapid development of many areas in Fairfax County from rural to urban and suburban has had a striking effect on flood flows. P. L. Soule reported that results of studies indicate that urbanization—complete development of stream channel and basin surface—may increase the average flood flow up to eight times that of a natural basin. The effect and extent of future flooding is therefore a very necessary consideration in planning land use and development. Under a cooperative agreement with Fairfax County, the USGS is delineating flood plains of all county stream draining areas greater than 2.59 km^2. This delineation is done on special 1:1,200-scale maps and portrays flood-hazard areas for floods having recurrence intervals of 25-, 50-, and 100-yr under projected conditions of ultimate urban development. During the past year, 69 flood-inundation maps for 8 streams (59.7 lineal km) in Fairfax County were prepared for release. To date, maps of 18 streams (325 lineal km) in the county have been prepared and released, and 95 percent of the program has been completed. Flood-plain delineation and flood-profile information are used daily by the county in its analyses of land uses and review of plans for development. The program provides information to individuals whose property boundaries include flood plains, and to engineers, developers, and public agencies for land-use planning.

QUALITY OF STORM RUNOFF IN URBAN AREAS

Alaska

R. S. George, Chester Zenone, and L. L. Dearborn are studying urban hydrology in the Anchorage area to define the hydrology of the marshes, swamps, and associated lakes in the western part of the area, and to assess drainage and pollution problems in the Hillside area southeast of Anchorage. The purpose of these studies is to determine the effects of urbanization on the geohydrology of the area.

California

Studies by R. F. Middelburg, Jr., show that contamination levels of many samples of storm runoff from urbanized areas peripheral to San Francisco Bay are far in excess of acceptable levels for water-contact sports or shellfishing. Garbage and debris, consisting of such things as shopping carts, tires, auto parts, toys, balls, cans, plastic wrappings, paper, foodstuffs, building materials, Christmas trees, grass clippings, and furniture, are common in urban stream channels. The collected data are being classified and evaluated; they will be analyzed statistically and related to basin type and to storm frequency and duration.

Florida

C. B. Sherwood, Jr., H. C. Mattraw, Jr., and Jack Hardee have installed an automated storm-runoff quality measurement and collection system in Broward County to evaluate contaminant loads from residential areas. The system will collect rainfall, flow, and runoff samples over a 2-yr period. The objectives include an evaluation of the effects of antecedent dry periods, rainfall-event size, and rainfall intensity on pollutant loads.

Analyses of preliminary data collected by J. J. Schneider, in an investigation of the quality of ground water in the vicinity of the Pahokee sewage plant in Palm Beach County, showed chlorides content ranging from 1,300 to 3,200 mg/l chloride. The high ground-water chloride content is most likely due to the presence of residual salt from an ancient sea inundation.

Massachusetts

L. G. Toler, S. J. Pollock, and L. R. Frost reported that relatively constant chloride concentrations in the unsaturated zone in silt and fine sand adjacent to a highway at Chelmsford indicate that all salt applied to the highway for deicing purposes during a winter season is flushed from the soil profile during the following spring and summer. Peak concentrations in ground water near the highway occur in late summer and early fall. These studies to monitor the effect of deicing chemicals on surface and ground water show that the amount of highway deicing salt flushed away from the highway in surface runoff can be successfully monitored at some sites by using recorded values of discharge and specific conductance and relationships between specific conductance and laboratory analyses of chloride.

Calculations of chloride loads (as sodium chloride) in streamflow in Bolton for the 1972 water year indicate that about 75 percent of the salt applied to roads for deicing purposes leaves a 4.1-km^2 drainage basin via surface runoff.

HYDROLOGIC EFFECTS OF WASTE DISPOSAL IN URBAN AREAS

Alaska

In monitoring two active sanitary landfill sites in the Anchorage area, Chester Zenone and D. E. Donaldson (1974) studied the effect of waste disposal on the water resources. Leachate components were detected in ground water within and beneath the Greater Anchorage Area Borough's sanitary-landfill site, where the water table is near land surface. In contrast, no leachate components were detected in ground water beneath the Elmendorf Air Force Base landfill site where waste disposal is above the water table.

Florida

Monitoring of landfill sites in Hillsborough County was continued in 1974 to determine the effects of disposing of solid waste in surficial materials overlying a highly permeable limestone aquifer. According to J. W. Stewart and A. D. Duerr, slight changes in hardness, chloride, and conductivity were observed in shallow water-table wells constructed adjacent to filled trenches; however, no changes in the chemical quality of water in shallow wells were observed at distances of about 100 m from the trenches. No noticeable changes in the chemical quality of water from the limestone aquifer have been noted to date.

High concentrations of chloride, potassium, and calcium continued in the shallow water-table aquifer of a 12-yr-old inactive landfill site in the northwestern part of Hillsborough County. None of the constituents appeared to have moved laterally during the year. At an active landfill site in the eastern part of the county, vertical movement of leachate was observed several years after landfilling began.

Results of an investigation conducted by D. H. Boggess indicated that leachates from a landfill operated by the city of Fort Myers have continued their lateral movement and have contaminated the water-table aquifer in an area about 150 m farther north of the waste-disposal site than was previously determined. The leachates are transported downgradient in the aquifer; the direction of movement apparently is largely controlled by local variations in the permeability of the sediments and the relative position of underlying clay beds.

Studies conducted by W. A. J. Pitt, Jr., indicated that in the Biscayne aquifer below a depth of 9.1 m there is little difference in ground-water quality between areas serviced by septic tanks and unpopulated areas. The studies also showed that contaminant concentrations differ in areas serviced by septic tanks because of distance to the water table, permeability of the aquifer, filtering properties of the soil, and the rate and direction of ground-water movement. Fecal coliform bacteria were not found below the 3.0-m level, although total coliforms were found as deep as 9.1 m. Attenuated polio virus injected into a septic tank was not found in the ground water because it was held by the septic-tank sludge and could not be removed without changing the pH of the sludge to levels not normally found in septic tanks. Three septic tanks per 0.4 ha do not observably affect ground-water quality more than one septic tank per 0.4 ha does.

State and Federal pollution-control agencies are requiring Tallahassee to expand its Southwest Water Pollution Control Facility (renamed the Thomas P. Smith Waste Water Renovation Plant) or to install expensive advanced waste-water treatment devices. The plant had been experimentally disposing of its effluent by spray irrigation since 1966. As much as 234,000 $m^3\ km^{-2}d^{-1}$ was applied continuously for 7 d without causing serious flooding.

On the basis of analyses of the hydrochemical data collected during the first 18 mo of the Tallahassee study, L. J. Slack reached the following conclusions: (1) There is a southerly movement of ground water from the spray area, (2) there is no significant distortion of the regional pattern of ground-water flow by the effluent applied, (3) there is a limited area where mounding of ground water occurred beneath the spray area (Application of effluent was discontinued in this area in February 1973; the mounding disappeared, and water levels returned to normal by the end of March 1974), (4) the BOD and phosphorus concentrations of the effluent are greatly reduced by passing through the soil column before mixing with the underlying ground water, (5) some denitrification of the effluent is occurring before dilution by aquifer water (The presence of nitrifying and denitrifying bacteria is much greater in the soil in the area sprayed than in native soils), and (6) ground-water quality at major points of ground-water discharge downgradient from the area of applied sewage effluent remains unchanged, regardless of activities at the plant or of high rainfall.

A nine-well system has been installed at the Davie sanitary landfill, Broward County, by H. C. Mattraw, Jr., and C. B. Sherwood, Jr., to measure the extent and degree of contamination of ground water. An oil and grease pit which is receiving septic-tank sludge is the primary concern. Leachates have contaminated three water zones in a small area adjacent to the sludge pits. Temperatures, conductance, bacteria, and other water-quality parameters have been affected by the sludge-pit leachates.

The effects of land disposal of solid wastes and septic-tank sludge is being studied at St. Petersburg's 100-ha Toytown landfill in eastern Pinellas County. A 20-ha sod-farm test site was constructed in an effort to determine alternative methods for disposing of the sludge effluent. Solid-waste trenches and sludge reservoirs are in a surficial aquifer with a high water table. The surficial aquifer is a 7-m-thick fine sand, which grades downward to an 8-m-thick dense clay bed. The clay, which is the confining bed for the underlying limestone artesian Floridan aquifer, hydraulically separates the two aquifers. According to J. W. Stewart and C. B. Hutchinson, the lower two-thirds (3 m) of the filled trenches and reservoirs is 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 μmho were observed in some shallow wells at the landfill. Water in some peripheral ditches has a total coliform count of more than 100,000 colonies per 100-ml 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.

New York

G. E. Kimmel and O. C. Braids continued their investigation of ground-water contamination at solid-waste disposal sites in Suffolk County. Lengths of plumes of leachate-enriched ground water downgradient from 41- and 26-yr-old solid-waste landfills are 3,200 m and 1,500 m, respectively. The plumes sink vertically through the upper glacial aquifer to hydrologic boundaries 22 m and 52 m, respectively, below the water table at the two sites. Leachate-enriched ground water is higher in HCO_3^{-1}, Cl^{-1}, SO_4^{-2}, and conductance than ambient ground water. In the plumes, NH_4^{+1} is the predominant form of nitrogen; outside the plumes, NO_3^{-1} is generally dominant. Metals other than iron and manganese are either absent or are in very small concentrations.

EROSION AND SEDIMENT

Maryland

A study of hydrology and sedimentation is being continued in an urbanizing area of Montgomery County. T. H. Yorke, Jr., and W. J. Herb reported a decreasing trend in the sediment-load–storm-runoff relationship of streams in the study area. Between October 1962 and September 1967, suspended sediment was transported by the Northwest Branch Anacostia River near Colesville at a rate of 2,300 t/hm^3 of storm runoff. The rate decreased to 1,800 t/hm^3 between October 1967 and September 1970 and to 1,300 t/hm^3 between October 1970 and March 1972. This decrease may have resulted from less urban construction, less erosive site conditions, or increased runoff from impervious surfaces; however, most of the decrease is believed to be attributable to the implementation of sediment-control practices at construction sites within the basin.

URBAN LAKES

Arizona

Existing techniques have been modified by J. W. H. Blee to determine the evaporation and seepage losses from Upper Lake Mary, a 19.2-hm^3 municipal reservoir used as a water supply for the city of Flagstaff. Evaporation losses were determined using a mass-transfer equation. The equation allows the use of the mass-transfer method for computing evaporation without using an independent measure of evaporation to define the mass-transfer coefficient. The mass-transfer coefficient was defined as a function of wind shear and atmospheric stability, using wind fetch and the ratio of wind speed at 4 and 2 m above the water surface as an index to wind shear. Long-term seepage losses were determined using a seepage probability curve, which was derived from a stage-seepage relation defined by a number of selected short-period water budgets and a lake-stage probability curve. The study revealed that evaporation losses were 28 percent (2.59 hm^3/yr) and that seepage losses were 42 percent (4.48 hm^3/yr) of the total reservoir inflow.

Colorado

There are more than 280 lakes in the Boulder-Fort Collins-Greeley area of the Front Range urban corridor, according to J. F. Ficke and T. W. Danielson (1973). Of these, 116 lakes have surface areas greater than 10 ha. The largest are Horsetooth Reservoir, Boyd Lake, and Carter Lake Reservoir. Specific conductance was 750 μmho/cm, or less, in about one-half of the 115 lakes sampled. Conductance exceeded 4,500 μmho/cm in only seven lakes. Most of the lakes are alkaline; only two have less than 7.0 pH. Values of pH exceeded 8.5 in about two-thirds of the lakes sampled. Transparency, measured by a Secchi disk, was less than 1.2 m in about three-fourths of the lakes measured, and ranged from 0.2 to 3.6 m. Algal concentrations range from 77 to

13,000 cells/ml in samples collected from 23 lakes. Concentrations were greater than 1,000 cells/ml in 10 of the lakes. Chlorophyll *a* concentration ranged from below detection limits to 117 μg/l. Sixteen different genera of algae were found as dominants or codominants in samples from 23 of the largest lakes. *Oscillatoria* was found as a dominant or codominant in 10 of the 23 lakes. Data presented on a map at scale 1:100,000 include surface area, shoreline length, specific conductance, algal concentration, pH, Secchi-disk transparency measurements, and chlorophyll concentrations.

WATER USE

Adequacy and quality of water supplies for industrial use in the United States

C. R. Murray reported that the energy crisis has caused concern about how development of new sources of energy will affect water supplies in certain areas. Officials responsible for planning water-resource development projects in various regions of the United States have requested unpublished data on water use in water-resource subregions. These data were acquired in 1970 for the most recent national water-use survey (C. R. Murray and E. B. Reeves, 1972).

With a finite quantity of water available, the past rate of increase in the use of water (fig. 5) cannot be maintained indefinitely. Because the economy of the United States depends heavily on the use of water for the development of natural resources and energy, degradation of water quality must be prevented so that water may be reused to the greatest possible extent.

About 90 percent of all water withdrawn for industrial use other than thermoelectric-power production is used for manufacturing mineral products (chemicals, petroleum, coal products, and the primary metals) and organic products (foods, pulp, and paper); less than 10 percent is used by nonmanufacturing segments of the mineral industry.

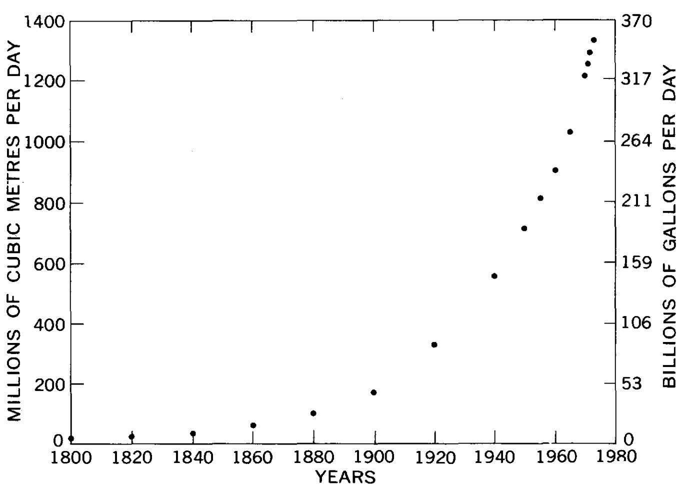


FIGURE 5.—Estimated water withdrawals in the United States from 1800 to 1973.

In 1973, uses of key natural resources were of the following orders of magnitude: 130 million t of iron ore, 15 million t of aluminum ore, 1.8 million t of copper, 900 million t of sand and gravel, 13 billion barrel-equivalents of mineral fuels, and 492 km^3 of water.

Of the estimated 492 km^3 (490×10^9 t) of freshwater and saline water withdrawn from surface- and ground-water sources in 1973, about 56.8 km^3 of freshwater was used for manufacturing and 189 km^3 was used for thermoelectric-power generation. The mineral industries use about 5.68 km^3 annually, whereas construction activities use only about 0.057 km^3.

Water use in the mineral industry, based on an assumed continued availability of traditional fuels for greater energy production, may increase from the 5.30 km^3 used in 1968 to about 7.57 km^3 in 1980 and to 15.1 km^3 in 2000, while water use in manufacturing may increase from 56.8 km^3 in 1973 to 75.7 km^3 in 1980 and to 114 km^3 in 2000.

Projections of water withdrawals by industry are highly speculative, for it is impossible to predict when new forms of energy will be developed or old energy forms will be revived to supplement energy derived from petroleum products. It appears likely that water demands will increase—particularly in areas in the West where there are rich deposits of oil shale and coal—and it will be necessary to devote more attention to the maintenance of water quality through pollution abatement in order to increase the possible reuse ratio for industrial water. It is estimated that water withdrawn for manufacturing is reused between 2.5 and 3 times, and water withdrawn for production and processing of mineral products is reused between 4 and 4.5 times. As these reuse ratios increase, more care in water management will be needed so that degradation of water quality will be prevented.

Water for energy

Concern over whether water supplies are available for national energy self-sufficiency focused attention on the need for information on unit water demand for various energy-production processes. G. H. Davis and L. A. Wood (1974) reported that water use for cooling processes in thermoelectric powerplants was by far the largest consumptive water requirement in the energy industry. Other substantial water demands are for uranium-fuel processing, oil refining, and oil-field water flooding. In the future, water demands for oil-shale production and for coal gasification and liquefaction will become increasingly important.

Use of ground water for irrigation in Clay, Hamilton, Seward, and York Counties, Nebraska

E. K. Steele, Jr., reported that pumpage records from selected irrigation wells indicate that ground-water withdrawals during 1973 totaled about 986.4 hm^3. The resultant net lowering of water levels from spring to fall in the same wells averaged 0.58 m. Even though pumpage during the 1973 season was 197.3 hm^3 more than in 1972, in the fall of 1973 water levels averaged 0.125 m higher than those in the fall of 1972. In the spring of 1973 water levels indicated that a net recharge of about 91.2 hm^3 had occurred since the spring of 1972. This gain in storage was the result of moderate pumpage and favorable precipitation conditions during 1972. As precipitation during the spring and fall of 1973 was above normal for the area, water levels in the spring of 1974 may indicate that recharge equaled or exceeded pumpage during the 1973 season. The number of irrigation wells in the 4-county area continued to increase; new installations—266 in 1973—have increased the total number of registered wells to 5,951.

Ground-water withdrawal and energy demand in southwestern Kansas

Recent studies by E. D. Gutentag and L. E. Stulken (USGS) in Lane and Scott Counties and by S. E. Slagle (USGS) and E. C. Weakly (Kansas Geological Survey) in Greeley and Wichita Counties indicate that 114,500 ha are irrigated by about 2,000 large-capacity wells. The 1972 pumpage, computed from power records, was 390 hm^3 or an average application of 0.34 m. The irrigation pumpage results in mining of ground water, which causes an annual decrease in storage of 230 hm^3 to 290 hm^3, and a 0.4-m average annual decline in water level.

Natural-gas consumption for irrigation was about 60×10^6 m^3. Total 1972 natural-gas production in southwestern Kansas was reported by the Kansas Corporation Commission as 22.4×10^9 m^3 from 5,396 wells. Thus, the natural gas consumed for pumping irrigation water in the 4-county area was 0.27 percent of the total 1972 southwestern Kansas gas production, and equal to the average annual gas production from about 15 wells.

Ground-water withdrawals in central Florida

A. F. Robertson and L. R. Mills have determined that ground-water withdrawals in the upper Peace and upper Alafia River basins of central Florida increased from about 189×10^6 m^3 in 1950 to about 455×10^6 m^3 in 1970. Pumpage for industrial use, principally phosphate mining and processing, accounted for about 66 percent of the withdrawals in 1970. Water levels in the Floridan aquifer in the area of greatest withdrawals have declined by more than 12 m during this period.

Pumpage for rice-irrigation water measured in northeastern Arkansas

M. E. Broom and H. N. Halberg reported that in 1973, pumpage of water from the Cache River alluvial aquifer-stream system in northeastern Arkansas for rice irrigation was about 0.7 km^3. This value for total pumpage from the system was derived from the median value of water-application measurements at 86 test sites. The median application rate was about 0.8 m.

INTERNATIONAL HYDROLOGICAL DECADE, 1965-74

The USGS continued its participation in IHD, the 10-yr program of cooperative international 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 the discharge of dissolved and suspended material from the continent to the oceans. Collection of hydrologic data also was continued at 23 lake and reservoir stations and at 34 selected observation wells; these stations provided information on water-level fluctuations and on the chemical quality of lake, reservoir, and ground waters.

Hydrologic bench marks, established early in the decade, provide continuing information at 46 localities throughout the country on natural hydrologic conditions largely removed from man's activities. Measurements of the tritium content of water in the 20 principal rivers in the United States and of tritium in precipitation at 16 localities are being used to evaluate the effect of precipitation on the chemical character of inland waters.

USGS hydrologists participated in international meetings of working groups, in intercountry exchange of experts, in discussions of selected activities chosen for particular years, and in 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 a meeting of the Bureau of the Coordinating Council for the IHD in Paris in February 1974.

R. L. Nance continued his activities for the IHD as a member of the Working Group on Water Balances, and participated in the review of its draft report, "Methods of computation of large-scale water balances."

W. F. Curtis, J. K. Culbertson, and E. B. Chase (1973) prepared a report on "Fluvial sediment discharge to the oceans from the conterminous United States."

R. L. Cory continued monitoring water quality and studying 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.

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. At the Interdisciplinary Symposium on Advanced Concepts and Techniques in the Study of Snow and Ice Resources, held at Monterey, Calif., in December 1973 (National Academy of Sciences, 1974), Meier was coauthor of two papers presented at sessions V and VII and served as chairman of session VII. Meier and his colleagues also prepared a brochure, "Snow and ice," summarizing the accomplishments to date of the Work Group on Snow and Ice Hydrology, organized by the U.S. National Committee for the IHD.

G. H. Davis continued to serve as Chairman of the Working Group on Ground-Water Studies, and served also as a member of the Working Group on the Application of Nuclear Techniques in Hydrology.

Seymour Subitzky reviewed and revised the English-language part of the International Hydrological Glossary sponsored by UNESCO.

A. I. Johnson was appointed U.S. Coordinator for the forthcoming Tercentenary of Hydrology, to be held as part of the End-of-Decade Conference at UNESCO House in Paris in September 1974.

J. R. Williams, A. H. Lachenbruch, O. J. Ferrians, Jr., and Reuben Kachadoorian attended the Second International Conference on Permafrost at Yakutsk, U.S.S.R., in July 1973. Lachenbruch and Ferrians presented papers on heat flow and on permafrost, respectively; Williams presented a theme paper on the relationship between permafrost and hydrology.

R. F. Hadley assisted in the review of supplementary chapters to the report, "Representative and experimental basins—An international guide for research and practice," which was sponsored by the U.S. National Committee for the IHD.

Allen Sinnott edited, abridged, and updated C. L. McGuinness' introductory general section of USGS Water-Supply Paper 1800 (1963), "The role of ground water in the national water situation," and the section on "Puerto Rico and Virgin Islands." These sections will be included in a volume in preparation by the U.N. Water Resources Section, Resources and Transport Division, to be entitled, "Ground water in the Western Hemisphere."

International Field Year for the Great Lakes

Streamflow from New York State into Lake Ontario was computed and compiled by G. K. Schultz for the period April 1, 1972, to March 31, 1973, which constituted the International Field Year for the Great Lakes (IFYGL). Mean weekly surface flows into Lake Ontario were computed for 27 small basins near the lakeshore and 3 major river basins (Genesee, Oswego, and Black) which constitute the New York part of the Lake Ontario drainage basin. The mean weekly flow from New York during IFYGL was 926 m^3/s. The highest mean weekly flow during the year, 2,120 m^3/s, occurred from June 24 to July 1, 1972. The lowest mean flow, 189 m^3/s, occurred September 10–16, 1972. Precipitation was above normal during most of the IFYGL period.

Following the IFYGL, which ended on March 31, 1973, studies of data collected during the year were continued.

W. J. Drescher, U.S. cochairman of the IFYGL steering committee, served as chairman of the Field Year Symposium at the annual meeting of the American Geophysical Union in Washington, D.C., in April 1974.

MARINE GEOLOGY AND HYDROLOGY INVESTIGATIONS

MARINE AND COASTAL GEOLOGY

ATLANTIC CONTINENTAL MARGIN

Coastal studies

Seismic-reflection profiles of 500 km of track lines taken by R. N. Oldale across Cape Cod Bay, Mass., reveal contrasting types of upper Pleistocene-Holocene deposits on the eastern and western sides of the bay. To the east, glaciolacustrine(?) sediments appear to be draped over an irregular surface believed underlain by bedrock, scattered erosional remnants of coastal-plain strata, and older glacial drift. Above the glaciolacustrine deposits is an acoustic unit characterized by gently to steeply dipping reflectors inferred to be the foreset beds of deltas deposited in the lake occupying Cape Cod Bay by meltwater streams that drained a glacial lobe east of Cape Cod. Profiles from the western part of Cape Cod Bay show a complex acoustic unit inferred to represent sediments deposited in contact with, or in close proximity to, the ice. This unit is underlain by an irregular reflector believed to be bedrock. Holocene marine deposits are represented in the uppermost part of the seismic records from Cape Cod Bay. Local deposits characterized by small-scale foreset bedding are inferred to be submerged beaches or bars formed when sea level was lower than at present. These features are potential sources of sand and gravel.

C. A. Kaye and G. W. Stuckey (1973) have found that the 18.6-yr cycle of the Moon's nodes dominate the annual means of low water, high water, and tidal range for Boston Harbor. This tidal force is also expressed in the variations of annual mean sea level although its influence is less pronounced. The long-term rising sea-level trend seems to have been steep from the 1930's through the 1950's, but the rate of change is now less, and the trend may reverse itself within this decade. The long-term trend in sea-level change may be the result of crustal movements of the ocean floor.

In analyses of colloidal substances isolated from sections of a 1.6-m-long core from Chesapeake Bay, I. A. Breger, Peter Zubovic, and J. C. Chandler found that the nitrogen content of these substances increases with depth. This contrasts with the fact that the nitrogen content of the total organic matter in such sediments decreases with depth. About 30 percent of the organic matter in the upper sections of the core is soluble, but little or no organic carbon is soluble in the bottom 15-cm portion. Either soluble fractions of the organic matter have been dissolved and removed with time, or the organic matter is undergoing diagenetic changes to convert it into what eventually will be kerogen.

Outer Continental Shelf environmental assessment off New Jersey

In a review of the existent data on the thermohaline structure of the waters, the circulation, the winds, and the distribution of suspended matter in the Baltimore Canyon area (a segment of the outer shelf off Delaware, Maryland, and New Jersey), H. J. Knebel (1974) found that the movement and dispersal of future oilspills cannot be reliably predicted. This is due primarily to the lack of quantitative relationships between the nontidal drift and its basic driving mechanisms, and to insufficient wind and storm statistics. Similar inadequacies in the existent data should be anticipated in other potentially leasable areas of the shelf because the movement of spilled oil has not been the underlying concern of most previous studies.

Outer Continental Shelf structural surveys

The first nonproprietary, common-depth-point, multichannel seismic-reflection profiles of the Baltimore Canyon area and Georges Bank (southeast of Massachusetts) were run under a contract during the summer of 1973. Scientists of the USGS and the Naval Oceanographic Office, cooperating in a cruise, collected gravity, magnetic, and single-channel-reflection profiles along the same track lines. J. C. Behrendt, J. S. Schlee, and R. Q. Foote (1974) reported that the sediments of presumed Mesozoic and Cenozoic age attain a thickness of 4.5 s (two-way travel time) over acoustic basement on the western Georges Bank profile. The thickened welt of sedimentary rocks is flanked at the shelf edge by a buried ridge that rises to within 1.7 s of the surface. A line seaward of New Jersey shows a seaward-thickening wedge of sediment that exceeds 7 s near the shelf edge and 5 s beneath the Continental Slope; a prominent domal structure at midshelf (lat 39°23′ N., long 73°03′ W.) is marked by a circular magnetic anomaly. The feature has a relief of 1.5 s (±1.5 km), is 20 km in diameter, and is beveled by an unconformity of possible Late Cretaceous age. A third line off the Delmarva Peninsula shows acoustic basement deepening seaward to nearly 7 s beneath the shelf and 4 s below the upper continental rise, 100 km seaward of the shelf break.

Seaward of South Carolina, W. P. Dillon encountered a long-existent fault zone in three seismic-reflection profiles parallel to the shore. The faults cut rock presumed to be Tertiary in age, and they occur approximately on the northwesterly trend of seismicity which crosses South Carolina near Charleston and which appears to be the only zone of earthquake activity in the United States east of the Appalachians and south of Cape Hatteras. Such faulting could constitute an environmental hazard in the development of offshore petroleum resources in the southeast Georgia embayment.

GULF COAST AND CARIBBEAN SEA

Coastal and nearshore studies

In Corpus Christi Bay, Tex., C. W. Holmes found significant levels of zinc and cadmium in the sediments; the source of the elements appears to be the harbor adjacent to the bay. His studies indicate that during the summer, the bacterial flora in the harbor play a significant role in the removal of zinc and cadmium from the water column. In the winter when the microbial activity decreases sharply and circulation between the bay and the harbor increases, significant amounts of the metals that have been deposited in the harbor are redissolved and transported to the bay. There, the metal-rich water is rapidly mixed with the bay water rich in suspended material. The suspended material scavenges the metals from the water and deposits them in the bay in a pattern determined by the winter current regime. A similar process appears to be going on in Matagorda Bay with anomalous amounts of mercury.

In a study of modern aeolian deposits on the Texas barrier islands, R. E. Hunter recognized at least five basic types of strata and pseudostrata in the eolian sands; they are termed "sand-flow cross-strata," "parallel strata," "ripple-form strata," "ripple-foreset cross-strata," and "climbing-ripple pseudostrata." The first is produced by sand flow on dune slip faces, the second by grains falling on smooth dune surfaces in zones of flow separation, and the last three by accretion on rippled surfaces. Climbing-ripple pseudostrata coexist with ripple-form strata when the angle of ripple climb is high, and with ripple-foreset cross-strata when the angle of climb is moderate. When the angle of ripple climb is low, ripple-foreset cross-strata are not visible, and climbing-ripple pseudostrata are the only visible layering. Subaqueous sand-flow cross-strata and layering produced by small-scale subaqueous ripples differ considerably from their aeolian analogs.

In an offshore study using ERTS–1 imagery and drift-bottle return, R. E. Hunter has been able to infer a zone of water movement to the southwest parallel to the shore, centered 20 to 30 km offshore. Surface-current speeds as high as 90 cm/s were calculated by measuring the movement of turbid-water masses and slicks shown on aerial photographs and ERTS–1 imagery. The restriction of the stronger currents to a relatively narrow zone at certain times is suggested by drift-bottle returns and by ERTS–1 imagery. The parabolic, convex-southward forms of some turbid-water bands shown on ERTS–1 imagery suggest that the strongest southward currents occur along the axes of curvature of the bands. The current appears similar to coastal jet currents in the Great Lakes; such currents are probably driven by a combination of wind stress and mass distribution under the influence of Coriolis, coastal-boundary, and bottom-friction effects.

In a survey of the submarine canyon system south of Puerto Rico, J. V. A. Trumbull and L. E. Garrison found that each of the five major rivers reaching the coast between Guanica and Ponce has a branch of the canyon system opposite it, extending across the insular shelf. Between each river-canyon pair, the shelf is grooved by a channel 20 to 30 m deep but only where the river mouth meets the ocean. The close association of rivers-shelf channels and submarine canyons indicates that the system may have formed at the same time and in response to lowered sea level.

R. W. Rodriguez (Department of Natural Resources, Puerto Rico) and W. P. Dillon (USGS) found that the rocks that floor Mona Passage are highly faulted in the vicinity of Mona Island. Mona Island is midway between Hispaniola and Puerto Rico and is not far south of the tectonic axis of the Greater Antillean Island Arc. A strongly developed zone of faulting passes about 10 km northeast of the island and is oriented northwest-southeast. This fault zone may form one element of a possible conjugate set of northwest-southeast- and northeast-southwest-trending topographic lineations, related to shearing between crustal plates.

Outer Continental Shelf and slope structure

Minimum sediment thickness, calculated from seismic-reflection data over and between domes and massifs of Louann(?) Salt (Early Jurassic in age), on the Texas-Louisiana Continental Slope (200–3,000-m water depths) averages about 1,400 m. From shallow core drilling (as deep as 300 m in sediment), it is estimated that most sediments on the slope are Pliocene and Pleistocene in age. In some synclinal basins between salt structures, sediments may be as thick as 5,000 m. Deposits in such basins on the upper part of the Continental Slope are significantly thicker than those in basins on the lower slope. In a statistical analysis of isopach data, R. G. Martin, Jr., (1973) found that the Continental Slope off Texas and Louisiana, exclusive of the Outer Continental Shelf, contains a minimum sedimentary volume (above the top of the salt) of about 170,000 km^3.

Deep-water lease areas (200–600-m water depths) off Louisiana and Texas, Martin found, contain a minimum of 14,500 km^3 of above-salt sediments considered for oil and gas production. Unless the average petroleum content of these sediments is greater than in typical basins (average U.S. basin yield of 1,900 kl/km^3), the upper continental slope of Texas and Louisiana contains a minimum of 28 million kl of recoverable reserves of crude oil. Recent discoveries in adjacent acreage on the Outer Continental Shelf suggest that the Texas-Louisiana upper continental shelf will yield mostly gas and very little oil. Assuming a gas content of 850,000 m^3/km^3 of sediment, the upper slope lease zone may produce more than 12.4 billion m^3 of gas.

Salt-influenced diagenetic trends in argillaceous sediments above salt structures

In an analysis of samples from six 330-m-deep drill holes on the Outer Continental Shelf, C. W. Holmes found significant mineralogical and chemical variations that relate to the presence of salt at depth. In the sediments above salt intrusions on the outer shelf, the abundance of expandable clays (14A), compared with the nonexpandable (10A) material, decreases with depth. Correspondingly, the cation exchange capacity and total organic content decrease with depth. These trends were not detected in the sediments away from salt structures or over one salt structure on the lower part of the upper continental slope. Analysis of the pore water and absorbed phases reveals that a diffusion-equilibrium gradient has been established in the sediments over the salt masses on the shelf but not over the salt intrusions on the slope.

Geologic-tectonic map of Caribbean region

Compilation of a geologic-tectonic map of both land and sea areas in and around the Caribbean, under the coordination of J. E. Case, is being made as a cooperative effort by nations having an interest in the circum-Caribbean region. Free-air and Bouguer anomaly maps have been completed, as have structure-contour and isopach maps, for the Venezuelan basin, Beata Ridge, Yucatan basin, Nicaraguan Rise, Aves Ridge, and Lesser Antilles. The compilation, which is at a scale of 1:2,500,000, indicates that many major geologic features of the region extend offshore. The borderlands of northern South America and northern Panama are clearly compressionally deformed features, in marked contrast to the block-faulted extension of borderland of the eastern Yucatan Peninsula.

PACIFIC COAST

California continental borderland

In an evaluation of the California continental borderland as a potential petroleum province, J. G. Vedder, L. A. Beyer, D. L. Durham, Arne Junger, T. H. McCulloh, A. E. Roberts, J. C. Taylor, and H. C. Wagner discovered it is difficult to evaluate the area with the degree of confidence ordinarily assigned to onland sedimentary basins, chiefly because of the shortage of detailed information on the bedrock of the sea floor and the absence of subsurface control. The large nearshore depositional troughs that underlie the Santa Monica and San Pedro basins and the Gulf of Santa Catalina presumably are favorable targets for exploratory drilling, as they contain relatively thick successions of post-Oligocene strata. Oil seeps have not been reported from the region seaward of the islands, but they are relatively common along the mainland coast between Point Conception and the Palos Verdes Hills. The apparent lack of a thick Pliocene section above a water depth of 600 m in the large outer basins is a discouraging factor, because this sequence is the most prolific producer of oil and gas in the Ventura and Los Angeles basins. Conversely, the basins nearer shore include a maximum thickness of 1,800 to 2,500 m of Pliocene and younger rocks. On the basis of its relatively thick sedimentary section, the part of the Santa Rosa-Cortes Ridge that lies between Begg Rock and

Santa Rosa Island is believed to have the best potential for petroleum production within the shallow-water areas seaward of the islands. The rocks on this ridge, however, are dominantly pre-late Miocene in age and have a minimal production history in southern California. The fact that parts of the Miocene section have been truncated by erosion along most of the ridge crests suggests the possibility that trapped oil may have been allowed to escape from former near-surface reservoirs.

Ancillary studies contributed to better definition of offshore structural trends and of the age and lithology of rocks in the borderland. Arne Junger and H. C. Wagner, in an interpretation of continuous seismic-reflection profiles taken south and east of Santa Cruz Island, found that the Santa Cruz Island fault extends eastward into the western part of the Santa Monica basin; its trend beyond that area is in doubt. An extensive program of coring and dredging has been completed for the northern part of the California continental borderland by G. W. Moore, J. E. Schoellhamer, and J. G. Vedder. A line of dart cores, collected on a cruise by Moore and J. D. Bukry 16 km north of San Nicolas Island, sampled lower and middle Eocene sandstone and shale along the axis of a submarine anticline. At all sampling localities, the environmentally sensitive nannofossil genera *Discolithina*, *Micrantholithus*, and *Rhabdospaera*, along with age-diagnostic species, indicate that an early Eocene continental-margin depositional environment extended southward from what is now central California through the California continental borderland.

Central California margin

In an interpretation of a free-air gravity map of the California continental margin from lat 35° to 40° N., E. A. Silver showed the distribution of major sedimentary basins and structural ridges. The north-trending Santa Maria basin and Santa Lucia Bank are cut off on their north ends by an east-trending structural ridge off Point Sur. The granitic Farallon Ridge can be traced offshore from Point Arena to just north of Santa Cruz, where it is apparently cut off by the San Gregorio fault. If right slip of 80 km is assumed along the San Gregorio fault, a continuous line can be constructed to connect the west side of the ridge with the Sur-Nacimiento fault zone on land to the south.

An interpretation of E. A. Silver and D. S. McCulloch (USGS) and J. R. Curray (Scripps Institution of Oceanography) of continuous acoustic profiles taken on the Continental Shelf and adjacent continental slope of central California, between Point Reyes and Point Conception, indicates that a considerable portion of the strike-slip motion between the North American and Pacific plates has occurred along an offshore fault that transects the Salinian block.

Washington-British Columbia structural studies

Preliminary gravity and magnetic maps of the Strait of Juan de Fuca between Vancouver Island, British Columbia, and the Olympic Peninsula, Wash., show patterns that relate to major faults. The gravity and magnetic data were collected along 2,300 km of track line aboard the CHS Parizeau during a cooperative investigation of the strait by P. D. Snavely, Jr., and N. S. MacLeod (USGS) and D. L. Tiffin (Geological Survey of Canada). The Leech River fault, which forms the boundary between Eocene volcanic rocks and pre-Tertiary metamorphic rocks on the southwestern part of Vancouver Island, can be traced on the gravity and magnetic maps southwestward across the entrance of the strait onto the Washington Shelf near Cape Flattery. To the east, the Leech River fault extends from near Victoria, British Columbia, eastward to Whidby Island, Wash. A northwest-trending linear gravity-and-magnetic anomaly just south of Cape Flattery on the Washington shelf is interpreted as the westward extension of the Calawah fault, a major fault that offsets Cenozoic strata on the Olympic Peninsula. The Leech River fault terminates against the Calawah anomaly, which is consonant with onland geologic observations that the Leech River fault has had no post-late Oligocene movement, whereas the Calawah fault offsets Pleistocene deposits. Two other major faults can be identified readily on the geophysical maps; one is the westward extension of the San Juan fault of southwestern Vancouver Island, and the other extends from near Victoria southward to near Dungeness Spit, Wash.

Coastal sedimentation

H. E. Clifton and R. L. Phillips continued sedimentological investigations of depositional environments and related processes in Willapa Bay, Wash., and along the Washington, Oregon, and northern California coasts. Investigations of modern marine depositional structures and of structures preserved in elevated marine terraces document the effects of storms. Cores taken in the present sea floor at various depths contain buried sedimentary structures or other features that are not known to form there under nonstorm conditions. An upward transition from relatively coarse, crossbedded sand to finer sand, planarbedded at the base and ripplebedded at the top, is commonly encountered in water depths where small ripples normally predominate. Such a sequence probably results from exceptionally large waves. In water deeper than 20 m, lag deposits of shells and pebbles a few centimetres beneath the sediment surface suggest storm effects. Ancient deposits that contain features attributable to storms are the Pleistocene terrace deposits that probably were formed under geographic and oceanographic conditions similar to those that prevail at the present-day coast. Large gravel ripple forms interbedded with finer sand are a common feature in terrace deposits but are observed only locally in the modern environment. Relatively thick, poorly bedded gravel deposits may also indicate storm activity. In finer sediment, offshore-facing ripple lamination may indicate seaward transport resulting from local storms.

ALASKA-ARCTIC INVESTIGATIONS

Coastal and nearshore studies

Completing a 4-yr program aimed at defining some of the sedimentary processes acting on the Beaufort Sea Continental Shelf of Alaska, P. W. Barnes and Erk Reimnitz have distinguished four shelf facies. Drifting and stationary ice interacts with the surface sediments and currents of the Beaufort Sea shelf to form a series of morphologies and sedimentary structures that are related to water depth, ice type and distribution, and season of the year. The four facies are defined as follows:

1. Inshore (2–10 m). River-water drainage through strudel in the shore-fast ice scours the bottom during the spring, creating circular depressions rimmed by leveelike deposits. During the summer, currents and drifting ice rework the sediments, resulting in the development of ripples, sediment ponding in scour depressions, ice-gouge depressions and grooves, and ice-plowed, metastable sediment ridges.
2. Inner shelf (10–25 m). Inside the shear line between shore-fast ice and pack ice (10–25 m), sediments are protected from extensive ice reworking. Horizontal layering of graded sandy silts interbedded with silty clays are common in the upper metre of sediment of this depth zone. Cross-lamination is notably absent, but bioturbation is intense.
3. Midshelf (25–40 m). Outside the shear line, ice gouging creates large channel-like features; benthic fauna is absent or patchy. Cores, photographs, seismic data, and diving observations reveal displaced blocks of sediment, slump features, disrupted layering, and an absence of small-scale bedding structures. These same data suggest a complete and total reworking of the Holocene section by ice gouging.
4. Outer shelf (40–130 m). Near the shelf break, older ice-gouged and ice-rafted morphologic-sedimentologic features are present. The disrupted relief is more often subdued; the benthic fauna is better developed; there is a fairly well defined surface gravel layer; and the near-surface sediments are stratified.

In a complementary study of modern ice rafting in the Beaufort Sea, Reimitz and Barnes concluded that most of the gravel in some areas of the sea floor are relict, apparently rafted there by ice from Canada during the Holocene Epoch. Modern rafted sediment is much finer grained and consists of fine sediment picked up by periodic adfreezing to the bottom as pack ice oscillates vertically under tidal forces (P. W. Barnes and Erk Reimnitz, 1973).

A study of the northeastern Bering Sea by C. H. Nelson revealed a late Holocene pattern of sedimentation for the area. The Yukon and Koskokwim Rivers annually discharge more than 90 million t of sediment into the eastern Bering Sea. Some silt is deposited in mudflats fringing the delta areas, and some fine sand collects in offshore bars bordering the mudflats. ERTS photos and suspended-sediment data suggest that much of the Kuskokwim River discharge of about 3.6 million t/yr is dispersed southward; the remainder is tranported westward and northward mainly along the delta complex. Most of the large input of Yukon River sediment is carried eastward and northward by the counterclockwise gyre in Norton Sound. Apparently, a significant portion of the Yukon sediment, 27 to 56 million t/yr, eventually bypasses the relict sediment flooring the northern Bering Sea and is flushed out of the Bering Sea. This is suggested by the general thinness (0.25–1 m) of deposits of Yukon sediment in Norton Sound, the lack of modern Yukon silt and sand on the northern Bering Sea floor, and the accumulation of Holocene Yukon sediment in the Chukchi Sea. Thin sand rhythmically interbedded with Yukon sandy silt of Norton Sound indicates that storm waves and currents intermittently re-suspend much of the accumulated bottom sediment, leaving thin lag layers of sand. The strong northerly currents of the Alaska coastal water carry the suspended sediment northward to the Chukchi Sea.

Continental margin geophysical studies

In 1973, Arthur Grantz, T. H. Nilsen, B. D. Ruppel, and A. G. McHendrie (USGS) were joined by C. Y. Yorath (Geological Survey of Canada) to complete a geophysical reconnaissance of the Alaskan Continental Shelf north of the Bering Strait and extending eastward to the MacKenzie Delta (450,000 km^2). Using the USCG icebreaker *Burton Island*, the cruise members collected single-channel seismic-reflection, magnetic, and gravity profiles along 4,500 km of track lines. The profiles show that the Continental Shelf east of Pt. Barrow is constructional and, in its upper part, consists of thick Cretaceous and Tertiary sedimentary rocks on the north flank of the Barrow arch. From Pt. Barrow to about long 145° W., these beds dip gently and, in general, uniformly seaward with a local flattening or arching under the outer shelf. East of long 146° W., the shelf structure is dominated by large-amplitude folds in Tertiary rocks. These folds are parallel to the north-northeast-striking Marsh anticline of the North Slope. Locally, they extend to the Continental Slope where further investigation was blocked by pack ice.

A study of the Aleutian Ridge by D. W. Scholl disclosed that along the crest of this ridge there are roughly rectangular shaped basins as large as 35 km by 90 km. The floors of these basins, such as Amukta and Amlia Basins and Pratt Depression, are covered by about 1,000 m of water, but they are underlain by as much as 4,000 m of upper Miocene and younger sedimentary beds. Greatly deformed and faulted, these strata are likely prospects for energy resources.

GENERAL OCEANIC AND INTERNATIONAL STUDIES

Mineralogy of the Red Sea and other deep-sea deposits

A detailed investigation of the mineralogy of Red Sea hot-brine deposits by J. C. Hathaway and C. C. Woo (USGS) in cooperation with Peter Stoffers (Heidelberg Univ.) has revealed unusual minerals and unusual forms of more common minerals. These include ilvaite and manganosiderite as so-called sand crystals which include fine-grained hematite. Hematite in large plates is embedded in fine matrices of hematite. Magnetic hematite that does not have the X-ray pattern of maghemite has also been observed. Other minerals include lizardite, unusual chlorite, extremely well crystallized montmorillonite, veins of chalcopyrite, and relatively large authigenic crystals of pyrite accompanying the lizardite. Other zones contain siderite, rhodochrosite, disordered cristobalite, or talc. The complexity of the assemblages is greater than has heretofore been reported.

In a study of marine and nonmarine manganese nodules, C. C. Woo distinguished two petrographic units that form alternate layers. The scanning electron microscope shows that one type of layer which is usually dense tends to be amorphous, but when heated or aged in the laboratory, it yields a weak X-ray pattern of todorokite. The other type of layer, always sooty and porous, shows a spongy boxwork of thin plates of birnessite or δMnO_2. This material forms birnessite on heating overnight and therefore may be considered as protobirnessite.

Deep-ocean biostratigraphy

Miocene strata containing abundant fossil phytoplankton have been dart-cored from the seabed of the southern California borderland. J. D. Bukry reported that biostratigraphically diagnostic assemblages of calcareous coccoliths and siliceous silicoflagellates occur together near the boundary between the lower and middle Miocene; this association permits the assignment of an age, previously unknown, to the silicoflagellate assemblage. Coeval sediment south of New Zealand at DSDP site 278 (lat 57° S., long 160° E.) lacks diagnostic coccoliths, but it can be correlated and dated as early and middle Miocene because of similar silicoflagellate assemblages. The lower Miocene *Helicopontosphaera ampliaperta* Zone of coccoliths (15–17 m.y.) in California occurs with a distinctive *Distephanus crux-D. schauinslandii* association of silicoflagellates. The same silicoflagellates occur at DSDP site 278 in a continuous section that includes coccoliths and older silicoflagellates not yet recognized in California.

Quarternary history of Eniwetok and Bikini Atolls, Marshall Islands

In the published records of drilling at Eniwetok and Bikini, J. I. Tracey, Jr., and H. S. Ladd have distinguished at least four stratigraphic intervals representing reef growth and associated lagoonal sedimentation during relatively brief periods of Quaternary interglacial high sea levels, the unconformities between intervals representing periods of emergence and weathering during glacial lowering of sea level. The unconformities separating near-reef lagoonal facies are approximately 10, 25, 50, and 85 m below present mean low water. The equivalent reef facies for each interval ranges from a few metres to as much as 50 or 60 m higher.

The uppermost unconformity separates Holocene sediments generally less than 6,000 yr old from sediments about 120,000 yr old; lower intervals are not accurately dated, in part because of increasing alteration and recrystallization. The lowest unconformity probably represents an early Pleistocene glaciation.

Present information is insufficient to determine either Pleistocene rates of subsidence of this region or the relative heights of successive interglacial sea levels.

Holocene history is reflected in surface features of the reefs. The reef flat at Eniwetok and Bikini—the presently forming unconformity—is a lithified plate containing corals in position of growth. The plate can be examined in detail in explosion craters on the Eniwetok reef. Carbon-14 dates of corals and algal reef rock show that sea level was less than 3 m below present level 6,000 yr ago, more than 0.3 m higher than at present 4,000 yr ago, and more than 1 m above present levels 3,300 to 2,200 yr ago. The reefs probably started to emerge about 2,000 yr ago, and large areas of the flat were killed, beveled by erosion and solution, and covered by coral rubble probably more than 1,000 yr ago. The rubble and associated islands are now much eroded.

Tracey and Ladd estimated that the rate of growth of coral-algal reef rock at Eniwetok and Bikini is 1 to 2 mm/yr. The estimated rate of solution, erosion, and biological degradation of intertidal limestone is 0.5 to 1 mm/yr.

The inferred sea-level curve for Eniwetok and Bikini for the last 6,000 yr is generally, but not closely, similar to that of many other islands of the Central Pacific. The indicated emergence of 1 m probably results from a regional postglacial response to eustatic loading rather than from a higher worldwide eustatic sea level.

Mineral resources of the sea

A report on mineral resources of the sea was prepared by F. H. Wang, in cooperation with the U.N. Secretariat, as an updated supplement to the previous U.N. publications on this subject. The latest report presents a scientific, technological, and economic assessment of potential hydrocarbons and minerals of the world's continental margins and ocean basins, an assessment based on the latest results of scientific investigations and offshore petroleum and mineral exploration. The report forms part of a broader U.N. study of the international aspects of subsea mineral development, jurisdictional problems, environmental considerations, and possible impact on the world economy.

Marine-geology investigations of the coastal zone of Almeria Province, Spain

Geologic investigations were conducted on the southeastern Spanish continental shelf and the adjacent coastal zone of Almeria Province as part of a NSF-funded cooperative program between the USGS and the Spanish National Organization of Mineral Research. The three major topics studied were: (1) Tertiary tectonic and stratigraphic framework, (2) sedimentological processes and environmental problems, and (3) geologic framework of the Continental Shelf.

The stratigraphic succession of more than 1,500 m of upper Tertiary sedimentary rocks was established by P. D. Snavely, Jr., and W. O. Addicott. Four regional unconformities were recognized within the Tertiary sequence, which ranges in age from middle(?) Miocene to late Pliocene. Algal and coral reef limestone of middle(?) Miocene age, which overlies subaerial andesitic and dacitic flows and breccias, was recognized in the northern part. The richly organic and vuggy reef limestones are potential targets for oil and gas exploration on the Continental Shelf, where they are overlain by a thick section of upper Tertiary sedimentary rocks. The Tertiary strata and Quaternary deposits are cut by numerous faults, some of which apparently are still active. The trace of the Serrata fault is marked by a well-defined rift valley, and numerous streams are offset in a left-lateral direction along the fault. Small, relatively unweathered fault scarps occur in Holocene fan and stream deposits in several places north of Almeria. Since Almeria was severely damaged by earthquakes in 1487, 1522, 1756, and 1804, some of the scarps probably formed during these events.

H. E. Clifton and R. J. Anima studied coastal dynamics by combining onshore and underwater observations and by comparing ancient and modern coastal maps. Two areas along the coast showed evidence of large-scale changes during the last 100 years; one of these, about 2 km^2 of agricultural land, was lost to coastal erosion, which resulted from diversion of the Rio Adra. Underwater traverses indicated the presence of sand bars composed of well-sorted, medium-grained sand. These bars provide a potential source for sand, although the interrelation between the bars and the beaches must be studied before they can be mined. Conglomerate that crops out seaward from many beaches indicates that the amount of beach sand is limited, and any small loss of beach sand may reduce the touristic value of the coastal area.

In the Gulf of Almeria, detailed geophysical surveys by H. G. Greene, W .P. Dillon, J. M. Robb, and J. W. Lee collected intermediate-penetration seismic-reflection, high-resolution seismic-reflection, magnetic, and bathymetric data along approximately 2,000 km of track lines. In the Alboran Basin, intermediate-penetration seismic-reflection, magnetic, and bathymetric data were collected along more than 3,000 km of reconnaissance track lines. Preliminary interpretation of geophysical profiles from the Gulf of Almeria indicates the presence of a moderate-size Tertiary sedimentary basin, bounded on the south by a volcanic ridge that is the southeastward extension of the middle Miocene(?) volcanic rocks exposed in the Sierra de Gata. The basin is bisected by a major northeast-trending fault zone that shows evidence of recent movement. This fault zone is well defined in the submarine topography as a distinct rift valley, or structural graben, and it may be the offshore extension of the active left-lateral fault on the north side of the Sierra Serrata. At depth, the fault brings the Sierra de Gata volcanic rocks into juxtaposition with the Triassic dolomites of the Betic Alpujarride complex. Preliminary interpretations of the seismic data gathered in the Alboran Basin indicate that several small to moderate-size Tertiary sedimentary basins underlie the Continental Shelf and Continental Slope between Malaga and Sierra de Gata. Several seismic profiles across the Alboran Ridge show that the easternmost is a horst of volcanic rocks with locally infolded units of highly deformed sedimentary rocks.

ESTUARINE AND COASTAL HYDROLOGY

Estuarine open-water metabolism

R. L. Cory used 24-h records of DO, temperature, and salinity to estimate the amount of daily net primary plant production, P, and nighttime plant and animal respiration, R, for open estuarine waters. Biweekly measures of P and R (in terms of carbon, C), from April through December 1973, in the Rhode River and West River estuaries of Maryland have been completed. The findings represent volume averages for each of seven subsections of the estuaries, whereas previous studies have considered only limited areas or single-station analyses. A summary of the data indicates that average daily $P=1.18$ g C m^{-2} d^{-1} and $R=1.14$ g C m^{-2} d^{-1}. A data projection for the entire water mass of the Rhode River and West River estuaries indicates that 6,771 t of organic carbon may be available annually for export to Chesapeake Bay or for storage in bottom muds.

Estuarine circulation, advection, and water quality

D. H. Peterson and T. J. Conomos suggest that phytoplankton-abundance variations in the San Francisco Bay estuary are largely due to the seasonal variations in river inflow. Low river discharge during the summer results in reduced advection and associated flushing of the northern San Francisco Bay estuary. During this season, high phytoplankton growth rates which depress nutrient levels are observed. Lower levels of nutrients prevail in years of lower river discharge, apparently owing to high levels of phytoplankton growth in these years.

C. R. Goodwin reported that results of tests, using a two-dimensional computer model of Tampa Bay, Fla., indicate that tidal circulation and flushing characteristics will increase up to four times in parts of the bay if proposed islands, to be created from channel-deepening material, are properly located. Results of the tests also indicate that water quality in the most degraded section of the bay will be significantly improved.

Moving-boat equipment was used by S. R. Ellis and Fernando Gómez-Gómez to produce bathymetric maps of Condado, San José, Torrecilla and Piñones Lagoons in San Juan, Puerto Rico. All except Piñones contain large areas dredged for sand extraction or navigation. Piñones is in a pristine state with depths of 0.5 to 1.7 m. The deepest dredged area, in the southeastern part of Torrecilla Lagoon, is 18 m deep. The dredged areas in San José Lagoon and the southern half of Torrecilla Lagoon act as traps for high-BOD materials and high-salinity water which cause stratification and DO depletion below depths of 1 to 2 m. No DO has been observed in the lower depths of these areas throughout the period of study. Observed DO readings drop from a high of 12 to 14 mg/l to zero in less than 0.5 m.

Estuarine-sediment transport

As part of an investigation of the movement of radionuclides in the Columbia River estuary, H. H. Stevens, Jr., D. W. Hubbell, and J. L. Glenn (1973) developed methods for determining the temporal variations in salinity and suspended-sediment concentrations in a cross section of the lower end of the estuary at Astoria, Oreg. The salinity distribution is mathematically generated between successive high and low extremes; the magnitude and time of occurrences of these extremes are first determined from correlations with the volumes of flow associated with each ebb and flood phase of the tidal cycle. Suspended-sediment concentrations are similarly generated between adjacent maximum and minimum values whose magnitudes and times of occurrences are defined by dimensionless relations with parameters related to salinity and water discharge and by concentrations determined from samples collected several times each week. The dimensionless relations reflect the influence of a so-called turbidity maximum that develops in the estuary.

Transport rates determined by integrating the product of model concentrations and water discharges over time show that, during the late summer months, the net transport of suspended sediment through the cross section at Astoria tended to be landward, whereas at other times, it tended to be seaward. On the basis of 2 yr of record at Astoria and at the site of the former Beaver Army Terminal, it appears that sediment is accumulating in the estuary between river miles 14 and 53.

Estuarine modeling techniques

According to J. P. Bennett, an efficient and stable technique for computing one-dimensional, unsteady, nonuniform flows in an unstratified many-branched estuary is one in which the equations of motion are linearized over each time step and all quantities are expressed at forward positions in time. Prediction errors for estuarine-flow computations, using this technique, are not very sensitive to the resistance coefficient or to minor variations in cross-section shape or areas. However, they are very sensitive to tail-water elevation. Automatic model-calibration procedures, which have been developed to utilize optimization techniques designed for use with least-squares objective functions, significantly reduce calibration costs.

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.

CLASSIFICATION AND EVALUATION OF MINERAL LANDS

The organic act creating the USGS gave the Director the responsibility of classifying and evaluating the mineral resources of the public-domain lands. There are about 101 million ha 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 1974, examination was completed of more than 45,000 ha in Montana, Nevada, North Dakota, and Washington. Mainly as a result of the USGS leasable-mineral mapping program, the lands were formally classified as follows: Montana, 65 ha coal land, 17,831 ha noncoal land; Nevada, 1,633 ha sodium land; North Dakota, 30,474 ha coal land; and Washington, 423 ha noncoal land. Most of these lands had been previously withdrawn to prevent alienation of the leasable minerals until an examination and classification could be made. More than 8 million ha remain withdrawn for coal; 648,000 ha, for phosphate; and 3,600,000 ha, for potash.

Known Geological Structures (KGS) of producing oil and gas fields

By the provisions of the Mineral Leasing Act of 1920, the Secretary of the Interior is authorized to grant to any applicant qualified under the act a noncompetitive lease to prospect for oil or gas on any part of the mineral estate of the United States that is not within any KGS of a producing oil or gas field. Lands within such known structures are competitively leased to the highest bidder. During fiscal year 1974, over 174,000 ha of onshore Federal land were determined to be in KGS.

Known Geothermal Resources Areas (KGRA)

The Geothermal Steam Act of 1970 provides for development by private industry of federally owned geothermal resources through competitive and noncompetitive leasing. Subsequently, over 740,000 ha have been included in KGRA's and nearly 40 million ha are classified as being prospectively valuable for geothermal resources. During fiscal year 1974, over 11,100 ha have been leased through competitive bidding.

Known Coal Leasing Areas (KCLA)

During fiscal year 1974, the USGS inaugurated a program of defining those areas subject only to competitive leasing of coal on Federal land in the United States. Since most Federal land is in the Western United States, the major activity in the KCLA program of the USGS is concentrated in Colorado, Montana, New Mexico, North Dakota, Utah, Washington, and Wyoming. Eleven KCLA's totaling over 3,387,000 ha were defined in 4 of these States.

WATERPOWER CLASSIFICATION—PRESERVATION OF RESERVOIR SITES

The objective of the waterpower-classification program is to identify, evaluate, and segregate from disposal or adverse use all reservoir sites on public lands that have significant potential for future development. Such sites are an increasingly scarce and valuable natural resource. USGS engineers study maps, photographs, and waterflow records to discover potential damsites and reservoirs. Topographic, engineering, and geologic studies are made of selected sites to determine if the potential value is sufficient to warrant formal classification of any Federal land within the site. Such resource studies provide land-administering agencies with information basic to management decisions on land disposal and multiple use. Previous classifications are reviewed as new data become available, and if the land is no longer considered suitable for reservoir development, the land is released for return to the unencumbered public domain for other possible disposition. During fiscal year 1974, about 40,800 ha of previously classified lands were released, and the review program was carried on in nine 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 1974, maps were being prepared for several damsites and reservoir sites for potential pumped-storage development in the State of Washington.

SUPERVISION OF MINERAL LEASING

Supervision of competitive and noncompetitive leasing activities to develop and recover leasable minerals in deposits on Federal and Indian lands is a function of the USGS, under delegation from the Secretary of the Interior. It includes (1) geologic and engineering examination of applied-for-lands to determine whether a lease or a permit is appropriately applicable, (2) approval of operating plans, (3) inspection of operations to insure compliance with regulations and approved methods, and (4) verification of production and the collection of royalties. (See table 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 1974. During sales held in December 1973 and in March and May 1974, 598 tracts comprising 1,256,637 ha were offered. High bids totaling $5,055,427,916 were accepted for 595,841 ha in 280 tracts. USGS geologists, geophysicists, and engineers evaluated each tract offered to ensure receipt of fair market value to the government.

COOPERATION WITH OTHER FEDERAL AGENCIES

The USGS acts as a consultant to other Federal agencies in land-disposal cases. In response to their requests, determinations are made as to the mineral character and water-resources development potential 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 1974.

TABLE 1.—*Mineral production, value, and royalty for fiscal year 1974* [1]

Lands	Oil (tonnes)	Gas (thousand cubic metres)	Gas liquids (litres)	Other [2] (tonnes)	Value (dollars)	Royalty (dollars)
Public	23,275,000	27,575,000	1,947,856,000	35,160,000	$1,445,135,000	$155,709,000
Acquired	957,000	796,000	18,223,000	913,000	146,472,000	9,552,000
Indian	3,917,000	3,516,000	159,564,000	12,621,000	233,435,000	29,769,000
Military	53,000	746,000	87,446,000	---------	1,009,000	1,602,000
Outer Continental Shelf	53,344,000	98,610,000	6,881,106,000	1,425,000	4,247,319,000	509,778,000
Naval Petroleum Reserve No. 2	276,000	102,000	54,439,000	---------	12,412,000	1,523,000
Total	81,822,000	131,345,000	9,148,634,000	50,119,000	6,085,782,000	707,933,000

[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 studies related to geothermal resources and the San Andreas fault system

Recent heat-flow work by A. H. Lachenbruch, J. H. Sass, R. J. Munroe, and T. H. Moses, Jr., was focused almost exclusively on a continuous program of diamond core drilling within the geothermal resources and earthquake tectonics programs. The earthquake-related drilling was aimed at refining knowledge of the San Andreas fault zone as a thermal-mechanical system (Lachenbruch and Sass, 1973; see also Earthquake Studies, Theoretical and laboratory studies of earthquake mechanics, p. 180). The resource drilling had three main purposes: (1) To understand the thermal background and thermal regime of known geothermal resource areas, (2) to define and delineate regions of high heat flow suitable for geothermal-resource exploration, and (3) to devise a strategy for the optimum use of heat-flow measurements in geothermal exploration and exploitation. Interim results from the drilling program have provided significant new information on such areas as the Long Valley caldera (see Geothermal Resources, Long Valley, California, p. 11) and the Battle Mountain heat-flow anomaly in northern Nevada. These data are being compiled (together with previously published data) as a heat-flow map of the Western United States at a scale of 1:2,500,000.

Prediction of thermal conductivity of rock

Engineering calculations in such diverse underground operations as geothermal-energy extraction, coal gasification, nuclear explosions, nuclear-waste storage, and storage of liquified natural gas require estimates of thermal conductivity of the rocks involved. The range of possible conductivities for a given class of rocks is usually very large. The variations are caused primarily by variations in porosity and by differing proportions of highly conducting minerals (for example, quartz, olivine, metallic oxides, and sulfides). In some vesicular rocks, the apparent porosity, measured by standard techniques, can be appreciably underestimated because the rock contains impervious gas-filled micropores which act as thermal insulators, causing actual thermal conductivities to be as much as 40 percent below predicted values. The conductivity of most sandstones, shales, and felsic igneous rocks can be calculated within 10 percent from their porosity and quartz content; that of vesicular basalts, from their porosity and olivine content. These conductivities are calculated by using empirically determined quadratic or parallel-series models developed by E. C. Robertson and D. L. Peck. The models predict conductivities sufficiently accurate for all but the most refined heat-conduction calculations, and provided that the necessary mineralogy and porosity data are available, they eliminate the need for the tedious process of conductivity measurement.

ROCK MAGNETISM

Precambrian polar wandering, correlations of Precambrian rocks in Arizona

A stratigraphically controlled polar wandering path derived from red beds and basaltic flows of the Precambrian Unkar Group and Nankoweap Formation of the Grand Canyon, northern Arizona, has been reported by D. P. Elston, C. S. Grommé, and E. H. McKee (1973). These rocks of the Grand Canyon Supergroup are about 1.4 to 1.0 b.y. old; basaltic flows at the top of the Unkar Group are 1,090±70 m.y. old. The apparent polar wandering path lies in the area of the present central Pacific Ocean, near and north of the Equator, and is doubly looped and elongated in a north-south direction; the younger part of the path is displaced to the west. The complex character of the path underscores the difficulty in constructing a detailed Precambrian polar wandering path solely from isotopically dated rocks. Nonetheless, the poles from the northern Arizona rocks coincide broadly with poles from other Precambrian rocks of North America for this interval of time, which suggests that much of the North American craton as presently known was in existence at this time. Poles from the upper part of the Apache Group, lower part of the Troy Quartzite, and diabase that intrudes these units, coincide with part of the Grand Canyon polar wandering path derived from the Dox Sandstone of the Unkar Group, which suggests that the upper Precambrian rocks of central Arizona were deposited and intruded during deposition of the Unkar Group in northern Arizona.

Continental drift during the Precambrian

Precambrian paleomagnetic pole paths have recently been proposed for North America, Africa, and Europe. According to H. R. Spall (1973), two facts appear to be emerging. First, it is difficult to overlap the various pole paths either beginning with the present continental outlines or beginning with the late Paleozoic fit of Pangaea. Second, the basic shapes of these pole paths are different. Both facts lead to the conclusion that independent drift of these continents took place during the Precambrian.

Ancient magnetic-field intensities from submarine pillow basalts

Small-scale variations are often seen in magnetic-anomaly profiles obtained close to the sea floor by deep-towed magnetometers. A major possible cause of these variations is fluctuation of the geomagnetic-field intensity when the anomaly-producing lavas were erupted. Several dredged fragments of young sea-floor basalt from the Pacific and Indian Oceans have been investigated by C. S. Grommé, C. M. Marshall, and E. A. Mankinen to see if reliable paleointensities could be determined from them using the conventional Thellier double-heating method in vacuum. The results are exceptionally good, chiefly because of the fine grain size and concomitant single-domain magnetic structure of these rocks. Ancient field intensities from 0.30 to 0.50 oersteds were obtained from very fresh samples, in general agreement with the present-day magnetic-field intensities at the dredge-haul sites. Slightly to moderately weathered samples give lower values and markedly decreased internal consistency, indicating that the method is applicable only to basalts younger than a few tens of thousands of years.

New technique for paleointensity measurements

D. E. Watson developed a new method for measuring paleointensity which incorporates gas-mixing techniques to control the oxygen activity (or fugacity) around a rock sample within a furnace chamber. In addition, two other innovations were used with success. There were (1) the use of a much smaller than standard rock size (approximately 0.06 cm^3 compared with 9.0 cm^3), which minimizes the heating and cooling time, and (2) the use of a cryogenic magnetometer to measure the intensities of these small samples. With the advent of such a system, it is now possible to use rock types that would ordinarily alter chemically and magnetically during normal heating experiments. Specifically, this development may make possible more reliable lunar paleointensity measurements.

Glacial history of Patagonia

R. J. Fleck and E. A. Mankinen (USGS), in cooperation with J. H. Mercer (Ohio State Univ.), have completed studies of basaltic lava flows from southern Argentina as part of a study of the glacial history of Patagonia (Fleck and others, 1972; Mankinen and others, 1973). The most extensive glaciation of Patagonia occurred between 0.2 and 1.24 m. y. ago, but its age has not yet been more closely determined. The oldest known till, exposed at Rio Cangrego, Argentina, is immediately overlain by a flow with a weight-averaged age of 3.50±0.14 m.y. Two basalt boulders from this till have an identical maximum age. At a second locality, the oldest till is overlain by a flow with an age of 3.49±0.04 m.y., and is underlain by a flow with an age of 3.48±0.06 m.y. No glacial material was found at this site in the underlying sequence of flows that range in age up to 4.5 m.y., suggesting that Cenozoic glaciation in the area began 3.5 m.y. ago. The present data, combined with those reported previously by the authors, locate a paleomagnetic pole at lat 75° N., long 175° E. with $\alpha_{95}=11°$. This paleomagnetic pole is not significantly different from the geographic pole, or the paleomagnetic pole reported previously by Creer and Valencio (1969) for the Cenozoic lavas from this area.

COMPUTER MODELING OF GEOLOGIC PROCESSES

Earthquake modeling

D. J. Andrews reported that numerical calculations have been performed for dynamic motion in an elastic medium from slip on a fault with unstable friction. Nonuniform initial-stress states corresponding to idealized seismic gaps have been assumed. In these models, fault slip stops naturally. In addition to near-field motion, source functions for far-field waves have been obtained. The seismic gap can be characterized by a moment and energy. Parameters of the idealized models have been varied systematically to find relationships between the moment and energy of the earthquake and the moment and energy of the seismic gap.

W. D. Stuart has proposed that various time-dependent geophysical anomalies observed prior to earthquakes can be explained qualitatively on the basis of nonlinear constitutive properties of crustal rocks. This model relies on the formation of pervasive cracks in crustal rocks, as does the conventional dilatancy fluid-diffusion model, but eliminates the necessity of extensive pore-fluid migration. Stuart and J. H. Dieterich have suggested a general nonlinear constitutive law for brittle rocks that may permit careful analysis of earthquake precursory phenomena. The constitutive equation appears to describe dilatancy in laboratory experiments. If deformation of crustal rocks near active faults is similar to that of laboratory specimens, then the equation can be used to calculate the extent of dilatancy in the crust prior to an earthquake. Tilt and strains at the surface, as well as directional variations of seismic-wave velocities, can also be determined easily.

Resource modeling

L. S. Drew reported that simulation-model studies were used to examine the effects of resource-base exhaustion and intensity of exploration upon a suite of evaluation criteria. A principal result obtained is the relationship among exploration efforts of various sizes to achieve a given rate of return in the face of the exhaustion of the resource base. Another model study showed that long-range regional exploration is approximately three times as effective as the short-range local exploration effort expended during the periods when exploration plays are active.

GEOMAGNETISM

In September 1973, the geomagnetism program in NOAA was transferred to the USGS. The geomagnetism program has three main functions.

1. Collect, analyze, process, and disseminate data from a worldwide network of geomagnetic observatories and from periodically occupied magnetic repeat stations.
2. Produce U.S. and World Magnetic Charts.
3. Conduct research on long-term secular change of the Earth's magnetic field, as well as on the phenomena associated with short-term field fluctuations.

Geomagnetic data collection

Daily recordings of the 3 components of the Earth's magnetic field are made at 13 permanent geomagnetic observatories located in the continental United States, Alaska, U.S. possessions, and Antarctica. This program is directed by A. W. Green, Jr. Absolute observations, made with other independent sets of instruments referenced to international standards, are also taken at least once a week at each observatory to achieve an accurate base-line control. Copies of the daily magnetograms, calculations of various magnetic indices, base-line values, and mean hourly values of the field are distributed to scientific users around the world from the individual observatories and by international agreement through the world data centers.

The observatory and repeat-party data is processed, analyzed, quality checked, and permanently recorded by a data-processing group directed by R. J. Main.

The daily magnetic field variation data is obtained in the form of traces on photographic printing paper. In order to provide basic data in computer-compatible form and to eliminate hand scaling, A. W. Green, Jr., and L. R. Alldredge (1973) have completed the design for a new geomagnetic data acquisition system for the U.S. magnetic observatory network. The new system is based on a three-component fluxgate magnetometer plus a proton magnetometer and is capable of collecting and displaying Earth magnetic field data in both analog and digital form in real time. System outputs are in the form of standard magnetograms and digital magnetic tapes. The new systems will eventually be installed at all 13 of the U.S. magnetic observatories around the world.

During 1973, repeat magnetic surveys by J. D. Wood, G. D. Broughan, and R. G. Green were conducted at 28 stations dispersed throughout the conterminous United States. This repeat-party data collected during 1973 and previous years, along with control data from the permanent observatory network, represents the principal data resource for the compilation of the 1975 U.S. Magnetic Charts.

Magnetic charts

In 1975, the USGS will compile and publish a series of five magnetic charts of the United States. The charts will depict the main field and annual change for five magnetic components: declination, inclination, horizontal intensity, vertical intensity, and total intensity. Presently, survey data are being assembled and reviewed, and the techniques for analysis and automatic contouring are being tested. The charts will utilize a Lambert conformal projection at a scale of 1:5,000,000.

Magnetic data from worldwide sources have been assembled prior to an analysis to derive the mathematical models suitable for the creation of World Magnetic Charts. These data—from land, marine, aeromagnetic, and satellite surveys—are being evaluated by E. B. Fabiano to determine the final data set to be used in the analysis.

Geomagnetic research

L. R. Alldredge has been investigating the contribution of external sources to the secular variation of the Earth's magnetic field. In particular, it was found that so-called magnetic secular change impulses are likely caused by sunspot variations and ensuing changes in the ring current encircling the Earth at a distance of a few Earth radii. These changes in the rate of secular variation have important implications to the useful lifetime of magnetic charts, in that significant components of this variation have approximately the same periodicity (5–10 yr) as the chart publication cycle.

A. W. Green, Jr., has been conducting a cooperative program of research and data exchange with V. A. Troitskaya and others (Institute of Physics of the Earth, Moscow, U.S.S.R.). This research has resulted in a new description of the worldwide patterns of magnetic and electric fields associated with a certain class of geomagnetic pulsation phenomena (Pi2). These results were presented in a paper by Belen'kaya and others (1973).

W. H. Campbell (1973) has been deriving spectral density estimates of long-period fluctuations of the Earth's magnetic field (periods of 5 min to 2 h). These data, computed from geomagnetic observatory records during the 1965 interval of low geomagnetic activity, show the global distribution of magnetic energy to be such that 91 percent is found in the auroral geomagnetic latitudes (60°–80°) and only 1 percent between the Equator and 15° geomagnetic latitude.

APPLIED GEOPHYSICAL TECHNIQUES

Geophysical prospecting for ground water in Alaska

Seismic-refraction and electrical-resistivity surveys by H. D. Ackermann have indicated locations probably favorable for water wells at Cape Newenham in northwestern Bristol Bay and Tin City, at the tip of Seward Peninsula. At both places, present sources of water freeze in the late winter and early spring. In the Tin City area, permafrost is more than 30 m deep; however, a narrow thawed zone was delineated at the base of a mountain, at the contact between limestone country rock and a granitic stock. At Cape Newenham, a zone 10 m wide and 30 m deep was identified, where the volcanic country rock is probably severely fractured and weathered. Test wells were recommended for these locations.

Models of the geomagnetic field

L. R. Alldredge and C. O. Stearns have investigated the effect of a simulated current ring as an external source to the Earth's measured surface magnetic field. They found that when external sources were not allowed in the spherical harmonic analysis, errors of the order of the secular change occurred in the analysis. They also found that the Earth's magnetic field may be modeled as dipole sources within the Earth's liquid core with results at least as good as those from spherical-harmonic-analysis methods, and the dipole method gives more meaning to the physical processes (C. O. Stearns and L. R. Alldredge, 1973). A correction for poor site distribution of the measured data is critical for spherical harmonic analyses of the surface magnetic data.

Seismic survey of the Caloosahatchee Estuary and San Carlos Bay, Florida

A seismic survey of the Caloosahatchee Estuary and San Carlos Bay, Lee County, Fla., by R. A. Gardner and T. M. Missimer, revealed previously unknown folds in rocks of Hawthorne age at depths of 10 m to 130 m. The survey was made to determine whether fault zones provided avenues for the movement of water into shallow freshwater aquifers, but no clear evidence of faulting at these depths was detected in the surveyed area. The equipment used included a 300-J energy source, high-resolution boomer, and a 45-element sparker array.

Self-potential surveys define hot areas beneath Kilauea Volcano, Hawaii

Self-potential (SP) surveys at Kilauea by C. J. Zablocki have been useful in identifying localized thermal areas. All known fumarolic areas surveyed are characterized by positive potential as large as 1.8 volts, and subtle warm areas identified from an infrared scanner survey have been corroborated by SP anomalies. Anomalies which may contain localized heat sources have been delineated in areas without obvious surface thermal manifestations. The potential of this method in predicting eruptions is suggested by the fact that east-rift eruptions in May and November of 1973 occurred in an area of previously defined SP highs.

Airborne geophysics aids in geologic mapping

Detailed aeromagnetic and aeroradioactivity maps for a large area of the Piedmont of Alabama and Georgia have been analyzed by T. L. Neathey (Alabama Geological Survey), R. D. Bentley (Central Washington State College), M. W. Higgins (USGS), and Isidore Zietz (USGS). These aeromagnetic and aeroradioactivity maps proved to be useful tools for geologic mapping in the crystalline Appalachians. They are particularly valuable in deeply weathered or poorly exposed areas. To illustrate this, the geophysical maps were compared with almost completed geologic maps of the crystalline-rock area of Alabama, in areas where the geologic control is very good, and then extrapolated to places where geologic control is poor.

D. A. Swanson and T. L. Wright, while mapping the Columbia River Basalt in south-central Washington, reported a good correspondence between mapped geology and detailed aeromagnetic data. The magnetic contours clearly define a zone of north-northwest-trending dikes and associated small folds which extends for about 60 km. In this area of poor exposures, without the magnetic data the evidence for the dike swarm would be much less convincing.

Geophysical surveys for ground water in Quitman Arroyo, Presidio, and Eagle Flats bolsons, Texas

In three separate bolsons in west Texas, electrical-resistivity soundings and seismic-refraction profiles have been used by W. D. Stanley and H. D. Ackermann to estimate the alluvium thickness and ground-water quality. In the Presidio bolson, alluvium thickness ranges from 300 m to more than 2,000 m. Large thicknesses of clay were mapped near the surface over most of the bolson, and water quality was found to be poor. An exception is in the Alamito Creek area where there probably is good-quality water in alluvium as thick as 300 m. In the Eagle Flats bolson, good-quality water is interpreted to exist in alluvium as thick as 1,000 m, and the water table appears to occur from 60 to 200 m below the surface. In the Quitman Arroyo area, much of the subsurface appears to consist of volcanic rocks; however, an area of alluvial deposits as thick as 500 m with good-quality water exists on the east side of the bolson where a well drilled in cemented alluvium produced a flow of 240 to 400 l/min.

Three-dimensional electromagnetic model studies

F. C. Frischknecht's scale-model measurements, made over three-dimensional inhomogeneities immersed in an electrolytic tank which was excited by a uniform field, showed that the response over the center of a conductive cylinder is virtually the same as that for a two-dimensional structure having the same cross section, if the length of the cylinder is equal to several skin depths in the surrounding media. The surface impedance is less for cylinders having a length on the order of a skin depth than it is for longer cylinders. The magnetic-field anomaly tends to fall off faster with height than does the corresponding electric-field anomaly: a fact important in airborne measurements. Because the shapes of corresponding electric- and magnetic-field anomalies usually differ significantly, a considerable advantage is obtained by measuring electric and magnetic fields separately rather than by measuring only their ratio.

GEOCHEMISTRY, MINERALOGY, AND PETROLOGY

EXPERIMENTAL AND THEORETICAL GEOCHEMISTRY

Evaluation and correlation of thermochemical data pertinent to interpretation of geochemical systems

J. L. Haas, Jr., has developed a computer program (identified as PHAS 20) that uses a method of multiple-regression analysis to evaluate, test for consistency, and correlate calorimetric, electrochemical, and phase-equilibrium data for groups of related chemical species, components, and phases. The program is based on an extension of a method developed by Maier and Kelley (1932) that was used to express heat capacities as functions of temperature. Compatible expressions for entropy, enthalpy, free energy, equilibrium constants, and electrochemical potentials are derived from the heat-capacity data, using standard thermodynamic relations defined on the basis of a convention for which the free energy of formation of the elements is zero in a standard state at a temperature of 298.115 K and a pressure of 1.01325 bar.

Using PHAS 20, J. L. Haas, Jr., and R. A. Robie have reevaluated 70 sets of selected calorimetric, electrochemical, and phase-equilibrium data for the system iron-carbon-oxygen-hydrogen. Heats of formation of wüstite, $Fe_{0.947}O$, hematite, Fe_2O_3, and magnetite, Fe_3O_4, agree with published data compilations within 0.2 percent. The free energies of formation are also in good agreement except for magnetite which is found to have a significantly less negative value than is given in the JANAF tables (Stull and Prophet, 1971) or USGS Bulletin 1259 (Robie and Waldbaum, 1968). The revised values (J. L. Haas, Jr., and R. A. Robie, 1973) are considered to give the best representation of all available data sources, and it is noted that some oxygen buffer curves involving magnetite may be in error by as much as two orders of magnitude in the fugacity of oxygen.

J. R. Fisher and J. L. Haas, Jr., have also applied PHAS 20 to the calculation of ionization potentials of liquid water to obtain thermodynamic data for the hydroxyl ion OH^{-1} (aqueous). They have also calculated thermodynamic data for H_2, N_2, NH_3, and NH_4^{+1} (aqueous states) to temperatures of 573 K or above along the liquid-vapor coexistence curve for H_2O.

New thermochemical data

R. A. Robie and B. S. Hemingway have measured heat capacities of the phases copper, gibbsite, illite, and muscovite between 13 and 380 K to obtain standard entropies needed in evaluating free energies of geologically important reactions. The enthalpy of formation of gibbsite at 30°C was also determined by HF solution calorimetry. The value obtained is significantly more negative than the previously accepted value. The revised value improves agreement between calculated and experimental phase-equilibrium data for the aluminum silicates. It is concluded that the free energies of formation of minerals based on the old value enthalpy for gibbsite are too positive by 2,830 cal per aluminum atom in their formula. These minerals include kaolinite, anorthite, muscovite, and low albite.

C. L. Christ and P. B. Hostetler (USGS) and R. M. Siebert (Univ. of Missouri) have obtained values for the activity-product constants of calcite and aragonite at temperatures ranging from 0° to 200°C (Siebert, Hostetler, and Christ, 1974).

J. V. Chernosky, Jr., has experimentally studied the breakdown reaction of clinochlore to form forsterite, spinel, cordierite, and H_2O (gas) at pressures from 500 to 3,000 bars. The Gibbs free energy of formation of anhydrous magnesium-cordierite from the elements at 298 K and 1 bar was calculated from the experimental bracketing data, using the method of Fisher and Zen (1971), to be —2,083 kcal/mole. Correction for the probable H_2O content of the experimental cordierite product makes the value more negative by about 14 kcal/mole. Chernosky also studied the breakdown reaction of clinochrysotile to form forsterite, talc, and H_2O (gas) at pressures from 500 to 5,000 bars using the same methods. Evaluation of thermochemical data for the reaction phases clinochrysotile and talc, using the method of Fisher and Zen (1971), gave results that are consistent with data tabulated by Robie and Waldbaum (1968), but they disagree with values recently proposed by Bricker, Nesbitt, and Gunther (1973).

Theory of phase diagrams

E. H. Roseboom and E-an Zen have succeeded in deriving all 62 possible forms of closed multisystem nets for a binary 6-phase multisystem (a system consisting a 2 components and 6 possible phases). The method of derivation can be applied directly to real systems as a test of internal consistency of experimental phase-equilibrium data.

Melting relations of rocks and minerals

R. T. Helz has studied the complex melting behavior of hornblende, augite, and plagioclase during partial-melting experiments of basalt at temperatures ranging from 680° to 1,045°C at 5,000 bars pressure of an H_2O gas phase. The increments of the chemical constituents given up by each of these phases during each new increment of increased partial melting is never identical to the stoichiometry of the dissolving (melting) mineral. In general, the composition of material entering the melt phase cannot be expressed in terms of any combination of amphibole, pyroxene, or feldspar stoichiometries. The same general conclusions hold for partial-melting experiments on ultramafic xenoliths containing pyroxene, hornblende, and biotite from Salt Lake Crater, Oahu, Hawaii. Thus, successive melt compositions obtained by any mechanism of partial melting results in composition variations that cannot be expressed in terms of simple subtractions of any reasonable residual mineral assemblages. These complex relationships between melt and solid-phase compositions during partial melting contrasts dramatically with the analogous relationships during fractional crystallization, where the composition difference between successive increments of decreasing melt percentage is always in some way proportional to the compositions and amounts of the crystallizing phases. These distinctions suggest that powerful chemical discriminants exist for separating magma series that may have been produced by partial melting from those produced by fractional crystallization.

Fluid inclusion geothermometry validated—one more time

In cooperation with O. C. Kopp (Univ. of Tennessee and Oak Ridge National Laboratories), Edwin Roedder and H. E. Belkin (USGS) have measured filling temperatures of fluid inclusions in synthetic quartz crystals grown in the Oak Ridge laboratories under various approximately known conditions (governed by the uncertainties of the static temperature gradient method; estimated temperatures in various runs ranged from 377° to 470°C, and pressures from 800 to 1,800 bars). The agreement between inferred and measured temperatures is generally within 10°C even though the correction to the homogenization temperature due to the effect of pressure was as large as 168°C. (Homogenization runs by Roedder and Belkin were made without any specific knowledge of experimental conditions to avoid subliminal bias.) Actually, it was found that the corrected temperatures inferred from fluid-inclusion geothermometry gave more consistent values than did the estimates of temperature based on external thermocouple measurements (because of distance from the growing crystal, steep gradients, and internal bomb configuration). This work again proves that if the composition of fluid inclusions is known (and consequent effects on pressure-volume-temperature properties), then pressure corrections can be very large and still permit remarkably accurate thermometry by means of fluid-inclusion homogenization studies.

Fluid inclusions in minerals from the Creede district, Colorado

Edwin Roedder and H. E. Belkin have found that fluid-inclusion homogenization and freezing temperatures in zoned sphalerite from Creede, Colo. are compatible with a temperature range of formation from 198° to 269°C and a salinity equivalent to 5.1 to 10.9 percent NaCl by weight. Variations in inferred temperature and salinity paralleled the variations in sphalerite stratigraphy, suggesting that the methods of stratigraphic correlation are valid.

MINERALOGIC STUDIES AND CRYSTAL CHEMISTRY

CRYSTAL CHEMISTRY OF THE SILICATES

Cation distributions in hornblendes

Keith Robinson (USGS), together with G. V. Gibbs, P. H. Ribbe, and M. R. Hall (Virginia Polytechnic Institute and State Univ.) (Robinson and others, 1973), refined and compared the crystal structure and site occupancies of pargasite, Ti-pargasite, and a hornblende whose structure has been previously reported. Within structures, the ratio of transition to nontransition elements is the same in the octahedral $M(1)$, $M(2)$, and $M(3)$ cation sites. The smaller $M(2)$ octahedron contains the smaller Ti, Al, and Fe^{+3} ions, whereas $M(3)$ and $M(1)$ octahedra are enriched in Mg and Fe^{+2}. There is a positive linear relationship between mean octahedral M–O distances and the average effective ionic radii of the M cations. The $T(1)$ tetrahedral site is enriched in aluminum relative to the $T(2)$ site, and for those clinoamphiboles containing comparable amounts of calcium in $M(4)$, it is possible to estimate tetrahedral aluminum content, using mean $T(1)$–O and $T(2)$–O bond lengths. Aluminum content also controls the relative sizes of $T(1)$ and $T(2)$ tetrahedra. The greater distortion of $T(2)$ than $T(1)$ may be related to the short $T(2)$–$O(4)$ bond length, the underbonded nature of $O(4)$, and the fact that $O(4)$ is involved in a shared edge between $T(2)$ and $M(4)$. These factors combine to produce greater angular variance in $T(2)$.

Physical properties of synthetic serpentines

Eleven synthetic sepentines with compositions along the join $Mg_6Si_4O_{10}(OH)_8$–$Mg_4Al_2Si_2O_{10}(OH)_8$ have been used by J. V. Chernosky, Jr., to determine the variation of unit-cell parameters and aggregate refractive indices with composition, and to obtain an X-ray determinative curve based on variation of $d(002)$ with composition. The aggregate refractive index increases nonlinearly with increasing alumina content from $n=1.553$ to $n=1.587$. Plots of a, b, and c vary nonlinearly with composition. The molar volume is a linear function of composition, suggesting that aluminous lizardites form an ideal solid solution series. The best determinative curve for estimating composition from measured values of $d(002)$ in A is given by:

$$x=2.449-7.1247\sqrt{d(002)-8.5277}.$$

where x is defined by the formula

$$(Mg_{6-x}Al_x)\,(Si_{4-x}Al_x)\,O_{10}(OH)_8.$$

Crystal structures of coexisting biotite polytypes

The crystal structures of chemically identical, coexisting $1M$ and $2M_1$ biotite polytypes has been completed by Hiroshi Takeda (Mineralogical Institute, Univ. of Tokyo) and Malcolm Ross (USGS) using the best single-crystal X-ray methods. The mean cation-oxygen bond lengths for the two structures are identical, as are the dimensions of the unit layer ($1M$ setting). Also, the tetrahedral rotations and cation distributions in the $M(1)$ and $M(2)$ sites are identical. There is, however, an important structural difference between the $1M$ and $2M_1$ polytypes, for in the latter there is a distortion of the octahedra not previously reported in mica structures. This distortion is caused by a relative shifting of the upper and lower triads of octahedral oxygens, reducing the symmetry of the $2M_1$ unit layer from $C2/m$ as in the $1M$ polytypes to $C1$.

Prior to this study, it was generally assumed that the structures of the unit layers of chemically identical micas would be the same whether the polytype was $1M$, $2M_1$, $3T$, or others. That this is not true suggests that the growth of biotite polytypes of many different layer-stacking sequences within a single rock specimen is not simply due to a chance crystal growth phenomenon, such as growth by spiral dislocations, but rather is related to the chemical content of the biotite crystal. It is well known through the work of D. R. Wones that biotites can readily lose hydrogen when exposed to the atmosphere at elevated temperatures. The biotite in question was collected by R. L. Smith and R. A. Bailey from a rhyodacite lava flow at Ruiz Peak, N. Mex. The biotite phenocrysts were probably close enough to the surface of the flow so that they lost hydrogen from their structures immediately after eruption. Chemical analysis of the bulk biotite sample shows that the phenocrysts possess 81 percent "oxy," 8 percent fluorine, and 11 percent "hydroxy" components. The sample is highly oxidized. Also, the work of Ross and Takeda in cooperation with D. R. Wones on hydrogenation-dehydrogenation experiments of the Ruiz biotite shows that the thickness of the unit layer changes very significantly with hydrogen content. Such changes in unit-layer thickness has a large effect on the shape and size of the octahedra, and this may effect a control on the mica layer-stacking sequences and thus on polytypism.

MINERALOGIC STUDIES

New data on synthetic dypingite

A sample of the synthetic equivalent of dypingite, carefully prepared by M. E. Mrose, was analyzed by J. W. Marinenko and was found to have the formula $Mg_5(CO_3)_4(OH)_2 \cdot 6H_2O$, as compared to the formula $Mg_5(CO_3)_4(OH)_2 \cdot 5H_2O$ reported in the literature. Scanning electron microscope (SEM) examination of the synthetic dypingite samples showed that those crystallized at 30°C formed lathlike aggregates, whereas those formed at 42°C formed spherical aggregates. The SEM photographs clearly demonstrated the complex morphological structure of the two types and also revealed the structural difference that exists between their nucleus and their outer surfaces. The information revealed by the SEM photographs have suggested new approaches to synthesizing material suitable for single-crystal X-ray study.

Crystal structures of the $Na_2Ca(CO_3)_2$ phases

The following changes were observed by H. T. Evans, Jr., when gaylussite, $Na_2Ca(CO_3)_2 \cdot 5H_2O$, is heated up to 650°C: (1) At 95°C all water is evolved, and a poorly crystalline phase is formed (corresponding to eugsterite) which has a hexagonal unit cell with $a = 10.17$A and $c = 6.58$A and contains four formula units; and (2) at about 250°C this phase transforms to another well-crystallized phase (corresponding to neyerereite) which at 450°C has a hexagonal unit cell with $a = 5.079$A and $c = 12.755$A and contains two formula units. A crystal structure study by Evans on these two higher temperature phases, based on intensity data estimated from the powder patterns, supports structures based on a layering of carbonate groups with cations in octahedral interstices in calcite and eitelite. In such structures, the carbonate groups may be staggered from one layer to the next (as in calcite), or superposed (as in eugsterite), or both (as in eitelite and neyerereite). With such limited data, no precise structure determination is possible, but surprisingly good images of the structures have been obtained by Fourier synthesis. In the highest temperature phase, considerable disorder in the attitude of the carbonate groups is present; the disorder is reduced by reversible transitions to two lower symmetry superstructures, one at 433°C and another at 384°C. The lower symmetry superstructures give X-ray patterns showing satellite reflections with spacings irrational to that of the sublattice; the patterns indicate some sort of short-range order of the carbonate groups extending through the structure with a period depending on the temperature.

New occurrance of ceruleite

A sample, probably from Bolivia, has been identified by R. C. Erd (USGS) and C. W. Chesterman (California Division of Mines and Geology) as the rare mineral ceruleite, $CuAl_4(AsO_4)_2(OH)_8 \cdot 4H_2O$, previously known only from Chile and Cornwall, England. The mineral occurs as massive sky-blue material composed of microcrystalline fibers as much as 12μm in length. The strongest lines of the X-ray pattern (in A) are 4.77 (100), 7.3 (96), 4.88 (59), 5.66 (57), 3.55 (56), and 3.24 (56). There are no previous X-ray data for this mineral in the literature. The indices of refraction are between 1.567 (2) and 1.598 (2).

Vapor-liquid-solid crystal growth in the system germanium-sulfur

The first terrestrial occurrence of vapor-liquid-solid growth has been documented by R. B. Finkelman, E. J. Dwornik, and R. R. Larson. The mechanism was first proposed by researchers at the Bell Telephone Laboratories to explain elongate crystals with bulbous tips frequently observed in synthetic crystals grown from a vapor phase. The process involves a liquid droplet forming on a solid substrate. The droplet acts as a sink for vapor-phase material which then crystallizes at the solid-liquid interface, with the droplet moving up the stalk. Such crystals, consisting of stalks of metallic iron with iron-sulfur bulbs, were described recently as occurring in a lunar breccia. The terrestrial occurrence was found in condensates from burning coal in culm banks. Scanning electron micrographs and energy dispersive analysis indicate the stalks are a germanium sulfide, GeS_2, capped with bulbs containing less germanium.

VOLCANIC ROCKS AND PROCESSES

BASALTIC VOLCANISM

Summary of 1973 Kilauea activity

Eruptive activity of Kilauea Volcano was confined entirely to the upper east rift zone, but exhibited a wide variety of behavior in 1973. The staff of the Hawaiian Volcano Observatory, under the direction of D. W. Peterson, observed and recorded the activity, monitored ground deformation, recorded the seismicity, and conducted a wide variety of related studies. From January until early May, moderate lava-lake activity continued at Mauna Ulu's summit with only minor variations in vigor, location of principal vents, and lava level; at Kilauea's summit region, the state of inflation remained nearly constant. During this period, however, activity at Alae was more vigorous. In early January, copious overflows from the perched lava lake at the summit of the Alae shield quickly became localized into two main streams, one flowing southerly and the other easterly, that within a short time developed into lava-tube systems. Lava conducted by the east tube system spilled into Makaopuhi Crater's west pit by the end of January, whereas lava fed by the south tube system, after descending Poliokeawe and Holei Palis, advanced slowly seaward and, by the end of February, entered the Pacific Ocean west of Apua Point. Meanwhile, the thin eastern edge of the lava pile accumulating in Makaopuhi's west pit had reached and ultimately veneered nearly two-thirds of the floor of its east pit (mezzanine). Inflow into Makaopuhi ceased by early March, but tube-fed lava continued to pour into the sea throughout March and nearly all of April, modifying the coastline and constructing a lava delta covering about 0.3 km^2 subaerially.

The April 26 earthquake (magnitude 6.2) centered near Honomu (16 km north-northwest of Hilo) apparently disrupted the lava-tube system, and flow into the ocean ceased completely within a few days. Because of probable earthquake-caused blockages in the lower distributaries of the tube-system, lava gushed out many existing tube openings upstream and broke out at several new sites near Alae, increasing the size of the Alae shield. The activity at Mauna Ulu at first did not show any changes, but during the early morning of May 5, lava drained completely from the Mauna Ulu lava lake and the Ala vent. A rubble-choked crater 200 m deep was exposed at Mauna Ulu. A few hours later, lava erupted from a fissure in the west pit of Pauahi Crater, marking its first activity in historic times; by early afternoon another outbreak began within and near Hiiaka Crater, 800 m uprift, as the activity at Pauahi waned. Later in Hiiaka's activity, a small eruptive fissure opened in the eastern end of the fault zone about 1 km west of Hiiaka. Most activity stopped by early evening, but minor lava bubbling in Pauahi persisted until early the next morning.

Lava moved quietly back into Mauna Ulu within 2 d and began to refill the emptied crater, and by early June moderate lava-lake activity had resumed. A small pool of lava also had reappeared at the Alae vent. However, on June 9, the level of the lake at Mauna Ulu dropped abruptly nearly 100 m, and the lava pool at Alae dropped from view, as collapsing walls filled the vent with rubble. The lava level at Mauna Ulu regained its early June stand within 2 weeks, but Alae never recovered and was inactive for the rest of 1973. The resumed lava-lake activity at Mauna Ulu was mild and short lived, lasting for only about a month. After mid-July, activity declined markedly and, except for a few days in early September, practically ceased for about 2 mo.

By September's end, vents at Mauna Ulu reopened, and as the lava level rose, an active lake again occupied its summit crater. The gradual rise of the lake throughout October and early November was paralleled by a steady inflation of Kilauea's summit region, ultimately recording the greatest tumescence since measurements have been made at Uwekahuna. On November 4, lava overflowed the western end of Mauna Ulu, the first overflow since March 1972. The overflow continued until November 8 and resulted in a pahoehoe-aa flow that advanced about 2.5 km south of the crater. Sudden draining of Mauna Ulu during the early evening of November 10, accompanied by high-amplitude tremor and sharp deflation at Kilauea's summit, preceded a major breakout at Pauahi Crater later that evening. An eruptive fissure first opened in its east pit, and the fountain-fed lava ponded to form a rapidly rising lake. Soon, lava burst from eruptive fissures within the west pit and from outside of the crater in a series of en echelon, N. 70° E.-trending fissures both west of Pauahi and from its east rim to north of Puu Huluhulu. At the height of the activity, lava from the lake in the east pit and from flows and fissures west of Pauahi cascaded into the west pit. All activity in the east pit and outside of Pauahi ceased by early morning of November 11, but minor activity continued in the west pit for nearly another month, building a spatter cone within a small perched lava lake on the creater floor. By December 9 all visible activity in Pauahi stopped, coinciding with the complete cessation of harmonic tremor in the Pauahi-Mauna Ulu area during December 9–12.

Lava again returned to Mauna Ulu on December 13, but the ensuing activity has been restricted to sporadic low fountaining from a spatter cone complex in a small, occasionally active lava lake. At year's end, activity at Mauna Ulu was intermittent and feeble, and Kilauea's summit region remained highly inflated.

Volume of Kilauea lava erupted during 1973 totaled approximately 42×10^6 m^3. Estimated volumes during specific eruptive periods are:

Jan. 1–May 1	$36\text{x}10^6$ m^3
May 5	$1\text{x}10^6$ m^3
Nov. 4–8	$2.5\text{x}10^6$ m^3
Nov. 10–11	$2.8\text{x}10^6$ m^3
	$42.3\text{x}10^6$ m^3

While eruptive activity at Mauna Ulu was almost continuous during other periods, lava was confined within the crater, and the net change of amount of lava in the crater throughout the year was small because of repeated drainbacks.

During the course of the year's activity on Kilauea, members of the Haiwaiian Volcano Observatory staff undertook many specialized studies. The following are brief accounts of the results of some of them.

Seismic evidence for magma intrusion, Kilauea

The 7-h-long eruption of May 5, 1973, on Kilauea's upper east rift was accompanied by an intense swarm of earthquakes that began 3 h before the eruption started, continued during the eruption, and tapered off about 10 h after the eruption had stopped. Analysis of the Hawaiian Volcano Observatory seismic records by R. Y. Koyanagi, J. D. Unger, and E. T. Endo (1973) showed that the initial earthquakes occurred near the active volcanic vents Mauna Ulu and Alae while the lava was draining from both of them. The epicentral region of the swarm shifted 2 km westward to Pauhi Crater shortly before the eruption broke out there. Volcanic activity later moved westward in two increments of about 0.7 and 1.5 km again following migration of the earthquake swarm. After the eruption died, the epicenters of the swarm continued to migrate farther west in discrete episodes. The swarm activity moved approximately 7 km in 20 h. Almost all of the earthquake foci in the swarm were less than 2.0 km in depth. The swarm migrated along a region of normal faults and tensional cracks which make up the Koae fault zone. Koyanagi, Unger, and Endo interpret the migration of the swarm as being caused by the intrusion of magma by shallow dikes into the Koae fault zone from the east rift zone. Horizontal changes detected by geodimeter measurements and vertical changes determined by precise leveling support this hypothesis.

New volcanic shields on Kilauea east rift

The 1969–73 eruptions of Mauna Ulu on Kilauea Volcano's east rift have produced two gently sloping volcanic shields and another prominent shield-like landform. R. I. Tilling, D. W. Peterson, R. L. Christiansen, and R. T. Holcomb (1973) have determined that the development of each of these landforms was by a distinctive process. The Mauna Ulu shield, covering about 2 km^2 and rising 100 m high above the pre-1969 ground surface, was built mainly by repeated overflows from a preliminary vent. The Alae shield, centered over the buried 165-m-deep Alae Crater, abuts the Mauna Ulu shield and covers approximately 1.5 km^2 and also rises nearly 100 m above the pre-1969 surface. This shield, however, was constructed by lava extruded from secondary vents, linked to the primary vent at Mauna Ulu, that fed a perched lava lake localized in the depression over the former Alae Crater. As the level in the lava lake rose, the levees confining the lake also grew by the combined processes of spatter accretion along the lake's margin and repeated overflows. Periodic flows across the levees radiated outward from the lake and gradually built the new shield. The other shieldlike landform is a complexly sloping lava pile in the west pit of Makaopuhi Crater that resulted from infalling of lava from an external source, tube-fed lava from Alae vent.

Lava subsidence terraces

Lava subsidence terraces, or "bathtub rings," surrounding ponded lava flows at Kilauea have been surveyed by R. T. Holcomb (1973) to determine primary surface slopes of the ponds. Undisturbed pond surfaces generally slope away from their points of inflow less than 0.1°, and slopes as small as 0.05° have been measured. Small ponds agitated by high lava fountains have steeper slopes; the steepest measured was 0.5°. The consistently small primary dips suggest that lava subsidence terraces may be useful for measuring tilts, for terrace dips larger than about 0.5° would indicate posteruption deformation. Surveys by Holcomb of older ponds on the Snake River Plain confirm this conclusion.

Development of lava tubes

During several periods of the nearly continuous activity on Kilauea's east rift zone since 1969, systems of lava tubes have developed that have transported lava as far as 12 km from the source vents. Based on observations in 1970–71, D. W. Peterson and D. A. Swanson (1974) concluded that growth of crusts across lava flowing in channels is a major process in the development of tubes. Observations were extended in 1972 and 1973 by Peterson, R. I. Tilling, R. L. Christiansen, and R. T. Holcomb, and flow rates, temperatures, and changes in configuration were systematically recorded. The studies show that lava tubes are highly efficient thermal insulators, enabling lava to reach sites far from its eruptive vent and still retain its fluidity. The sustained operation of lava tubes during long-lived eruptions suggest that they may be a major factor governing the gentle slopes of basaltic shield volcanoes.

Pahoehoe-aa transition in lava

In early January 1973, D. W. Peterson, R. L. Christiansen, R. I. Tilling, and C. J. Zablocki participated in a field expedition with helicopter support to (1) observe the nature and setting of the pahoehoe-aa transition and (2) sample on the same day lava of a channel-tube system from the Alae vent to the toe of an active flow approximately 7.2 km from the source vent. Samples were collected from the moving aa front, from pahoehoe lava in the transition zone and closer to the source, and from the vent itself. At each collection site, temperatures were measured with thermocouple and (or) optical pyrometer, and the slope gradient, lava flow rate, and channel configurations were determined where possible. For comparative purposes, both air-quenched and water-quenched samples were taken of the aa and the transition pahoehoe. Results of chemical and other studies in progress on this well-controlled suite of samples should give some insight into the dominant factors that determine whether lava forms an aa or a pahoehoe flow.

Island growth processes

Between 1969 and 1973, several basaltic lava flows from Kilauea Volcano's east rift reached the ocean, adding 850,000 m^2 of land along the south coast of the island. D. W. Peterson (1972) and colleagues from the Hawaiian Volcano Observatory have noted that, in contrast to most historic Hawaiian flows that were aa when they entered the sea, these flows formed pahoehoe. The lava retained its fluidity despite the 12 km flow from its source vents, because it lost little heat during its transport through thermally well-insulated lava tubes (Swanson, 1973). Although explosions did not normally occur when hot lava contacted seawater, it was quenched and shattered into cobble and smaller sized fragments of brittle, angular glass. These fragments gradually formed a submarine hyaloclastic delta (Moore and others, 1973). The shoreline moved seaward as subaerial pahoehoe flows advanced across the submarine debris to form a nearly horizontal cap on the lava delta. Some of the larger lava streams developed tubes across the land-sea interface to deliver molten lava below the ocean surface. Wave action cut a low vertical face at the delta's advancing margin. These processes indicate that some virtually horizontal areas of pahoehoe along Hawaiian coasts, whose gradients are significantly less than the slope of the shield volcanoes, may be the subaerial surfaces of seaward-advancing lava deltas fed by long-lived, tube-transported flows.

Calculated and observed cooling rates, Alae lava lake

Alae lava lake, a small 15 m-thick pad of tholeiitic basalt formed during the August 1963 eruption of Kilauea Volcano, Hawaii, solidified in 10 mo and cooled below 100°C in less than 4 yr. The rate of cooling as observed in 12 drill holes in the lava lake has been compared by D. L. Peck with theoretical cooling rates in a cooperative project with J. C. Jaeger (Australian National Univ.). The theoretical rate was calculated using heat conduction theory and thermal properties and temperatures appropriate to the Alae lava. In a preliminary comparison of the calculated and observed cooling rates, the observed rate of solidification soon after the formation of the lava lake, during a period of little rainfall, was found to be slightly greater than the calculated rate. The observed rate was appropriate for lava with a thermal diffusivity of 0.0053 cm^2/s, 25 percent greater than that calculated, suggesting a modest increase in thermal conductivity with temperature. As cooling continued, the observed and calculated rates became increasingly divergent. The observed solidification time of 10 mo, for example, contrasts with a calculated time of 14 mo, based on the observed initial cooling rate. The difference can be attributed largely to the cooling effect of heavy rainfall (200 to 250 cm/yr) on the lake surface, which severely depressed the 100°C isothermal surface. Final stages of cooling of the solidified lava lake, even at the lake center, were at rates much greater than calculated, mostly because of the combined efforts of heavy rainfall and cooling at the edges of the pad of lava.

Monitoring volcanic gases for eruption prediction

For the first time on any volcano, Motoaki Sato and Reginald Okamura have initiated a continuous monitoring of fumarolic gases directly in a fumarole at temperatures in excess of 120°C. The fumarole is in the vent area of the August 1972 eruption in the summit caldera of Kilauea. The sensor employed is a hydrogen-air fuel cell, specifically developed by Sato under the auspices of the EROS program, that generates electric current in proportion to the concentration of reducing gases in fumarole. Except for occasional interruptions caused by recorder malfunctioning and battery failure, the monitoring system has been producing a continuous recording of the dynamic chemistry of the fumarole since the beginning of July 1973.

The recorded sensor output indicates a cyclic nature of the chemistry of the fumarole gas with a periodicity of about 36 h during dormant magma activity. Typically, the reducing capacity of the gas increases gradually by as much as 10 percent for about 24 h, culminating in a series of small fluctuations which last for 6 to 8 h, and then is followed by a relatively rapid decrease to the initial low level. During eruptions, the monotonous cyclic pattern in reducing capacity is modified by occasional large abrupt increases of as much as 50 percent that last as long as 3 h. Very significantly, such increases occurred about 10 h before the November 10 Pauahi eruption, which took place 5 km away from the monitoring site. This observation supports Sato's hypothesis that hydrogen escapes much faster than the viscous lava, and therefore the monitoring of hydrogen flow in fumaroles is a possible predictive technique.

Fractionation of East Molokai Volcanic Series

M. H. Beeson (1973) has divided a 305-m section of the East Molokai Volcanic Series, Hawaii, into eight subsections on the basis of whole-rock composition and phenocryst content of the lavas. The flows of the lower subsections are transitional from tholeiitic to alkalic basalt, becoming distinctly alkalic upward and culminating in hawaiite. Each subsection is characterized by upsection enrichment in Na_2O, K_2O, and Al_2O_3 and depletion in MgO, NiO, and Cr_2O_3. The fractionation trend is discontinous; it proceeds with several steps forward to more fractionated compositions, then decreases sharply to a less fractionated composition. The subsections are believed to result from separate batches of magma, which are produced in the mantle on a periodic rather than a continuous basis.

Calculation of phenocryst-free compositions has, to a first approximation, removed variation of the whole-rock compositions resulting from shallow fractional crystallization and has allowed Beeson to discern an earlier fractionation event, one which was dominantly controlled by aluminous clinopyroxene. He concludes that the fractionation trends observed in the phenocryst-free lavas could be produced by fractional crystallization of an aluminous clinopyroxene or partial melting of garnet at depths of 50 to 80 km.

High-temperature oxidation of gabbro, Koloa Volcanic Series

An unusual, vesicular, porphyritic alkalic gabbro, rich in ultramafic inclusions, intrudes lavas of the Koloa Volcanic Series on the south slope of the island of Kauai, Hawaii. R. W. White has studied the mineralogy of this highly oxidized gabbro and suggested that the oxidation took place at or near the temperature of the liquids. Phenocrysts of ferrian titanaugite display unusual optical properties throughout the crystals, and phenocrysts of a spinel-group mineral are rich in magnesioferrite from center to edge. Lamellae within the spinel-group mineral consist of a high-temperature hematite-ilmenite solid solution. Minerals in the groundmass include anorthoclase, a pseudobrookite solid solution, ferrian ilmenite, and a rhonite-aenigmatite solid solution, all of which display high-temperature properties or compositions. The gabbro has an igneous texture, and evidence of postmagmatic recrystallization or oxidation is virtually absent.

Gas content of basalt, Reykjanes Ridge, Iceland

J. G. Moore (USGS) and J. G. Schilling (Univ. of Rhode Island) (1973) have analyzed dredge hauls of fresh submarine basalt collected from the axis of the Reykjanes Ridge south of Iceland. The samples show systematic changes as the water depth of collection (and eruption) decreases: radially elongate vesicles and concentric zones of vesicles appear at about 700-m depth and are conspicuous to shallow water; the smoothed volume percent of vesicles increases from 5 percent at 1,000 m, to 10 percent at 700 m, to 16 percent at 500 m, and the scatter in degree of vesicularity increases in shallower water; specific gravity decreases from 2.7 ± 0.1 at 1,000 m to 2.3 ± 0.3 at 100 m.

Bulk sulfur content for the outer 2 cm averages 843 ppm up to a depth of 200 m, then decreases rapidly in shallower water owing to degassing. Sulfur content below 200 m is independent of depth (or geographic position), and the melt is apparently saturated with sulfur, but the excess cannot escape the lava unless another vehicle carries it out. Only at depths shallower than 200 m, where intense vesiculation of other gases occurs, can excess sulfur be lost from the lava erupting on the sea floor.

The $H_2O+^{110°C}$ averages about 0.35 percent and $H_2O+^{150°C}$ about 0.25 percent, and both apparently decrease in water shallower than 200 m as a result of degassing. The H_2O+ (below 200 m) decreases with distance from Iceland or increasing depth, presumably as a result of either absorption of water on the surface of shallower, more vesicular rocks; or more likely due to the presence of the Iceland hot-mantle plume supplying undifferentiated primordial material, relative to lavas of the Reykjanes Ridge supplied from the low-velocity layer already depleted in volatiles and large lithophile elements. The $H_2O+^{110°C}/S$ ratio of lava erupting below 200-m water depth ranges from 3 to 5 which is comparable to reliable gas analyses from oceanic basaltic volcanoes.

Gas content of deep-sea pillow lava, Hawaii

Motoaki Sato and J. E. McLane have completed mass spectroscopic analysis of gases trapped in glassy deep-sea pillow lavas of Hawaiian tholeiite dredged by J. G. Moore. Each sample was pyrolized in vacuum at 1,300°C, and the evolved gas was spiked internally with a measured amount of neon. Carbon monoxide and nitrogen concentrations were determined and checked by two independent calibration methods. The average of nine deep samples gave the following amounts of gas-forming elements per gram of basalt: C, 116μg; H, 555μg; S, 447μg; N, 30μg; and O, 1,142μg. The average total volume of gas extracted from a gram of basalt was 7.33 cm^3 at standard temperature and pressure. The results indicated that water is the dominant volatile component and that carbon gases tend to be concentrated in early phenocryst minerals.

Volcanic gases and origin of life

Previous workers have estimated that volcanism, in terms of the available heat, could have contributed only about 0.02 percent of the energy available for the conversion of the gases of the Earth's primitive atmosphere into amino acids and other precursors of life. A detailed reevaluation by I. A. Breger of the role of volcanism, in terms of heat, associated electrical discharge (lightning), possible catalytic processes, and other factors, indicates that the published estimate is about 100 times too low. Moreover, localization of volcanic processes could lead to concentration of prebiotic molecules and, thus, greatly enhance the role of volcanism in the origin of life.

Melting-spot hypothesis and the Hawaiian-Emperor and Austral-Marshall volcanic chains

The hypothesis that the Hawaiian-Emperor and Austral-Marshall volcanic chains were formed by relative motion between the Pacific lithospheric plate and two melting spots in the mantle (G. B. Dalrymple, E. A. Silver, and E. D. Jackson, 1973) was the object of further testing by G. B. Dalrymple, M. A. Lanphere, and E. D. Jackson (USGS), in cooperation with D. A. Clague (Scripps Institute of Oceanography). The melting-spot hypothesis predicts that the ages of volcanoes along the chain will increase systematically away from the active volcanoes of Kilauea in the Hawaiian chain and Macdonald Seamount in the Austral chain. New age measurements on rocks from volcanoes along the Hawaiian-Emperor chain are generally consistent with the melting-spot hypothesis, but they also confirm that the rate of propagation of volcanism along the chain is nonlinear and may not directly reflect relative motion between the Pacific plate and the melting spot (Clague and Dalrymple, 1973). These new ages are:

Island or seamount	*Distance from Kilauea (kilometres)*	*K–Ar (10^6 yr)*
Nihoa Island	780	7.0±0.3
Necker Island	1,045	10.0±0.4
French Frigate Shoals	1,185	11.7±0.4
Pearl and Hermes Reef	2,270	20.1±0.5
Midway Atoll	2,430	17.9±0.6
Unnamed seamount (lat 28°49′ N., long 178°57′ W.)	2,590	27.3±0.4
HawaiianEmperor bend	3,540	--------
Yuryaku Seamount	3,580	42.3±1.6
Koko Seamount	3,835	46.4±1.1

The ages of Yuryaku and Koko Seamounts indicate that the Hawaiian-Emperor bend, which may be the result of a major change in Pacific plate motion, is about 42 m.y. old. The K–Ar ages of Rurutu (1.02–1.05 m.y.), Mangaia (16.6–18.9 m.y.), Rarotonga (1.19–1.83 m.y.), and Aitutaki (0.66–0.77 m.y.) volcanoes in the Austral chain, however, do not show a systematic increase with distance from Macdonald Seamount. This suggests that the melting-spot hypothesis may not be a valid explanation for the origin of the Austral-Marshall chain.

Melting anomalies and volcanic island chains

Based on recent studies of Hawaiian tholeiitic volcanic suites and of xenoliths of deep-seated material beneath Hawaii, H. R. Shaw and E. D. Jackson (1973) have concluded that source materials are not pyrolitic but, rather, are enriched in iron and in constituents such as potassium, water, phosphorus, and the larger rare earths. It is also concluded that residues from tholeiite melting are more dense than either the source rocks or the more magnesian rocks of the deeper mantle, which conclusion is considered by many other workers to be consistent with general models of seismic velocities and density distributions. Consequently, as a corollary to the thermal-feedback model of mantle melting of Shaw (1973), it is proposed that once such melting begins, a dense residuum is formed and sinks. This downsinking ultimately forms gravitational anchors that stabilize the position of the melting anomaly and cause inflow of new, partially fractionated parental materials into the source region of the asthenosphere. Thus, the volcanic activity at the ends of the Hawaiian, Tuamoto, and Austral chains is not a result of the fortuitous location of thermal plumes but rather is a consequence of shear melting caused by plate motion. The root zones of residual material do not drive the plates but rather represent pinning points for melting anomalies at both the top and bottom of the asthenosphere. Gravitational and bathymetric data, as well as heat-flow patterns and anomalous seismic velocities for wave paths through the deep mantle, all appear to be consistent with this model.

Sheeted dikes and plutonic rocks in ophiolite assemblages

Ophiolite complexes have been described as showing continuous transitions from alpine peridotite and gabbro through swarms of diabasic dikes (so-called sheeted dikes) into pillow lavas. The dike swarms are critical to this concept, because they supposedly tie gabbro petrologically to pillow lavas. In the Canyon Mountain Complex in Oregon, however, mapping by T. P. Thayer and others has shown that all basaltic dikes, whether individuals or in swarms, are chilled against gabbro and peridotite. The plutonic rocks were tightly folded, foliated, and turned to vertical before dike intrusion. Soda-rich silicic plutonic rocks (plagiogranite) were intruded intermittently with basalt dikes, because they recrystallized earlier dikes and gabbro masses to amphibolite and are cut by younger dikes. In places, dikes of diabase and plagiogranite form composite swarms. Both kinds of dikes are concentrated on the structurally high side of the gabbro, away from peridotite. Similar dike relations occur in Oman, Newfoundland, Hatay (Turkey), and Cyprus.

Because the geologic relationships explaining the intrusion of the sheeted dikes along a spreading oceanic ridge would require intense deformation of peridotite and gabbro, and rotation of large tectonic blocks at and toward the median valley before dike intrusion, the implied deformation is more compressional than tensional. The magnitude of deformation, sufficient to overturn blocks as much as 8 km thick by 45°, is comparable to major orogeny in a continental context. It seems obvious that relations between basaltic dikes, peridotite and gabbro, and plagiogranite in the ophiolitic assemblage are much more complex than has been generally conceived, and will be critical in determining the tectonic chronology and petrology of oceanic crust and mantle (Thayer, 1973).

Xenoliths in olivine tholeiite, Nunivak Island, Alaska

Lherzolite and augitite xenoliths found by J. M. Hoare and W. H. Condon in olivine tholeiite at Nanwaksjiak Crater, Nunivak Island, Alaska, appear to be less depleted than similar types of xenoliths that occur in the highly alkalic basalts on the island. The xenoliths are considered to be fragments of deformed mantle rock because olivine and orthopyroxene crystals exhibit strong deformation lamellae (kinkbands), and cleavage planes in the augitite xenoliths are curved. Chemical analyses of these xenoliths are not yet available, but thin-section comparison with other analyzed xenoliths allows the inference that they are less depleted than normal xenoliths. Most of the xenoliths in olivine tholeiite contain far more liquid and gas CO_2 inclusions and much more exsolved aluminous spinel than do similar types of xenoliths in the highly alkalic basalts.

Lherzolite xenoliths are generally considered to be the refractory residue of partial melting because they are strongly deficient in the more fusible elements, Al_2O_3, Na_2O, K_2O, and P_2O_5. Thin sections of typical depleted lherzolite xenoliths from Nunivak Island show that they contain few CO_2 inclusions and no exsolved spinel that can be recognized by ordinary petrographic means. Most, or all, of the spinel exsolved in lherzolite at Nanwaksjiak Crater is in chrome diopside. It is colorless or pale green and is probably pleonaste. Small yellow and reddish-brown spinels also occur in orthopyroxene but probably are primary rather than exsolved. Some diopside contains little or no recognizable spinel. In other crystals, spinel is moderately abundant. It exsolved as small blades and irregular blebs along cleavage planes. In one augitite xenolith, pale-green spinel constitutes at least 25 percent of some of the augite crystals.

The presence of highly aluminous spinel in these xenoliths implies that they are abnormally rich in Al_2O_3. This, in turn, suggests that they probably are enriched in Na_2O because R. W. White's pyroxene analyses show that Al_2O_3 and Na_2O increase coherently in clinopyroxenes.

Carbon dioxide inclusions are very abundant in most of the xenoliths in olivine tholeiite at Nanwaksjiak Crater. They range in size from submicroscopic to about 0.1 mm. They are characteristically most abundant in diopside crystals, and, except locally, are less abundant in orthopyroxene and olivine. They are common to abundant in the augitite xenoliths. Most diopside crystals are brown owing to abundance of CO_2 inclusions. Relatively few CO_2 inclusions have been identified in the augitite xenoliths.

The highly alkalic basalts on Nunivak are nepheline and analcime basanites and olivine nephelinites. Such basalts are commonly thought to come from deep in the mantle and to represent only a small amount of partial melting, whereas olivine tholeiites represent more extensive melting higher in the mantle. It is therefore difficult to explain the less depleted nature of the xenoliths in olivine tholeiite at Nanwaksjiak Crater.

Garnet peridotite xenoliths in Montana kimberlite

A kimberlite discovered by B. C. Hearn, Jr., within a swarm of subsilicic alkalic diatremes in north-central Montana contains fresh xenoliths of garnet peridotite, a xenolith type reported from only three other diatremes in North America. From electron-microprobe analysis of pyroxenes by F. R. Boyd (Geophysical Laboratory, Carnegie Institute of Washington), six xenoliths give five estimated depths and temperatures of equilibrium ranging from 920°C at 106 km to 1,315°C at 148 km, and show increasing amounts of deformation with greater inferred depths of origin. The temperature-depth points suggest a segment of an Eocene geotherm for Montana which is: (1) similar in slope to the steep part of the pyroxene-determined Lesotho, Africa, paleogeotherm, (2) steeper than typical calculated continental geotherms, and (3) a possible result of plate-tectonic shearing and magma ascension within a zone of low seismic velocity in Eocene time.

Petrogenesis of Reunion Island rocks

Completion of a trace-element study by H. T. Millard, Jr., and R. A. Zielinski of a differentiated series of rocks from Reunion Island has led them to the following conclusions: (1) Data from REE (rare-earth elements), uranium, and thorium from olivine basalt of the Reunion shield confirm its major-element identification as intermediate between Hawaiian tholeiite and Hawaiian alkalic basalt; (2) a likely origin for the olivine basalt is as the product of a small amount (5 percent) of partial melting of spinel peridotite; (3) the abundance of REE, Cr, Ni, Ba, Sr, and Zr in the differentiated-series rocks (hawaiite through trachyte) correlates well with a fractional crystallization model predicted from major-element abundances, starting with an olivine basalt parent, and the required crystallizing phases correspond to observed phenocrysts; and (4) a syenite with some anomalous trace-element abundances may be the product of a separate deep-melting event involving garnet.

Jointing in Triassic basalts, New Jersey

G. T. Faust (U.S. Geol. Survey, 1961, p. A77) has classified the cooling joint systems in the upper flow unit of the third Watchung Basalt flow of New Jersey as follows (in descending order): (1) Vesicular top, (2) columnar, (3) blocky, and (4) curvilinear joint systems, and (5) vesicular base. All of these joint systems are visible in the quarry at Millington, N.J. The same sequence was deduced for the lower flow unit on the basis of the observations at numerous localities along strike, but in no single locality could all the joint systems be observed in continuum. In 1973, however, a complete section was observed near Lincoln Park, N.J. The sequence starts in the curvilinear joint system and vesicular base of the upper flow unit, passes through the interflow contact into the vesicular top, columnar, blocky, and curvilinear joint systems, and vesicular base of the lower flow, and ends below the thin hornfels contact zone in the Brunswick Shale. The vesicular top of the lower flow unit is largely amygdaloidal. The blocky joint system at this excavation is not as well developed as in the Millington quarry but is recognizable.

RHYOLITIC VOLCANISM

Volcanic-plutonic activity in the San Juan Mountains, Colorado

Petrologic, stratigraphic, and structural features of the San Juan volcanic field, in southwestern Colorado, have been interpreted by P. W. Lipman and T. A. Steven as recording the rise and differentiation of a large composite batholith in Oligocene time. The San Juan field is well known for its spectacular accumulations of thick widespread silicic volcanics, mainly of ash-flow sheets erupted from caldera-collapse sources. Less widely recognized is the fact that andesitic rocks constitute about two-thirds of this field and appear to represent the parental material from which the more silicic ash-flow magmas were differentiated. Major middle-Tertiary volcanic activity broke out in the San Juan region about 35 m.y. ago with the eruption of andesitic, rhyodacitic, and quartz latitic lavas and breccias from numerous stratovolcanoes scattered over an area of approximately 25,000 km^2. The intermediate-composition rocks were covered by at least 15 silicic ash-flow sheets and were disrupted by a similar number of associated calderas about 30 to 26 m.y. ago. The calderas are localized within an area of about 10,000 km^2 and are distinctly more restricted than the earlier intermediate-composition volcanoes. The distribution of the calderas also coincides closely with a 50-mGal Bouger gravity low characterized by steep marginal gradients.

These relations are believed to reflect the rise and differentiation of a large composite batholith to shallow levels in the crust. The slightly differentiated and widely distributed early intermediate-composition rocks probably were derived from the batholith at a relatively deep, primitive stage. As the batholith rose to its final position marked by the gravity low and shallow cupolas approached the surface, great quantities of ash were erupted and calderas were produced by collapse at the major source areas. Donald Plouff and L. C. Pakiser (1972) have interpreted data as requiring the general top of mass deficiency to be within 2 to 7 km of the surface; the individual cupolas must have been shallower. Similar ages and dissimilar petrologic relations among the ash-flow sheets require that magmas in many of these cupolas underwent isolated simultaneous differentiation. Compositional zonations within some ash-flow sheets require the presence of more mafic material at depth, as does the recurrent emplacement of andesitic lavas and related intrusions during eruption of the ash-flow sequence.

Although well within the North American continent, the intermediate-composition rocks of the San Juan volcanic field are remarkably similar in major- and minor-element chemistry to those in modern continental-margin andesitic areas, such as the Andes, that are associated with relatively gently dipping Benioff-subduction zones.

Preliminary rare-earth analyses by H. T. Millard, Jr., and R. A. Zielinski, of alkalic andesite, rhyodacite, and rhyolite from a stratovolcano in the San Juan Mountains indicate that low-pressure fractional crystallization probably was not an important mechanism for generating the rocks. A more likely origin is as a partial melt, the products having been produced at depths where garnet is a stable phase.

Magmatic insurgence, Yellowstone rhyolite plateau, Wyoming

R. L. Christiansen has reviewed structures and rock-unit distributions in the Yellowstone caldera on the basis of new K–Ar dates by J. D. Obradovich. It had been known previously, on the basis of recent geologic mapping by Christiansen (USGS) and H. R. Blank (Univ. of Oregon), that the Yellowstone caldera formed by the collapse of two discrete segments as a result of voluminous ash-flow eruptions that formed the Lava Creek Tuff 600,000 yr ago. Resurgent doming occurred shortly afterward in the eastern segment, within a time after collapse that was too short to resolve by K–Ar dating; this time sequence is typical of resurgent calderas in general. Similar structures in the western segment suggested a similar resurgence there, but the stratigraphy of mapped rhyolite flows and the new K–Ar dates show that doming in the western segment occurred 150,000 yr ago and marked the beginning of an episode of major rhyolitic volcanism, producing flows that have nearly filled the western segment. This volcanism has continued, at least until about 70,000 yr ago, and appears to be related to the very high heat flow associated with Yellowstone's hottest and most vigorous geothermal systems. Thus, it appears possible that the doming and volcanism younger than 150,000 yr in the western segment of the Yellowstone caldera mark a magmatic insurgence that began about 150,000 yr ago and an episode of rhyolitic volcanism that may even be leading to a new climax, rather than marking the declining stages of the older Lava Creek Tuff cycle.

Resurgence and crystallization of Long Valley magma chamber, California

Potassium-argon dating of early postcaldera aphyric rhyolites from Long Valley caldera, Mono County, Calif., by G. B. Dalrymple, and M. A. Lanphere, in conjunction with geologic studies by R. A. Bailey (Bailey, Lanphere, and Dalrymple, 1973) shows that resurgent doming of the caldera floor immediately followed eruption of the Bishop Tuff and collapse of the caldera and spanned little more than 40,000 yr. Bailey thinks that this close association in time of caldera-forming eruptions and resurgence at Long Valley, as well as at other resurgent calderas, indicates a genetic relationship, and he suggests that the basic cause for resurgence is the isostatic adjustment required by eruption and dispersal of the magma represented by the caldera-forming ash flows. The sudden removal of hundreds of cubic kilometres of magma from a shallow magma chamber results in an isostatic imbalance, which is compensated for by rise of the residual magma accompanied by lateral inflow of deep crustal or upper mantle material in the root zone.

After resurgence at Long Valley, crystal-rich hornblende-biotite rhyolite erupted peripheral to the resurgent dome in counterclockwise succession at 200,000-yr intervals—500,000, 300,000, and 100,000 yr ago. During the latter part of this episode, more mafic rhyodacites erupted in three areas on the caldera walls. The ages and spatial relations of these postcaldera lavas suggest (1) that the Long Valley magma chamber is chemically zoned, with a rhyolitic top and a deeper rhyodacite zone, and (2) that the eruptions represent successive tappings along ring fractures of progressively deeper, more mafic parts of the crystallizing chamber.

Eruptions of basalts from vents 5 km within the western moat of the caldera between 145,000 and 62,000 yr ago indicate that the magma chamber had congealed inward that distance from its margins by that time, as it seems unlikely that liquid basalt could have penetrated the marginal zone of the rhyolitic chamber had it been entirely liquid. Thus, any rhyolitic magma remaining in the chamber 62,000 yr ago must have been deeper than 5 km from the roof of the chamber, which in turn, is at least 4 km below the surface, according to seismic-refraction studies of D. P. Hill, Stewart McHugh, and L. C. Pakiser (1973) and gravity studies by M. F. Kane and D. R. Mabey (1973). This estimate is in accord with that of A. H. Lachenbruch, (Lachenbruch, Lewis, and Sass, 1973) who, on the basis of preliminary heat flow data, concludes that there is no requirement that magma presently be shallower than 10 km within the caldera.

VOLCANIC HAZARDS

Mount Rainier hazards map

A map compiled by D. R. Crandell (1973) shows areas of potential hazards which are anticipated in future eruptions of Mount Rainier, Wash. The map is based on the assumption that future eruptions will be similar in kind and scale to those of the last 7,000 yr at Mount Rainier, and will affect areas of similar extent. The text accompanying the map points out tha; the chief hazards probably will be mudflows and loods moving along valley floors and fallout of airborne rock debris in areas downwind from the volcano. Future lava flows probably will not extend beyond the base of the volcano, but more extensive mudflows and floods may be caused by rapid melting of ice and snow by lava.

Lahars from Mount Baker volcano, Washington

A reconnaisance study by J. H. Hyde (Tacoma Community College) of the lower flanks of Mount Baker in northern Washington has shown that large clay-rich lahars (volcanic mudflows) have repeatedly moved down the east and west sides of the volcano in postglacial time. Lahars on the east side reached the Baker River valley, the floor of which is now occupied by Baker Lake, a hydroelectric reservoir impounded by Upper Baker Dam. The largest lahar recognized on the west side of the volcano moved at least 27 km down the valley of the Middle Fork of the Nooksack River; wood picked up by the lahar has a radiocarbon age of about 6,000 yr. By analogy with large clayey lahars which originated at Mount Rainier in postglacial time, those at Mount Baker probably were caused by avalanches of hydrothermally altered rock from the volcano.

Hawaiian eruptions, earthquakes, and tsunamis

An appraisal by D. R. Mullineaux and D. W. Peterson (1974) of potential volcanic hazards on the Island of Hawaii has shown that the principal risks are from eruptions of lava flows, rock fragments, and gases. Earthquakes and tsunamis caused by local or distant tectonic events are major hazards, but those caused directly by eruptions are not. The overall risk to lives on the island is low, except from tsunamis, but risk to property is high in some areas. Risks from volcanic hazards are highest in the caldera and rift zones of Mauna Loa and Kilauea Volcanoes, and are lower away from these zones and on Hualalai, Mauna Kea, and Kohala Volcanoes. The island has been subdivided into zones of different relative risk, which can be used to guide land-use planning and development.

PLUTONIC ROCKS AND MAGMATIC PROCESSES

Evolution of a plutonic series in the Cape Ann area, Massachusetts

Studies by K. G. Bell and W. H. Dennen (1972) have defined a plutonic series in the Cape Ann area, a comagmatic suite including the Salem Gabbro-Diorite, the Beverly Syenite, and the Cape Ann Granite. Further, the Lynn Volcanic Complex (Clapp, 1921), exposed in the Salem area, is clearly related to, and probably derived from, the same source as the alkali-feldspar granites of the Cape Ann area. The evidence for the comagmatic nature of the suite is based on petrographic and chemical data and on the relations of several sets of distinctive felsic and mafic dikes, which can be related to various members of the plutonic series. A suggested sequence of intrusive and eruptive events for the series begins with the differentiation of a parent magma at depth into mafic and salic fractions. The mafic part was then emplaced at higher levels and began to crystallize as gabbro-diorite, but before it was completely consolidated, it was injected by salic magma, which began to differentiate (principally by crystal settling) into an alkali-feldspar suite ranging from feldspathoidal syenite to granite. Concurrently the escape of material to the surface from the salic magma reservoir gave rise to a suite of extrusive rhyolites. Other differentiates of the salic magma intruded older dioritic and granitic rocks and crystallized as syenite and as aplitic and pegmatitic dikes and masses. Mafic dikes, the late differentiates of the gabbro-diorite mass, penetrated all the later rocks.

Possible anatectic origin of the northern Glastonbury Gneiss

The Glastonbury Gneiss crops out in a long narrow dome trending north-northeast about 65 km through Connecticut and Massachusetts; structurally and stratigraphically it is comparable to the gneiss domes of the Oliverian Plutonic Series in New Hampshire. Rocks in the northern part of the dome, recently studied by G. W. Leo, are granitic-looking, intrusive gneiss which appears relatively homogeneous but has much local compositional variation. The composition of the northern part of the dome is silica rich and potash poor, corresponding to trondhjemite in part; it approaches the composition of felsic layers in overlying Ordovician volcaniclastic units, and is quite distinct from calc-alkaline granitic rocks. The central part of the dome, by contrast, shows more textural variation, has the composition of granite and granodiorite, and exhibits textures suggestive of potash metasomatism. The origin of the Glastonbury dome is evidently complex; the dome probably was not formed by differentiation of a single magma. The present interpretation is that the northern part of the dome is the product of anatectic melting of rocks that were originally marine volcanic sediments, and that the central part may represent a separate intrusion.

The relation of density to chemical composition for crystalline rocks

E. J. Young (1973) has shown that the powder densities of 80 crystalline rocks plotted against their chemical composition, expressed as a felsic-mafic index $\frac{SiO_2+Na_2O+K_2O}{FeO+Fe_2O_3+MgO+CaO}$, produces a moderately good curve. Metamorphic rocks tend to plot above the curve, reflecting crystallization under high pressure; volcanic rocks plot below the curve reflecting crystallization under low pressure. Medium-grained intrusive rocks tend to plot close to the curve. Thus, the plot of powder density against the mafic-felsic index gives some indication of whether a rock crystallized under high or low pressure.

Meteoric water in magmas

The study of the oxygen isotopes of sanidine phenocrysts from eruptive-rock sequences in Nevada and Colorado and in Yellowstone National Park by Irving Friedman, P. W. Lipman, J. D. Obradovich, J. D. Gleason, and R. L. Christiansen shows that the δO^{18} decreases in these magmas as a function of time. This decrease in δO^{18} may be caused by isotopic exchange between fluid magma and δO^{18}-depleted ground water. The possibility of reaction between large magma bodies and meteoric water at liquidus temperatures has major implications in the possible differentiation history of the magma and in the generation of ore deposits.

Geochemistry of iridium

Neutron-activation determinations of iridium in rocks of the southern California and Boulder (Montana) batholiths by L. P. Greenland show that the iridium content is very low and variable in both batholiths, extending over 1 to 2 orders of magnitude and having a combined median value of about 0.006 ppb Ir. The data suggest that the calc-alkalic Boulder batholith (0.002–0.5 ppb Ir, median 0.007) may be slightly enriched in iridium relative to the calcic southern California batholith ($<$0.001–0.12 ppb Ir, median 0.005). No conspicuous relation is evident between iridium content and differentiation; however, the Boulder batholith rocks do show a slight tendency to concentrate iridium in the more mafic rocks. These results in conjunction with previous analyses of mafic rocks lead to a crustal-abundance estimate of 0.03 ppb Ir.

Origin of trondhjemite magmas

Eighteen whole-rock samples and several mineral separates from a gabbro-diorite-trondhjemite suite of southwest Finland have been studied petrographically and analyzed for major elements, rare earth, and other trace elements and $\delta O^{18}/O^{16}$ ratios by J. G. Arth, Fred Barker, Z. E. Peterman, Irving Friedman, and G. A. Desborough. The results place strong constraints on the origin of this magmatic suite and argue against the previously proposed origin of the potash-poor trondhjemite magmas by fractional crystallization of biotite and hornblende from water-rich mafic magma. An alternate origin for the dioritic and trondhjemite magmas by partial melting of eclogite and garnet peridotite at mantle depths is under consideration.

Depths of genesis of trondhjemites in Colorado and New Mexico

In a continuing investigation of the 1.7 to 1.8-b.y.-old trondhjemitic rocks of Colorado and nearby New Mexico, Fred Barker, J. G. Arth, and Z. E. Peterman (1973) have determined rare-earth contents and have deduced depths of magma generation. Rare-earth distribution patterns of the trondhjemite near Brazos Peak, the Twilight Gneiss of the West Needle Mountains, the Pitts Meadow Granodiorite of the Black Canyon of the Gunnison, and the Kroenke Granodiorite of the central Sawatch Range show progressively different patterns of europium anomalies and of heavy rare earths. From south to north, the inferred amounts of plagioclase in the residue (from the partial melting of a basaltic source rock) decrease and finally disappear with the Kroenke, and garnet appears with the Pitts Meadow and increases with the Kroenke. Thus, depths of magma generation are inferred to increase from about 30 km in New Mexico to a minimum of 60 km in the Sawatch Range in Colorado.

Timing of plutonic events in circumpacific North America

Evaluation of isotopic ages of granitic intrusive rocks of large batholiths in circumpacific North America by M. A. Lanphere and B. L. Reed (1973) indicates that Mesozoic and Cenozoic plutonism was episodic but not periodic. Three intrusive epochs have been defined in the Alaska-Aleutian Range batholith of Alaska on the basis of concordant K-Ar ages of coexisting biotite and hornblende or muscovite. Only two intrusive epochs based on concordant ages of mineral pairs and an older plutonic episode can be recognized in the Sierra Nevada and southern California batholiths. Detailed intrusive histories for other parts of Alaska, British Columbia, and Yukon Territory cannot be inferred from available data. The intrusive epochs in the Western United States do not correlate with the epochs in the Alaska-Aleution Range batholith. The spacing, duration, and synchroneity of intrusive epochs in the circumpacific batholiths of North America are not yet well established.

Cyclic units and lineated cumulates in the Vourinos Ophiolite, Greece—implications on the formation of Tethyan oceanic crust and mantle

E. D. Jackson has reported the discovery of a stratiform peridotite-gabbro complex that forms an integral part of the Vourinos Ophiolite in Greece. The layered rocks of the complex lie cleanly deposited on metamorphic harzburgite tectonites. The complex is now tilted vertically but otherwise shows little deformation. The stratiform complex is 1 565 m thick and is characterized by cyclic units, olivine rich at the base, increasing in clinopyroxene in the central part of the section, and plagioclase rich at the top. Several cumulus chromite layers occur among the olivine cumulates, and these indicate that two ages of chromites exist in the Vourinos Ophiolite. Near the uppermost contact of the layered complex, hornblende appears as a cumulus phase. Preliminary fabric diagrams show northwest lineate lamination and indicate the orientation of the oceanic ridge crest during cooling of the complex. The base of the stratiform complex would not correspond with the Mohorovičić discontinuity, as inferred by seismic data, but the central part would probably correspond with the seismic basal layer observed in Pacific sections, and its upper part would likely have oceanic layer seismic properties. The presence of the complex, and of the differentiated diorites above it, indicates that intrusion was a much more important process that extrusion in the formation of the Tethyan uppermost mantle and lowermost crust.

METAMORPHIC ROCKS AND PROCESSES

Burial metamorphism

E-an Zen has completed a study of published reports and descriptions of burial metamorphism from metamorphic terranes in many parts of the world. Most descriptions of burial metamorphism include rocks that have recrystallized without significant development of a tectonic fabric. Many such rocks consist of much volcanic material (tuff, lava, graywacke, and similar rocks) which are partially recrystallized and contain zeolitic assemblages. However, such rocks are not restricted to nondeformed terranes; the same rock types with an identical mineral assemblage have also been described from highly deformed belts (Taveyanne Formation in the Alps and Silurian-Devonian rocks in New Brunswick). Plots of mineral assemblages in rocks altered by burial metamorphism against reconstructed depths of burial from stratigraphic data show no quantitative correlation. Although the observations from geothermal areas show that temperature is the dominant control of mineral assemblages, a smooth geothermal gradient and isothermal conditions for a given depth cannot safely be assumed. Local geothermal gradients may be affected significantly by alteration processes; alteration of volcanic and volcanogenic rocks at near-surface conditions commonly is exothermic. Sample calculations on alteration of an olivine basalt to a prehnite-chlorite-quartz rock show that such heat production may be very important in a local thermal regime. With these considerations in mind, E-an Zen feels that the use of the term "burial metamorphism" as a special mode or kind of metamorphism is not warranted.

SEDIMENTARY ROCKS AND DIAGENETIC PROCESSES

Diagenesis of siliceous shales

Among the various diagenetic minerals present in the Miocene sedimentary rocks of California, the silica minerals of siliceous shales most clearly indicate the direct relation between reaction kinetics and depth of burial. Studies of unusually thick sections of the Monterey Shale in the Temblor Range by K. J. Murata and J. K. Nakata (1974) revealed a regular succession of silica mineralogy, biogenic opal to cristobalite to quartz, in the downward direction, with only the deeper beds having attained the ultimate stability of quartz. A depth-dependent contraction of the $d(101)$ X-ray spacing of cristobalite, from 4.12 to 4.04 A, allows a subdivision of the cristobalitic part of the section for detailed studies.

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

K. A. McGee and P. B. Hostetler determined the thermodynamic dissociation constants for the reactions:

$$Mg(OH)_2(c) = Mg^{+2}(aq) + 2\ OH^{-1}(aq)$$
$$MgOH^{+}(aq) = Mg^{+2}(aq) + OH^{-1}(aq)$$

The constants were determined experimentally from 10° to 90°C. The brucite ($Mg(OH)_2$) constants were determined by measuring the brucite solubility in pure water and in dilute HCl solutions. The $MgOH^{+1}$ constants were determined by titrating magnesium chloride solutions with barium hydroxide until brucite precipitated. Results are as follows:

	10°C	*25°C*	*40°C*	*55°C*	*70°C*	*90°C*	*+2σ*
$-\log K_{MgOH^+}$ ---	2.18	2.20	2.29	2.37	2.44₅	2.54	0.05
$-\log K$(brucite) -	10.89	10.88	10.90	10.90	10.90	11.10	0.10

Using data (from Parker, Wagman, and Evans (1971) for the ions, the $\Delta G°_f$ at 25°C of brucite is −831,580 J/mol, where $G°_f$ is Gibbs free energy of formation.

Processes of polymerization of aluminum hydroxide ions in supersaturated solutions were studied by

D. W. Brown, C. J. Lind, and J. D. Hem (Brown and Hem, 1974). Inert mineral surfaces in such solutions influence the process by absorbing the polymerized ions and preventing the attainment of crystallinity. When dissolved silica and small amounts of an organic complexing agent were present with the aluminum, the polymerization was slowed; but the alumino-silicate precipitate, although amorphous to X-rays, contained some well-crystallized kaolinite after 6 to 16 mo of aging at 25°C. This material was identified by electron microscopy. Organic material may play a significant role in clay-mineral formation and aluminum and silica solubilities in natural weathering solutions.

Redox potentials at ferric hydroxide surfaces in aqueous systems can be estimated from dissolved-iron activity and pH. The scavenging effect of ferric hydroxide on traces of dissolved copper attributable to surficial redox equilibria, was summarized in graphical form by Hem (1974). Metal ferrite layers forming on the surface of ferric hydroxide precipitates could lower solubilities of zinc, nickel, copper, and some other metals to extremely low levels. Although this process is thermodynamically feasible, the rate at which the reaction might proceed in aqueous systems at Earth-surface temperatures is unknown.

According to B. F. Jones (Jones and others, 1974), aluminum and iron values for dilute California stream waters filtered through 0.1 μm and field extracted with oxine to minimize particulate contamination compared favorably with the solubility of kaolinite and amorphous $Fe(OH)_3$ as determined by water-equilibrium (WATEQ) program computations. A preliminary compilation of the probable range for internally consistent stability-constant data was completed for most of the mineral phases considered by WATEQ. Furthermore, the solute-speciation model was satisfactorily tested against electrode measurements of Ca^{+2} activity in somewhat saline water from a stream of the Great Salt Lake.

Observations of saline crystallization in Owens Lake, Calif., were made by G. I. Smith, Irving Friedman, and R. J. McLaughlin during 1970 and 1971 while the lake desiccated after being flooded. They noted that saline minerals initially crystallized at the surface and that some subsequently dissolved whereas others sank to the bottom within hours; within days to months, most of the natron, nahcolite, and thernardite crystals that sank to the bottom were altered to other species without any textural or obvious chemical evidence of the change. At the end of 2 yr, all of the salt bed had recrystallized to a fine-grained mass composed of trona, halite, and burkeite. Water temperatures on the lake bottom (2.4–0.4 m below the surface) varied seasonally by 22°C, about the same range found in mean monthly air temperatures of the region. Dissolved solids increased during an 18-mo period of evaporation from less than 136,200 mg/l to 470,300 mg/l, and the deuterium content increased during the same period by about 80 per mil, with respect to the isotopic Standard Mean Ocean Water (SMOW).

B. F. Jones reported that analyses of 59 water samples (17 from 4 boreholes as much as 120 m deep) from the Lake Magadi area, Kenya, have been completed. These data together with earlier analyses have been examined statistically to refine the hydrologic model for the basin. The results emphasize recycling of sodium chloride and suggest that a source of heat, carbon dioxide, and bromine may be the hottest springs at the north end of the lake. The borehole brines show striking evidence of sulfate reduction and suggest some control of solution composition by iron minerals.

Recently developed principles and techniques of hydrogeochemistry and isotopic hydrology have been applied to a selected area of the Punjab Region of Pakistan by P. R. Seaber, William Back, C. T. Rightmire, and R. N. Cherry (1973) to refine and clarify the solution-evaporation hypothesis proposed by earlier workers. Results of the studies are described in the Pakistan section of the chapter on international cooperation in the Earth sciences.

Oil-field brines and mineral springs

According to R. A. Cadigan, middle(?) Holocene hydrothermal activity produced mineral springs, gas seeps, and geysers along the course of the Gunnison River and its north fork for a distance of about 25 km between the towns of Austin and Hotchkiss in Delta County, Colo. The mineral springs yield effervescent cold water containing as much as 18,000 mg/l of dissolved solids. Some of the springs are richly charged with carbonates and carbon dioxide gas; others contain sulfides and hydrogen sulfide gas, and many are churned vigorously by escaping gas. Some of the springs are radioactive. Based on spectrographic data from P. R. Barnett and E. C. Mallory, Jr., (1971), the maximum metal content of the spring water (seven samples) is: Al, 10,000 μg/l; Li, 10,000 μg/l; Fe, 47,000 μg/l; Sr, 6,600 μg/l; B, 5,300 μg/l; Mn, 6,600 μg/l; Zn, 570 μg/l; and As, 460 μg/l. Concentrations of radioactive elements were not determined.

Where the rock strata are relatively undisturbed, the springs issue from basal parting in the Dakota Sandstone (Cretaceous) or from the base of the immediately overlying highly carbonaceous, thick sandstone unit of the Mancos Shale (Cretaceous). Most of the springs are less than 30 m above river level and drain into the Gunnison River or its north fork. Travertine cones and aprons (2 or 3 m thick) around the springs are composed mostly of calcium carbonate but contain as much as 1 percent manganese and strontium. One 300-m-long area of closely grouped radioactive springs has a travertine apron with a volume of about 25,000 m^3; the concentration of radioactive elements in the travertine averages about 200 ppm eU. The most radioactive sample collected in preliminary sampling of the travertine contains 2,500 ppm eU. Radioactive springs are physically separated from nonradioactive springs. Not all radioactive elements present in the springs and travertine have been identified. Two of the mineral springs are active, carbon dioxide charged geysers.

Sulfur-impregnated rocks in significant volume occur in the carbonaceous basal sandstone unit of the Mancos Shale in the presence of sulfur gas seeps (H_2S and SO_x). These rocks contain native sulfur on joint surfaces or as interstitial impregnations in some sandstone strata. Exposed rock surfaces are yellow or white with sulfur or sulfate efflorescence. Some strata contain pyrite and (or) arsenopyrite. These rocks have been quarried at two localities and were then crushed and used as a soil conditioner.

Present erosion rates of travertine cones and wedges along the rivers are greater than formation rates of these features, which suggests that the rate of mineral-spring activity was much greater in the past than it is now. It is estimated that these surface mineral springs have a total flow of about 1×10^6 l/d. The amount of associated mineral-spring water which may enter the rivers by way of the riverbeds cannot be estimated.

L. M. Willey and J. B. Rapp reported that the alkalinity of oilfield waters from the Miocene of the Kettleman Hills oil field is comprised of short-claim fatty-acid anions. In order of decreasing abundance are acetate, propionate, butyrate, and isobutyrate. The ion HCO_3^{-1} is lacking in spite of being reported in earlier analyses. Amino acids are also being found in oil-field waters.

Alteration of rocks by ground water

D. A. Seeland noted that silicification of the Paleozoic clastic sedimentary rocks underlying the Challis Volcanics is common in an area as much as 3 km wide and 40 km long, from the Salmon River west of Clayton, Idaho, south into the Boulder Mountains north of Ketchum, Idaho. The sedimentary rocks are silicified for as much as 400 m below their contact with overlying volcanic rocks. The silicified rocks are substantially changed in appearance, and in an area such as this where the stratigraphy is imperfectly known, it is possible to regard the silicified rocks as new stratigraphic units. Where they have been silicified, carbonaceous blocky weathered black argillites become light-gray, silvery weathered siltites that appear phyllitic in places. The same rocks in intrusive contact with granitic rocks of the Idaho batholith show no visible changes even a few centimetres away from the contact. Near the volcanic rocks, gray calcareous sandstones, gray sandy limestones, and dark-gray quartzites are changed to quartzitelike rocks that, in many places, have obscured bedding and weather to shades of red and yellow.

The silica may have been derived from devitrification of volcanic glass in the Challis Volcanics and carried in cool ground water at relatively low pH into the underlying sedimentary rocks where the silica replaced whatever carbonate was present.

Field investigations by B. F. Jones off the Abert rim of south-central Oregon established that sources of the unusual mixed-layer clays of the saline lake sediments are altered dacite feldspar phenocrysts and basaltic scoria.

In every place observed by H. S. Puri, G. L. Faulkner, and G. O. Winston (1973) in a recent subsurface investigation of the distribution of saline-water zones of high transmissivity in the Upper Cretaceous and Tertiary carbonate section in southern Florida, the zones were in dolomitized parts of the section. Highly transmissive cavernous zones in deep saline-water dolomite aquifers may be ancient solution-channel systems resulting primarily from fresh ground-water circulation in limestone later invaded by salty water as the sea transgressed onto the Florida Peninsula. Dolomitization of the walls of the solution channels and, to a varying degree, of the limestone between solution channels, may have preserved the solution-channel system in much the same configuration it had at the termination of freshwater circulation. This being so, a good estimate of the distribution of a paleo fresh ground-water drainage system would be a valuable aid in predicting the movement of wastes injected into the presently saline-water aquifer.

In a study of the Edwards and associated limestones, Texas, R. G. Deike compared mineral assemblages and lithologic textures characteristic of the carbonates in the Edwards Limestone in saline water with those found in the freshwater aquifer. Collapse breccia zones in the subsurface Edwards carbonates in saline, noncirculating water correlate well with cavernous and other high-porosity zones in the freshwater aquifer. The breccia fragments are in a matrix containing porous, sucrosic dolomite and are interbedded with thick petroliferous, pyrite- and gypsum-bearing organic layers. Correlation is based in part on the following features of high-porosity zones in the freshwater aquifers: The absence of (1) parts of the tidal flat sequences in which the breccia zones are found, (2) organic layers, and (3) pyrite, gypsum, and celestite; and the presence of (1) the same delicate textures which contain pyrite in saline-water carbonate but the pyrite has apparently been altered to goethite by freshwater, (2) evaporite-associated chalcedony in thick calcitized zones, (3) silicified *Toucasia* shell material, with the same texture and composition as that found in the subsurface, and (4) chert-bearing horizons in the same vertical position as in the subsurface.

Isotope hydrology

The results of a series of experiments on ultrafiltration by compacted clay membranes were reported by T. B. Coplen II and B. B. Hanshaw (1973). The ultrafiltrates from both distilled water and 0.01 *N* NaCl solutions were depleted in D and ^{18}O. This suggests that oxygen and hydrogen isotopic fractionation of ground water during passage through compacted clayey sediments should be a common occurrence. Hanshaw and Coplen (1973) also showed that a theoretical treatment of ultrafiltration phenomena is in reasonable agreement with the observed chemical differences between the starting solution and the ultrafiltrate.

The ratios of the stable carbon isotopes ^{13}C and ^{12}C in carbonate dissolved in ground water may be useful indicators of the sources of that carbonate. C. T. Rightmire is studying the carbon-isotope content of soil CO_2, a major source of carbonate to ground waters. He reported (C. T. Rightmire and B. B. Hanshaw, 1973) that samples of soil organic matter and ground litter from the area of recharge to the principal artesian aquifer of central Florida have $\delta^{13}C_{PDB}$ values from —18.2 to —29.5 per mil, indicating the presence of both Calvin and Hatch-Slack cycle plants. The $\delta^{13}C_{PDB}$ values in soil CO_2 are from —14.7 to —21.3 per mil, consistent with the trend observed in the litter.

New information on the sources of sulfate dissolved in ground water is obtainable from the measurement of the sulfur-isotope composition of sulfates. Field studies of the Floridan aquifer and of the Edwards aquifer in Texas, by C. T. Rightmire, William Back, and F. J. Pearson, Jr., showed that the use of sulfur-isotope data in conjunction with hydrologic and geochemical techniques permits refinements of interpretation. The interpretation of the chemical data for the Floridan, particularly the SO_4^{-2} concentration and the SO_4^{-2}/Cl^{-1} ratio, leads to the conclusion that recharging maritime rainfall, solution of intraformational gypsum, and mixing with oceanlike saline waters are the sources of sulfate in the ground water. Sulfur-isotopic data substantiate this interpretation.

The Edwards aquifer in the area studied can be separated into two hydrologic units on the basis of water chemistry and aquifer characteristics. The sulfide-free waters in the part of the aquifer upgradient from a distinct sulfide boundary are low in sulfate (less than 100 mg/l) and contain no sulfide. The waters downgradient from that boundary contain more than 150 mg/l sulfate, and all contain measurable quantities of sulfide. Interpretation of the SO_4^{-2} concentration and SO_4^{-2}/Cl^{-1} ratio on the basis of the Florida study may lead to the erroneous conclusion that the solution of intraformational gypsum is again a major source of sulfate in the sulfide-free part of the aquifer. Isotopic analyses, however, show that the gypsum probably is of Permian age and was introduced into the aquifer by the recharge water. The absence of evidence for enrichment in ^{34}S in the sulfate in the sulfide-bearing part of the aquifer leads to the possibility of H_2S migration upgradient from downdip oil fields (Rightmire and others, 1974).

Carbon-14 in ground water

Much of the ground water in the arid North Eastern Province of Kenya is saline, but a body of freshwater is present southeast of Habaswein. F. J. Pearson, Jr., and W. V. Swarzenski (1974) used stable and radiocarbon isotopes and carbonate geochemical measurements to investigate mechanisms by which the freshwater might be recharged. They reported that the higher measured ^{14}C values are associated with the fresher water body, but there is no strict correlation between ^{14}C and salinity. The samples fall into several groups, the members of each of which show a striking correspondence between measured ^{14}C contents and $(C_{total})^{-1}$ values. Apparently each of the ^{14}C–C_{total} groups represents a single recharge event, and the different ^{14}C contents within each group are due to additions of varying amounts of ^{14}C-free carbonate—by aquifer carbonate solution or mixing with older water—to water from a single recharge event.

Because of the lack of general knowledge about arid-region carbonate chemistry and the lack of samples to show chemical and isotopic variations with depth in the aquifer, Pearson and Swarzenski do not assign absolute ages to these waters but conclude that the recharge events probably occurred at intervals of a few milennia.

Major assumptions common to interpretive studies of ^{14}C in ground-water systems are: (1) No CO_2 is introduced after recharge, (2) $\delta^{13}C$ of carbonate phases in the aquifer is known and taken to be zero, and (3) interformational flow can be neglected. I. J. Winograd and G. M. Farlekas (1974) showed that none of these assumptions are fulfilled in deltaic and marginal sediments comprising the Potomac-Raritan-Magothy aquifer system of New Jersey, and it is likely that the first two asumptions are not valid for most aquifers of deltaic to marginal marine origin. Despite regular variations of ^{14}C and $\delta^{13}C$ down the hydraulic gradient, meaningful interpretation of relative ^{14}C ages and ground-water velocities could not be made in the New Jersey aquifer. They suggest that similar difficulties should be anticipated in all aquifers of deltaic or marginal marine origin.

STATISTICAL GEOCHEMISTRY AND PETROLOGY

Q-mode factor analysis

A. T. Miesch has extended the method of *Q*-mode factor (vector) analysis to allow development of factor models that can be used to reproduce the matrix of chemical or mineralogic data, or an estimate of the data, in units of percent or parts per million. Previously, factor models have been used to reproduce the data only in normalized form. As a consequence, the factor loadings generally have not summed to unity for each sample and could not be interpreted as proportions of end members. Also, because the factor scores were available only in normalized form, they could not be easily interpreted as end-member compositions. The only requirement of the extended form of the *Q*-mode method is that the rocks of the original data matrix, each representing the composition of a sample, sum to a constant (generally 100 percent).

The extended method appears well suited for purposes of summarizing multivariate geochemical or mineralogic data or for classifying samples on the basis of composition, but its principal use may be for the development of petrologic mixing models. Development of mixing models begins with the construction of a factor-variance diagram which gives the proportion of the variance in each constituent that may be accounted for by models containing various numbers of end members. After the proper number of end members has been determined, their compositions are sought either by examination of selected vectors or by testing actual compositions of materials thought to have been involved in the genesis of the petrologic system. The second of these approaches has proved more fruitful, especially where it has included thorough systematic testing of compositions throughout such systems as albite-anorthite-orthoclase, forsterite-fayalite, and hypersthene-wollastonite-ferrosilite.

Factor-variance diagrams are significantly more useful for determination of the proper number of end members the model should contain than are the eigenvalues of the similarity matrix customarily used. The eigenvalues indicate the general degree to which the normalized data may be reproduced by the model but give no information about specific compositional variables. Also, the sample communalities indicate the degree to which the normalized data for each sample may be reproduced by the model, but they do not indicate whether all variables are accounted for to the same degree or whether they vary a great deal in this regard. Factor-variance diagrams are constructed directly from comparison of the reproduced and original data matrices, and they commonly show that a small number of end members accounts for all but a few of the compositional variables in a petrologic system. The few remaining variables are then best explained by specific processes that affect their variability alone.

In conventional factor analysis, the signs of the factor loadings are regarded as arbitrary and may be changed across all samples. Consequently, the question of whether an end member has been mixed in or unmixed (separated) from the system is not resolved in the analysis. With the extended *Q*-mode method, the signs of the loadings are fixed and depend on the choice of end members and the compositional variation of the rocks under examination. Negative loadings are interpreted as proportions of the end member separated from the system, such as the separation of olivine from a magma during fractional crystallization.

Q-mode models have been developed to summarize the compositional variation in agricultural soils of

Missouri (with R. R. Tidball), in native soils of Missouri (with J. A. Erdman), in selected bedrock units of Missouri (with R. J. Ebens), and in the major geohydrologic units of Missouri (with G. L. Feder).

Petrologic mixing models have been developed for (1) a rhyolite-basalt complex on Gardiner River, Yellowstone Park, Wyo. (Fenner, 1938), (2) a granitoid intrusive in the southern Snake Range, Nev. (Lee and Van Loenen, 1971), (3) the 1959 summit eruption at Kilauea, Hawaii (Murata and Richter, 1966), and (4) the layered series of the Skaergaard intrusion, Greenland (Wager and Brown, 1968).

The factor-variance diagram for the rhyolite-basalt complex on Gardiner River clearly indicates that most chemical constituents can be accounted for by mixing of only two end members; the only constituents not accounted for by such mixing are Na_2O, H_2O+, and Fe_2O_3. The resultant model shows that the rhyolitic and basaltic extremes in the compositional series formed by the samples are entirely adequate end members, and that if one of the end members were a gaseous component as proposed by Fenner (1938, p. 1482–1483), the composition of this component would have necessarily been about equal to that of total rhyolite. The model supports the interpretation of Wilcox (1944) that the complex formed by the mixing of two lavas.

The factor-variance for the granitoid intrusive in the southern Snake Range shows that much of the compositional variation can be explained by mixing of two end members; constituents not explained by such a process are Na_2O and H_2O+. One of the end members is interpreted to have been a felsic magma similar in composition to the most siliceous part of the intrusive. The other end member had the composition of dark inclusions which are abundant in the intrusive's eastern part. Although Lee and Van Loenen (1971) interpret the inclusions as xenoliths of Pioche Shale, the factor analysis shows that they are much more similar in composition to an argillite of Precambrian age that occurs in the area. The possibility that the inclusions are of igneous origin cannot be ruled out.

The factor-variance diagram for the lavas and pumices from the 1959 summit eruption at Kilauea shows that mixing or unmixing of four end members will explain nearly all of the variation in the nine major oxides, except K_2O. The resultant model explains the variation as having been caused by the mixing of a parent magma with either a second magma or an older cumulate in the lower part of the magma chamber. Additional variation, according to the model, was caused by the separation of olivine ($Fa_{13.6}$) and clusters with a normative composition of enstatite, anorthite, forsterite, and magnetite.

The factor-variance diagram for the layered series of the Skaergaard intrusion shows this to be the most complex of the four series examined. However, assuming that the parent magma had the composition of sample 4507 of Wager and Brown (1968, table 7) but with a water content of 0.25 percent (Wager and Brown, 1968, p. 192), the compositional variation can be explained perfectly by precipitation and redistribution of plagioclase (containing 2 molar percent orthoclase), olivine, Fe-augite, Mg-augite, low Ca pyroxene, and clusters of magnetite, ilmenite, and chromite. The model requires an addition of iron to the parent magma; if the iron were derived from the hidden zone beneath the layered series, the hidden zone must form at last 50 percent of the total intrusive.

Variograms and variance components

Two seemingly different approaches that have been used in the examination of compositional variations in rock bodies have been shown to be basically the same. One of these approaches is the method of variography developed over the past 10 yr by the French school of geostatistics; the other is the classical analysis of variance approach which was used in geochemistry as early as 1937. A. T. Miesch (unpub. data, 1974) has shown that the points on a variogram are exactly equal to the cumulative sums of corresponding variance components, and that the variance components may be used to construct the variogram, thereby allowing geochemists to employ the theory of variography in the analysis of geochemical data. The finding may also be of use to proponents of variography, in that the hierarchical sampling designs used in the classical analysis of variance approach may be employed; such designs are commonly more practical and efficient than the equal-interval designs sought in variography.

ISOTOPE AND NUCLEAR GEOCHEMISTRY

ISOTOPE TRACER STUDIES

Lead isotopes applied to ore genesis and ore-prospect evaluation

The current status of the use of lead isotopes applied to problems of ore genesis and ore-prospect evaluation has been reviewed by B. R. Doe and J. S. Stacey (unpub. data, 1974).

Lead-isotope data are now available not only for ores but also for cryptic rock leads from ultrabasic, oceanic and continental volcanic, granitic, metamorphic, oceanic-pelagic, and continental sedimentary rocks. The data show great application to problems of ore genesis and show great promise in ore-prospect evaluation.

In ore genesis, the major applications are (1) in defining the source material for the lead in the ores and (2) in determining an estimate of the age of mineralization. For an example of each application, isotopic studies have shown that (1) the lead in the Phanerozoic galena ores of southeast Missouri has been mainly from a Cambrian sandstone aquifer unit and perhaps partly the Precambrian basement and Paleozoic carbonate host rock units (in agreement with a lateral secretion hypothesis) and (2) the age of the bulk of the ores in the Coeur d'Alene district in Idaho now is established as Precambrian, whereas some scientists previously thought the deposit to be Cenozoic.

Applications to ore-prospect evaluation are as follows:

1. Most major base-metal ore deposits of the world have characteristic lead-isotope ratios, and many appear to have lead-isotopic compositions that evolved under conditions approximating single-stage conditions. Under these conditions, no changes would have occurred in the value of U:Pb and Th:Pb in the source of the ores since the formation of the Earth, other than those resulting from radioactive decay of uranium and thorium. Many minor deposits appear to have leads not evolved under these conditions. This difference in lead-isotopic composition between major and minor ore deposits provides an isotopic tool for ore-prospect evaluation anywhere in the world.
2. A refined application involves matching the lead of a prospect with that of a producing deposit in the same district, because different producing deposits within a district often have similar lead-isotope compositions. This application extends the use of lead isotopes in ore-prospect evaluation to certain major ore deposits that have anomalous leads, such as those of the Mississippi Valley.
3. The leads in the high-temperature copper ores of Utah are similar in isotopic composition to leads in the igneous rocks, and the leads in the low-temperature lead-zinc-silver ores at Creede, Colo., have characteristics that must be related to underlying Precambrian country rocks, which suggests that the lead isotopic composition might parallel the zoning of the ore metals in a district.

Strontium isotope relations in ophiolites of the Western United States

M. A. Lanphere (1973) has studied the strontium isotopic relations in two ophiolite complexes in the Western United States. The Canyon Mountain, Oreg., and the Red Mountain, Calif., ophiolites, slices of oceanic crust and upper mantle tectonically emplaced at continental margins, have well-developed alpine peridotite-gabbro complexes of the harzburgite subtype and mafic to felsic intrusive and extrusive rocks. At Canyon Mountain, $^{87}Sr/^{86}Sr$ initial ratios of gabbro, trondhjemite, albite granite, and keratophyre range from 0.7031 to 0.7044. At Red Mountain, hornblende and (or) plagioclase from gabbro and cumulus peridotite in the gabbroic complex have $^{87}Sr/^{86}Sr$ initial ratios ranging from 0.7030 to 0.7041. Keratophyre at Red Mountain has a $^{87}Sr/^{86}Sr$ initial ratio of 0.7052. These strontium isotopic ratios are significantly higher than $^{87}Sr/^{86}Sr$ ratios in Holocene ocean-ridge tholeiites from the East Pacific and mid-Atlantic Rises, but they are not significantly different from tholeiites from the mid-Indian Rise. Clinopyroxene from pyroxenites in the ultramafic complexes at Canyon Mountain and Red Mountain have $^{87}Sr/^{86}Sr$ ratios greater than 0.708. The strontium isotopic relations suggest that the ultramafic complexes at Canyon Mountain and Red Mountain have had a different history from the overlying constructional parts of these ophiolites. Thus, the ultramafic complexes can be regarded as blocks of mantle material independent in origin from the overlying gabbroic and volcanic rocks.

Strontium isotopes applied to problems involving the San Andreas fault, California

R. W. Kistler, Z. E. Peterman, D. C. Ross, and David Gottfried (1973) have determined that initial $^{87}Sr/^{86}Sr$ ratios of Mesozoic granitic rocks in the vicinity of the San Andreas fault zone from the Gualala area in the north to the Southern California batholith in the south, relative to ratios of granitic rocks in the Sierra Nevada, are distributed in such a way as to be compatible with a suggested large-magnitude right-lateral offset along the San Andreas fault zone. Two stages of motion of basement terrane are suggested to bring the granitic rocks with distinctive initial $^{87}Sr/^{86}Sr$ ratios to the west of the San Andreas fault zone into a reasonable prefault configuration. The first of these stages occurred after the Late Cretaceous and prior to the middle Eocene and used the San Andreas fault north of the Garlock fault, the southern part of the Sur-Nacimiento fault, and the Reliz-Espinosa-San Marcos-Rinconada fault zone as the break between lithosphere blocks. The second of these stages occurred after the early Miocene and used the entire length of the present-day San Andreas fault plus the San Gabriel fault zone as the break between lithosphere blocks.

Strontium isotopes applied to the origin of the Pikes Peak batholith, Colorado

A study of the initial $^{87}Sr/^{86}Sr$ ratios and Rb:Sr abundances in various intrusive rock types of the Precambrian Pikes Peak batholith by C. E. Hedge and Fred Barker indicates that more than half of the batholith was derived from slightly older, preexisting granitic rocks. New data of this type have been obtained from gabbro, anorthosite, syenite, fayalite granite, and the predominant hornblende-biotite granite of this 1,040-m.y.-old batholith. The initial strontium isotope ratios show a progressive and unexpectedly wide range—from about 0.704 in the gabbro and anorthosite to 0.710 in the hornblende-biotite granite. These ratios and the Rb:Sr abundances confirm a model for generation of the batholith now being proposed by Fred Barker, D. R. Wones, W. N. Sharp, and G. A. Desborough (unpub. data, 1974). That model involves emplacement of an alkali basalt magma body in granulite-facies lower crust; settling of olivine, clinopyroxene, and plagioclase; vigorous convection; and reaction with, and partial melting of, the roof rocks by Bowen's mechanism. In this way, Na_2O, Al_2O_3, and SiO_2 are selectively added to the liquid, which becomes syenitic and about 58 to 62 percent in SiO_2 content. When the liquid makes contact with the root zones of the 1,700–1,450-m.y.-old granitic batholiths, at least half of those older rocks melt, temperature of the liquid drops 200° to 250°, convection homogenizes the new granitic liquid, and failure of the roof permits upward movement to present-day positions.

Further work on hornblende-free biotite granite of the batholith is being done by Hedge and Barker, in the hope of quantifying the model, and coordinated minor-element studies by H. T. Millard, Jr., and oxygen isotope studies by J. R. O'Neil also are being made to test or elaborate the model.

STABLE ISOTOPES

Panasqueira tin-tungsten deposits

R. O. Rye (USGS) and W. C. Kelley (Univ. of Michigan) have completed a fluid-inclusion and stable-isotope study of the Panasqueira, Portugal, tin-tungsten deposit. This is a Hercynian deposit, which occurs in a horizontal vein system through a central cupola. It is the largest supplier of tungsten to Western Europe.

The δD values of waters in fluid inclusions in quartz, cassiterite, sphalerite, wolframite, pyrite, arsenopyrite, pyrrhotite, chalcopyrite, fluorite, apatite, calcite, and dolomite range from -45 to -126 per mil and indicate that both deep-seated and meteoric waters were present in the ore fluid. The data suggest that one type of fluid was responsible for deposits or ore minerals, whereas another fluid was associated with quartz deposition. The $\delta^{18}O$ values of quartz gangue vary systematically from the central cupola outward into the surrounding pelitic schist and prove that the ore fluids flowed outward from the central cupola. The $\delta^{34}S$ values of early sulfides fall in a narrow range near 0 per mil, suggesting a deep-seated source for the early hydrothermal sulfur. The late $\delta^{34}S$ values of the sulfides have a wide range of positive values, suggesting a shallow source for the late hydrothermal sulfur. The $\delta^{13}C$ values of carbonates range from -10 to -14 per mil and suggest a substantial graphitic source for carbon in the hydrothermal fluids.

Epithermal gold-silver deposits

J. R. O'Neil and M. L. Silberman have measured the oxygen-isotope ratios of hydrothermal minerals from 22 Tertiary epithermal gold-silver vein deposits mainly in the Great Basin, Nev. Most of the samples have relatively light $\delta^{18}O$ values, indicating a meteoric-water component to the ore fluid; however, $\delta^{18}O$ values of samples from a few deposits are relatively heavy. Deuterium analyses of fluid inclusions in quartz and adularia from 15 deposits, including those with ^{18}O-rich minerals, are uniformly isotopically light with a δD range of -90 to -139—virtually identical to the range of δD observed for modern spring waters in the Great Basin. The deuterium measurements clearly demonstrate the dominance and probable exclusivity of meteoric water in the hydrothermal fluids of such deposits.

Knowledge of the age, location, and isotopic composition of meteoric waters allows possible reconstruction of ancient topographies and climates. These initial measurements indicate that such reconstructions are quite feasible for the Great Basin in Tertiary time.

The results of isotopic analysis of a sample of quartz in bonanza silver ore from the 1200-foot level of the Con Virginia mine of the Comstock Lode district are unique in this study. The δD of inclusion water from this sample is −68.5, implying that approximately 80 percent of the water in the ore fluid was magmatically derived.

Climax molybdenum deposit

W. E. Hall, Irving Friedman, and J. T. Nash have made a fluid-inclusion and stable-isotope study of the Climax molybdenum deposits in Colorado. The Climax mine contains three molybdenite ore bodies and widespread late quartz-pyrite-sericite barren mineralization, each related to separate intrusive phases of the Climax stock. Alteration zones spatially related to each molybdenite ore body include a silica zone below, a potassium-silicate zone that approximately coincides with ore, and overlying quartz-sericite-pyrite topaz, argillic, and propylitic zones.

The $\delta^{18}O$ values of quartz range from +8.4 to 10.9 per mil; $\delta^{18}O$ values of muscovite and sericite range from −0.8 to +7.5 per mil. Eight of ten sericite values are between +5.8 and +7.5 per mil. All of the quartz and most of the sericite is in isotopic equilibrium with a calculated water at 350°C with $\delta^{18}O$ values of +3.0 to 5.5 per mil. The $\delta^{18}O$ values of potassium feldspars range from −4.5 to +7.5 per mil. This wide range indicates partial reequilibration of the feldspar with later isotopically light waters.

Two muscovites have δD values of −146 and −91 per mil; sericite ranges from −168 to −116 per mil. The calculated δD values of water at 275°C in equilibrium with sericite are −144 to −92 per mil. This range is the same as that of fluid inclusions in ore samples. Kaolinite in the argillic zone has $\delta^{18}O$ values of −0.9 to −2.2 per mil and δD values of −162 per mil. Calculated water at 250°C in equilibrium with kaolinite has $\delta^{18}O$ values of −4.7 to −6 per mil and δD of about 130 per mil.

The isotopic and fluid-inclusion data best fit a model whereby the Climax ore bodies were formed from a hydrothermal fluid that originated by mixing of light and heavy waters. The light water is isotopically similar to present-day meteoric water; the heavy water has the isotopic composition postulated for magmatic water, although it could be meteoric water that was heavier than present-day meteoric water.

Ore fluids of diverse origins

D. E. White has summarized current isotope data available for deducing the origin of the dominant fluid of about 40 ore deposits, ore districts, and active geothermal systems high in ore metals. The number of systems with sufficient isotope data to permit deductions has increased spectacularly since 1967, when the fluids of only five systems were well enough known. White's earlier conclusions seem to be strongly supported, that fluids of two or more origins are involved in the generation of most but perhaps not all ore deposits. Introduction of meteoric water is evident in an overwhelming fraction of many deposits, probably during ore-emplacement stages. The evidence is especially clear for epithermal gold-silver and epithermal base-metal deposits. Solid evidence for magmatic water as a dominant or important fraction is indicated for many porphyry copper and base-metal deposits, but many other deposits, including those of mercury, provide no support for magmatic fluids.

Brines of high salinity (>2 percent and generally 5–40 percent) were involved in all or nearly all base-metal deposits; they have various origins, including ocean, evolved connate, meteoric plus evaporites, metamorphic, and magmatic. The metals, sulfur, and other dissolved constituents do not necessarily have the same origins as the transporting fluids. Thus, no simple model of origin explains all or even most metalliferous ore deposits.

Revised fractionation factor

Knowledge of the oxygen-isotope fractionation factor between CO_2 and H_2O at 25°C is of prime importance in oxygen-isotope geochemistry. Published values range from the generally accepted value of 1.0407 to 1.0428, while precision associated with the determination is ±0.0001. New independent determinations have been made by Irving Friedman and J. D. Gleason in Denver and by J. R. O'Neil and L. A. Adami in Menlo Park. Their values are 1.0414 and 1.0412, respectively. It is clear that the true factor is larger than the accepted value of 1.0407.

Oxygen-18 in organic matter

Until now it had been impossible to make precise determinations of O^{18}/O^{16} ratios in organic material. Irving Friedman and K. G. Hardcastle have developed a technique whereby milligram quantities of organic material are pyrolyzed in the presence of diamonds heated to 1,250°C. The carbon monoxide formed is converted to carbon dioxide by gaseous discharge. The precision obtained is ±0.35 per mil.

Oxygen-18 rich dolomite

Irving Friedman and T. J. Donovan find that samples of dolomitic cap rock from the apex of several oil fields have anomalous δO^{18} values which range from +38 to+45 per mil. These are in comparison to maximum values of about +30 per mil found for normal dolomites or limestones. The cause of the O^{18} enrichment is still unknown and under investigation.

ADVANCES IN GEOCHRONOMETRY

Volcanic history of southwestern Saudi Arabia and the opening of the Red Sea

Studies by R. G. Coleman, R. J. Fleck, C. E. Hedge, and E. D. Ghent of the Tertiary igneous history of southwestern Saudi Arabia shows that Sirat Plateau Volcanics erupted between 29 and 24 m.y. ago, and that these volcanics are equivalent to the widespread Yemen and Ethiopian trap series. Early Sirat eruptions were picritic and evolved into alkali olivine basalts, basanites, and finally into hawaiites. Associated feeder pipes have complementary compositions, and their distribution indicates a much larger outcrop area than is presently exposed. In Miocene time (about 22 m.y.), the Jabal Turf volcanic rift zone developed as a result of crustal thinning and warping. Diabase dike swarms, layered gabbros, granophyres, and rhyolite dikes invaded this rift zone and are representative of a differentiating subalkaline tholeiite. The fractionation trends recorded by these rocks are similar to those in previously described areas where tholeiitic magmas have differentiated at shallow levels within the crust. The early Miocene development of the Jabal Turf volcanic rift zone was a short-term event and was followed by Pliocene-Pleistocene-Holocene eruptions of alkali basalts on the tilted rift zone. These later eruptions consist of nepheline-bearing alkali basalts, basanites, and hawaiites which contain xenoliths of websterites and harzburgites. Contemporaneous with the Coastal Plain alkali basalts was the Red Sea axial trough subalkaline tholeiites resulting from the continental breakup of Africa and Arabia. Strontium-87/strontium-86 ratios combined with information on the incompatible elements indicate that the southwestern Saudi Arabian volcanics may have been derived from the same mantle material but have been modified later by different degrees of partial melting, fractionation, or tectonic setting.

The alkali basalts of Sirat, Yemen, and Ethiopia appear to occupy separate large-scale north-south arches with the Precambrian basement and preceeded rifting in the Red Sea by 20 to 30 m.y. There appears to be no direct relationship between these structures and the later northwest-trending Red Sea rift. The earliest volcanism (22 m.y.) related to the Red Sea structure was crustal attenuation and formation of the Jabal Turf volcanic rift zone. This short-lived (2- to 5-m.y.) event was followed by a long period of evaporite development in the Red Sea depression and only intermittent volcanic activity. Red Sea axial rifting commenced in the Pliocene or latest Miocene with the development of axial trough subalkaline basalts and apparent continuation of alkali basalt volcanism on the Arabian and Nubian plates following preexisting structural highs. Hot spots or mantle plumes cannot be effectively utilized to explain the sequence of tectonic and volcanic events.

Age of tonalite-granodiorite gneisses, western Saudi Arabia

R. J. Fleck, W. R. Greenwood, D. G. Hadley, and W. C. Prinz (1973) have shown that large areas of the shield area of western Saudi Arabia are made up of bodies of massive, vaguely foliated, tonalite to granodiorite gneiss. Many of these gneisses retain original igneous characteristics, although all have been subjected to a 500 to 600-m.y. orogenic event correlated with the Mozambiquian or pan-African orogeny. Two mineralogically separable units were studied: a granodiorite (biotite-muscovite) gneiss and a tonalite (biotite-hornblende) gneiss. Potassium-argon ages of biotite and muscovite from the granodiorite gneiss average 558 m.y. and 567 m.y., respectively, whereas hornblende K-Ar ages from the tonalites average 732 m.y. (R. J. Fleck, R. G. Coleman, H. R. Cornwall, W. R. Greenwood, D. G. Hadley, W. C. Prinz, J. C. Ratte, and D. L. Schmidt, 1973). Rubidium-strontium whole-rock isochrons were obtained on both units with no evidence of disturbance of total-rock strontium isotopic ratios. An age of 758.6±36.0 m.y. with an initial Sr^{87}/Sr^{86} of 0.7037±0.0002 was obtained for the granodiorite gneiss. The tonalite gneiss samples yield an age of 957.6±21.6 m.y. and initial ratio of 0.7029±0.0001. The low initial Sr^{87}/Sr^{86} values of these rocks argue against an anatectic origin and are more consistent with a subcrustal source. Because the tonalites intruded a thick sequence of metasedimentary and metavolcanic rocks, the ages obtained confirm the presence of rocks at least 1,000 m.y. old in the Arabian Peninsula.

Dating of the Silver Cliff-Rosita volcanic centers

Geologic relationships, as developed by W. N. Sharp, illustrate at least five separable volcanic events in the area of Silver Cliff and Rosita, Colo.

Fission-track ages by C. W. Naeser and K-Ar ages by C. E. Hedge and R. F. Marvin indicate that this volcanic activity occurred in two periods at 29 to 30 and 26 to 27 m.y. ago. The total time interval at Silver Cliff-Rosita is the same as that for the major intermediate to silicic volcanism in the San Juan volcanic province 80 km to the west. Economically significant mineralization, at Silver Cliff-Rosita, was later than the active volcanism.

Determining age of mineralization from potassium-silicate altered wallrock

In many mineral deposits, hydrothermal alteration has produced vein and wallrock mineral assemblages that can be dated by the K-Ar method. An example has been studied by M. L. Silberman at the Aurora mining district in western Nevada. Hydrothermal alteration adjacent to the vein system has caused recrystallization and replacement of the andesitic host rocks to an assemblage of potassium-feldspar, sericite, quartz, and pyrite. The mineralization was dated by separating adularia from one of the gold-bearing veins and obtaining a K-Ar age of 10.3±0.2 m.y. A whole-rock K-Ar age on a sample of altered wallrock (K_2O=8.0 percent) was 10.7±0.4 m.y. Evidence supporting this approach to the dating of hydrothermal deposits can be found in recently published reports on the Bodie mining district, California (Silberman and others, 1972), and the Battle Mountain replacement copper-gold deposit (Theodore and others, 1973). Those results indicate that it may be possible to determine the age of mineralization of many ore deposits in which suitable vein minerals are not present for isotopic dating. Careful study of the wallrock alteration mineral assemblages should be made before using whole-rock dates for this purpose. Samples consisting of argon-retentive mineralogy such as adularia (monoclinic feldspar) and muscovite appear to give good results. The presence of inert minerals such as pyrite, quartz, and chlorite do not appear to adversely affect the results. Samples with potassium-bearing but nonargon retentive minerals such as clays and zeolites should be avoided.

Dating minerals from a deep test hole

Fission track and K–Ar ages have been determined on minerals separated from core from the Eielson deep test hole, Alaska. The deep test hole penetrated 2,981 m of crystalline schists in the basement complex of the Yukon-Tanana Upland. The K–Ar ages determined by D. L. Turner (USGS) and R. B. Forbes (Univ. of Alaska) on biotite separated from core taken at depths of 2,979 m and 1,873 m have ages of 65.3 m.y. and 84.9 m.y., respectively. Fission-track ages determined on apatite by C. W. Naeser (USGS) separated from cores at depths of 2,979 m, 1,873 m, 974 m, and 316 m have ages of 12 m.y., 56 m.y., 116 m.y., and 101 m.y., respectively. The apatite and biotite ages extrapolate to a surface age for both minerals of about 120 m.y. This age is consistent with other biotite K–Ar ages determined in this area.

The temperature at the bottom of the hole is 94°C. The thermal gradient is about 30°C/km. Extrapolating the age data to depth shows that a 0 age for apatite would occur at a depth of 3,355 m and a temperature of about 112°C, and that a 0 age for biotite would be reached at a depth of 6,862 m and a temperature of about 230°C.

By looking at the apatite fission-track and biotite K–Ar ages from test holes in prospective geothermal areas, it may be possible to determine the thermal history of the area. Discordant age patterns, such as those observed here, if found at the surface would indicate a potential geothermal area.

Uranium-series dating of fossil bones

Quaternary deposits are exposed on numerous bluffs along the South Saskatchewan River near Medicine Hat, Alberta, Canada. These deposits, which are several hundred metres thick, record at least four separate glacial advances and several interglacial and interstadial intervals. The vertebrate fossils are being studied and identified by C. S. Churcher (Univ. of Toronto) and the deposits are being described and correlated by A. M. Stalker (Geological Survey of Canada).

Ten fossil bones, mainly mammoth and horse, have been analyzed for uranium-series dating by B. J. Szabo (USGS) and others (1973). The uranium-series date of the post-Wisconsin fossil is in agreement with that of radiocarbon (9,500±1,500 yr). The bones from the "Sangamon" bed at Mitchell Bluff are dated to be 72,000±6,000 yr old. Interestingly, Stalker reports numerous poorly worked or flaked stones in this unit that indicate the presence of an early man.

Bison and mammoth bone fragments from three Pleistocene deposits along the Rocky Mountains front have also been dated by the uranium-series method. One sample, collected near the base of Slocum Alluvium near Canon City, Colo., indicates migration of uranium; however, it was possible to calculate an open-system date of 160,000±60,000 yr, which appears to be consistent with the geologic estimate. A sample from the bison horn from the lower part of the Louviers Alluvium near Denver, Colo., yielded a Th^{230} date of 84,000±5,000 yr and a Pb^{231} date of 92,000±8,000 yr. Thus, the two measurements gave concordant results within limits of error. The Louviers is believed to be younger than the Slocum and has been correlated with Bull Lake Glaciation.

Uranium-series dating of nonglacial marine deposits

Major climatic variations during the Pleistocene appear to be a worldwide phenomenon associated with large changes in climate and the level of the sea. Uranium-series dating of marine strand lines and other continental glacial and nonglacial deposits helps to develop the absolute chronology of paleoclimatic changes and allows the correlation of these various marine deposits and soils. Previous dating of marine strand lines of Barbados, Oahu, and New Guinea indicates that the nonglacial period at about 125,000 yr ago was a worldwide phenomenon associated with large change in the level of the sea. This conclusion is supported by a study by B. J. Szabo, who determined uranium-series ages for nonglacial marine deposits from three widely spaced locations —Australia, the Bahama Islands, and the Aleutian Islands.

Five samples (four corals and one shell) have been dated from the elevated coral reef terrace at Rottnest Island, Australia. The average age is calculated to be 132,000±5,000 yr. One coral and one shell sample have been dated from the elevated fossil beach deposit at Mores Island, Bahamas, and the average age is 126,000±12,000 yr. From the fossiliferous marine deposit at the South Bight locality, Amchitka, Aleutian Islands, three shells and one bone sample have been dated. The average age is calculated to be 117,000±5,000 yr.

GEOTHERMAL SYSTEMS

Prehistoric temperatures of geothermal fields

E. W. Roedder (USGS), in cooperation with P. R. L. Browne and Anthony Wodzicki (New Zealand Geological Survey) (Browne, Roedder, and Wodzicki, 1974) studied primary aqueous inclusions in hydrothermal quartz, sphalerite, and adularia from boreholes in the Broadlands geothermal field, New Zealand. Homogenization temperatures from various depths range from 37°C below to 28°C above present borehole temperatures, and they average 16°C below the boiling point curve for pure water at equivalent depths. Paired vapor-rich and liquid-rich inclusions in quartz, however, suggest entrapment of boiling solutions at no more than 0.25 atmosphere of CO_2 pressure. Inclusion-freezing temperatures (−0.3 to −0.8±0.05°C) indicate fluids of 5,100 to 13,600 ppm NaCl equivalent, whereas present salinities in the borefield are only about 3,000 ppm.

The differences between the fluid-inclusion data and the present borehole temperatures and compositions appear to represent changes in the fluids with time, although the actual time of growth of the crystals during the 100,000-yr life of the Broadlands field is uncertain. Continuous throughput of meteoric water appears to have flushed much of the original salt out of the geothermal system. The heat-flow regime, however, has been stable with time, as indicated by the relatively small differences between homogenization temperatures and borehole temperatures.

Numerical modeling of geothermal systems

J. W. Mercer and G. F. Pinder have derived the partial differential equations describing the transport of heat in a single-phase (hot water) geothermal system and have developed a numerical-solution technique using the Galerkin criterion with the finite-element method. Steady-state and transient conditions from 1953 to 1962 at the Wairakei geothermal system in New Zealand were modeled. Results compare well with observed data, indicating that the model can be used to aid in the evaluation of hot-water geothermal systems. The single-phase model could not reproduce the more recent Wairakei production data because of the steam developed in the aquifer after 1962.

Production characteristics of hot-water geothermal wells

Manuel Nathenson has developed a method of calculating the expected production of hot-water geothermal wells that flash to steam-water mixtures in the cased part of the hole. The method assumes a rudimentary reservoir model with steady Darcy flow, and it utilizes an approximate analysis in the region of flashing steam-water flow. Mass flow is calculated for base temperatures of 200°C to 250°C, several depths to water table, and a range of permeability. Predicted flows agree with field data from geothermal wells in the Imperial Valley, Calif., and at Wairakei, New Zealand.

Geophysical logging of geothermal wells

A project under the direction of W. S. Keys has developed the capability to log geothermal wells at temperatures up to 250°C. Natural gamma, gamma-gamma, neutron, temperature, and caliper probes are either completed or under test, and other probes are under development.

Since secondary (or fracture) porosity appears to be of major importance as a source of hydrothermal water in many areas, R. H. Merkel has developed computer programs that calculate primary and secondary porosity from geophysical log data. Also, Merkel has developed programs that utilize standard logs to determine mineralogy at each depth interval. This information is combined with the porosity log to give the thermal conductivity, which in turn is integrated with the temperature log to give an estimation of heat flow.

Deep drill hole at Kilauea Volcano, Hawaii

A drill hole to 1,292 m was completed at Kilauea Volcano, Hawaii, by G. V. Keller (Colorado School of Mines) with funding by the National Science Foundation and in cooperation with the staff of the USGS Hawaiian Volcano Observatory. The drill hole is located 1.1 km south of the summit of Kilauea and is centered over an electromagnetic anomaly interpreted by D. B. Jackson and Keller (1972) as due to a hydrothermal cell. The locality also coincides with centers of ground deformation and frequent shallow earthquakes. Equilibrium temperature at hole bottom was about 138°C. After drilling, fluid level stabilized at 488 m, about 610 m above sea level, indicating a local, high-level water table. Core recovery was disappointingly meager, about 4 percent. Schlumberger resistivity logs display significant conductivity changes with depth, but interpretation has been hampered by the small amount of core recovered and the lack of satisfactory formation fluid samples.

Convection in nonflowing geothermal wells

Using newly designed equipment with an accuracy of ±1°C and a precision of ¼°C, Manuel Nathenson (1974) has studied buoyancy-induced convective flow in a 73-m-deep well filled with warm to hot water. The temperature gradient in the well is between 500 and 2,000 times the critical gradient for the onset of convection. As a consequence, the convection departs from steady state and is expressed as eddies of various sizes continually forming and decaying. The highest gradient measured was 4°C/m. The largest change in temperature in any particular eddy was about 1°C, indicating that the fluid came from about 25 cm from the point of measurement.

Chemical and isotopic studies of hot-spring waters and gases from Shoshone Geyser Basin, Yellowstone National Park

Studies by A. H. Truesdell showed that hot-spring character and chemistry change systematically from east to west across Shoshone Geyser Basin, Yellowstone National Park, Wyo. These trends are oblique to four N. 50°E. lineaments, along which occur almost all of the hot springs, fumaroles, and sublacustrine gas vents. Chemical changes from east to west include decreasing $H_2S:CO_2$, (H_2S+CO_2):total gas, and total gas:water. Furthermore, the neutral and alkaline springs show decreasing chlorine content and $Cl:HCO_3$ from east to west. The SiO_2 contents and Na:K:Ca relationships indicate subsurface reservoir temperatures ranging from 203°C in the east to 160°C in the west. Although salinity of waters varies widely, Cl:B is +20 percent in all samples.

These chemical patterns indicated to Truesdell (1974) that as the thermal water flows obliquely upward from east to west, it undergoes steam separation, reacts with rocks, and is diluted with low-chloride ground water.

Carbon-isotope analyses by J. R. O'Neil (Truesdell and O'Neil, 1974) range in δC^{13} of CO_2 from −10.3 to −3.8, with the lighter values related to the higher temperature waters on the east. A narrow range of −4.4 to −3.0 is found for the δC^{13} of HCO_3^{-1}. The CO_2 carbon is too low in δC^{13} to have originated from thermal decomposition of limestone, but is compatible with a volcanic source with a possible organic component. Carbon-isotope temperatures calculated from CO_2-HCO_3^{-1} pairs correlate well with the chemical geothermometers.

Seismic noise in Yellowstone geyser basin

Seismic-noise data from Yellowstone National Park indicated to H. M. Iyer that high noise levels with predominant energy in the frequency band of 2 to 8 Hz are associated with all the major geyser basins. The noise is probably of deep origin, because surface phenomena such as geysers and fumaroles were shown to have characteristic seismic noise with frequencies much higher than 8 Hz.

New boiling springs in Long Valley, California

R. A. Bailey reported that several new boiling springs broke out on Hot Creek on August 25 and October 17, 1973, days on which earthquakes were felt in the vicinity of Long Valley. Although the epicenters of these earthquakes were determined by D. W. Steeples to be in the Sierra Nevada south of

Long Valley, the ground motion along Hot Creek apparently was sufficiently great to affect the plumbing of the hot springs. On the day following the August 25 event, Bailey remeasured the temperatures of 23 hot springs along Hot Creek and found that 13 of these had increased 3°C to 18°C over the previous year. This increase may also reflect the disturbance caused by the August 25 earthquake.

SEDIMENTOLOGY

Sedimentology, the study of sediments and sedimentary rock, encompasses investigations of principles and processes of sedimentation and includes development of new techniques and methods of study. Sedimentology studies in the USGS 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 studies involving sedimentology are directly applied to other topics such as marine, economic, and engineering geology, and to regional stratigraphic and structural studies; these are presented elsewhere in this volume under their appropriate headings.

Studies of fluvial sedimentation are directed toward the solution of water-resources problems involving water-sediment mixtures. Sediment is being considered more and more in terms 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.

VARIABILITY OF SEDIMENT YIELDS

Sediment transported into Lake Tahoe

Streamflow and fluvial-sediment discharge data are being collected, for a program started in the 1972 water year, at selected streams and highway gutters in the California part of Lake Tahoe basin. The program is designed to determine the extent of erosion from highway cuts. C. G. Kroll (1973) reported that the major part (87 percent) of suspended-sediment discharge by streams during the 1972 water year occurred during the snowmelt period, March through June. Precipitation in the Lake Tahoe area during the 1973 water year was 94 percent of normal. Seventy-one percent of the total 1973 annual runoff was recorded from March through June.

In a continuing study of streamflow and sediment transport into Lake Tahoe, P. A. Glancy (1973) reported that, during the 1971 water year, runoff of the five major streams in the Incline Village area, Washoe County, Nev., was about 21.7 hm^3. About three-fourths of the run-off was from Incline and Third Creeks. Sediment transported to Lake Tahoe by these streams was estimated to be about 9,980 t, of which about 60 percent was from Incline and Third Creeks. About 90 percent of the sediment was discharged to the lake during the snowmelt runoff period. The annual sediment load was estimated to consist of 78 percent sand and gravel, 13 percent silt, and 9 percent clay. Sediment transported by streams during periods of rainfall runoff generally contained greater percentages of silt and clay than that transported by snowmelt runoff. Estimated annual sediment yields ranged from 21 to 325 t/km^2 from undeveloped areas, and from 217 to 2,660 t/km^2 from developed areas. Estimates suggest that about 78 percent of the 9,980 t of sediment transported to Lake Tahoe during the year came from the undeveloped area. The resultant yield estimates (t/km^2) suggest that the estimated annual yield from the developed area was about 13 times that from the undeveloped area. Although 1971 cumulative runoff and cumulative sediment loads from the five major Incline Village streams were nearly identical to those of 1970, runoff and sediment-transport characteristics of individual streams varied considerably from year to year.

Sediment yields returning to normal six years after logging

The sediment yields from a small Oregon coastal watershed, 6 yr after the area was logged, are progressively diminishing toward prelogging loads, according to D. D. Harris. The annual yields from the Alsea watershed had jumped from a prelogging period (1959–65) of about 35 t/km^2 to more than 300 t/km^2 in 1967, the first full water year after logging. The largest decrease in yield after logging occurred in 1968, the second year after logging. The 1971 sediment yield was larger than the 1970 yield but was less than yields for other years after logging. Yields continued to decrease in 1972 and 1973. These reductions in yield are attributed to the stabilizing effect from the regrowth of small brush over the watershed; prior to logging, 85 percent of the area was covered by Douglas fir, and 15 percent was covered by alder and vine maple.

Sediment yields from highway construction in Pennsylvania

According to L. A. Reed, data are being collected from five adjacent drainage basins in Pennsylvania to determine the effect of highway construction on sediment discharge and to determine the effectiveness of different types of erosion- and sediment-control measures.

The data show that earthwork for the highway construction, which affects 8 percent of a drainage basin underlain by Martinsburg Shale near Harrisburg, Pa., has increased the suspended-sediment load tenfold. The transported sediment is about 60-percent clay, 40-percent silt, and less than 1-percent sand. Material being used in the earthwork averages about 40-percent sand, 35-percent silt, and 25-percent clay. Turbidities of the water discharged during storm events have increased about twentyfold. Sedimentation ponds between the earthwork area and the stream, which trap and store runoff from the construction area, appear to be the most effective method evaluated for reducing sediment discharge.

Stream turbidities documented during flood in southwestern Oregon

Turbidimeters installed in 1973 have recorded continuous turbidity readings through a flood on each of three streams in southwestern Oregon. R. L. Kraus reported that turbidity readings on the South Umpqua River near Days Creek exceeded 800 JTU. On Elk Creek near Trail, and on Rogue River near McCleod, where flooding was less severe than on the South Umpqua River, turbidity readings exceeded 400 JTU. At one site, the turbidity peak occurred 4–5 h before the flood peak. At a fourth site on the Applegate River near Cooper, turbidity readings reached and probably exceeded the 1,000-JTU limit of the turbidimeter scale just before the meter was inundated by floodwater.

TRANSPORT PROCESSES

Bed-material movement

A study of the bed-material movement of the West Branch Susquehanna River near Watsontown, Pa., was started by J. R. Ritter during the summer of 1973. Painted rocks of measured dimensions and weights were placed on the river bed at known locations. Other data on the riverbed were collected for computing bedload. According to preliminary computations, bed material of the sizes of the painted rocks will move only at extremely high flows, but apparently some of the rocks have moved at much lower flows. Nine cross sections of the river channel were surveyed and compared with surveys made previously. These nine sections will be resurveyed at least once a year.

Stochastic analyses of dune-bed profiles and transport rates

Application of stochastic models of bedload transport and dispersion requires a knowledge of the probability distributions of the step lengths and rest periods of single sediment particles. A procedure for determining these distributions from sounding records of the bed elevation has been developed by B. K. Lee and H. E. Jobson (1974). The procedure was tested on data for sediment under three different flow conditions in a large recirculating flume. It was found that the total sediment-transport rate could be predicted to within ± 3.5 percent for dune runs with any significant sediment movement. These predictions were based only on the sonic-sounder records.

Suspended- and bedload-sediment transport in large rivers

The transport rates of suspended and bedload sediment are being determined for the Snake and Clearwater Rivers in the vicinity of Lewiston, Idaho. W. W. Emmett (1973) reported that although the data-collection program is continuing indefinitely, data collected thus far have provided the U.S. Army Corps of Engineers with computer-input information to determine the height of levees necessary in the Lewiston area because of pending impoundment of water at Lower Granite Dam. Although suspended-sediment data are routinely collected by the USGS, the bedload data are unique. To date, they represent the largest assemblage of data collected for deep, fast rivers in the United States.

Growth and evolution of aeolian dune field in New Mexico

E. D. McKee reported (McKee and R. J. Moiola, 1975) that studies of the cores from four drill holes at White Sands dune field in New Mexico demonstrated that the body of sand below the present active dunes ranges from 5.5 to 10.4 m in thickness in the area tested and consists of two to three discrete sand sequences, or cross-stratified units of sand, not counting the current surface-sand deposits. Thick sequences of clean, well-sorted dune sand are separated from one another by thin layers of darker colored poorly sorted sediment accumulated in interdune areas and buried by the advance of migrating dune sands. Parallel parting planes appear in vertical sections of test trenches and in cores as thin, parallel layers of dark sediment between relatively thick units of white cross-stratified sand.

GLACIOLOGY

Monitoring of glaciers under the IHD program

Runoff and water-balance measurements made at South Cascade Glacier in the North Cascades, Wash., by R. M. Krimmel and W. V. Tangborn (1974) demonstrate the role of glaciers in moderating runoff. The summer runoff from mountain drainage basins that do not have glaciers is highly variable from year to year. Drainage basins that have a small fraction of glaciers have a natural variance which is considerably less. The mechanisms that cause this decrease in variance are: (1) The increased albedo of a glacier surface during years of high snowfall results in decreased ablation, hence less runoff. During years of low precipitation and less snowfall, much more low-albedo ice is exposed and runoff is increased. (2) The release of liquid storage from within the glacier is nearly independent of climatic variations and acts as an additional runoff moderator. A regression line of observed runoff versus winter-snow accumulation for 9 yr from the South Cascade Glacier basin has a slope of almost zero, whereas calculated runoff (which assumes no glacier) has a slope of nearly unity. Thus runoff from the glacier basin is remarkably independent of winter accumulation.

Similar results from the Maclure Glacier drainage basin, Sierra Nevada, Calif., an IHD study area, were reported by W. W. Dean (1974). The available data for 6 yr show that the glacier mass is sensitive to changes in annual precipitation. An average depth of 1.2 m of water equivalent was added to the glacier in the heavy-snow year of 1967, and 0.7 m was added in 1969. In 1968 and 1972, precipitation was below average and there was an average depth loss of 0.8 m of water equivalent from the glacier during each of these years. Annual runoff from the Maclure Creek basin fluctuated much less than annual precipitation. The basin accumulated 2.0 m of snow-water equivalent in 1967 but only 0.6 m in 1968. Yet, total runoff depth was 1.5 in 1967, when an average of 0.4 m of water was stored over the basin, and 0.9 m in 1968 because of the melting of 0.3 m of old ice and firn over the basin. The small Sierra Nevada glaciers provide natural cyclic water storage that smooths effects caused by fluctuations in precipitation.

L. R. Mayo and D. C. Trabant compared 1967 high-altitude snowpack data from the Gulkana and Wolverine Glaciers, Alaska, (IHD stations) with low-altitude snow from central and southern Alaskan valleys. The comparisons showed that in most characteristics (snow depth, density, temperature, and change in balance over a year), the interior Alaska Range snowpacks were strikingly similar to those in the coastal mountains. The coastal-valley snow was also similar, although it warmed up and melted off earlier in the year. The interior-valley snow, on the other hand, was notably shallower and less dense and represented a different climatic and hydrologic environment. Thus the Alaska Range has a north-Pacific maritime climate, whereas the adjacent valleys are characterized by a subarctic continental climate.

Glacier variations

Emmons Glacier on Mount Rainier, the largest glacier in the conterminous United States, is now advancing 30 m/yr and has advanced 183 m from September 18, 1967, to September 24, 1973, according to M. F. Meier and Austin Post. On other sides of the same mountain, the Cowlitz-Ingraham Glacier is currently advancing 17.6 m/yr; the two terminal lobes of the large Tahoma Glacier are advancing 5.1 and 2 .5 m/yr; and the Carbon Glacier is advancing about 16.2 m/yr. Other glaciers on Mount Rainier are retreating, and some have shown virtually no change during the last several years. Although Nisqually Glacier advanced 39.9 m from 1964 to 1968, it retreated 54.2 m from 1968 to 1973; a kinematic wave of thicker, faster ice is now traveling down the glacier and will cause the terminus to begin an advance in a few years.

A recent study of Portage Glacier, Alaska, was made by L. R. Mayo, Chester Zenone, and D. C. Trabant (unpub. data, 1974). Since 1880 the glacier has receded 4 km, leaving 190-m-deep Portage Lake in the glacially scoured valley. The mass-balance study revealed that the spectacular calving from the glacier terminus is caused primarily by thinning and retreat of the glacier; the current weather conditions are not producing sufficient snowfall to halt the recession. Thus, Portage Glacier will probably continue to retreat an estimated 1.5 km unless a relatively large climatic change occurs in the future.

Volcano-glacier interaction

Results of a study by D. J. Frank, Austin Post, and J. D. Friedman (1975) of debris avalanches on the east slope of Mount Baker, Wash., indicated that geothermal heat has triggered large slides from Sherman Peak, a crater rim remnant, every 2 to 4 yr since 1958. In the latest avalache, between August 20–21, 1973, approximately 35,000 m^3 of mostly snow and firn, with some hydrothermally altered rock and mud, slid 2.6 km down Boulder Glacier. It appears that the recurrent avalanches have a potential for damming water that drains the fumarole field in the crater. Such an ice dam would present a serious danger to the lower Boulder valley should the dam break.

D. J. Frank and S. M. Hodge demonstrated the existence of a subglacial tunnel through the length of the Boulder Glacier in Washington. Rhodamine B tracer dye was injected into the upper glacier where a stream (water temperature 4°C) composed of snow and ice melt water and thermal-spring water entered beneath the ice. Dye was detected at the glacier terminus (discharge temperature about 0°C) 4.9 km downslope within 2 hr and 55 min. Because of this discovery, a means of monitoring changes of thermal effluent from the core geothermal area of Mount Baker may be possible by sampling the chemical content of the Boulder Glacier discharge.

Subaqueous deposits in Lituya Bay, Alaska

In 1958, an 8.3-magnitude earthquake dislodged a 30,000,000 m^3 rockslide which fell into Gilbert Inlet at the head of Lituya Bay, Alaska. This avalanche did not come to rest in Gilbert Inlet, but instead, the bulk of the debris moved on into Lituya Bay. Austin Post compared NOAA hydrographic surveys of 1926 and 1959 and determined that between these dates more than 493,300,000 m^3 of sediments accumulated in the bay, forming an almost level-topped deposit in the deepest part. His 1973 survey indicated that further filling had occurred both in the main bay and in the inlets at its head. As only a part of this immense deposit can be attributed to avalanches, much of the remainder is attributed to turbidity-current movement of debris released from the tidal glaciers which discharge into the head of the bay.

The tilted forest; vegetation-covered neoglacial ice at Lituya Bay, Alaska

Forest-covered neoglacial ice remaining from a large glacier which retreated from Lituya Bay more than 300 yr ago was investigated in 1973 by Austin Post (USGS) and Gregory Streveler (NPS). From the amount of down wasting which has occurred since the glacier ice stagnated and from the depth of ice remaining, it is estimated that some ice may persist as much as 1,000 yr after the glacier has retreated. This is considered as evidence to the correctness of the suggestion by Porter and Carson (1971) that forest-covered stagnant ice persisted as much as 2,000 yr in the Puget Sound lowlands in Washington following the retreat of Pleistocene (Vashon) ice.

Basal shear stress of Pleistocene glaciers

On the basis of theoretical and empirical studies, the basal shear stress of a glacier appears to be rather constant, indicating a simple relation between the cosecant of the surface slope and the ice thickness. Most observed glaciers have values of basal shear stress between 0.5 and 1.5 bars, and a given glacier system appears to have rather constant values. K. L. Pierce reported that basal shear stress calculated from a reconstruction of the last major glaciation of northern Yellowstone Park ranges between the rather narrow limits of 1.2 and 0.6 bars. The higher values of basal shear stress occur in areas of convergent flow as they did in the northern Yellowstone area where four flow segments from ice caps converged to form the northern Yellowstone outlet glacier. Thus a check can be made of the mapping of various Pleistocene glaciers to determine if the reconstruction yields reasonable values of basal shear stress.

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 programs 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 Investigations."

PALEOZOIC OF THE UNITED STATES

Late Cambrian trilobite distribution and early Paleozoic lithospheric plate reconstructions

The geographic distribution of Late Cambrian trilobites along a shelf-to-basin profile from the upper Mississippi Valley to south-central Nevada has been compared by M. E. Taylor with the known distribution of Holocene isopod crustaceans from the northwestern and southern Atlantic Ocean. Taylor concludes that patterns of habitat endemism, geographic endemism, and boundaries between faunal subprovinces suggest that temperature differences are strongly associated with both the isopod and trilobite distributional patterns. This conclusion is consistent with general lithofacies patterns which show that deep-water (presumably cryophilic) trilobite assemblages were apparently not able to penetrate into warm shallow-water depositional sites. An implication of the inferred temperature control on distributional patterns is that reconstruction of early Paleozoic continental lithospheric plates should not be based on resemblance data based on deep-water trilobite assemblages. The latter, however, in conjunction with geological and geophysical data, may provide supportive evidence for rise and decline of midoceanic ridges that may have served as barriers to faunal dispersal in early Paleozoic ocean basins.

Ordovician bryozoan biostratigraphy in Kentucky

Continuing studies of the Bryozoa from Ordovician strata in Kentucky by O. L. Karklins now permit the recognition of the boundaries of some of the major biostratigraphic units (stages) away from the standard reference sections in the Greater Cincinnati area. The bryozoan faunule from the type section of the Bull Fork Formation (Peck, 1966) in Mason County at the boundary with Lewis County, indicates that the formation is of Richmondian Age. The Bull Fork Formation is 69.5 m thick at its type section, and the lower boundary of the Richmondian Stage at that section coincides with the base of the formation. Study of the 63 m of rock exposed in the Owingsville West section, 2.1 km west of Owingsville, Bath County, indicates that the lower Richmondian boundary occurs between 9 m and 18 m above the base of the section. The recognition of this biostratigraphic boundary in the Owingsville West section allows one to correlate the as yet unnamed lithic units at that section with the Bull Fork Formation in Mason County and with the standard section of Richmondian Age in Ohio and Indiana.

Ordovician and Silurian in a newly discovered window in central Idaho

The lithologic and paleontologic equivalent of the Silurian part of the Roberts Mountains Formation of Nevada is present in the Wildhorse Creek window, Standhope Peak quadrangle, Idaho. Mapping by J. H. Dover (Colorado School of Mines) has delineated the extent of the window. Paleontology by R. J. Ross, Jr. (USGS) and W. B. N. Berry (Univ. of California, Berkeley) demonstrates the Wenlockian Age of the Roberts Mountains beds and the Caradocian or younger age of underlying carbonate rocks comparable to the Hanson Creek Formation of Nevada. The Silurian unit, in particular, contrasts markedly with the thick quartzites and black shales of the Trail Creek Formation exposed in a thrust sequence to the southwest.

Silurian and Devonian pelecypods with European affinities in wells from the southeastern United States

John Pojeta, Jr., in collaboration with Jiří Kříž (Czechoslovakian Geological Survey) and J. M. Berdan, has completed a study of early Paleozoic pelecypods from four deep wells (1,049–2,140 m) in Florida and Georgia. The Paleozoic sedimentary rocks beneath northern Florida and adjacent parts of Georgia and Alabama compose a sequence of quartzitic sandstones, micaceous shales, dark gray shales, and red and gray siltstones ranging in age from Early Ordovician to Middle Devonian.

The faunas from the wells range in age from Wenlockian or Ludlovian (Silurian) to Middle Devonian. The strata in the wells represent shallow-water normal marine environments, and all pelecypods known from them belong to one of three life-habit groups—byssally attached, burrowing, or reclining. Analysis of the taxonomy and geographic distribution of the pelecypod genera shows that they are closest to forms found in central Bohemia and Poland; elements of this fauna also occur in Nova Scotia, North Africa, and South America.

Conodont biostratigraphy provides evidence for a new Devonian lithostratigraphic unit in Idaho

Conodont determinations by C. A. Sandberg of eight samples collected with B. A. Skipp from lower-plate miogeosynclinal rocks in the core of the Fish Creek Reservoir window in Idaho provide evidence for establishment of a new formation of Middle Devonian age. This formation unconformably underlies the Jefferson Formation of late Middle Devonian (Givetian) to Late Devonian (Famennian) age on the west side of the reservoir. The new unit was previously assigned by Skipp and Sandberg (1972) to the Laketown Dolomite (Silurian) of nearby areas on the basis of lithologic similarity to that formation. The conodont assemblages present in the new formation date it as early Middle Devonian (Eifelian); the assemblages are nearly identical to those being studied by H. R. Lane (Amoco Production Co.) from reefoid facies in the type Salmontrout Limestone of Alaska. It is concluded, therefore, that Silurian rocks are no longer known to be exposed in the lower plate, although they may be present at depth. The upper-plate transitional rocks within the window do, however, include strata of Silurian age, assigned on the basis of conodonts to the *Ozarkodina eosteinhornensis* Zone. These Silurian rocks rest directly on the unnamed Eifelian unit on the east side of the reservoir. Thus, conodont dating supported by geologic mapping suggests the existence of an older, middle Paleozoic thrust within the Paleozoic carbonate rocks exposed in this structural window.

Late Devonian ammonoids in the Sierra Nevada

Mackenzie Gordon, Jr., has completed a preliminary study of ammonoids from a new fossil locality in the Sierra Buttes Formation of McMath (1966). These were collected by G. D. Woodard and others from the Geology Department of California State College at Sonoma during a mapping program in Sierra County, Calif. Two genera of Late Devonian (Famennian) ammonoids, *Platyclymenia* and *Tornoceras*, were found preserved in quartzite locally intruded by an irregular gabbroic stock; *Platyclymenia* is by far the more common genus. The *Platyclymenia* Zone is middle Famennian in age and is known in many parts of the world. This constitutes the first well-established record of datable Devonian rocks in this part of California. The occurrence is of particular interest because the Sierra Buttes Formation is part of the country rock invaded by the Sierra Nevada batholith.

Conodont zonation near the Middle and Upper Devonian boundary in western New York

The exact position of the Middle-Upper Devonian boundary is not yet established in Europe but that boundary must lie within the sequence of the Tully Limestone to Genesee Formation in New York. The Tully and Genesee thin westward and northward against the Algonquin arch in Ontario. The Genesee Formation overlaps the Tully Limestone and rests on the older Windom Member of the Moscow Shale west of Canandaigua Lake. J. W. Huddle reported that the onlaping relationship of the Genesee is demonstrated by the successive appearance of progressively younger conodont species in the base of the formation toward the west. The Middle Devonian *Polygnathus varcus* Zone is represented in the Tully Limestone. The Lower *Schmidtognathus hermanni-Polygnathus cristatus* Zone of Europe is not recognized in New York, but the upper part of this zone seems to be represented in the base of the Geneseo Shale Member of the Genesee Formation from Bellona, N.Y., to Cazenovia Creek. The Genundewa Limestone Member and the lower part of the West River Shale Member of the Genesee Formation seem to represent the upper part of the Lower *Polygnathus asymmetricus* Zone of Europe and the *Ancyrodella rotundiloba* Zone of North America. The *Spathognathodus incitus* fauna was not found in New York.

Paleontological zonation of the Mississippian of the United States

Zonation of Mississippian rocks in the United States has been studied by J. T. Dutro, Jr., (brachiopods), Mackenzie Gordon, Jr., (cephalopods), and J. W. Huddle (conodonts). A series of charts shows stratigraphic distribution of selected genera and species plotted against the foraminiferal zonation of Bernard Mamet (Univ. of Montreal) and B. A. Skipp. Seven brachiopod assemblage zones are recognized, including three subzones. Four cephalopod megazones, considered to be broad-assemblage zones by Gordon, are known. The *Goniatites* Megazone includes four standard zones, two in the Meramecian and two in the lower Chesterian; the *Eumorphoceras* Megazone contains two standard zones in the upper Chesterian. Five conodont assemblage zones are recognized; from oldest to youngest these are the *Siphonodella, Bactrognathus, Taphrognathus, Cavusgnathus,* and *Adetognathus unicornis* Zones. Interregional correlations were studied, and some of the difficulties and inconsistencies were evaluated. These are shown to involve relatively short time intervals, and it is suggested that they can be resolved by consideration of all aspects of the faunal ranges.

Evolution of the pinnate habit in cycadalean leaves

Leaves of modern cycads are all pinnate or bipinnately compound. They fall into two basic morphologic types: the cycadaceous type, in which the leaflet has only one vein, and the zamiaceous type, in which the leaflet has several veins. Origin of these leaves has been highly speculative, although it is generally agreed that the cycads evolved from the Paleozoic seedferns.

In reviewing the foliar types associated with fossil cycad fruiting parts, S. H. Mamay has noted that *Taeniopteris* or taeniopteroid leaves are usually associated with the fructifications. *Taeniopteris,* which first appeared in the Pennsylvanian, is a simple or pinnate leaf with numerous parallel lateral veins and usually entire margins. In the Permian, however, there were forms with shallow marginal dentations; in some, each tooth received a single vein, but in others several veins entered a tooth. By Triassic time, marginal incision had proceeded to as much as half way to the midrib, again involving either one or several veins to a segment. Jurassic forms are known in which the incision is complete, reaching as far as the midrib and resulting in the two basic cycadalean leaf forms. Mamay thus concludes that late Paleozoic taeniopteriod foliage was ancestral to modern cycad leaves. This opinion is bolstered by the Paleozoic appearance of cycadalean fructifications and their consistent associations with taeniopterid leaves.

MESOZOIC OF THE UNITED STATES AND PUERTO RICO

A significant section of Melones Limestone (Cretaceous) in southwestern Puerto Rico

A small-scale quarrying operation of limestone for local use has exposed especially significant rocks of Late Cretaceous (Maestrichtian) age in the San German quadrangle in southwestern Puerto Rico (P. R. Metre grid 29750EX22559N). During the spring of 1973, N. F. Sohl and W. O. Ross measured 263 m of interbedded fossiliferous limestones and shales belonging to the Melones Limestone of Mattson (1958, 1960). Among the varied fauna of bivalves, gastropods, corals, and echinoids, several species provided especially useful biostratigraphic information. The rudist bivalve *Chiapasella* is common in rocks of Maestrichtian age in Jamaica (*Titanosarcolites* limestones) and in coeval rocks in Chiapas, Mexico, and Costa Rica. Associated with *Chiapasella* in the lower part of the section but ranging upward into limestones that contain *Titanosarcolites*—a caprinidrudist— is a new species of the hippuritid *Barrettia.* This new species has heretofore been known only from the upper part of the Botijas Limestone member and Revés Member of the Coamo Formation (now reassigned to Pozas Formation) in the Barranquitas quadrangle of central Puerto Rico. The fauna of this section thus provides a more precise dating of the limestones of the Barranquitas quadrangle than was previously available and also provides an additional basis for the correlation of this part of the Cretaceous sequence of Puerto Rico with that of other Antillean Islands, Central America, and Mexico.

Cretaceous foraminiferal assemblages and distribution patterns

W. V. Sliter has found that distinctive foraminiferal assemblages and dissolution patterns are associated with Cretaceous clastic sediments that represent bathyal, low-oxygen, chemically reducing environments. These assemblages resemble modern faunas from low-oxygen environments on the continental slope and in deep-water basins in both species composition and morphology. The Cretaceous life assemblage is characterized by species of the genus *Praebulimina,* the subfamily Chilostomellinae, and several agglutinated and nodosariid genera, among others. In southern California, this assemblage is restricted to the laminated mudstone facies of the Point Loma Formation. Differential preservation of the life assemblage produced a residue assemblage enriched in resistant forms such as thick-walled, compact, calcareous, and agglutinated benthic species, and impoverished in planktonic and less resistant benthic species. From these data, Cretaceous planktonic and benthic species can be ranked according to their resistance to dissolution.

Palynomorphs from the Dakota Sandstone (Cretaceous)

Exact age of the widespread Dakota Sandstone of the Colorado Plateau has been difficult to determine because megafossils are not common in the formation, and many of its included carbonaceous beds lack plant microfossils. Work by R. A. Scott has revealed that a series of samples from a section through the Dakota Sandstone in McKinley County, northwestern New Mexico, collected by J. F. Robertson, has yielded numerous palynomorphs including a diverse assemblage of megaspores. A late Albian-Cenomanian Age range is indicated for these Dakota beds. This is consistent with the age recently reported on the basis of plant microfossils for the formation in northeastern Arizona and southern Utah.

CENOZOIC OF THE UNITED STATES

Pollen zones across the Paleocene-Eocene boundary

Coal and organic shale samples have been collected from a reference section in the Powder River Basin of Wyoming by R. H. Tschudy. Three successive floral zones, termed *x*, *y*, and *z*, were recognized in upper Paleocene-lowermost Eocene beds. Zone *z* is correlative with the lower Eocene as recognized on the basis of fossil vertebrates and heavy minerals. In this area, however, vertebrate fossils have been found no closer than 92 m above the lithological Paleocene-Eocene boundary. This boundary, normally delineated on the basis of lithological and heavy mineral changes, occurs within the *y* floral zone. The *x* zone definitely represents the Paleocene. The principal pollen change observed in the reference section occurs in the lower part of the Wasatch Formation and therefore does not coincide with the lithological and heavy mineral changes characteristic of the Fort Union-Wasatch transition.

North Pacific Miocene and Pliocene correlations

W. O. Addicott has concluded that a newly recognized group of rugose mussels of the genus *Mytilus* is useful in generalized correlation of middle Miocene sequences of Asian and North American continents. Species referable to this group occur in western Kamchatka, the Gulf of Alaska, and the west coast of the conterminous United States. The widespread species *M. middendorffi* is of special importance as an index to middle Miocene formations from Alaska to southern California. New records of *M. condoni*, morphologically a similar but unrelated mussel with unique divaricate sculpture, demonstrate its utility as a Pliocene-Pleistocene index species along the Pacific coast.

A Miocene age for a flora from the Kenai Formation of Alaska

The description and analysis of the largest known Alaskan late Tertiary flora has been completed by J. A. Wolfe (USGS), in cooperation with Toshimasa Tanai (Hokkaido Univ.). The determination of species in the flora, previously known only from eastern Asia, made the cooperative study particularly beneficial. This middle Miocene flora was collected from the Kenai Formation of the Cook Inlet basin and once was considered to be of Eocene age and one of the major cornerstones of the Arcto-Tertiary Geoflora. Wolfe and Tanai's analysis of this flora clearly establishes a Miocene age for the assemblage. A paleoclimatic analysis of this assemblage indicates that since the middle Miocene the climate in southern Alaska has become more equable; this increase in equability resulted primarily from a strong decrease in the mean of the warm month of about 7° C. Such a decrease in summer temperatures at high latitudes during the later Tertiary may have bearing on the initiation of continental glaciation.

Atlantic Coastal Plain Pliocene correlations

Biostratigraphic studies of the Yorktown Formation in North Carolina by J. E. Hazel have led to a correlation scheme for the Pliocene of the middle and southern Atlantic Coastal Plain and Florida. The correlations are based on new and published ostracode and planktonic foraminifer data and recently published helium-uranium radiometric dates (Bender, 1973). It is suggested that the Yorktown Formation, which has traditionally been considered to be of late Miocene age, is entirely of Pliocene age (about 5.0–1.8 m.y.). As the term Yorktown has been used in North Carolina, the formation represents virtually the entire Pliocene. Correlatives of parts of the Yorktown include the Duplin, Waccamaw, James City of DuBar and Solliday (1963), and Bear Bluff of DuBar (1969, 1971) Formations in the Carolinas and the Tamiami Formation, Pinecrest Beds of Olsson (1964), and Jackson Bluff Formation of Puri and Vernon (1964) in Florida.

Age of the Biscayne aquifer, south Florida

Biostratigraphic and stratigraphic studies of subsurface rocks in Dade County, Fla., area by J. E. Hazel, Druid Wilson, and Z. S. Altschuler, initially in connection with the RALI program in the Miami area, have led to the conclusion that the well-known and productive Biscayne aquifer is in rocks of middle Pleistocene and middle Pliocene age rather than largely in rocks of late Pleistocene age as previously thought.

Analyses of the mollusks and ostracodes of the principal water-bearing beds—alternating marine and freshwater beds below the Miami Oolite and Key Largo Limestone—indicate that this unit represents an undescribed formation known locally in south Florida as Unit A. An as yet unpublished helium-uranium date on coral from Unit A by M. L. Bender (Univ. of Rhode Island) suggests that Unit A is middle Pliocene in age (about 1.0 m.y.). These beds had been thought to represent the Fort Thompson Formation of late Pleistocene age.

In the eastern part of Dade County, the calcareous sands and sandy limestones below Unit A are also part of the Biscayne aquifer. These had been assigned to the Caloosahatchee Formation; ostracode, mollusk, and foraminifer data suggest, however, that they represent or at least correlate with the Pinecrest Beds of local usage (see Olsson, 1964) which are known to occur in western Dade County and elsewhere in south Florida and which are of middle Pliocene age (Bender, 1973).

GEOMORPHOLOGY

Windblown origin of so-called residual soils on basalt

Soils that have been considered to be residual on basalt-capped mesas near Raton, N. Mex., and on the Columbia River Group near Emmett, Idaho, have been studied by R. W. White. He has found that the soils in these areas are made up of a coarse fraction consisting of hard fragments of basalt scattered through a fine matrix that consists of clayey silt. The silt-sized fraction, however, contains large proportions of angular quartz and some other exotic minerals. The basalts exhibit little weathering and are free of quartz. The surficial soils in both areas probably have formed from a thin blanket of loess that has been mixed with fragments of the underlying basalt. The importance of loess as a soil-forming material on basalt and other quartz-free volcanic rocks in both areas has not been fully realized.

Channel morphology related to water quality

W. W. Emmett (1973) has evaluated some of the baseline hydrologic characteristics in a little-disturbed natural environment, the upper 4,680 km^2 of the Salmon River drainage in south-central Idaho. One aspect of the study is the relation between channel geometry and streamflow characteristics. A second aspect is the use of streamflow characteristics to assist in the interpretation of water-quality data.

Bankfull discharge is determined by channel-geometry survey, and streamflow characteristics for all streams are normalized on the basis of the ratio of discharge to bankfull discharge. Likewise, this discharge ratio is used to normalize water-quality data among streams. When the concentration of a water-quality parameter is plotted as a function of the discharge ratio and the procedure is replicated for all streams, differences in water quality among streams can be detected immediately. Since a dilution factor is not responsible for the differences in water quality, the differences can be related to upstream rock type or environmental impact.

The Great River Raft

Remnants of what is believed to be the Great River Raft were found in a meander of the Red River in Louisiana. The raft was a gigantic logjam which, during its most advanced stage in the latter part of the 19th century, extended from about the city of Natchitoches to the Arkansas-Louisiana State line, a distance of about 260 river kilometres. The raft had a profound influence on the course of the Red River, and caused the formation of many lakes along the flanks of the valley (Veatch, 1906). A. H. Ludwig reported that the remnants, consisting of a mass of stumps and roots, have been uncovered by the river in a meander near the settlement of Lake End, in Red River Parish, La. The exposure is about 100 m long and clearly shows a former surface approximately 4.6 m below the present flood plain. Fragments of wood from the same horizon have also been recovered from test holes in the area, an indication that a fairly extensive segment of the raft still remains beneath the flood plain.

The investigation is part of a cooperative ground-water study with the U.S. Army Corps of Engineers and the SCS.

Channel geometry

The rates at which mean velocity, mean depth, and water-surface width change with discharge at a station on an alluvial stream can be approximated from certain measurements of the channel cross section. The pertinent measurements are the water-surface width, cross-sectional flow area, and mean depth at both maximum and minimum flow. Empirical relations involving these measurements are being developed by G. P. Williams. The relations apply only to flow within the banks and are not valid for stages at which the boundary configuration undergoes radical changes in direction.

GROUND-WATER HYDROLOGY

USGS research on ground-water hydrology continues to cover a broad range of subjects with the common objectives of (1) better understanding of ground-water systems and (2) developing and applying new methods to improve management of ground water as an important national resource.

Artificial-recharge studies ranged from geological and geochemical aspects of artificial recharge to quantitative tests of percolation basins, injection-well systems, and connector-well systems.

Problems relating to subsurface waste disposal received attention. The problem of determining the maximum injection pressure that can be imposed without threat of inducing fractures through the otherwise confining zones is being studied. In another study, the response of natural water-level fluctuations in a deep disposal well to changes in atmospheric pressure and oceanic and Earth tides is used to estimate aquifer hydraulic characteristics. Analyses of test data for a site in Florida suggest that leakage may occur through the confining layers and that reaction of the injected waste fluids could reduce the effectiveness of the confining zones.

Digital-modeling techniques have been improved to permit greater flexibility in types of hydrologic problems that can be modeled. Evapotranspiration can now be treated as a function of depth to water. Problems involving changes from confined conditions to water-table conditions can be solved. A hybrid computational system utilizes a small digital computer to facilitate acquisition and processing of data from resistor-capacitor aquifer analogs. The capability to rapidly simulate multilayer aquifer systems, using a hybrid computational system, is being developed.

Artificial recharge

Alaska.—Feasibility studies of artificial recharge by surface-water spreading to increase and sustain ground-water sources are continuing. Results of studies by R. S. George and G. S. Anderson at a recently excavated 40,500-m^2 pit indicate an infiltration rate of 0.3 m/d based on infiltration of 15,100 m^3/d. The potentiometric head near the pit rose 5.5 m during the 2-mo test.

Florida.—A pilot study of natural-recharge improvement was started in western Orange County. Test water was transferred through a gravity pipeline from Lake Wekiva, a lake with poor recharge potential, to the Crooked Lake basin, a lake system with good recharge potential. F. A. Watkins, Jr., reported that although only a limited amount of water was available for the study, Horseshoe Lake, the receiving lake at the upper end of the lake system, appeared to be losing water at a rate greater than could be accounted for by evapotranspiration and, therefore, has good recharge potential. No conclusions could be drawn for Crooked Lake, at the lower end of the lake system, because it received only a fraction of the water that entered the basin.

Several connector wells, which provide a direct hydraulic connection between the water-table aquifers and deeper secondary artesian and Floridan aquifers, have been in operation at International Minerals and Chemical Corp.'s Kingsford phosphate mining area in Polk County, Fla., for 1.5 yr. R. W. Coble reported that water levels in the water-table aquifer range from 1.5 to 4.5 m below land surface, and the potentiometric surface of the artesian aquifers is about 30 m below land surface. In 1972, recharge to the artesian aquifers ranged from 4 to 17 l/s in individual connector wells. In 1973, flow had increased in several wells, and the maximum rate was 42 l/s. Flow rates probably increased as silt and clay were gradually flushed from the aquifer materials adjacent to the wells.

W. C. Sinclair reported that 300 m of subsurface draintile was installed in the shape of a large H at the test site—a 2.8-ha poorly drained pasture surrounded by cypress swamp. The tile is 100-mm-diameter, perforated plastic tubing laid in pea gravel about 1.5 m below land surface. The tile drains to a well that penetrates the underlying Floridan aquifer. Initial drainage from the tile system was in excess of 800 m^3/d. After 10 d, drainage from the system stabilized at about 150 m^3/d.

An injection well was constructed near Bear Creek in St. Petersburg, Fla., to inject storm water into the Floridan aquifer. According to G. E. Seaburn, preliminary tests indicated that water could be injected into a zone 320 m below land surface at a rate of 190 l/s under 3.5 kg/cm^2 of pressure.

Kansas.—J. B. Gillespie reported that artificial-recharge tests in Kearny County show that significant quantities of water will infiltrate loessial soil covered by native pasture. Using ponds 7.3 m in diameter, infiltration ranged from 1.9 m/d after 6 d of ponding, to 0.9 m/d after 27 d, and to 0.15 m/d after 135 d. The water, from the Ogallala Formation, contained 500 mg/l dissolved solids. After 25 d, the percolating water reaching the water table 19.8 m below the pond was similar in chemical quality to the input water.

When Arkansas River water (dissolved-solids concentration 2,500 mg/l) was used, infiltration ranged from 1.2 m/d after 3 d to 0.2 m/d after 31 d. After 12 d, the percolating water reaching the water table was similar in chemical quality to the input water.

New York.—Over a 6-mo period, approximately 158,000 m^3 of reclaimed water (tertiary-treated sewage) was injected intermittently through a 146-m-deep screened well in the Magothy aquifer, according to S. E. Ragone, John Vecchioli, and H. F. H. Ku. For each cubic metre of water injected, the required injection head increased an average of 0.24 mm, mainly because of an accumulation of injected suspended solids on the face of the aquifer. Frequent redevelopment by backflushing was needed to maintain a practical injection specific capacity; in the longest recharge interval (20 d) between redevelopment episodes, 37,850 m^3 of reclaimed water was recharged.

Chemical relationships observed in this long recharge test were similar to those observed earlier in shorter tests. Dissolved-iron concentrations of a few tenths of a milligram per litre in the expanding frontal zone of mixed native and reclaimed waters increased to as much as 3 mg/l in the mixed water (Ragone, Vecchioli, and Ku, 1973). The increase in iron is attributed to reaction of the reclaimed water with pyrite in the Magothy. Phosphorus content of the reclaimed water was reduced by a factor of 10 or more within 6.1 m of travel radially from the recharge well. Content of COD and MBAS decreased less than 50 percent; there was no apparent decrease in nitrogen concentration.

Texas.—Studies of artificial-recharge basins by W. W. Wood (1973), and by R. F. Brown, D. C. Signor, and R. L. Bassett showed that bacterial growth beneath a recharge basin dramatically changed the water quality and reduced the infiltration rate. Buried suction lysimeters at 0.6, 2, 8, 16, 23, and 33 m below the bottom of the basin permitted identification of changes in chemical quality in the unsaturated zone during artificial recharge.

After relatively stable readings at the 0.6-m sampling depth, the pH of the input water suddenly dropped from 8.2 to 7.0, sulfate concentration dropped from 270 to 180 mg/l, and bicarbonate increased from 190 to 345 mg/l. At the time of the rapid water-quality change, the infiltration rate dropped from 0.83 to 0.48 m/d. Suction lysimeters at the 2-m sampling depth detected these quality changes 1 week before they were detected at the 0.6-m sampling depth, thereby indicating an upward movement of the anaerobic zone with time.

Two important conclusions are apparent from these findings: (1) It is now possible to differentiate between the loss in hydraulic conductivity due to anaerobic growth and those losses due to physical and chemical factors. Suction lysimeters buried at shallow depths beneath a recharge pond offer a method of monitoring these potential anaerobic conditions by rapid chemical analyses of bicarbonate and sulfate concentrations and pH. (2) Growth of anaerobic bacteria in this environment permits evaluation of the effects of DO and dissolved biodegradable carbonaceous material.

Virginia.—D. L. Brown and W. D. Silvey (1973) reported that the Norfolk injection project was completed with the successful injection of 76,000 m^3 of freshwater into the Lower Cretaceous brackish-water sand aquifer. In three previous injection tests, irreversible clogging of the injection well became a serious problem when the freshwater caused clay to disperse and plug the aquifer. The specific capacity of the injection well decreased nearly 75 percent by the end of the third injection test. In the fourth injection test (76,000 m^3 injected), a preflush of calcium chloride prevented dispersion of the formation clay, and the specific capacity of the injection well remained relatively constant through the injection of 60,000 m^3. If clogging can be prevented during injection, as much as 85 percent of injected water that will meet USPHS drinking-water standards can be recovered.

Deep-well waste disposal

Colorado.—R. G. Wolff, J. D. Bredehoeft, W. S. Keys, and Eugene Shuter conducted a series of hydrofracturing experiments designed to determine the safe injection pressure for deep-well disposal and the regional state of stress in the Piceance oil-shale basin of northwestern Colorado. Combining hydrofracture-test results with borehole-televiewer-logging results permitted a determination of the magnitude and direction of the least principal stress tensor. This technology is directly applicable to proposed subsurface waste-injection-site investigations.

Field observations showed that fractures can occur at hydraulic pressures as low as six-tenths of the overburden stress. These fractures are usually vertical in tectonically relaxed areas and are propogated vertically as long as injection continues unless stress-field orientation changes or a highly transmissive zone is intersected. Such fractures could permit vertical migration of disposed waste fluids across confining zones into permeable zones that are sources of water supply. Small-scale stress-field measurements before utilization of a site for subsurface waste injection would provide data necessary for the determination of a maximum permissible injection pressure possible without inducing vertical fracturing.

Florida.—Results obtained by W. E. Wilson III, J. S. Rosenshein, and J. D. Hunn (1973) from injection tests in the deepest well (1,520 m) drilled in Florida for subsurface storage of liquid wastes, emphasize the need to include at least one observation well in the injection zone and to obtain bottom-hole pressure measurements in systems designed to place reactive waste fluids at depth. Results of injection tests at the well near Mulberry, in central Florida, where dense acidic liquid waste was injected into a carbonate aquifer of low permeability, indicated that the permeability and porosity of the carbonate rocks in the injection zone were altered by reaction with the acid waste and that there may be some leakage through the confining beds. Initially this leakage probably would chiefly represent movement of displaced native fluid. However, as the injected fluid spreads, reaction of the injected wastes with confining beds could reduce their effectiveness as confining units.

F. W. Meyer has analyzed natural water-level fluctuations in the 898-m-deep disposal well near Miami, Fla., to determine the hydraulic characteristics of a deep saline-aquifer system which may be one of the world's most permeable. The fluctuations are caused chiefly by oceanic and Earth tides and by changes in atmospheric pressure. The oceanic tidal fluctuations probably result from tidal loading in Biscayne Bay. The transmissivity and storage coefficients of the disposal zone are estimated to be 298,000 m^2/d and 1.53×10^{-5}.

New York.—R. M. Waller reported that data for a 2-yr operation of a brine disposal well near Seneca Lake indicate that hydraulic conductivity has increased near the disposal well. This is inferred from a general decline in pressure needed to inject the brine at virtually the same rate. Solution activity in the calcite-lined dolomite fractures probably is responsible for the increased hydraulic conductivity.

Results of laboratory experiments by F. S. Riley show that injection of steel-mill pickling liquor into cores of Theresa Formation (Cambrian) resulted in a radical reduction of hydraulic conductivity. Cores from the pickling-liquor disposal well at Lackawanna were first tested with synthetic formation water (a saturated brine) and then with the pickling liquor, which has an extremely high hydrochloric-acid and dissolved-iron content. In one place, a reduction in hydraulic conductivity of more than three orders of magnitude was observed after about seven pore-volumes of pickling liquor had been forced through a core. The plugging was found to be a function of volume of pickling liquor passed through the cores rather than of contact time.

Contamination of deep aquifers in coal regions in western Pennsylvania

The Allegheny and Pottsville Groups (major coal producers) and the Burgoon Sandstone of the upper part of the Pocono Group consist of complex units that may be considered individual aquifer units in the Clarion River and Red Bank Creek basins, according to H. E. Koester and D. C. O'Hara. These units display considerable internal variability and little vertical leakage through confining beds of clay and shale. The lower part of the Pottsville Group and the Burgoon Sandstone contain many water-flooded oil and gas sands that have been exhausted by the withdrawal of oil and gas from several thousand wells, most of which have been plugged and abandoned. Corrosion of some casings and plugs has permitted the movement of poor-quality water from these zones through the open boreholes downward into lower thieving zones in many places. Many wells in the area have increased the potential recharge rate to the Burgoon Sandstone which is a major source of fresh-water supply and a recharge source for the Clarion and Allegheny Rivers. The downward movement of previously confined poor-quality mine water is increased by the mining of coals and refractory clays underlying the coal. Another source of pollution is water discharged from coal mines and their washeries that percolates into deep boreholes.

Estimating annual recharge to the Edwards Limestone

Studies of the hydrology of the Edwards Limestone and associated beds in the Balcones fault zone in the San Antonio, Tex., area by R. W. Maclay, P. L. Rettman, T. A. Small, and Celso Puente show that the areal recharge to the Edwards Limestone ground-water reservoir can be reliably estimated by using data from a network of precipitation stations. An empirical method, based on time of occurrences of high precipitation, is used to modify the annual precipitation values. The modified precipitation values are used to predict annual recharge.

Rock-core and borehole geophysical data are being used to classify storage characteristics of the limestone reservoir rocks. Rock texture, porosity, and pore-size distribution are the significant parameters. Mercury-injection tests conducted on a rock core indicate that high effective porosities occur in the intercrystalline space of dolomites. Where the dolomites are fractured, drainage of water is from the intercrystalline space to fracture openings. The specific yield of the fractured dolomites is expected to be as high as 15 percent.

Development of an improved digital computer program for aquifer evaluation

P. C. Trescott has developed a computer program for aquifer analysis that in part supplements and in part supersedes the computer program for aquifer analysis documented by G. F. Pinder (1970).

Trescott's program permits consideration of an aquifer that is heterogeneous, anisotropic, and irregularly bounded. The aquifer may occur under water-table or confined conditions at any point, or part confined and part water-table conditions, depending on the relation of the head to the elevation of the aquifer at that point. This option permits consideration of the case where the head changes enough to convert the aquifer at some places from confined to water-table conditions or vice versa. The storage coefficient assigned to a node depends on whether or not the aquifer is confined at that time. Also the program limits leakage into the aquifer when the head declines below the top of the aquifer.

Water may be derived from storage in the aquifer, uniform areal recharge, recharge wells, constant-head boundaries, and leakage from confining beds (or stream beds) in which the effects of storage are considered. Discharge may be from wells, constant-head boundaries, or evapotranspiration. The model assumes that evapotranspiration decreases linearly from a specified maximum value at the land surface downward to a given depth where evapotranspiration ceases. The model accomodates multiple pumping periods, and incorporates several improvements in data input and output.

Hybrid computational system for multiaquifer problems

A general-purpose interface is being developed to enable analog models representing as many as five aquifers and including associated interaquifer flow to be connected to a minicomputer system to facilitate the acquisition and processing of data from the analog model. The interface is being assembled using quick-disconnect multipin patch-board panels. Most of the interconnecting wiring necessary to link one aquifer with another will be permanently wired internally in the computer system. Only the resistor-capacitor networks representing the aquifers for a specific model will be linked via the multipin connectors to the computer.

Due to hardware limitations in the past, only single aquifer models have been connected to the minicomputer system. Upon completion of the new hardware patch-board system, the linking of very large multilayer aquifer models to the minicomputer will be possible. From an operational standpoint, connection or disconnection of a model from the minicomputer will involve no more than inserting or removing various patch-board plugs, and the entire circuit panels representing an aquifer or circuitry simulating flow between aquifers can be quickly replaced; thus the time to initiate or to continue a model study can be greatly reduced.

Aquifer model studies

Colorado.—The analog of the San Luis Valley has been used to analyze various water-management proposals since 1970. O. J. Taylor reported that a recent analysis using that model showed that withdrawals from a small number of wells in the confined aquifer could be used occasionally to supplement the flow of the Rio Grande River and to partially fulfill delivery requirements ordered by the Rio Grande Compact Commission.

A calibrated digital model of the northern part of the northern High Plains of Colorado was used to predict water-level changes by 2000 A.D., assuming a 40-percent depletion rate of stored ground water in 25 yr. W. E. Hofstra and R. R. Luckey estimated that for the period 1964–2000, $8.0\times10^{9}m^{3}$ of pumpage will result in water-level declines of less than 3 m to more than 36 m in Phillips County and the part of northern Yuma County included in the model. Although large declines were forecast for some areas, the rate of decline was within the range permitted by the present management formula. The stored water at the beginning of the model period was about $2.5\times10^{10}m^{3}$, and it was predicted that stored water in the year 2000 will be about 1.6×10^{10} m^{3}.

New York.—O. L. Franke and R. T. Getzen used a series of cross-sectional analog models of the Long Island ground-water reservoir to estimate the vertical hydraulic conductivities of near-surface aquifers and confining beds. The vertical hydraulic conductivity of the upper glacial aquifer is estimated at 10 to 30 m/d, about one-fifth to one-tenth as great as the horizontal conductivity. The underlying Magothy aquifer has a vertical hydraulic conductivity of 0.2 to 0.6 m/d; its horizontal conductivity is more than 25 times greater. The vertical conductivity of the Gardiners Clay, which occurs between the glacial aquifer and the Magothy, is estimated to be 3×10^{-4} to 2×10^{-3}m/d.

Washington.—Digital-computer models of the Quincy, Pasco, and Royal areas were designed to simulate the head response to natural or manmade stresses in a hydraulically connected two-aquifer system of the Columbia basin irrigation project. According to H. H. Tanaka, A. J. Hansen, Jr., and J. A. Skrivan, the models were calibrated for steady-state and transient conditions when the field-observed and model-computed heads were in general agreement. The natural ground-water inflow and outflow from the upper (silt, sand, and gravel) and lower (basalt) aquifers in the steady-state analysis, in cubic metres per year, were 1.3×10^8 for the Quincy model, 3.6×10^6 for the Pasco model, and 1.8×10^6 for the Royal model. Results of the transient analyses, which simulated changes for the 1952–68 water levels in the upper and lower aquifers as a result of imported irrigation water, indicated that the accumulated storage of water between 1952 and 1968 for the upper and the lower aquifer, respectively, was about $3.3\times10^9 m^3$ and $3.6\times10^7 m^3$ in the Quincy model, $4.7\times10^9 m^3$ and $2.8\times10^7 m^3$ in the Pasco model, and $9.2\times10^8 m^3$ and $1.7\times10^7 m^3$ in the Royal model.

Wisconsin.—A digital-computer-model analysis of the aquifer system in Dane County by R. S. McLeod indicated that by 1990 water-level changes in the upper aquifer should range from 0 to 9 m below prepumping levels. Natural streamflow of the Yahara River passing a stream-gaging station near McFarland would be reduced by approximately 55 percent of the prepumping flow.

Ground-water movement

Arizona.—According to W. R. Osterkamp, recently constructed maps of the Tucson area, which show well yields and ground-water velocities, indicate that fracture permeability in the basin-filled deposits may be an important control on ground-water movement. Stratigraphic data do not indicate the parts of the basin-filled deposits having high primary permeability, but the hydrologic data show the occurrence of long narrow areas of high transmissivity and ground-water velocity that are generally coincident or subparallel to major stream channels. Supportive evidence is provided by M. E. Cooley through examination of high-altitude and ERTS imagery. The photographs show possible fracture zones, often coincident with the areas of high transmissivity and velocity in the basin-filled deposits. It is inferred, therefore, that the fracturing not only provides significant secondary permeability but also influences the positions of some parts of the major stream channels.

Ground-water velocities in the uppermost metre of saturated alluvial deposits near Tucson are estimated by Osterkamp to range from about 0.1 to nearly 3,000 m/yr. The highest velocities occur near mountainous areas where the water moves through coarse stream-channel alluvium having high water-level gradients, and the lowest velocities occur where the permeability of the basin-filled alluvium is low or the water-level gradient is low. Most of the area that is underlain by saturated alluvial deposits, however, has ground-water velocities ranging from about 10 to 200 m/yr.

Kentucky.—Results of investigations by R. O. Plebuch in the Princeton area suggest that, in general, ground-water divides coincide approximately with surface-water divides. The area, which is largely underlain by the St. Louis and Ste. Genevieve Limestones of Mississippian age, contains several well-developed karst areas. South of the divide, the water appears to move rapidly through cavernous limestones. An accidental spillage of chemical foam is reported to have occurred along U.S. Highway 62 about 2 mi west of Princeton. The foam soon appeared in Hayes Spring about 1.5 mi to the south, temporarily disrupting the Princeton water system, which at that time used the spring for water-supply purposes.

Delineation of buried glacial-drift aquifers in Minnesota

Most hydrologists, when they are attempting to show the horizontal and vertical boundaries of glacial-drift aquifers, make use of multiple sets of maps, such as slice maps or a combination of maps and sections. By calculating the mean position (center of gravity) and standard deviation of the distribution of sand units within glacial drift, T. C. Winter was able to depict the vertical and horizontal distribution of sand (aquifers) on a single map by delineating areas characterized by selected combinations of center-of-gravity and standard-deviation values. Winter noted that the center of gravity could be used as a predictor of the principal sand unit within the drift (although with some caution) because it either fell within or was within 15 percent (based on total drift thickness) of the principal sand units in 56 of 63 holes drilled to bedrock in northwestern Minnesota.

Effects of fish-hatchery water management on the hydrologic system

As part of a study in Wisconsin of the effects of fish-hatchery water management on the hydrologic system, R. P. Novitzki investigated the water-quality changes of ground water recycled through an infiltration pond at the pumping site. Effluent from a fish-rearing facility has been recharged, without pretreatment, into the surficial-drift aquifer at a rate of 19 l/s for the past 13 mo. In a closed system, the nutrient load from the rearing facility would have increased the nitrate (NO_3)

concentration by 6 mg/l or more. Actual observed increases have been considerably less than 2 mg/l, and intermittent decreases occurred during the study period. A model has been developed to predict concentration changes of a conservative ion in the recycling system as a function of the recycling efficiency within the local aquifer system.

Predicted effects of withdrawals from the Fort Union Formation

In a study of deep aquifers as water sources used for secondary recovery of oil in the Hilight oil field in Wyoming, M. E. Lowry (1973) found that the Fox Hills Sandstone, the Lance Formation, and the Tullock Member of the Fort Union Formation function as a single aquifer and that recharge to the aquifer is largely by vertical movement, rather than by recharge from the outcrop areas on the eastern side of the Powder River basin. Upon completion of the 10-yr water-flood project, maximum possible drawdown resulting from pumping any one well at a distance of 16 km from the pumped well would be about 4.6 m if the projected pumping were evenly distributed among the seven project wells. Within a few years after pumping has ceased, water levels in the project wells will approach the prepumping levels. An irreversible effect of pumping will be compaction of shale, with attendant subsidence, because water from the shale will not be replaced.

SURFACE-WATER HYDROLOGY

The objectives of research in surface-water hydrology are to develop procedures for use in estimating flow characteristics and to predict how surface-water flow will be affected by man's activities. Hydrologic modeling is used to estimate the time and space distribution of streamflow, and hydraulic modeling is used to estimate the movement of flow in stream channels. Results from laboratory models and from digital simulation are used in conjunction with theoretical principles to predict the rate of movement and dispersion of pollutants in streams.

Hydrologic modeling

Results of a flood-frequency study for Missouri streams by L. D. Hauth (1974) indicated that the slope of the relation between the logarithms of peak flows and the logarithms of drainage-area size was so much steeper for small drainage areas than for large ones that separate regressions would be required unless a more suitable model could be found. Using Hauth's flood data in an investigation of transformation alternatives, P. H. Carrigan, Jr., showed that the logarithm of the drainage area divided by the drainage area raised to the 0.02 power gave the best transformation. Using this transformation, Hauth developed a regression equation applicable to drainage areas ranging from 0.3 km^2 to 39,000 km^2.

C. H. Hardison (1974) found that average skew coefficients for use in computing T-year peaks by the log-Pearson type III procedure range in the United States from 0.6 along the eastern seaboard to −0.5 in Indiana and Illinois and to be between 0.2 and −0.3 in most of the Western States. Skew coefficients given by a map are offered as alternatives to skew coefficients based on observed annual peaks, particularly when less than 30 annual peaks are available.

T. R. Cummings (1973) used data on mean depth and mean velocity to estimate reaeration coefficients by the Bennett-Rathbun equation for 142 sites on Michigan streams; he then related these coefficients to channel slope by regression analysis. The results indicate that the reaeration coefficient is about twice as large for 7-d, 10-yr low flows as for mean flows, and that it increases about fourfold for a tenfold increase in channel slope.

The weighted averages of estimates of low-flow characteristics obtained from a regression with basin characteristics and from a regression with concurrent discharge at a nearby gaging station were found to be more accurate than either of the individual estimates, according to J. R. Williams and G. D. Tasker. They also concluded that little accuracy is gained by obtaining more than six base-flow measurements at an ungaged site for use in a regression with concurrent flows at a nearby gaging station.

By using streamflow records as input to a hydrologic routing model, S. E. Rantz (1973) estimated daily values of snowmelt which he then related to daily temperature and water equivalent of the snowpack by regression analysis. The resulting equations, which change as the season progresses, give daily values on snowmelt (for use in computing snowmelt runoff) that are more accurate than those given by degree-day relations. The equations are proposed for use where the specialized meteorologic data required for more sophisticated snowmelt equations are not available. The water-equivalent index of the snowpack is determined from a snow-survey value at a high elevation on about April 1 each year and a daily decrease of this value by the amount of snowmelt estimated from one of the regression equations.

Hydraulic modeling

R. K. Livingston (1973) and R. R. Luckey have developed a digital model which modifies reservoir releases conveyed by the upper Arkansas River for the effects of bank and channel storage, inadvertent diversions, evapotranspiration, and travel time. The model can provide a routed-release hydrograph at any desired location along the river. This model will be a useful water-management tool for canal and reservoir operations and determination of transportation losses.

Turbulence and diffusion in open channels

By measuring the mean and fluctuating components of motion in the flow in a long straight channel having a primary flow section adjoining an overflow section, H. J. Tracy found that in the wall regions the momentum exchange due to secondary motions (mean motion normal to the principal direction of the stream) is of the same order of magnitude as that due to turbulent fluctuations.

Chintu Lai found, in the solutions of a mathematical model of two-dimensional transient flows by the method of characteristics, that treatment of boundary conditions was much more difficult than had been expected.

By relating flow-dispersion coefficients, which can be estimated from mean flow parameters, to solute-dispersion coefficients by analogy with the linear one-dimensional dispersion equation, R. S. McQuivey and T. N. Keefer developed a simple method for estimating longitudinal-dispersion coefficients. By comparing dispersion coefficients estimated from flow parameters with those observed during 40 time-of-travel studies on 18 streams, McQuivey and Keefer concluded that the standard error of estimate of the relation is about 30 percent.

By adding Rhodamine WT dye to the treated effluent from a paper mill on Lake Champlain at a constant rate over a 4-hr period, L. A. Wagner and P. H. Hamecher were able to define the dispersion pattern of the effluent and to measure the volume of effluent in a defined area downstream from the diffuser pipe. Color aerial photographs were taken to outline the area of dispersion, and depth-integrated samples were used to obtain the dye concentration at 12 sampling sites throughout the 4-hr period.

CHEMICAL, PHYSICAL, AND BIOLOGICAL CHARACTERISTICS OF WATER

Drainage from metal-mining areas adversely affects the quality of some Colorado streams

A reconnaissance of 995 stream sites in Colorado during 1971–72, by D. A. Wentz (1974) and R. E. Moran, indicated that approximately 725 km of streams are adversely affected by low pH and (or) high dissolved trace-element concentrations in drainage from 25 metallic sulfide mining areas. Coal-mine drainage was found not to be a problem, apparently because of the low sulfur content of Colorado's coal. Manganese, selenium, and sulfate concentrations, and specific conductance appear to be poor indicators of mine drainage because natural sources can cause values of these parameters to be high even in relatively undisturbed areas.

The amounts of cadmium exceeded USPHS drinking-water standards more often than did any other toxic metal surveyed, whereas copper and zinc appeared to present the greatest danger insofar as toxicity to resident aquatic life is concerned. Acid production is less of a problem in Colorado streams draining metal-mining areas than in streams draining the coal-mining areas of Appalachia.

Intensive study of 18 of the 25 affected areas during 1972–73 revealed that dissolved-metal concentrations were inversely proportional to pH. In several areas, tailings piles were the major sources of total and dissolved metals in the surface water. Maximum suspended-and dissolved-metal concentrations and loads from mine drainage generally occurred during spring runoff, apparently owing to flushing of metals and acid that had accumulated during the winter months. Metal loads increased downstream during high-flow periods, owing to tailings contributions and scouring of iron hydroxide precipitate from the streambed. Geochemical mobilities, based on the percentage of each metal in the dissolved phase during low flow follow the sequence: $Mn \cong Zn > Cu > Cd > Fe > Ni > Pb$.

Selenium in ground water widespread in southwestern Colorado

E. R. Hampton reported that selenium occurred in 18 of 19 samples of water from wells, springs, and streams in southwestern Colorado. Water from six wells exceeded the 10 μg/l selenium-content limit set by the USPHS for drinking water; concentrations ranged from 21 to 120 μg/l. Three of the wells with high-selenium-content water are in the San Jose Formation, and one each is in the Entrada, Mancos, and Dakota Formations. To date, water samples from wells in about one-third of the 46,600-km^2 study area have been analyzed.

Evaluation of surface-water data in Wyoming

On the basis of a statistical study of water-quality data for 36 Wyoming stream sites having more than 3 yr of record, S. J. Rucker IV was able to confirm a very high correlation between total dissolved solids and specific conductance. Excellent correlations also exist between most major inorganic constituents and specific conductance. Useful correlations with discharge were found for the same constituents for some of the sites. These correlations made it possible to (1) monitor long-term changes in water quality at sites with sufficient historical data, and (2) modify the data-collection program in Wyoming to obtain a greater amount of information with the funds available. As a result, the sampling and analysis procedures for most daily stations have been changed from compositing daily samples for complete analysis to determining specific conductance daily and performing a complete analysis monthly.

Migration of nutrient-rich back-pumped waters in Florida's Conservation Area I

Specific conductance has been used by B. F. McPherson and H. C. Mattraw to trace the migration of high-conductance back-pumped surface waters from peripheral canals into the marshes of Conservation Area I in West Palm Beach County, Fla. The sluggish sheetflow of water through dense emergent marsh vegetation has confined infiltration of the nutrient-rich back-pumped water to a zone adjacent to major canals in the storage area. Nitrogen and phosphorus are removed from the migrating surface water more rapidly than would be expected from simple dilution by nutrient-deficient marsh waters.

Downstream water quality and streamflow affected by filling of Flaming Gorge Reservoir

E. L. Bolke and K. M. Waddell reported that the depletion of flow in the Green River downstream from Flaming George Dam between the time of the dam's closure and the end of the 1972 water year was 5,551 hm^3. Of this total, water stored in the reservoir accounted for 4,317 hm^3; evaporation consumed 863 hm^3; and 370 hm^3 went into bank storage.

The net load of dissolved solids, due to leaching and chemical precipitation, added to the river system during the water years between 1963 and 1972 was 1,569,000 t. The leaching rate was 181,000 t/yr between 1963 and 1968, 109,000 t/yr for 1969–70, and 136,000 t/yr for 1971–72.

The most significant increase in concentration of the chemical constituents in the water below the reservoir involved the sulfate ion, which increased from about 115 mg/l (42 percent of the anions) in 1957 to about 200 mg/l (54 percent) in 1972. But the highest concentration, about 290 mg/l (58 percent), occurred in 1963, immediately after closure of the dam.

Prior to closure of the dam, the average monthly temperature of the Green River below the damsite ranged from 0°C to 19.5°C, compared with 3.5°C to 10°C after closure of the dam.

Dissolved oxygen conditions improve in North Platte River reservoirs

Reporting on studies of quality of water in Seminoe, Pathfinder, Alcova, and Glendo Reservoirs on the North Platte River in Wyoming, S. J. Rucker IV noted that during 1972 releases from the reservoirs were minimal, resulting in critical DO-concentration levels at depths greater than 9 m and near-zero concentration levels near the reservoir bottoms. In contrast, 1973 releases were much higher and resulted in significantly higher DO levels. The minimum observed concentration of DO in 1973 was approximately 3.5 mg/l near the bottom of one reservoir. Water depths in the reservoirs are usually in the 30-to-60-m range at the points sampled.

Waste-assimilation capacity of Arkansas streams determined with the aid of recently developed water-quality model

The Arkansas Department of Pollution Control and Ecology has requested that the USGS determine waste-load-assimilation capacities at 7-d 10-yr low-flow conditions for 30 of the 35 water-quality planning segments into which the major streams and tributaries in the State have been divided. J. E. Reed reported that by using a water-quality model (Jennings and Bryant, 1974) for stream DO and conservative minerals (total dissolved solids, chloride, and sulfate), waste-load capacities of approximately one-third of the segments have been determined.

The model is calibrated by using streamflow data collected by the USGS during summer low-flow conditions and existing waste-load data provided by the Arkansas Department of Pollution Control and Ecology. After calibration, 5-yr projected waste loads are substituted for existing waste loads and 7-d 10-yr low flows are substituted for observed flows. The model predicts the water quality under the projected conditions. Where water-quality standards are exceeded, projected waste loads are reduced until water-quality standards are met.

Mathematical models of surface-water quality

A preliminary mathematical model of Uvas Creek, Calif., has been constructed by S. M. Zand. A first test of the structure-imitating model, which utilizes the first-order decay-type sink, was successful in closely simulating the spatial and temporal concentration of chloride and sodium tracers introduced into Uvas Creek.

Fatty acids used as molecular markers in lake sediments

Preliminary results of studies of the distribution and type of fatty acids in hypersaline lake sediments from Searles Lake, Calif., by R. E. Miller, show the fatty acids in the lake to be similar to those in the oil shales of the Green River Formation. The distribution of key fatty-acid molecular markers in the saline-carbonate facies from Searles Lake show important correlations with changes in early Wisconsin lake levels. These key fatty acids exhibit similar distributions in the Green River sediments.

RELATION BETWEEN SURFACE WATER AND GROUND WATER

Hydrology of carbonate-rock terranes

Unusual streamflow characteristics in some regions underlain by carbonate rocks are correlated with an uneven pattern of permeability, according to H. E. LeGrand and V. T. Stringfield (1973a, b). Their study showed that fractures enlarged by solution in near-surface carbonate rocks lead to linear zones of high permeability and to a low water table. Where these zones of high permeability are beneath surface streams, some or all streamflow may be diverted locally to the ground-water reservoir. Results of other studies by Stringfield and LeGrand show the sensitive relations of hydrology to problems in karst regions, including scarcity of surface streams, uneven distribution of permeability, leakage of some surface reservoirs, land subsidence resulting from pumping ground water, and poor waste-disposal conditions in the ground (LeGrand, 1973).

Stream-aquifer interaction

A. F. Moench reported that a significant revision has been made in the approach to modify routed-open-channel-flow hydrographs for bank-storage effects. The revision involves a more accurate method for determining average-stage fluctuations by including time of travel along the reach. Two one-dimensional models of the aquifer were used—a semi-infinite model and a semi-infinite model with a semipervious stream bank. The latter provided improved agreement, compared with that previously reported by A. F. Moench, D. B. Sapik, and V. B. Sauer (1973), between computed and actual-flow hydrographs for reservoir releases on the North Canadian River in central Oklahoma.

Relationship between ground-water development and flow of South Platte River

Historically, irrigation-water requirements in the South Platte River valley in northeastern Colorado have been supplied by surface-water flow and precipitation. Surface water, however, has not always been a dependable source of water; consequently, the use of wells to provide irrigation water has increased from about 250 wells in 1933 to 3,205 wells in 1970. Importation of surface water into the South Platte River basin has increased from about 81 hm^3/yr from 1928 to 1949 to about 391 hm^3/yr from 1953 to 1970, according to R. T. Hurr, P. A. Schneider, Jr., and D. R. Minges. Annual ground-water withdrawal averaged 478 hm^3 from 1951 to 1960, and 686 hm^3 from 1961 to 1970.

From 1947 to 1970, ground-water seepage to the river between Henderson, Colo., north of Denver, and Julesburg, Colo., near the State line, has decreased by about 308 hm^3/yr. Despite this decreased seepage, the volume of surface-water flow at Julesburg has been maintained because of decreased surface-water diversions and increased importation of water into the basin .

Yield of stratified-drift aquifer, Blackstone River area, Rhode Island and Massachusetts

The potential yield of the principal stratified-drift aquifer in the Blackstone River area in Rhode Island and Massachusetts was evaluated by H. E. Johnston and D. C. Dickerman (1974). The evaluation was made by mathematically simulating withdrawals from selected schemes of wells in simplified models of thick, highly transmissive parts of the aquifer. Computations were made by a computer program based on the Theis nonequilibrium equation and image-well theory. The program was written by A. W. Burns. Effects of stream infiltration, the principal source of recharge, were simulated by a subprogram that iteratively shifts the position of a line source of recharge until the combined pumping rate of a scheme of wells is balanced by stream infiltration. Results indicate that ground-water withdrawals can be increased from a 1970 level of 0.44 m^3/s to as much as 1.97 m^3/s without causing streams to go dry.

Modeling ground-water flow near lakes

Lake coring revealed important information with respect to digital modeling of the surficial aquifer in the Pearl-Sallie Lakes area near Detroit Lakes, Minn. S. P. Larson collected cores from four sites on Pearl and Dart Lakes. Hydraulic conductivities of lake sediments determined by laboratory methods ranged from 2.4×10^{-9} m/s to 1.2×10^{-7} m/s. A sample of till was collected from the bottom of one core, and its hydraulic conductivity was determined to be 3.8×10^{-10} m/s. Modeling results were sensitive to the hydraulic conductivity of the till, with best results obtained using a value of 7.0×10^{-9} m/s. The confirmation of till beneath the lake sediments and a measure of its hydraulic conductivity removed much uncertainty from questionable model parameters.

In addition to natural phenomena, waste water from a gravel-washing plant north of Dart Lake significantly affects the surficial-aquifer system. The washing plant uses an average of 8.59×10^5 m^3 of water per year, some of which infiltrates into the surficial aquifer and causes water-table fluctuations of as much as 4.3 m near the place of recharge. The effect of this localized recharge was detected in observation wells in a large part of the study area, causing difficulty in the determination of steady-state-flow conditions.

Apparent streamflow loss from Loup River

In a study of inflow-outflow records for the 66-km reach of the Loup River between St. Paul and Genoa, Nebr., Ray Bentall found evidence for substantial loss of streamflow from the reach. Gaged inflow was less than gaged outflow in 88 of the 120 mo in the 1961–70 decade. Adding estimates of ungaged inflow increased to 113 the number of months in which losses apparently occurred and indicates that losses during the 10-yr period totaled about 1,911 hm^3, or an average annual loss of 3.1 hm^3/km of river. That any loss could occur in the reach is surprising because the configuration of the water table and other factors indicate that the river should gain from ground-water seepage into the stream channel.

Seepage study in southeastern Pennsylvania

A reconnaissance seepage study of some streams crossing Chester Valley in Chester County, Pa., was made November 13–14, 1973, by L. J. McGreevy (1974). Results of the study confirm that streams gain significantly from ground-water discharge within the valley, and that significant interbasin flow of ground water is unlikely. The possibilities of stream loss and interbasin flow of ground water were considered because carbonate-rock aquifers underlie the valley, and, whereas the valley is a topographically low physiographic feature, principal streams cross at approximately right angles, and only tributaries flow parallel to the valley. At the time of the study, which was a time of negligible direct runoff from precipitation, about one-third to two-thirds of the flow in the streams leaving Chester Valley was gained within the valley.

Low-flow-discharge measurements of the Spokane River

A series of low-flow measurements of the Spokane River during an extended dry period were made as part of an intensive ground-water study of the Spokane River Valley near Spokane, Wash., according to H. H. Tanaka and D. A. Myers. The results indicated that the river lost 3.03 m^3/s to ground water along an 8-km reach between the State boundary and Greenacres, gained 7.08 m^3/s from ground water along a 19-km reach between Greenacres and Greene Street, and lost 4.02 m^3/s to ground water along an 8-km reach between Greene Street and the Spokane gage. These measurements and other long-term discharge measurements on the Spokane River will be the basis of quantitative estimates of the gain and loss of the river during low, normal, and high stage for use in a ground-water digital-computer model of the Spokane River valley.

Water resources of Grand Teton National Park

In a study of hydrologic conditions in Grand Teton National Park, E. R. Cox (1974) found that ground water in alluvium and glacial deposits in Jackson Hole moves toward the Snake River and the lower reaches of Pacific Creek and Buffalo Fork. The movement of ground water toward these streams indicates gaining reaches in them, whereas in several other stream valleys, movement of ground water is parallel to or away from the streams and indicates losing reaches. Measured gains in flow of the Snake River from ground-water inflow in Jackson Hole were 0.10 m^3s^{-1} km^{-2} in a 28.2-km reach and 0.87 m^3s^{-1} km^{-2} in an 11.3-km reach. The largest measured loss from a stream was 0.20 m^3s^{-1} km^{-2} in a 6.8-km reach of Cottonwood Creek. On the basis of a flow-net analysis, the average transmissivity is 2,800 m^2/d for the alluvium and glacial deposits in Jackson Hole between Jackson Lake Dam and the town of Moose.

SOIL MOISTURE

Soil moisture monitored in Black River basin, New York

W. N. Embree, who had used neutron-scatter logging equipment to determine soil-moisture content at 11 sites in the Black River Basin from April 1, 1972, through March 31, 1973, gave further study to the collected data. They indicated that soil-moisture content in the unsaturated zone was greatest in April (125 cm) and least in August (95 cm). Moisture content per metre of depth at sites in stratified glacial deposits was less than that for sites in till. The International Field Year for the Great Lakes study showed that the average basinwide thickness of the unsaturated zone, determined from the logs, was greatest in April (5.5 m) and least in June (4.9 m). Depth to the water table averaged 1.5 m at the till sites and 5.5 m at the stratified glacial-deposit sites.

EVAPOTRANSPIRATION

Evapotranspiration, the conversion of water to vapor that is mixed with the atmosphere, accounts for approximately 70 percent of the 760-mm average annual precipitation in the conterminous United States. Because a large part of our water resource is being lost by evapotranspiration, measurements of the losses are very important for planning purposes.

Measurements of evapotranspiration by the USGS are made frequently by using indirect methods such as the water budget. Studies of indirect-method techniques are continuously being made in order to improve their accuracy and to reduce the cost of their use.

Saltcedar varies its use of water

T. E. A. van Hylckama (1974) observed evapotranspiration rates in six plastic-lined evapotranspirometers (tanks), each with a surface area of 81 m^2. With a depth to ground water of 1.5 m, the average use of water was 215 cm/yr; with a depth of 2.1 m, the use diminished to 150 cm/yr; and with a depth of 2.7 m, the use was less than 100 cm/yr.

Water varies greatly with salinity of the soil moisture. If the salinity is expressed in terms of specific conductance of the saturation extract (EC_s) in millimhos per centimetre at 25°C, it was found that in tanks with $EC_s=30$, the water use was only 50 percent of the use in tanks with $EC_s=10$. In tanks with $EC_s=20$, the water use was 70 percent of the use in tanks with $EC_s=10$.

The maximum yearly use of water (311 cm) was measured in 1965 in a tank with a high water table, a dense vegetation, and an EC_s less than 10. Although in half of the 36 tank years (6 tank×6 yr) the yearly use of water was 150 cm or less, there were 11 tank years when the use of water was 200 cm and more under conditions of high water table, comparatively low salinity, and medium to high vegetation density.

Phreatophytes in the southern Uinta Basin

Phreatophytes, mostly greasewood (*Sarcobatus vermiculatis*) and saltcedar (*Tamarix gallica*), consume an estimated 254 hm^3 of water each year in the southern Uinta Basin, according to Donald Price and L. L. Miller. These plants draw water from the stream-aquifer systems for virtually all perennial and large intermittent streams in the subbasin, causing rapid depletion of streamflow and deterioration of water quality.

The hydrological history of San Carlos Reservoir, 1929–71

The historical hydrologic records of the San Carlos, Ariz., reservoir have been summarized by F. P. Kipple. Methods were developed for estimating tributary and ground-water inflows and for making annual adjustments for storage-capacity changes due to sedimentation. Also, ratings were established between stage and subsurface storage capacity, because indications were that at the stage of maximum reservoir capacity usable subsurface storage was about 15 percent of total storage. Annual water budgets for the reservoir were computed, and the residual was used as a measure of evapotranspiration from the vegetation surrounding the reservoir. Mean annual evapotranspiration losses of almost 33.3 hm^3 were computed and when combined with the measured mean annual losses of evaporation of 30.8 hm^3, the total of the two represented 22 percent of mean annual inflow to the reservoir.

Error analysis of water-budget data

R. L. Hanson and D. R. Dawdy analyzed the accuracy of more than 400 evapotranspiration values computed from 9 yr (1963–71) of water-budget data collected on 2,200 hm^2 of the Gila River flood plain in southeastern Arizona. The values defined 2- and 3-week evapotranspiration rates from dense stands of phreatophytes and from bare ground. The accuracy of the rates was determined from an analysis of the error in each of 12 components of the water-budget equation.

The largest components, generally the inflow and outflow of the Gila River, produced the largest errors. High tributary inflow and high precipitation also produced large errors, but their occurrence was relatively infrequent. Errors in the measurement of the soil-moisture component were significant during periods of large change in the level of ground water. Evapotranspiration values were frequently in error by 100 percent or more during winter periods of high flow and low evapotranspiration; however, the late spring and early summer periods of low flow and high evapotranspiration were generally in error by less than 25 percent.

Evaporation from Colorado reservoirs

According to J. F. Ficke and T. W. Danielson, studies of evaporation from three Colorado reservoirs—Gross Reservoir (altitude 2,219 m), Elevenmile Canyon Reservoir (altitude 2,620 m), and Dillon Reservoir (altitude 2,749 m)—have shown that 60 to 70 cm of water evaporates from the reservoirs from mid-May to mid-October. The maximum computed rate from the three reservoirs was 0.6 cm/d for a 2-week period.

LIMNOLOGY

Limnology is the study of aquatic ecology. It deals with the relations between inland surface waters and the organisms that inhabit them. Data from geology, hydrology, chemistry, and biology are synthesized and interpreted to evaluate the interactions between aquatic environments and their living communities. The results of these studies are used by planners and managers, especially in relation to water-quality problems.

Current research includes both streams and lakes and, when investigated, many of the lakes exhibited summer thermal stratification. Such lakes are separated into three horizontal strata as a consequence of solar heating and wind action at the surface. The uppermost warm and well-mixed layer, the epilimnion, overlies an intermediate layer, the metalimnion, wherein water temperature decreases sharply with depth. The metalimnion rests upon a cold, stagnant layer, the hypolimnion, at the lake bottom. Plant production occurs in the well-lighted epilimnion in contrast to the hypolimnion where decomposition of sedimented organic material dominates.

Water quality of Colorado lakes

A reconnaissance of 25 Colorado lakes by D. A. Wentz in August and September 1973 revealed that most were thermally stratified. The lakes were from three of the four recognized limnologic zones in the State: (1) Plains zone (altitude less than 1,700 m), 4 lakes; (2) foothills zone (altitude from 1,700 to 2,500 m), 7 lakes; and (3) montane zone (altitude from 2,500 to 3,200 m), 14 lakes. Lakes in the alpine zone (altitude greater than 3,200 m) were not surveyed.

Five of the lakes were devoid of DO in the hypolimnia. These lakes, which ranged in altitude from 1,562 m to 3,068 m, had higher phytoplankton populations (average of 13,000 cells/ml in samples taken 0.5 m below the lake surface) than lakes whose hypoilmnia were oxygenated (average of 1,500 cells/ml). Total dissolved phosphorous also was higher in the lakes devoid of DO in the bottom waters (average of 0.08 mg/l as P for samples taken 1 m above the lake bottom) than in the oxygenated lakes (average of 0.02 mg/l as P).

Chemical, physical, and biological characteristics of reservoirs

Limnological data were compiled for 21 reservoirs in the San Francisco Bay area by L. J. Britton, R. F. Ferreira, and R. C. Averett. The largest reservoir surveyed has a volume of 1,975 hm^3 with a drainage area of 1,490 km^2, and the smallest has a volume of 3.8 hm^3 with a drainage area of 9.8 km^2. Eleven of the reservoirs are open to the public for recreation. When sampled during the summer, all but three of the reservoirs were thermally stratified, and eight showed evidence of DO depletion in bottom waters. Two of the reservoirs are mechanically aerated in order to increase DO concentration and lower surface-water temperatures. In two of the reservoirs, drainage from abandoned mercury mines has resulted in mercury concentrations which exceed U.S. Food and Drug Administration's limitations (0.5 $\mu g/g$) for mercury in fish for human consumption.

Characteristics of Eagan Township lakes

Small glacial ice-block (kettle) lakes in Eagan Township, Minn., range in depth from less than 2 m to more than 15 m. Biannual analyses of samples for chemical quality, turbidity, and phytoplankton, and periodic bottom-sediment sample analyses provide background information for detection of changes in water quality due to increased urbanization.

W. L. Broussard and M. R. Have reported that the low dissolved-solids content (less than 200 mg/l) of the lake waters is typical of drainage from well-leached glacial deposits and surficial sand and gravel aquifers. Water samples from two lakes located adjacent to industrial and residential developments show significant increases in chloride concentrations following snow- and ice-melt runoff. Elevated concentrations subsided when rainfall runoff and groundwater seepage diluted and replaced earlier runoff. Bicarbonate concentrations (170 mg/l or less) are not adequate to buffer pH and support accelerated photosynthesis. Carbon, phosphorus, and nitrogen are present in bottom sediments. Eight of the 17 shallow lakes (less than 3 m in depth) develop large populations of phytoplankton with 1 million or more cells per litre, presumably by recycling of nutrients from the sediments.

First samples taken from three lakes in Lebanon Township, south of Eagan Township, indicate that the chemical quality is similar to that of lakes in Eagan Township.

Limnological characteristics of Donner Lake, California

A. E. Dong found that there was an ice cover on Donner Lake between January and April. The lake was thermally stratified when sampled after ice breakup, and stratification continued until December when the water column became thermally homogeneous. Dissolved oxygen was near saturation in the epilimnion and above saturation in the metalimnion. In the hypolimnion, DO increased slowly with depth, reaching a 70-percent saturation level near lake bottom. Concentrations of nitrogen and phosphorus were extremely low and, at times, below detection limits. Comparison of nutrient concentrations and primary productivity measurements with those reported in the literature indicate that Donner Lake is in an unenriched state. The principal algal groups present were diatoms, green algae, and yellowish-brown algae. Dominant zooplankton organisms were rotifers, cladocerans, and copepods. The relative abundance of these groups of organisms varied greatly from one sampling period to the next. Low densities of benthic invertebrates were found in August; dipterans (Insecta) and mysidaceans (Crustacea) were the dominant organisms.

Dissolved carbon dioxide in New York lakes

Concentrations of dissolved minerals and gases in two lakes were determined during conditions of late-summer stratification using equipment especially designed to sample gases evolved from water pumped from known depths. The gases were analyzed chromatographically, and gas concentrations and partial pressures in the lake waters were calculated from these values together with observed lake-water temperatures, vapor and liquid volumes of the analyzed samples, and published gas-solubility data.

The lakes are at altitudes of about 500 m in the Shawangunk Mountains of eastern New York. F. J. Pearson and D. W. Fisher found that dissolved CO_2 concentrations increased with depth in the hypolimnia, reaching 5.6 mg/l near the deepest point in Lake Awosting, and 14.5 mg/l in Lake Mohonk, suggesting a source of CO_2 at the lake bottoms.

Chemical analyses of Lake Awosting water indicated no noticeable increase in dissolved cations with depth, so the CO_2 is not derived from dissolution of carbonate minerals in the resistant Shawangunk Conglomerate which underlies the lake. Rather, CO_2 generation in this lake must be associated with reactions of organic materials, and because concentrations increase with depth, bottom sediments are the likely source of the gas.

Evidently no significant sources of alkalinity are available to neutralize the acidity of Lake Awosting water. The pH of rain and snow in the area is typically about 4; the lake water pH is approximately 4.2. At this pH, concentrations of HCO_3^{-1} are negligibly small, so that dissolved CO_2 derived from the bottom sediments is virtually the only internal source of carbon for primary productivity. Moreover, the CO_2 concentrations observed were supersaturated with respect to an atmosphere containing 0.035 percent CO_2, and thus the gas should be expelled into, rather than absorbed from, the atmosphere above the lake surface. These restrictions on the supply of carbon may contribute substantially to maintaining the lake in its present near-sterile condition.

Lake Mohonk, unlike Lake Awosting, supports a fish population, and its water is not strongly acidic (pH about 6). The lake bottom is in shale beneath the Shawangunk Conglomerate. Slight increases in cation concentrations at increasing depth below the metalimnion of this lake indicate the presence of some reactive minerals at the lake bottom. However, most of the large increase in CO_2 and HCO_3^{-1} downward in the hypolimnion must be attributed to sources other than carbonate minerals. Reactions of organic sediments almost certainly provide much of the observed carbon species. In addition, comparisons of equilibrium and analyzed concentrations show that the water is undersaturated in CO_2 at depths in the lake. Thus, in Lake Mohonk, there is a potential for absorption of CO_2 from the atmosphere, and a corresponding tendency to sustain the fertility of the lake.

Diatom distribution in lake sediments

The eutrophic history of lakes can be determined through study of pollen, diatom, and other biological remains in lake sediments. A basic assumption to interpretation of diagrams of diatoms or other biological remains (graphs showing the variability of organisms with sediment depth) is that the remains of the different communities of the ecosystem should be completely mixed and deposited uniformly. To test this assumption, T. C. Winter collected a series of eight samples of the surface sediment along a transect in Lake Sallie, in northwestern Minnesota. The diatoms were identified and counted and the variations in each taxon across the transect were shown by percentage and by absolute numbers per cubic centimetre of sediment. The study showed that diatoms which live attached to higher plants, such as *Fragilaria construens* var. *binodis, F. brevistriata, Achnanthes* sp., and *Navicula* sp., dominated the littoral zones. The true planktonic diatoms, *Melosira granulata, Stephanodiscus niagarae, S. minutus,* and *Fragilaria crotonensis,* dominated the profundal zones of the lake. From these data, it is evident that interpreting paleoecologic conditions from the study of a single core should be done with extreme caution.

One hundred-year flood stage for a closed lake in California

Shoreline features that represent former high-water stages on Baldwin Lake in the San Bernardino Mountains of California are found at 10 different altitudes, ranging from 2,042 to 2,046 m. Stage frequencies were assigned to these stages, but the actual date of formation of the features could not be determined.

Stage-frequency analyses involving 39 yr of observed and 40 yr of synthetized annual-maximum-stage record resulted in an estimate of 2,045 m for lake altitude corresponding to a 100-yr flood event, according to J. J. French.

Effects of air injection at Prompton Lake, Pennsylvania

A 2-yr investigation to determine the effects of compressed air injected into the hypolimnion of Prompton Lake, Wayne County, Pa., was conducted during 1972 and 1973 in cooperation with the U.S. Army Corps of Engineers, Philadelphia District. A systematic sampling program included data collection prior to, during, and following air injection to destratify the reservoir. Prompton Lake is a 113.4 hm^2 impoundment with a maximum depth of 11.9 m, a mean depth of 3.7 m, and a normal pool capacity of 4.19 hm^3.

According to J. L. Barker, air injection during a 65-d period (July 27 to September 30) produced the following results and conclusions: (1) Although the air temperature averaged only 0.3° C higher, the mean lake temperature increased by 2.0° C with the surface temperatures averaging 1.1° C higher than for the same period in 1972; (2) although complete destratification was not accomplished, the DO-free region of the lake decreased from below 5.0 m to below 9.0 m, an increase of 12 percent in the volume of water available to oxygen-dependent life; (3) phytoplankton attained densities more than 20 times that observed in 1972; (4) *Anabaena flos-aqua* appeared to be growth-stimulated by destratification and dominated the population during the injection period; and (5) concentrations of nitrogen and phosphorus temporarily increased during air injection.

Preimpoundment studies

In June 1972, the collection of physical, chemical, and bacteriological data at the proposed U.S. Army Corps of Engineers Blue Marsh and Trexler Lake sites in the Delaware River basin was initiated to determine the probability of accelerated eutrophication and epidemiological bacterial populations following impoundment.

J. L. Barker reported that data for the first 18 mo indicate that both impoundment sites contain sufficient nitrogen and phosphorus to support nuisance growths of algal and (or) weed growth, and that accelerated eutrophication is likely. Bacterial populations at the Blue Marsh Lake site indicate that excessive fecal contamination will likely restrict water-contact recreation, whereas moderate fecal contamination at the Trexler Lake site should not limit water-contact recreation.

Limnology of an arctic stream in the Brooks Range, Alaska

A reconnaissance study of the Atigun River, which drains north from the Continental Divide in Alaska's Brooks Range, was conducted by J. W. Nauman and K. V. Slack. Eight stations were sampled over an 80-km reach from the headwaters at the elevation of about 1,372 m, just below a small glacier, to the gorge, below Galbraith Lake, at an elevation of 689 m. Terrestrial vegetation consists of tundra species with shrubby willows on the streambanks, especially at the lower elevations. The water was remarkably uniform in composition when sampled in late August. Specific conductance ranged from 125 μmho at 25° C in the headwaters to 160 μmho at 25° C in the gorge. The relative proportions of dissolved sodium and calcium increased and magnesium decreased in the downstream direction. The pH ranged from 8.2 to 8.5; alkalinity ranged from 64 to 86 mg/l; and DO was just under saturation at all stations when measured. Water temperature did not exceed 9° C. The total carbonaceous and total organic carbon contents of water samples were low and lacked clear trends with station location. Values ranged between 15 and 20 mg/l for total carbon and between 1 and 3.5 mg/l for total organic carbon. Total organic nitrogen and nitrate concentrations were low and exhibited a decrease downstream; nitrite was undetected; and ammonia nitrogen was found in only a few samples. Orthophosphate was not detected, but low concentrations of particulate phosphate, ranging from 0.01 to 0.08 mg/l as P, were measured in all samples.

Benthic invertebrates generally increased in variety of species and abundance between the headwaters and the lower stream reaches. Thus the Atigun River exhibits the same pattern of change of aquatic communities with stream order as has been observed for streams in temperate climates.

Water quality of a subarctic stream system

G. A. McCoy analyzed chemical and biological data for the Chena River and its tributary, the Little Chena River, to determine the water quality of these Alaskan rivers prior to construction of the Moose Creek and Little Chena River Dams by the U.S. Army Corps of Engineers. The results indicated that the two subarctic streams have water of excellent quality and that their chemical and biological water-quality parameters are relatively uniform. The diverse flora and fauna are characteristic of cold-water streams high in DO and low in productivity. The construction and operation of the Moose Creek Dam probably will have little effect, except possibly temporarily, on present water-quality conditions.

Benthic invertebrate sampling with artificial substrates

During determination of preconstruction characteristics of waters along the trans-Alaska pipeline corridor, benthic invertebrates were collected using artificial substrate samplers. Three kinds of samplers were tested at 41 sites: (1) Wire baskets lined with fine-mesh nylon screen cloth and filled with cleaned rocks, (2) unlined baskets filled with rocks, and (3) multiple-plate samplers consisting of a stack of eight plates of tempered hardboard with spaces between the plates to permit colonization. J. W. Nauman and D. R. Kernodle (1973) reported that in streams, the lined baskets and multiple-plate samplers collected six and two times as many organisms, respectively, as the unlined baskets. Lined baskets also collected an average of two more taxa per sample than unlined baskets. Other observations at a marine site, Jackson Point at Port Valdez, showed that lined baskets and multiple-plate samplers collected an average of nine and two times as many organisms, respectively, as the unlined baskets. Lined baskets also collected an average of four more taxa per sample than did the other two types. Laboratory analyses for the rock-filled baskets takes two to three times as long as those for the multiple-plate samplers.

Collectively, the artificial substrate samplers at Jackson Point demonstrated that Mollusca (Pelecypoda and Gastropoda) were more abundant during summer and fall while Crustacea (copepods) were more abundant during winter and spring.

ATP as a measure of biomass

M. J. Sebetich evaluated the application of ATP (adenosine triphosphate) as a routine laboratory bioassay of biomass. Preliminary findings show that ATP is directly related to chlorophyll *a* concentration, population size of phytoplankton, and size of individual zooplankters.

PLANT ECOLOGY

Botanical data support geologic evidence of rockfall age

Results of a study by R. S. Sigafoos support geologic evidence (D. R. Crandell, D. R. Mullineaux, and Meyer Rubin, 1974) that the rockfall-avalanche deposits, Chaos Jumbles, in Lassen Volcanic National Park, Calif., were formed approximately 300 yr ago by at least three avalanches. Vegetation indicates that the avalanches occurred in quick succession. Apparently, the striking differences in tree form and the minor differences in tree proportions on various parts of the deposit are related to microenvironmental differences such as soil texture, soil moisture, and light intensity. Thickness of humus layers, even under dense stands of big trees, does not exceed 2 cm, whereas humus on nearby forested surfaces underlain by older deposits may be as much as 15 cm thick.

Nitrogen and phosphorus in sediments and plants

At the request of the U.S. Army Corps of Engineers, B. F. McPherson and H. C. Mattraw analyzed sediments and plants in Florida's Water Conservation Area I. Chemical analyses showed marked differences in quantities of nitrogen and phosphorus. Storage of agricultural runoff has not significantly affected nitrogen and phosphorus levels in several plant species tested. Analyses of sediments, on the other hand, showed 1,000 times greater enrichment of nitrogen and 500 times greater enrichment of phosphorus than were found in analyses of plants collected in the same area. The retention of the essential nutrients, nitrogen and phosphorus, within the sediments appears to be a rate-controlling process in this part of the Everglades ecosystem.

NEW HYDROLOGIC INSTRUMENTS AND TECHNIQUES

MISCELLANEOUS NEW AND COMPUTER-AIDED HYDROLOGIC INSTRUMENTS

G. F. Smoot and H. O. Wires reported that fabrication has been completed for the prototype of a streamside, multiparameter, water-quality monitor capable of accepting data from as many as 10 standard water-quality sensors. Twenty-five operational models will be ready for field use in 1974.

Smoot reported that several rainfall-runoff data-collection systems, providing both qualitative and quantitative data, have been installed in sewered urban areas. The instrument package consists of a constriction device installed in the sewer to measure flow, several precipitation gages, and a sampler designed to collect and refrigerate samples for water-quality analysis. Data are collected on a single recorder which has been designed to accept channel-identification data and thereby provide parameter identification.

Wires and S. E. Rickley designed an add-on memory system to be used with ground platforms of the satellite hydrologic data-collection system. Use of the memory system will permit an extension of time coverage of the orbiting satellite.

Wires also reported that three all-digital systems designed to collect data for flow computation at large dams are being readied for installation.

Differential conductivity equipment has been used by V. C. Kennedy, R. J. Avanzino, and S. M. Zand to detect and monitor changes of 0.1 percent or less in the conductivity of stream water. Such equipment has been used in measurement of stream discharge with a probable accuracy of within 1 to 2 percent by locating the reference conductivity cell above the point of injection of a known constant flow of salt solution and the measuring cell downstream from the injection point. The measuring cell is moved laterally and vertically in the stream to determine whether complete mixing is achieved at the downstream point and also is used to establish when a plateau or steady-state concentration of salt solution is achieved. At that time, water sampling near the sensors above and below the injection point permits the amount of salt dilution and, hence, water discharge to be calculated.

Another use of the equipment has been that of monitoring the time of travel of a salt injection through a stream reach by repeatedly and sequentially comparing the water conductivity measured by a series of downstream sensors with that measured by a sensor above the salt injection point and recording the comparisons on a potentiometric strip-chart recorder.

A six-channel servo programer, which is being used in conjunction with a digital punch recorder and float-operated potentiometers, is proving to be satisfactory for recording water levels in as many as six wells, according to O. J. Loeltz and D. W. Wilkins. One channel sometimes is reserved for recording river stage. Where the range in fluctuation is more than 1.5 m, resistors are added to the potentiometer circuit in order to keep the output of the servo programer within its operating limits. Water levels are being recorded to within 3 mm for a 1.5-m-range circuit.

Automated techniques were devised and used by G. C. Bortleson, J. B. McConnell, N. P. Dion, and J. D. Wilson to expedite the collection and processing of data for lake-bottom contour maps and calculation of morphometric parameters for several hundred lakes in Washington. Bathymetric data were collected by boat where possible and by a helicopter equipped with floats and a small outboard motor on lakes which were remote and inaccessible by land. A portable recording fathometer was used to record the lake-bottom configuration at each of several transects across a lake. Price current meters with magnetic counters were used to determine distance from shoreline starting points to ending points. After the bathymetric data were collected from the lakes, the data were digitized for shoreline configuration from aerial photographs and for lake depths from the transects; the data were then transferred to computer cards. The digitized bathymetric data were converted by computer to inputs for a contouring program to generate bathymetric maps. A computer program was also used to calculate several morphometric parameters, such as volume, surface area, maximum and mean depth, and shoreline length and configuration.

A sediment oxygen-demand regeneration chamber, designed by J. V. Skinner, was installed in Lake Shagawa, Minn., by EPA. To minimize corrosion, most of the cylindrical-shaped chamber (112 cm by 92 cm) was fabricated from polyvinyl chloride plastic. The cover is equipped with gas-vent valves, access ports, a lifting ring, and fittings for water exchange. The exchange system relies on thermal stratification to minimize disturbances at the sediment-water interface.

A portable battery-powered pumping sampler was also constructed and tested by Skinner. The sampler can be triggered either by a clock or by incremental changes in water stage and can store up to 30 samples. To facilitate installation, the sampler is housed in a weatherproof enclosure (99 cm by 58 cm by 71 cm) and can be transported by two men.

J. P. Beverage reported that two new suspended-sediment samplers were designed to facilitate collection of 1-l volumes. The new depth-integrator can be cast in either bronze (weight 25 kg) or aluminum (weight 8 kg). The new point-integrator is a modification of the bronze P–61 (weight 25 kg). The new aluminum sampler will weigh 18 kg.

L. M. MacCary, using USGS and service company logs digitized on magnetic tape, has made cross-plot calculations to determine porosity, secondary porosity, matrix and bulk density, and formation factor for selected zones in four core holes drilled in the Edwards Limestone of Texas. Neutron, gamma-gamma, acoustic-velocity, and resistivity logs were used. The geophysical log values measured in the core holes are corrected on the basis of laboratory data from the core samples. A logging system calibrated in this way can then be used to measure the same rock and fluid parameters in other drill holes such as irrigation wells or municipal water-supply wells.

J. E. Eddy and J. J. Hickey reported that videotaped pictures were taken during inspection of a well near Clearwater, Fla. The pictures were obtained to a depth of 300 m by side scanning with a mirror positioned in front of the camera.

COMPUTER PROGRAMS FOR MODELING AND SOLVING HYDROLOGIC PROBLEMS

Applied research and field studies in modeling surface-water and water-quality processes resulted in development of several operational computer programs. M. E. Jennings (1974) and D. P. Bauer (1973) developed steady-state and unsteady-state DO and DO-nutrient models for streams and estuaries. A steady-state DO model was tested and utilized in waste-load allocation studies required by EPA for Arkansas streams. Bauer developed a system of computer programs for analyses of generalized stream-temperature problems. J. O. Shearman (1973) developed computer programs for stream-reservoir flow-routing problems. Field studies in Kentucky, Arkansas, and California were used to develop these computer programs. A sediment-transport computer program was developed using data from the Mad River in California. Jennings and J. B. Peterson developed and applied a lake-inflow forecast model to Lake Marion-Moultrie, S.C., hydropower investigations.

R. H. Merkel developed computer programs which used the digitized logs from the core holes in the Edwards Limestone to calculate and plot corrected porosity, matrix density, matrix velocity, and secondary porosity at 15-cm intervals. Programs were also written to combine various logs to plot mineralogy in terms of percent porosity, limestone, dolomite, sandstone, anhydrite, and gypsum. The numerous core analyses available are being used to calibrate this plot.

SEA-ICE STUDIES

The highly mobile character of sea ice has resulted in the extensive use of remote-sensing techniques and numerical modeling to study the dynamics and morphology of the ice pack. Important recent advances have been made in remote-sensing techniques involving sea ice, and these have been applied to some specialized problems of sea-ice studies.

Microwave remote sensing of sea ice

W. J. Campbell reported that the feasibility of identifying first-year and multiyear sea ice according to its emission of thermal radiation has provided an all-weather, all-time tool for monitoring sea ice (Gloersen, Chang, and others, 1973; Gloersen, Nordberg, and others, 1973; Gloersen, Wilheit, and others, 1973). A comparison of aircraft and surface microwave measurements with those received from ESMR aboard the Nimbus–5 satellite shows that large discrepancies exist between the climatic-norm ice cover depicted in various atlases and the actual extent of the canopies. The distribution of multiyear ice in the north-polar region differs from that predicted by existing ice dynamics models; previously unknown irregularities in the edge of the Antarctic sea ice have been observed. Regions of unexpected brightness temperatures have been found in the glaciers of Greenland and Antarctica. Microwave radiometry has also been used to observe seasonal changes in sea-ice compactness and to monitor first-year ice that remains through the summer melt and consequently forms multiyear ice.

Oil and ice in the Arctic Ocean

If oil resources in the Arctic Ocean are to be developed, there is a likelihood of oil spills within or on the borders of the Arctic Ocean. Three basic mechanisms, according to W. J. Campbell (USGS) and Seelye Martin (Washington Univ.) (1973), would serve to diffuse oil within a floating ice pack and eventually deposit the oil on the ice surface where it would lower the surface albedo. Lead-matrix pumping involves the transfer of oil from lead array to lead array through the action of the opening and closing of leads. When oil incorporated in a newly formed hummock by closing leads hastens the melting of the hummock, this oiled-hummock melting spreads out the oil onto the surrounding ice. Under-ice transport is the most efficient spreading method, in which an oil-water emulsion, formed under the ice, increases the individual floe drift speed, and therefore increases the area affected by the oil, which would be smudged along the ice-water interface by the traveling ice floe.

Icebergs as a water resource

W. F. Weeks (CRREL) and W. J. Campbell (USGS) (1973a, b, c) reported that towing tabular icebergs from the Antarctic to some arid areas to provide a freshwater source is feasible and that further detailed study is warranted. Joint CRREL-USGS studies are investigating two aspects of the problem—a study of the heat transfer from the water to an iceberg and a time-dependent study of the equations of motion for iceberg trajectories.

ANALYTICAL METHODS

ANALYTICAL CHEMISTRY

Determination of small amounts of selenium

A sensitive and rapid spectrofluorimetric procedure for determining microgram amounts of selenium in rocks was developed by M. M. Schnepfe. An alkaline sinter of a sample is leached with water, and selenium is isolated by coprecipitation with tellurium. After dissolution of the precipitate, selenium is reacted with 2,3-diaminonaphthalene to form 4,5-benzopiazselenol which is extracted into cyclohexane. The fluorescence of the extract is compared with that of known amounts of selenium carried through the procedure. The determination limit is approximately 0.01 μg/g Se in a 1.0-g sample; a relative standard deviation of 10 percent or less can be obtained on amounts of selenium greater than 0.1 μg.

Rapid determination of silica at high concentrations

A rapid procedure to determine silica at high concentrations was developed and described by Leonard Shapiro (1974). Solutions containing in excess of 200 μg/ml silica form polymers which do not react with molybdate in the spectrophotometric determination of silica. Fluoride ions catalyze the depolymerization of silica so that precise spectrophotometric determinations of silica can be made even when silica is present predominantly as polymers.

Total-water determination in submilligram amounts in silicate and carbonate minerals

A gas-chromatographic technique for determining submilligram amounts of total water in silicate and carbonate minerals was developed by J. W. Marinenko. Five milligrams of powdered sample is fused with a sodium tungstate-vanadium pentoxide flux in a Vycor combustion tube. Evolved water vapor is swept through a plug of silica gel where it is collected. After collection, the silica gel is heated at a controlled rate, and the released water vapor is detected by thermal conductivity using helium as a carrier gas.

Effect of grinding on quantitative determination of dawsonite in shale of the Green River Formation by X-ray diffraction

A systematic study of the effect of mechanical grinding on the X-ray peak intensities of dawsonite by E-an Zen and J. G. Hammarstrom (unpub. data, 1974) showed that these intensity values are severely affected. The intensities decrease as a function of time and of the proportion of hard minerals (such as quartz) to soft minerals (such as dawsonite and mica); the decrease is most marked for short grinding times and for the most intense dawsonite peak. The most intense dawsonite peak also suffers interferences by a strong analcime peak, and analcime is commonly found in dawsonite-bearing shale of the Green River Formation. High concentrations of organic matter could also affect the X-ray intensity of minerals differentially. The use of X-ray diffraction for rapid quantitative determination of dawsonite in oil shales does not appear promising.

Determination of organic carbon in modern carbonate sediments

Work completed by A. A. Roberts, J. G. Palacas, and I. C. Frost (1973) demonstrated that many analytical methods currently used for the determination of organic carbon in modern sediments produce only a minimum value. The common procedure is to remove the carbonate carbon by acid treatment and to analyze the organic carbon in the residue obtained after filtration. However, it was demonstrated that as much as 44 percent of the organic carbon in modern carbonate sediments from Florida Bay, Fla., is solubilized and lost in the acid solution that is discarded. Researchers working on modern sediment analogs of petroleum source rocks, as well as others interested in the organic-matter content of modern sediments, are advised that the amount of carbon in the acid solution must also be included in the analysis for an accurate determination of the percentage of total organic carbon in the sample.

ACTIVATION ANALYSIS

Analysis of neutron-activation borehole-logging data

A technique to determine the position of the activated volume relative to the neutron source has been developed by F. E. Senftle, R. M. Moxham, and A. B. Tanner from the results obtained at a test site near Ely, Minn., using a ^{252}Cf-Ge(Li) neutron-activation probe. The gamma activity measured comes from an elongated volume about half way between the source and detector rather than from a volume adjacent to the source as might be anticipated. Data-reduction methods have been developed to partly correct for flux variation down hole, and a computer program has been prepared to automatically identify the peaks by element.

Application of the method to the detection of mercury in water has been made in laboratory tank studies. Concentrations of 10 ppm with an error of a few percent have been made with relative ease, and it is felt this limit could be reduced to 1 ppm with some additional work.

X-RAY FLUORESCENCE

X-ray fluorescence analysis of sulfur in geologic samples

A quantitative X-ray-fluorescence technique for the analysis of sulfur in geologic samples has been developed by H. N. Elsheimer and B. P. Fabbi (unpub. data, 1974) using a cerium ammonium nitrate, $Ce(NH_4)_2(NO_3)_6$, flux. This flux is necessary to convert the several sulfur species to the stable sulfate. It was found that X-ray intensities of sulfur vary nonproportionally with concentration owing to the valence state of sulfur. Samples containing sulfur as the sulfate yield 35 percent higher intensity than do those having an equivalent amount of sulfide sulfur. Free sulfur volatilizes rapidly during short exposure to X-rays in a vacuum. The fluxing method is applicable over a wide range of concentration (0.01–30 percent) with a detection limit of 0.01 percent S.

ISOTOPE DILUTION

Determination of arsenic at low levels in soil and rocks

A radioisotope-dilution method for the determination of arsenic in soils and in rocks in μg/g concentrations has been developed by F. W. Brown, F. O. Simon, and L. P. Greenland. Arsenic-76 is added to the sample which is then fused with a sodium peroxide-sodium hydroxide flux. After hydrochloric acid dissolution, arsine, evolved by the addition of zinc, is absorbed and oxidized to arsenic acid in an iodine-iodide-sodium carbonate solution. The arsenic yield is determined by counting the 0.56-MeV gamma-ray photo peak of As^{76} with a single-channel analyzer. Total arsenic in solution is determined spectrophotometrically after development of molybdenum blue. Standards ranging from 1 to 10 μg As are carried through the procedure, corrected for yield, and the amount of arsenic is determined from the standard curve.

EMISSION SPECTROSCOPY

Spectrographic analysis of 1-mg geologic samples using a controlled-atmosphere d-c arc

A procedure for the spectrographic analysis of small grain or 1-mg geologic samples has been developed by Norma Rait. This is a modification of a technique previously reported by C. L. Waring (1962). Samples arced in an 80 percent argon-20 percent oxygen atmosphere permit the use of many lines not available by air arcings because of the cyanogen band interference. Crystalline carbon rather than graphite electrodes are used which permit an increased rate of sample consumption and reduce arc wandering. The limits of detection for 36 elements of the 69 tested have been improved. The sensitivity of beryllium determinations in particular was greatly improved.

Spectrographic determination of wear metals in aircraft engine oils

Emission-spectrographic techniques have been applied to determining wear metals in aircraft engine oils by Joseph Haffty. The method has been designed to determine Al, Fe, Mg, Ti, Ag, Cr, Cu, Mo, Ni, Pb, Sn, V, and Zn. The method is flexible and can be modified for other metals and other oils. The procedure has been used to study USGS aircraft oils at various stages of engine operation.

An approach to correction of line intensities using temperature and electron-pressure determination in the d-c-arc plasma

Matrix-induced variation in spectral-line intensity arising from effects of temperature and electron pressure are corrected by computer techniques using methods developed by D. W. Golightly and C. P. Thomas. Arc temperatures ranging from 4,500 to 6,500 K and electron pressures from 10^{-6} to 10^{-2} atmospheres give degrees of ionization and molecular dissociation which can be determined from Boltzman and Saha equations (Boumans, 1966). Improved analytical accuracy can be obtained. These calculations have become practical only since the advent of rapid computer capability.

Extended detectabilities and accuracy of element determinations by computerized spectrographic analyses

Previous computer interference subprograms have been completely rewritten by F. G. Walthal (unpub. data, 1974) to be more general. As a result, 112 interferences are checked and corrections made automatically when necessary. The 4 interference subprograms have improved the accuracy of 96 lines representing 45 elements. These changes permitted the extension of analytical limits for Co, Cu, Pt, Sc, Tb, Tm, and Yb. A unique problem for copper is related to the paucity of lines having a measurable density. Copper determinations between 20- and 100-ppm concentration had previously been determined by manually plotting the line width below a certain transmission reading against the corresponding concentration. This procedure has now been incorporated in the computer program and is accomplished during the normal evaluation of other element concentrations.

ANALYSIS OF WATER

Atomic-absorption spectrophotometry

The direct determination of Cr, Cu, Cd, Co, Ni, Pb, and Zn by the atomic-absorption spectrophotometric method for analyzing unfiltered water samples and samples of bottom material was investigated by M. J. Fishman. The extent of possible interference from other substances was checked, including interference from Na, K, Cl, and SO_4 up to 9,000 mg/l; Ca, Mg, and Fe up to 4,000 mg/l; NO_3 up to 100 mg/l; and trace metals mentioned above to 10 mg/l. Copper, nickel, lead, and zinc do not interfere. Calcium in excess of 1,000 mg/l suppresses cadmium absorption, and chromium absorption is suppressed by iron, nickel, and cobalt. As little as 1 mg/l of nitrate interferes with the determination of cobalt, although this interference and that due to the presence of iron, nickel, and cobalt when determining chromium can be eliminated by preadjusting the sample to contain at least 18,000 mg/l of ammonium chloride. Potassium concentrations greater than 500 mg/l and magnesium concentrations greater than 1,000 mg/l enhance chromium absorption. In spite of the above-noted interferences, the direct determination of all of these trace metals in samples of unfiltered water and of bottom material is still preferred because of the serious interference of iron when a chelation-extraction technique is used.

Flameless atomic-absorption spectrophotometry

W. M. Barnard (State Univ. New York, Fredonia) and M. J. Fishman (USGS) (1973) evaluated a flameless atomic-absorption spectrophotometric technique, using a heated-graphite atomizer, for the routine determination of trace metals in water. Analysis by direct comparison with aqueous standards is impractical because of matrix interferences. Analysis by combining chelation and solvent extraction with subsequent atomization is effective for copper, lead, and chromium but not for cobalt and manganese. Analysis by the method of standard additions is reliable but time consuming. The sensitivity of the flameless technique for determining arsenic, silver, and selenium is too poor for the routine determination of these elements in water. The heated-graphite atomizer has a high capability for good sensitivity and low detection limits for many elements, and may have potentialities for specific problems in water analysis. Its use, however, for the routine determination of trace metals in water samples of varying composition, especially by laboratories engaged in the analysis of large numbers of samples, is limited.

Automated analyses

An automated, catalytic method for determining iodide ion has been developed by D. E. Erdmann for use with Technicon Autoanalyzers I and II. The method, which is similar to the USGS manual method (Brown, Skougstad, and Fishman, 1970) is based on the catalytic effect of iodide on the ceric-arsenious oxidation reaction in acid solution. The extent of reduction of ceric ion is directly proportional to the iodide concentration when reaction temperature and time remain constant. The concentration ranges are 5 to 60 μg/l and 1 to 60 μg/l with sampling rates of 20/h and 30/h for Technicon Autoanalyzers I and II, respectively. This method is comparatively free of interferences; however, it cannot tolerate excess acidity ($pH<3$) or iron concentrations in excess of 2 mg/l.

Erdmann also developed a Technicon Autoanalyzer method for determining fluoride ion. This method employs an ion-selective electrode. The sample stream is mixed with a solution containing a buffer and a chelating agent, and is then passed through a 55° C heating coil before the fluoride concentration is determined potentiometrically. As much as 10 mg/l Fe, 2 mg/l Al, 100 mg/l SiO_2, and 25 mg/l PO_4–P can be tolerated without interference. The range of this method is 0 to 2 mg/l, and the sampling rate is 30/h. Reproducibility and accuracy of the method are excellent.

Methylation of humic-acid fractions

R. L. Wershaw, D. J. Pinckney, and S. E. Booker have developed a new procedure for the methylation of humic-acid fractions isolated from soils, sediments, or natural waters. Lactam, 2-pyrrolidone, is used as a solvent for methylation with diazomethane. This is the first time that 2-pyrrolidone has been used in this way, and the procedure should have broad application in the methylation of other materials that are not soluble in the usual solvents such as diethyl ether. By the procedure, all of the derivatized humic acid becomes soluble in organic solvents such as dioxane, or in mixtures of benzene and methanol. Preliminary mass spectrometric studies indicate that the methylated humic-acid fractions are sufficiently volatile to permit their spectra to be determined. (Underivatized humic acids are not sufficiently volatile to give mass spectra.) The mass spectra of the methylated humic-acid fractions should provide new insight into their chemical structure.

Neutron activation analysis

L. L. Thatcher developed an analytical technique for the determination of rare-earth elements in water. The method separates rare-earth elements as a group by surface reaction with finely divided calcium fluoride. The separation is specific for the rare earths, tungsten, and a few other rare elements. The calcium fluoride separation is applied following irradiation of the sample for NAA (neutron-activation analysis) of rare-earth elements. Thatcher also expanded the short-irradiation, instrumental NAA method (Thatcher and Johnson, 1973) to include Sb, Co, Sm, Se, and W.

GEOLOGY AND HYDROLOGY APPLIED TO ENGINEERING AND THE PUBLIC WELFARE

EARTHQUAKE STUDIES

GEOPHYSICAL STUDIES

Transfer of programs from NOAA to USGS

In an agreement that became fully effective on September 16, 1973, the USGS assumed responsibility for most of the seismological activities formerly carried out by NOAA. The consolidation of these activities was accomplished in two phases beginning with the transfer of five organizational components on May 27, 1973. The transfer of the remaining five components took place on September 16, 1973. As a result of the consolidation, the USGS now has the primary responsibility and capability within the Federal Government for accomplishing operational research and service activities in seismology.

The activities transferred to the USGS include operation of seismic observatories and research networks, management of the Worldwide Standardized Seismograph Network, operation of the NSF-sponsored strong-motion program, operation of the National Earthquake Information Service, management of research programs in seismology, and the publication of reports, summaries, and maps of the results of these activities.

Under the agreement, NOAA will continue some seismic-data services for the USGS, other Federal agencies, academic institutions, industry, and other private users. These services include collecting and maintaining indexes or archives of data from all available domestic and foreign sources, assessing data quality, reformatting data for archiving and secondary use, and preparing data summaries and other standardized products such as abstracts, indexes, maps, and other user-oriented services. NOAA will also continue to operate World Data Center A for seismology and geomagnetism. The geophysical observatories located at Honolulu, Hawaii, and at Palmer and Adak, Alaska, will remain in NOAA to support the Tsunami Warning System. Routine seismic data collected by these observatories will be given to the USGS.

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 net work includes 112 high-gain vertical-component seismographs and 10 horizontal-component seismographs. These stations permit the accurate location of thousands of local earthquakes each year. In 1973, some 4,200 earthquakes were located, ranging in magnitude up to 4.0. (Unless noted otherwise, all magnitudes cited in this section, "Earthquake Studies," are Richter scale.) As in previous years, most of these events were concentrated along the San Andreas fault south of Corralitos, and along the Calaveras, Sargent, and Hayward faults.

S. W. Stewart, P. R. Stevenson, and T. C. Jackson are adapting small specialized computer systems to permit rapid analysis of earthquake waveforms from large seismic arrays. One system consists of a computer dedicated full time to monitoring seismicity along the San Andreas fault system in central California. In this system, the output from an array of 100 seismometers is scanned at a rate of 50 times per second. One minute after the occurrence of an earthquake within the array, the computer reports information that allows quick determination of the approximate location and magnitude of the event. The system detects nearly all earthquakes of magnitude 1 or greater within the array. The computer-based system has application both in the systematic study of seismicity in this region of California, and in the development of larger systems for earthquake prediction, modification, or control.

W. H. Bakun and C. G. Bufe studied the attenuation characteristics for propagation paths through fault-zone material. Extension of the study to propagation paths through the granitic Gabilan Range to the west and the Diablo Range to the east of the San

Andreas fault will lead to station-source correction schemes for National Center for Earthquake Research central California net stations useful for both magnitude determinations and earthquake-source studies.

In southern California, D. P. Hill found that all earthquakes of roughly magnitude 1 or greater recorded on the 16-station Imperial Valley seismic array from its installation in April 1973 through December 1973 show a linear concentration along the trace of the Imperial fault. This linear trend of epicenters continues northward from the Imperial fault, passes beneath Obsidian Buttes, and extends in a diffuse pattern beneath the Salton Sea toward the Banning-Mission Creek fault. Two earthquake swarms that occurred in June punctuate the linear trend on either side of Brawley. Both individual and composite fault-plane solutions for earthquakes on this trend show right-lateral motion along planes parallel to the Imperial fault trace. A diffuse pattern of earthquakes extends northwestward from the Imperial fault toward the San Jacinto fault.

On April 26, 1973, a magnitude 6.2 earthquake occurred at a depth of about 45 km beneath the northeast coast of the island of Hawaii some 15 km north of Hilo. This event caused about $5.6 million damage on the island and is the first earthquake larger than magnitude 6 since 1962. A study of the main-shock and aftershock data by J. D. Unger, R. Y. Koyanagi, and P. L. Ward (1973) showed that the main shock and larger aftershocks have two well-defined nodal planes: one striking north-northeast and dipping steeply northwest, and the other striking west-northwest and dipping steeply south. The admissible fault motions are right-lateral strike slip on the north-northeast plane and left-lateral strike slip on the west-northwest plane. Additional evidence shows that the north-northeast plane is most likely the fault plane. The main shock apparently triggered seismic activity at least in two other regions on the island, as well as an eruption on Kilauea 9 d later. About 100 aftershocks were located, ranging in magnitude from 1.0 to 4.0. They crudely outline a broad zone about 25 by 10 km extending northeastward perpendicular to the coast.

Analysis by J. C. Lahr and R. A. Page of data recorded by a network of 32 seismograph stations in southern Alaska indicates that earthquakes deeper than 50 km in the Cook Inlet region are concentrated within a narrow Benioff zone less than 25 km thick and in places as thin as 5 km. To assess the effect of using a flat-layer velocity model in the determination of hypocenters, 37 events were relocated using a more realistic high-velocity dipping-plate model in E. R. Engdahl's (NOAA–CIRES) ray-tracing program. Systematic shifts of up to 25 km in epicenter and 10 km in depth were found. This bias, which increases with depth, is tentative, because the actual three-dimensional velocity structure is not currently known. Focal-mechanism solutions are generally consistent with down-dip tension on the Benioff zone, although some exceptions were found. Two solutions were obtained for crustal events above the Benioff zone and showed nearly horizontal compression with an east-west orientation.

R. A. Page, M. E. Blackford, J. C. Lahr, Barbara Bench, and W. H. Gawthrop found that recent seismic activity within 90 km of Valdez has been concentrated primarily north and west of Valdez. This conclusion is based on preliminary results from a 5- to 6-week reconnaissance study of seismicity along the southern end of the Richardson Highway in the Chugach Mountains during August and September 1971, a detailed 30-d investigation of earthquakes in the Port Valdez and Valdez Arm area in July and August 1972, and the continuous monitoring of earthquake activity in the Valdez area since August 1972 by a tripartite array of telemetering seismographs spaced 10 to 15 km apart. The most intense seismic activity since August 1972 occurred in two earthquake sequences associated with magnitude 5 earthquakes that occurred 25 km southwest and 45 km west of Valdez in late August and September 1973. Consideration of the pattern of 100 well-located earthquakes suggests that the principal mode of tectonic deformation may be low-angle thrusting in response to a compressive-stress system acting across the coastal margin.

In response to a magnitude 6.7 earthquake off the coast of southeast Alaska on July 1, 1973, R. A. Page and W. H. Gawthrop operated a temporary network of six portable seismographs from July 5 through 12 on the adjacent shore areas to record aftershocks. To supplement the land stations, 15 sonobuoys were deployed in pairs in the epicentral zone by Michael Reichle (Scripps Institute of Oceanography) and A. C. Jones (USGS) during the last day of the recording period. Epicenters of the small locally recorded aftershocks and 14 larger teleseismically recorded aftershocks define a west-northwest trending zone about 60 km long and 15 km wide that alines with the isobaths along the Continental Slope west of Cross Sound (about lat 58° N., long 138° W.). The focal mechanisms of the two largest shocks in the sequence indicate thrust faulting at shallow depth (within the crust). This earthquake sequence is inferred to mark the southeast end of the active southern coastal thrust belt.

A. C. Tarr studied Antarctic seismicity and found that, apart from a small zone of seismic activity near Deception Island, the Antarctic Continent appears to be aseismic at current detection levels. Nevertheless, Antarctic seismograph stations are exceedingly important in improving the accuracy of detecting earthquakes occuring at the margins of the Antarctic plate, and in maintaining a monitoring capability for those few, but significant, intra-Antarctic plate events. South Pole station SPA has provided exceedingly important seismological data during its operation not only because of its unique location but also because it is a high-gain installation owing to low noise background, which permits detection of small-magnitude shocks worldwide.

In 1886, Charleston, S.C., was the site of a large and damaging earthquake which killed 60 persons. Quantitative seismic data, which are an essential element in an objective assessment of the seismic hazard in South Carolina, are now provided by a network of seismograph systems installed under the direction of K. W. King at 10 sites on the Coastal Plain between the Savannah and Lynches Rivers. Preliminary analysis of data by A. C. Tarr indicated that earthquakes of low magnitude are occurring in a zone coincident with the area of maximum intensity of the 1886 earthquake. This result indicates the need for continued monitoring of the Charleston-Summerville area and suggests the need for detailed geologic and geophysical investigations.

S. T. Algermissen, J .W. Dewey, C. J. Langer, and W. H. Dillinger, Jr. have determined a very accurate hypocenter for the destructive December 23, 1972, Managua, Nicaragua, earthquake using an accelerograph record recorded during the earthquake and observed intensities. This accurate location was used to compute station corrections for seismograph stations throughout the world and to recompute the location of the larger earthquakes in the Managua area during the past 50 yr.

The Ghir, Iran, earthquake killed more than 5,000 people and left tens of thousands homeless. The extreme damage was evidently due to the effect on adobe structures of very high accelerations from the shallow earthquake source. J. W. Dewey and Arthur Grantz (1973) completed a 6-d field reconnaissance of the heavily damaged zone and used the joint-epicenter method to recompute the locations of the larger aftershocks. The causative fault of the earthquake was a thrust fault striking west-northwest which ruptured for about 35 km of its length. There is excellent correspondence of the size and orientation of the source inferred from seismological data with the region of most intense damage.

P. L. Ward, E. T. Endo, D. H. Harlow, R. V. Allen, D. J. Marquez, and J. P. Eaton developed a prototype global volcano-surveillance system. Evaluation of the results to date shows that such a system is now technologically and economically feasible, but that considerable work is still left to demonstrate the scientific feasibility of such a system. More specific results are as follows:

1. A new seismic-event counter, that reliably indicates order-of-magnitude changes in seismicity, was designed, deployed at 19 locations, and thoroughly tested. This event counter is significantly more reliable than any such system previously available.
2. A tiltmeter adapted from a defense application was successfully deployed at seven remote locations and was shown to operate reliably and stably for at least 1 yr. This meter can be installed quickly and easily in remote locations.
3. The event counters and tiltmeters were interfaced with satellite transmitters and were installed reliably, securely, and simply in remote areas and in many environmental extremes.
4. Local earthquakes were observed on all volcanoes monitored in this study, demonstrating that even the Cascade volcanoes are not extinct.
5. An order-of-magnitude increase in seismicity was observed several days prior to the eruption of Volcan Fuego in Guatemala in February 1973.
6. Tilts of 20 to 150 microradians were observed on the volcanoes Kilauea, Fuego, and Pacaya.
7. A volcano-surveillance system monitoring seismicity and tilt at 1,000 locations around the world could be installed and operated for 5 yr at a cost of about $11 million, if the satellite relay system were shared with many users. This expense might be shared by many countries.

Theoretical and laboratory studies of earthquake mechanics

A laboratory model of an active fault with a stress system analogous to a strike-slip fault was studied by Louis Peselnick and J. H. Dieterich. The material simulating the fault gouge was Westerly Granite. With a constant normal stress across the gouge zone, the compressional (*P*-wave) velocity in the gouge was determined as a function of increasing shear stress. The progressive increase in shear stress culminates in sudden slip (equivalent to an earthquake), or stable sliding (equivalent to fault creep). A decrease of the *P*-wave velocity (about 7 percent) in powdered granite subjected to critical values of normal and shear stress occurs prior to the onset of slip. Most field observations of possible premonitory velocity effects have thus far been obtained for earthquakes in thrust-fault systems. These results indicate that similar premonitory effects may exist for strike-slip systems. Inspection of the rock gouge after completion of the experimental runs showed lineations, which are probably small cracks, oriented at approximately 45° to the normal and shear stress. This strengthens the argument for the dilatancy model as the physical basis for such precursory phenomena.

A family of theoretical predicted *S*-wave polarization angles for focal-mechanism studies was compiled by W. H. Dillinger, Jr. In this catalog, there are 172 different diagrams which will allow an observer to approximate the orientation of any focal-mechanism solution to within 5° of the strike and dip. The main purpose of this catalog is to present a rapid procedure to evaluate the focal-mechanism parameters using *S*-waves.

Heat-flow results from the California Coast Ranges reported by A. H. Lachenbruch and J. H. Sass (1973) suggest that the San Andreas fault system is contained within a 100-km-wide band of high heat flow with no local thermal anomaly at the main fault trace. Thermal models constructed from the data yield temperature profiles useful for estimating temperature-dependent properties that control fracture and flow at depth. One plausible thermal model attributes the anomaly to mechanical heat generation in a broad shear zone between the North American and Pacific plates. On the assumption that this thermal model is correct, the magnitude, breadth, and uniformity of the measured anomaly impose severe constraints on steady-state mechanical models of the San Andreas fault system. They imply that much of the relative plate motion is distributed throughout the shear zone, that the right-lateral motion of the system is driven by tractions at the edge of the shear zone in the superficial seismogenic layer, and that the motion of the system is resisted at the base of this layer. The model implies that the (time-averaged) shear stress for the system is a minimum (not a maximum) at the trace of the San Andreas fault, and that earthquakes are confined to a superficial layer because of increased ductility at depth.

The development of a two-dimensional dynamic finite-element program by S. T. Harding (1973a) has allowed the theoretical computation of the displacements due to a sudden stress drop on a fault model which simulates the San Fernando, Calif., earthquake of 1971 (A. F. Espinosa, S. T. Harding, and Alfonso Lopez-Arroyo, 1973). The theoretical displacements at near and intermediate distances compare well with the observed strong-motion displacement records. The stress drop required by the finite-element theoretical model in the near field is 30 bars, which is twice as large as the computed stress drop from teleseismic observations. The peak ground acceleration measured from the computed theoretical record is 22-percent higher than the horizontal peak ground acceleration recorded at the Pacoima Dam station.

Crustal stress and strain studies

It has been reported previously that geodimeter lines in the vicinity of the epicenters of moderate earthquakes (magnitude >4.5) exhibit anomalous changes in length preceding the event. A careful study by W. H. Prescott and J. C. Savage of four earthquakes (magnitudes 4.7, 4.7, 4.8, and 5.1) in the Hollister, Calif., area failed to disclose any significant premonitory anomalies in geodimeter line length. In fact, the strain steps associated directly with the earthquakes could not be resolved. These results are consistent with dislocation models which suggest changes of less than 1 mm in line lengths.

R. O. Burford found that the fault-creep rate along a segment of the San Andreas fault northeast of King City, Calif., keeps pace with the rate of crustal block movement measured across a 10- to 20-km-wide zone covering the San Andreas fault. Fault-creep displacement along that segment accumulates in a steady way, generally without significant contribution from distinct events and in the absence of significant seismicity. This type of fault behavior contrasts sharply with that observed in areas of high seismicity, which are associated with sections along the fault where the rate of fault creep has steep gradients or is locally retarded. Episodic creep activity is generally associated with fault sections characterized by high seismicity. These relationships may be explained by the existence of patches on the fault plane on which slip is relatively difficult, and where slip is generally accomplished by a combination of sudden failure resulting in earthquakes mixed with or followed by accelerated creep.

Geodetic surveys carried out before and after 1906 have provided considerable information on the crustal deformation which accompanied the great San Francisco earthquake. Reexamination of these data by W. R. Thatcher showed that there were significant aseismic movements on or near the San Andreas fault in the years following the earthquake. The inferred slip is comparable to the sudden seismic slip (about 4 m) but occurred at depths greater than those at which most of the seismic slip took place. This conclusion suggests that strain accumulation for large earthquakes on the San Andreas fault does not occur primarily as a result of relatively continuous aseismic motion on the fault plane immediately below the seismic zone, as has been previously supposed. Rather, it appears that seismic slip loads the fault at depth for subsequent postearthquake recovery.

M. J. S. Johnston obtained information on the modes of near-field strain accumulation and release associated with earthquakes along the San Andreas and other active faults in the Western United States. The primary technique for direct measurement of deformation has been to install arrays of shallow-borehole tiltmeters and some strainmeters along the most active section of the fault. One indirect technique, based on the stress sensitivity of the magnetic properties of rocks (the seismomagnetic effect), is being used on a broad-scale basis because of the ease with which fundamental data can be obtained. Preliminary results indicate possible block-type tilting associated with earthquakes on the San Andreas fault with an elastic behavior of fault materials following the earthquake. Anomalous changes in the direction of tilting seem to occur before earthquakes, and this may be a useful method of prediction if further studies confirm these results. Broad-scale local magnetic-field anomalies appear correlated with regions of high seismicity on the San Andreas fault.

J. H. Healy developed equipment to make stress measurements in rocks to depths of 152 m by the hydrofrac technique. Preliminary tests along the San Andrea fault are favorable, and the method will be applied in a number of holes to evaluate the usefulness of the technique.

H. W. Oliver made comparative gravity studies in the area of the 1971 San Fernando earthquake on the basis of preearthquake measurements made mainly in 1958 and 1970 and postearthquake measurements made in 1971–72. Statistically significant changes of −0.45 to +0.31 mgal were found at about 20 stations. The gravity changes (Δg) are generally proportional to changes in elevation. According to the least-squares relation, $\Delta g = -0.215\ \Delta E \pm 0.026$ (standard deviation), where ΔE in metres yields Δg in milligals. As the slope, −0.215 mgal/m, corresponds to a Bouguer reduction density similar to that of surficial rocks (2.2 g/cm^3), as compared with the free-air gradient of −0.309 mgal/m, it follows that mass has been added in the region of uplift. This mass may have come from the region of the epicenter, where an inverted U-shaped area of gravity increase can be explained by subsidence and mass removal. Continuous recording of gravity at milligal sensitivity at Olive View Hospital from April 1971 to February 1972 suggested gradual subsidence of the area that had been uplifted at the time of the earthquake. Remeasurements of gravity at 15 stations in June 1973 confirmed a partial collapse of the area just north of the San Fernando fault zone but suggested that the central area of uplift has begun rising again.

Earthquake control and prediction

C. B. Raleigh, J. H. Healy, J. D. Bredehoeft, J. P. Bohn, and L. G. Peake continued the earthquake-control experiment at the Rangely, Colo., oil field. The experiment was designed to test the hypothesis that earthquakes triggered by subsurface fluid injection are caused by a reduction in the effective normal stress brought about by an increase in fluid pressure. The existing state of stress in the Weber Sandstone was measured by hydraulic fracturing, which permits a calculation of the critical fluid pressure required for shear failure along a preexisting fault. The fluid pressure has been reduced below that critical level for approximately 2 yr, during which time the earthquakes averaged about 1/mo within 1 km of the injection wells. Prior to reducing the pressure, the earthquake frequency was about 40/mo. The pressure was raised by injection again to above the critical level and the earthquake frequency increased to about 30/mo in the first months of 1973. Withdrawal of the fluid from the injection wells in May 1973 resulted in immediate termination of the earthquake sequence. Since the fluid pressure has been reduced again below the critical level, no earthquakes have occurred within 1 km of the injection wells. The experiment demonstrated that the Hubbert-Rubey effective-stress hypothesis is adequate to explain the inadvertent triggering of earthquakes at Rangely. Earthquakes may be turned off by reducing the fluid pressure, should such inadvertent triggering occur elsewhere in the future.

Russell Robinson, Jr., R. L. Wesson, and W. L. Ellsworth found that *P*-wave-traveltime residuals at a seismograph station near Bear Valley, Calif., for small, precisely located local earthquakes at distances of 20 to 70 km show a sharp increase of nearly 0.35 about 2 mo before a magnitude 5.0 earthquake that occurred within a few kilometres of the station. This indicates that velocity changes observed elsewhere premonitory to earthquakes, possibly related to dilatancy, occur along the central section of the San Andreas fault system.

Seismic-risk evaluation and fault mapping

S. T. Harding (1973b) edited a collection of papers entitled "Contributions to Seismic Zoning." The main purpose of the report is to present an integrated approach to the problem of seismic zoning. Topics included are seismology, hypocenter location, focal mechanisms, wave attenuation, seismicity and risk statistics, microseismicity, soil response, finite-element modeling, the response of structures, and economic studies. It is hoped that eventually an approach to seismic-risk evaluation based on this wide range of considerations will be sufficiently quantitative to be of value to building-code officials at all levels of government, land-use planners, and structural engineers.

At the request of the U.S. Bureau of Reclamation, W. V. Mickey and C. W. Stover prepared a map indicating the historical seismicity of 17 Western States. The map also shows maximum intensities and will be used to help evaluate the seismic risk at various damsites in the Western United States.

S. T. Algermissen and D. M. Perkins developed a seismic-risk map for Utah and Arizona. The map depicts (as contours) the maximum horizontal ground acceleration in a 50-yr period. The accelerations mapped have a 10-percent probability of being exceeded.

In the vicinity of Hollister, Calif., five detailed gravity profiles were surveyed across the Calaveras fault. These profiles show a small, distinctively shaped gravity anomaly on the east side of the fault. S. L. Robbins believes that this anomaly may be present to the south of the southern end of the exposed fault trace, thus allowing the fault to be traced farther to the south.

Crustal structure

J. H. Healy interpreted seismic-refraction data from the Long Valley, Calif., caldera and suggested that a basement refractor with *P*-wave velocity of 5.8 to 6.0 km/s is 1 to 2 km deep beneath the highlands east and north of the caldera. The basement is 2 to 3 km deep in the west-central part of the caldera and as deep as 4 km beneath the northern and eastern sides of the caldera. Volcanic rocks forming the low mountain mass in the western half of the caldera have *P*-wave velocities ranging from 2.5 to 4.5 km/s. Rocks with similar velocities are covered by 1 to 2 km of elastic deposits with *P*-wave velocities of 1.5 to 2.0 km/s in the eastern half of the caldera.

GEOLOGIC STUDIES

Earthquake recurrence from sedimentary structures

J. D. Sims (1973a, 1973b) recognized three zones of earthquake-generated sedimentary structures within modern sediments deposited in Lower Van Norman Reservoir near San Fernando, Calif. The reservoir, which was drained after it was severely damaged by the 1971 San Fernando earthquake, contained a continuous sequence of silty and clayey sediments laid down since the reservoir was filled with water in 1915. The observed structures chiefly are load structures, although some pseudonodules and small-scale folds occur and presumably were caused by liquefaction at a sediment-water interface. In addition to structures formed in the upper 4 to 5 cm of the sediments by the February 9, 1971, earthquake, two widespread zones were discovered in older deposits of the reservoir. Analysis of sedimentation rates indicates that the lower two zones formed in the then existing upper few centimetres of sediments within the periods 1951–55 and 1929–36, respectively.

The three zones correlate closely with three major earthquakes that have shaken the San Fernando area during the 56-yr life of the Lower Van Norman Reservoir. These shocks and their estimated intensities at San Fernando are: August 30, 1930, Santa Monica Bay earthquake (VI Modified Mercalli); July 21, 1952, Arvin-Tehachapi earthquake (VI Modified Mercalli); and February 9, 1971, San Fernando earthquake (VIII to X Modified Mercalli). Earthquakes of lesser intensities have affected the area but have left no evidence of their occurrence in the lake sediment.

Recognition of previous earthquakes in modern sediments suggests that a search for similar features in ancient sediments would be useful for determining recurrence intervals of major earthquakes for many regions. Adequate assessment of earthquake recurrence within the United States has been hindered by the relatively short and inadequate historic seismic record. Analysis of earthquake-generated sedimentary structures within Holocene and Pleistocene sediment would permit sampling of a significantly longer period of time.

Recency of movement along faults in southern Alaska

The Castle Mountain fault, one of the major faults in southern Alaska, is of importance for earthquake-hazard studies because it is located near Anchorage, the major center of population and growth in the State. Detailed mapping along the fault, which was carried out during the 1973 field season, indicates that the 40-km segment of the fault that crosses the Susitna Lowland is a reverse fault that has been active in late Holocene time. The most recent displacement along the fault has produced scarps that are slightly more than 2 m high. Analysis of tree rings from trees growing in the fault zone indicates that the offset occurred more than 225 yr ago. The maximum age of the scarps, indicated by radiocarbon dating of organic material from an offset soil horizon, is 1,860±250 yr B.P. The amount of horizontal offset related to formation of the scarp is not known, although there is local evidence that there was a horizontal slip component. The Castle Mountain fault does not show any evidence of recent activity where it is exposed along the front of the Talkeetna Mountains to the east of the Susitna Lowland.

The Bagley fault is a major structural boundary in the Chugach Mountains that for most of its length separates the Valdez Group (upper Mesozoic) on the north from interbedded sediments and volcanics of the Orca Group (Paleocene) on the south. For more than 250 km in the area east of the Copper River, the fault is marked by spectacular linear trenches that are occupied by the Bagley Icefield and the Miles, Columbus, and Seward Glaciers. The linearity of the fault has prompted speculation that it is the western continuation of the active right-slip Fairweather fault. George Plafker and M. A. Lanphere reported that in the Miles Glacier area, a granodiorite stock that has been intruded across the fault zone has not undergone any detectable postemplacement offset. Two samples taken from the pluton north and south of the projected trace of the fault have yielded potassium-argon ages of 49.3 and 49.2 m.y., respectively. The ages confirm that the Bagley fault in the Miles Glacier area has not undergone significant displacement since early Eocene time and, therefore, that it probably cannot be related to present movement on the Fairweather fault.

Sag pond deposits reflect periodic seismic activity of San Andreas fault

Samples of organic sediments obtained by A. M. Sarna-Wojcicki from a sag depression along the San Andreas fault zone approximately 5 km northwest of Pajaro Gap near Watonsville, Calif., have been dated by the radiocarbon method. Comparisons of sediment depth versus time suggest very unequal rates of filling of the depression, with a rapid period of alluviation from approximately 3,600 to 3,400 yr B.P. Little or no alluviation took place from 3,400 yr B.P. to about 900 to 1,500 yr B.P., since which moderate rates of alluviation have prevailed. Both periods of alluviation, particularly the older, may reflect periods of increased seismic activity along the fault zone.

Possibly active fault zone borders Santa Clara Valley

Geologic mapping by R. J. McLaughlin and D. H. Sorg (McLaughlin, 1974; McLaughlin and Sorg, 1974) along the southwest margin of the Santa Clara Valley between Los Altos Hills and Los Gatos, Calif., has delineated a major fault zone 93 km long. This fault zone extends from Los Altos Hills to San Juan Bautista and is named the Sargent-Berrocal fault zone. Much of the foothill areas between Los Gatos and Los Altos Hills contains landslides, and in many areas large block slides obscure the fault zone. Field evidence in the area between Los Gatos and Los Altos Hills indicates that Pliocene and Pleistocene strata of the Santa Clara Formation are offset and deformed into Pleistocene southeast-plunging folds between two major branches of the fault zone. Old alluvial-fan and terrace deposits of middle to late Pleistocene age are largely undeformed, although there is indication that considerable uplift of old terraces has occurred across the fault zone in some areas. Numerous minor earthquakes in the vicinity of Stevens Creek Reservoir with magnitudes ranging from 0.5 to 3.6, and a magnitude 4.2-to-4.7 earthquake at Los Gatos, can be associated with the fault zone.

Holocene behavior of the Garlock fault

M. M. Clark and K. R. Lajoie (1974) observed that a linear gravel bar deposited during the late Pleistocene highstand of ancient Lake Koehn has been offset about 80 m by left-lateral movement on the Garlock fault. Displacement occurred across a zone about 30 m wide, with no obvious horizontal bending or drag beyond the zone. The segment north of the fault has also been relatively downdropped several metres. Incremental Holocene displacement is shown by similar but smaller vertical displacement of the adjacent and much younger playa surface. A thin layer of tufa, deposited near the crest of the bar before it was significantly offset, yields a C^{14} age of 11,360±160 yr B.P. The offset thus suggests an average horizontal displacement rate of 7 mm/yr at Koehn Lake during Holocene time.

Comparison of the Garlock fault with the more seismically active San Jacinto fault suggests possible patterns of Holocene behavior for the Garlock fault. The two faults are grossly similar in length and abundance of well-preserved evidence of recent faulting. Although the average Holocene displacement rate for the Garlock fault is roughly double the 2.5 to 3-mm/yr rate estimated for the San Jacinto fault, the Garlock has had no historic earthquakes of magnitude 6.0 to 6.8 since 1899. This comparison suggests that one of the three following behavior patterns probably applies to the Garlock fault: (1) It is not now accumulating tectonic strain; (2) accumulating strain is being relieved by aseismic creep; or (3) the Garlock fault typically relieves strain with infrequent (about every 200 to 1,000 yr?) earthquakes of about magnitude 7.0 or greater. Available evidence favors the third possibility.

Transverse Ranges frontal fault system a seismic hazard

The Point Mugu earthquake (February 21, 1973), the Anacapa Island earthquake (August 6, 1973), and the San Fernando earthquake (February 9, 1971) together focus attention on the likelihood that many faults within the Transverse Ranges province are seismically active and that the east-west faults of the southern frontal fault system constitute serious seismic hazards. The latter system includes the Malibu Coast, Santa Monica, Raymond Hill, Sierra Madre, and Cucamonga faults which can be traced eastward through Santa Monica, Hollywood, Los Angeles, Glendale, Pasadena, Monrovia, and Glendora. The strata adjacent to these north-dipping faults have undergone north-south crustal shortening since at least Pleistocene time by reverse faulting accompanied by some left-lateral slip, a mode of deformation that is consistent with the focal mechanisms of the Point Mugu and Anacapa earthquakes. W. L. Ellsworth and others (1973) concluded that the stresses that caused the Pleistocene and Holocene deformation are still operative and that the southern frontal fault system of the Transverse Ranges should be considered a potential seismic hazard to the Metropolitan Los Angeles area.

Character of San Jacinto fault zone in the Salton Trough, California

An important question posed by the pattern of active strands of the San Jacinto fault zone is how regional continuity of right-lateral strain is achieved within the several large gaps separating the principal fault strands. A possible explanation is provided by northeast- and north-trending faults mapped by R. V. Sharp within a large area lying astride the San Jacinto fault zone southwest of the Salton Sea. These faults are post-middle Pleistocene in age, and some show clear evidence of Holocene slip. Because the newly discovered faults occur in an area where the continuity between the major strands of the San Jacinto fault zone is obscure or nonexistent, it is likely that at least some of the regional strain is being released along the north- and northeast-trending structures. Evidence obtained to date suggests that (1) horizontal displacement is combined with locally dominant vertical components of slip, (2) major folding of the adjoining sediments is locally required to achieve fault displacement, and (3) near-surface folds transfer displacement from one fault break to another in many cases.

ENGINEERING GEOLOGY

Studies near coastal communities

A comparative study by C. A. Kaye (1973) of aerial photographs taken at 10-yr intervals from 1938 to 1969, and of maps published between 1776 and the present, showed that Martha's Vineyard, Mass., loses about 6.5 ha of land every year owing to wave erosion. Modern erosion-control engineering on the island has been only partly successful and has induced some erosion on adjacent shores. The greatest rate of erosion occurs at the southeast tip of the island where as much as 107 m of island was washed away in 1 yr, and over 610 m has been eroded since the Des Barres map of 1776. Erosion of the north shore is at an overall lesser rate, and some places show no erosion.

Geologic reconnaissance and evaluation of geologic hazards at Sitka, Alaska, by L. A. Yehle, revealed that ground shaking during anticipated major earthquakes may locally be severe in areas underlain by thick muskeg or loose fill. The fill is particularly susceptible if it incorporates material obtained from the 1.5-m-thick layer of volcanic ash that lies beneath much of Sitka. Only moderate shaking is anticipated elsewhere in the city. Extensive liquefaction and landsliding are not expected. High waves, most of them caused by earthquakes, could damage shore and other low-lying areas. An eruption of a volcano on Kruzof Island, about 20 km west of Sitka, could affect the area. Several ash deposits, one of which is about 10,000 yr old, underlie the Sitka area, and pioneer accounts and Indian legends suggest minor eruptions in early historic time.

Slope-stability investigations

Study of creep in steeply dipping rock layers as much as 1 m thick, which can be observed at the surface, lends insight into the mechanism of similar movement that is thought to take place at greater depth. Slope-stability studies by D. H. Radbruch-Hall have shown that horizontal benches and trenches on steep slopes of the Santa Ynez Range in southern California are caused by downslope creep of interbedded sandstone and shale whose bedding parallels the slope. Sandstone layers at the ground surface, as thick as 1 m, evidently creep downward along bedding planes and buckle upward, while the underlying shale deforms into folds and elaborate convolutions. The resulting arches in the sandstone generally trend horizontally across the hillside. Dips are flattened immediately upslope from the axis of the arch and steepen below it. The flattened part of the sandstone layer is poorly supported and tends to slide downslope over the lower steepened part. Shale that is exposed by the removal of sandstone slides down or is washed away, so that a bench or trench remains on the hillside. The trench commonly has a very steeply dipping sandstone bed on its downslope side, which flattens into a normal dip a few metres downhill from the trench.

Gravitational slope movement of this type may be widespread. A similar type of movement on a larger scale possibly contributed to the disastrous 1963 landslide in Italy (Mencl, 1966), in which a huge mass of rock slid into the Viaont Reservoir, resulting in extensive damage downstream and the loss of nearly 2,000 lives. Investigations of geologic conditions at construction sites where this slow but potentially hazardous movement occurs may avert similar disasters.

Other studies by Radbruch-Hall indicated that slope stability in the Cloverdale area of central California is directly related to the lithology and tectonic history of the northern Coast Ranges. These ranges have been uplifted and deformed since Pliocene time; erosion has been rapid, and steep slopes are common. Parts of the Franciscan Formation in the Cloverdale area, which are chiefly shale, are intensely sheared from severe tectonic stresses and have low strength. Most massive landslides in the area occur in these rocks and in mantle overlying them; some of these slides involve entire ridges several kilometres in length. Parts of the Franciscan Formation that consists of more resistant rocks, such as chert and greenstone, are fractured but not as badly sheared, and form more stable slopes. Shale and sandstone of the contemporaneous Great Valley sequence in the same area also are fractured but are not intensely sheared, presumably because of less severe tectonic stresses. Slopes underlain by these rocks have fewer landslides; those slides that do occur are small and shallow and involve mainly soil and weathered bedrock. Younger Franciscan rocks, predominantly sandstones, contain some landslides, but in general they are relatively stable because of their lithology and the fact that they were not subjected to as much tectonic stress as were the older Franciscan rocks. An understanding of regional factors which affect slope stability is essential to the selection of safe and economical sites for structures, particularly for large dams and major highways.

Rockfalls are geologically important in the development of Kilauean pit craters at Kilauea Volcano, Hawaii, because they measurably increase the size and modify the shape of the crater walls, and also are possible hazards to visitors at the Hawaii Volcanoes National Park. The observation areas for many of the park's scenic attractions, including the ongoing eruption of Mauna Ulu, are situated at the rims of pit craters and are susceptible to collapse. Staff members of the observatory, under the direction of D. W. Peterson, have undertaken systematic study of some aspects of this kind of rockfall activity.

Preliminary analysis of steel-tape measurements and creepmeter records which have been made to monitor the rate of opening of cracks around Mauna Ulu's crater rim suggests that as soon as the average rate of continuous movement exceeds 2 mm/d, the moving block will break away and fall within 10 d or less. Closure of certain public-viewing areas at Mauna Ulu, recommended to NPS officials on the basis of such measurements, was followed by the collapse of these areas into the pit crater.

Continued examination of the shore of Lake Powell in Utah and Arizona, by A. L. Brokaw (1974), reinforced the conclusion gained from an earlier reconnaissance that unstable conditions were produced by fluctuating water levels along segments of the shoreline. The water causes instability where it encroaches on sandpiles, talus piles, rockfalls, and other landslides.

Sandpiles, which are as much as 30 m high in the lee of vertical cliffs formed by the Navajo, Wingate, and Entrada Sandstones, can become undermined and waterlogged. Dormant landslides and talus slopes, which are common along outcrops of the Chinle Formation, may become saturated by the rising waters. Large masses of all these deposits may possibly slide into the deep near-shore waters.

The most dangerous potential hazard, and the one least predictable, is the possible fall of large sandstone slaps from the Wingate and Navajo Sandstones. These falls occur where the lake waters have either removed or saturated the upper part of the underlying Chinle Formation. Large slaps released along near vertical joints can suddenly topple into the water. The fall of a single slab 90 m long and 46 m high has been documented, as have several smaller falls. One of the most dangerous aspects of such rockfalls is the large waves they produce, which increase in height as they bore into the narrow canyons.

As part of an agreement between the USGS and the Appalachian Regional Commission, J. S. Pomeroy and W. E. Davies are locating areas of ground disturbed by slope failures in Allegheny County, Pa., using 1:12,000-scale aerial photographs flown for the purpose, coupled with field verification. Results of the inventory are being transmitted as Environmental Problem Notices to officials of Allegheny County, including those of the County Department of Planning and Development. Early results include the identification of active slope failures that had not been previously known.

Engineering-geologic benefits from wilderness study

Geologic information pertinent to the location of a possible future highway was obtained during an evaluation of mineral resources in the Indian Peaks Wilderness study area, Colo., by R. C. Pearson. Geologic mapping shows that a prominent fault extends through Arapahoe Pass and Caribou Pass, long considered as a potential highway route through the mountains. According to Pearson, the width and intensity of deformation of the rock along the fault is similar to that along the Loveland Pass-Berthoud Pass shear zone, which has caused many engineering problems in highway and tunnel construction in the past.

Engineering-geologic reports used by governmental agencies

A systematic study of the geologic hazards on the island of Hawaii by D. R. Mullineaux and D. W. Peterson was made at the request of HUD. The study was particularly timely because new and proposed residential and commercial developments are encroaching on sparsely inhabited areas where the impact of volcano-related geologic hazards on people has been low in the past. Such hazards include lava flows, pyroclastic fragments, corrosive gases, particle-and-gas clouds, ground subsidence, and surface ruptures. Other significant hazards include earthquakes and tsunamis. Mullineaux and Peterson designated zones according to approximate degree of risk for each type of hazard as well as zones of combined hazard. Areas of highest risk include the summit areas and rift zones of Hawaii's two active volcanoes, Kilauea and Mauna Loa; relative risk generally decreases with increasing distance from these zones. However, some degree of risk remains everywhere on the flanks of these volcanoes. Other potentially hazardous areas include several active fault zones, such as on Kilauea's south and southeast flanks and on Mauna Loa's west flank. Results of this study can aid civil authorities and land developers in planning for the most beneficial use of the land on the island.

The sites of more than 40 VA (Veterans Administration) hospitals were evaluated by H. H. Waldron and T. C. Nichols, Jr., during the past year as part of an evaluation program which was started after the destructive San Fernando earthquake in 1971. Five of these sites were briefly examined in the field by Nichols. Administrative reports regarding the sites which were transmitted to the VA delineated potential geologic and earthquake hazards that might affect the future safety of the hospital buildings and patients.

Research in soil engineering

A preliminary map showing liquefaction potential divides the unconsolidated sediments in the southern San Francisco Bay region, Calif., (T. L. Youd and others, 1973) into four zones on the bases of detailed geologic studies and of analyses of lithologic and water-table data and standard-penetration tests. Criteria for evaluating liquefaction potential were formulated by extending the "simplified procedure for evaluating liquefaction potential" of Seed and Idriss (1971), to relate to the extreme seismic conditions likely to occur in the bay area. Information obtained from boreholes was used to determine the location and extent of clean-sand layers throughout the area and to estimate the average liquefaction potential for each zone mapped.

Ambiguities in published definitions of the term "liquefaction" and the lack of a clear distinction between liquefaction and the ground failures which result have hindered communication between workers in various disciplines as well as between specialists in the same field, and have led to possible misinterpretation and improper application of liquefaction-potential analyses. To reduce this problem, T. L. Youd (1973) proposed to define the term "liquefaction" as the transformation of a granular material from a solid into a liquid state as a consequence of increased pore-water pressures. He also suggested that ground failures associated with liquefaction be described in three categories. The first two categories include either limited or unlimited flow, depending on whether reductions in pore-water pressure caused by dilatant tendencies within the flowing material are or are not sufficient to arrest flow. The limited-flow category includes earthquake-induced failures known as lateral-spreading slides where ground displacements are on the order of centimetres and metres; the unlimited-flow category includes slides where ground displacements are on the order of tens and hundreds of metres. The third category of failures due to liquefaction consists of those caused by a so-called "quick" condition. Such a condition can reduce bearing capacity under building foundations. Youd showed that these definitions provide a useful basis for distinguishing between the concepts of liquefaction potential and the potential for ground failure. Present criteria for liquefaction susceptibility are only pertinent to the evaluation of liquefaction potential and not to potential for ground failure, for which more sophisticated evaluation techniques are needed.

Existing methods for analyzing seismic ground motions are based on linear approximations of the nonlinear stress-strain behavior of soil. To provide a basis for evaluating the errors arising from these approximations, A. T. F. Chen has developed a rigorous numerical method for calculating the response of a horizontally layered system to horizontal base motions. The numerical stability of the method is limited only in that spurious oscillations occur in computed surface accelerations when input values of damping are small. However, it was found that these oscillations can be controlled by digital filtering.

Research in rock mechanics

A special study of rock stress in the Sunshine mines, Coeur d'Alene mining district, Idaho, is being conducted by F. T. Lee in cooperation with M. J. Beus and other personnel of the Spokane Mining Research Center of the USBM. Definition of in-place stress conditions and stress changes is essential before a circular shaft, the first in the district, is excavated. It was found that the severely fractured and brittle nature of the Revett Formation (Belt Supergroup) at many locations limited the kinds of instruments that could be used. The USGS solid-inclusion borehole stress probe and several other types of instruments have been installed in the walls and roofs of rooms on two levels of the mine, each more than 1,000 m below the surface. An initial installation of three USGS probes has been supplemented by three more such probes. Residual stress and anisotropy of rock properties are being tested by the USGS and USBM. Preliminary results indicate there is as much as 1.4×10^7 N/m^2 releasable stored stress in this rock.

A preliminary interpretation of data from the USGS instruments indicates that the in-place maximum principal stress is subhorizontal and bears approximately east-west, parallel to the strike of the steeply dipping beds, and the minimum principal stress bears north-south and has a subhorizontal plunge. The ratio of the maximum and minimum principal-stress magnitudes is 6:1, which is a highly directional stress field. These stresses agree in orientation and magnitude with those necessary to produce the observed elliptical deformation of a nearby vertical borehole of large diameter.

A series of hydrofracturing experiments designed to determine the regional state of stress in the Piceance Creek oil-shale basin of northwest Colorado were conducted by R. G. Wolff, J. D. Bredehoeft, W. S. Keys, and Eugene Shuter. The test results, combined with the results of logging with a borehole televiewer, permitted the determination of the magnitude and direction of the least-principal-stress tensor. Field observations showed that fractures can occur at hydraulic pressures as low as 0.6 of the overburden stress, as predicted by Hubbert and Willis (1957). Most fractures are vertical and are propagated vertically as long as injection continues unless the orientation of the stress field changes or a highly transmissive zone is intersected. Subsurface stress-field measurements before fluid wastes are injected would provide data concerning safe injection pressures at any site.

ENVIRONMENTAL GEOLOGY

URBAN-AREA STUDIES

Urban-studies target areas produced reports and maps dealing with geologic hazards, influences of geologic factors on man's management of the environment, basic data for land-use decisionmakers, and some historical detective work in one of the Nation's oldest cities.

Boston still yields historical secrets to urban geologists

In plotting the distribution of Holocene estuarine deposits (harbor muds and salt-marsh deposits), as reported in the logs of foundation borings, C. A. Kaye found evidence that the early colonial shoreline of one of the oldest and best known cities of the United States differed in detail from that shown on 18th-century maps. For example, Boston Neck (the narrow neck that connected the city with the mainland) was tidal marsh at two places. The geologic data show that in order to make this journey dry-shod, a causeway first had to be built. This fact is not indicated by the historic record. Other localized fillings of this type were done in the 17th century. Kaye is preparing a geologic map which will show the original colonial shoreline more accurately than any early document.

Sophisticated geologic tools measure water pollution in Duluth

A suite of surface-water samples collected in the Duluth, Minn., watershed area was examined by E. J. Dwornik, R. B. Finkelman, and R. R. Larson as part of a study of alleged pollution of the Duluth water supply by local asbestos-mining activities. Three water samples contained more than 1 billion particles of a fibrous material per litre. This fibrous material was analyzed by electron microscopic observation (morphology), scanning electron microscopic energy-dispersive analysis (composition: magnesium- and iron-silicates), and powder diffraction (mineralogy); it was found to consist of asbestos of the cummingtonite-grunerite group of amphiboles.

No safe level of exposure to asbestos has been established, although asbestos is a proven human carcinogen (Carter, 1974). The analyses of these samples provide a baseline of data for future studies.

Environmental mapping of the Metropolitan Washington, D.C., area uses soils data

A. J. Froelich, J. T. Hack, and S. K. Neuschel extensively used published soils maps of the SCS as an aid in environmental geologic mapping of the Washington, D.C., metropolitan area. In the Piedmont, the crystalline rocks are covered by saprolite to depths as great as 50 m. Saprolite is a soft, earthy, clay-rich, thoroughly decomposed rock, formed in place by weathering of igneous or metamorphic rocks. Saprolite thickness, critical to many aspects of environmental analysis, is determined from well logs and outcrops. The nature of the saprolite, equally important, is determined in part by bedrock composition and is reflected in the composition of the soils. Thus, soils maps help the geologist to delineate differences in both saprolite and bedrock. Other areas of the Piedmont underlain by sandstone, shale, and conglomerate have a mantle of weathered rock generally less than 6 m thick, with characteristic soils.

The Coastal Plain is underlain by a complex wedge of Cretaceous to Pliocene sediments with a wide range of physical properties. In areas of low relief and few outcrops, clay lenses are clearly delineated by a few characteristic soil groups; elsewhere, glauconitic sands are defined by different soil assemblages. Because geologic units of the Coastal Plain are variable and thinly stratified, more than one unit may be present in a single complex soil profile. Thus, through the use of soils maps, Survey geologists are able to characterize the physical properties of underlying geologic materials and are able to contribute indirectly a scientific basis to land-use decisions.

SAN FRANCISCO BAY REGION

Active geologic processes inferred and confirmed

While examing gross characteristics of terrain in the bay region on high-altitude aerial photographs, V. A. Frizzell, Jr., and C. M. Wentworth, Jr., noticed a northwest-trending alinement of linear features northeast of Alexander Valley, in Sonoma County, Calif., that suggested to them a possible active fault. Later, while mapping landslides in the same area from more detailed aerial photographs, Wentworth recognized specific evidence of active faulting along the same linear feature. Evidence included places where streams had been dammed by fault movement and the depressions filled with sediment. That interpretation was later corroborated when D. H. Radbruch-Hall found two redwood-stake fences on an old homestead that were each offset about 0.3 m by the fault. The result is recognition of another active fault in the San Francisco Bay region, at least 35 km long, with historic right-lateral offset of about 0.3 m.

Terrace studies reveal active faults

Studies of terrace deposits in San Mateo County by K. R. Lajoie, G. E. Weber, and J. C. Tinsley III resulted in detection of far more late Quaternary fault movement and tectonic deformation than was previously known. Fault movement has produced a 1-m-high scarp in Holocene alluvial deposits in the Seal Cove area. Weber mapped alluvial deposits 10,200 yr old, which have been deformed by movement on a newly discovered strand of a major ocean-floor fault previously mapped by H. G. Greene, W. H. K. Lee, D. S. McCulloch, and E. E. Brabb. The tectonic deformation in the coastal area has locally created conditions which contribute to a high rate of cliff erosion resulting in loss of beaches and endangering of homes.

Another new active fault near San Francisco

A creep zone on a heretofore unknown active fault has been recognized and mapped through the town of Antioch, Calif., by D. B. Burke and E. J. Helley. Offset curbing, sidewalks, railroad tracks, and cracked and buckled pavement delineate the creep zone. Two existing schools and the site of a planned high school are within the zone of creep.

Mountain lion helps date fault activity

While tracing a major fault zone in northwestern Santa Clara County, Calif., D. H. Sorg and R. J. McLaughlin discovered a fossil mountain lion in the Santa Clara Formation. The fossil occurred with other vertebrates and with freshwater mollusks in sandstone and mudstone, about 366 m above the base of the 670-m-thick formation. The locality, near the town of Saratoga, is in the type area of the formation. C. A. Repenning has identified the skull and some limb bones of the lion as *Felis (Puma) studeri*, an extinct species. The skull was found in association with bones of elk, horse, duck, and abundant fish. The assemblage appears to have an age of late Blancan in the North American land-mammal scheme, indicating a very late Pliocene age in West Coast provincial usage. D. W. Taylor has assigned a late Pliocene age to freshwater mollusks from the Santa Clara, and Erling Dorf (Princeton Univ.) has assigned plant fossils from the Santa Clara to the late Pliocene. The Blancan age of these fossils from their stratigraphic position in the Santa Clara Formation indicates that only the upper 275 to 305 m of the Santa Clara can be Pleistocene in age, a matter heretofore in doubt. Environmental significance of these discoveries is that these strata are broken by a major fault zone in the Saratoga-Stevens Creek Reservoir area; many recent minor earth tremors have been recorded along this fault zone, but Santa Clara Formation strata are the youngest deposits known with certainty to have been offset.

FRONT RANGE URBAN CORRIDOR, COLORADO

Mapping of land-resource characteristics in the Front Range urban corridor (FRUC), which centers on Denver and extends from the Colorado-Wyoming border south to Pueblo in a corridor about 30 km wide, proceeded toward fruition in 1973. A project to produce a 1:100,000-scale, three-part base map of the corridor entered the final stages of preparation. Maps and reports dealing with several aspects of physical characteristics of the corridor were produced, and many others are near completion. W. R. Hansen, FRUC-project director, reported that several resource-inventory maps, on the new 1:100,000 base map, are nearing completion.

Five interpretive and derivative maps of geologic nature and directed to the needs of those interested in land-use planning were prepared by H. E. Simpson for the Golden quadrangle, Jefferson County, Colo. The maps, derived from geologic maps by M. E. Gardner, Simpson, and S. S. Hart (1972), and Richard Van Horn (1972), express various engineering and lithologic characteristics of the bedrock and surficial materials in terms understandable to planners, civil engineers, landowners, students, and others. Of particular interest to many is a brief text that accompanies each map. The text explains the origin or cause and general behavior of the characteristic mapped, indicates the relation of the map to land-use planning, defines technical terms where needed, and in some cases suggests some possible methods of reducing, correcting, or avoiding problems associated with the mapped characteristic.

The distribution of unconsolidated material and bedrock is of importance in planning and designing urban developments, highways, reservoirs, utility corridors, and other works of man in the mountains in the western part of the Front Range urban corridor. K. L. Pierce and P. W. Schmidt prepared maps showing four soil-terrain units and two alluvial units for the Boulder, Eldorado Springs, and Ralston Buttes quadrangles at a scale of 1:50,000. The thickness and distribution of unconsolidated material above hard crystalline rock is mapped using arbitrarily defined soil-terrain units with the end members of "mostly soil more than 2 m deep" and "mostly rock."

Outstanding natural and historic landmarks in the FRUC were cataloged in an inventory prepared by N. G. Petrie (Denver Univ.), consultant in land-use planning. The chief purpose of the inventory is to help assure that these landmarks will enter into land-use planning as a part of our national heritage as enunciated in the National Environmental Policy Act of 1969. The inventory consists of maps that identify the specific localities, and of short descriptions and appropriate photographs of the individual landmarks.

Maps showing present land use in the FRUC are being readied for publication by L. B. Driscoll (Denver Univ.), consultant in remote sensing and land use. The maps provide a comprehensive 2-level classification of the distribution of 5 main categories of land use and about 24 subordinate categories. Categories are based on ground-checked interpretations of high-altitude color-infrared photographs.

Gravel resource maps compiled on the new base maps by R. B. Colton, D. E. Trimble, and H. R. Fitch, show the distribution, size range, spot thickness, and general quality of gravel resources in the rapidly growing FRUC. The general distribution of rock suitable for crushed-rock aggregate is also shown. Although this gravel resource is very large, it is being depleted rapidly in some parts of the area—or taken from production—by exploitation, urban growth, and restrictive zoning. However, under a law recently enacted by the Colorado Legislature, no land use will be permitted in the populous counties of Colorado that would interfere with present or future extraction of commercial gravel deposits. These maps are keystones in the support of the new State law.

Availability of hydrologic data in the Boulder-Fort Collins-Greeley area of the FRUC, information vital to land and water-resource planners and managers, is shown by symbols and colored areas on the new base map. The information was compiled by E. R. Hampton, G. A. Clark, and M. H. McNutt, and shows 12 climatologic data sites, 30 surface-water data sites (streams and reservoirs), 440 wells where water-level and chemical-quality data have been collected, 10 areas where boundaries of periodic flooding have been mapped, and 6 areas of ground-water studies. A brief text describes the significance of the data and directs the reader to reference sources.

J. F. McCain prepared a map showing flood-prone areas along principal streams in the Boulder-Fort Collins-Greeley area of the FRUC. A total area of 338 km^2, about 7 percent of the study area, is subject to inundation by the 100-yr flood. This reference flood has a 1-percent chance of being equalled or exceeded during a given year. The map will be useful in regional land-use planning, especially as an index to more detailed flood-plain information contained in referenced reports.

More than 280 lakes are located in the northern part of the FRUC (lat 40°00′ to 40°37′30″ N., long 104°37′30″ to 105°22′30″ W.). Of these, 116 lakes have surface areas greater than 10 ha. The largest are Horsetooth Reservoir, Boyd Lake, and Carter Lake Reservoir. Specific conductance was 750 μmho/cm or less in about-half of the 115 lakes sampled. Conductance exceeded 4,500 μmho/cm in only seven lakes. Most of the lakes are alkaline, only two having pH less than 7.0. Values of pH exceeded 8.5 in about two-thirds of the lakes sampled. Transparency, as measured by a Secchi disk, was less than 1.2 in about three-fourths of the lakes measured, and ranged from 0.2 to 3.6 m. Algal concentrations ranged from 77 to 13,000 cells/ml in samples collected from 23 lakes. Concentrations were greater than 1,000 cells/ml in 10 of the lakes. Chlorophyll *a* concentration ranged from below detection limits to 117 μg/l. Sixteen different genera of algae were found as dominants or codominants in samples from 23 of the largest lakes. *Oscillatoria* was found as a dominant or codominant in 10 of the 23 lakes. Data presented on the new base map include surface area, shoreline length, specific conductance, algal concentration, pH, Secchi-disk transparency, and chlorophyll concentrations.

GREATER PITTSBURGH REGIONAL STUDIES

Slope failure is a principal geologic hazard in the Greater Pittsburgh metropolitan area, where significant differences in permeability are found in rock types that make up the Pennsylvanian layered-rock sequence of Allegheny County. Where these rock layers are near the surface and dip gently, ground water in the more permeable layers is directed downdip. Where the dipping layers crop out on hillslopes that dip more steeply but in the same direction, that is, in overdip slopes, the ground water acts as an agent in enhancing slope instability. R. P. Briggs prepared a map of Allegheny County, which identifies overdip slopes on which mechanical resistance to slopes failure is less than on other slopes.

In the course of an inventory of disturbed ground in Allegheny County, J. S. Pomeroy identified one moderately extensive area of so-called "breathing ground" and tentatively identified others. Identification is based on dense misty patches caused by warm air exhalations from landslide deposits into colder winter air, largely an early morning phenomenon but one that continues for appreciable periods in the larger earth and rock masses. Breathing ground demonstrates the presence of extensive interconnecting water-free voids in some landslide deposits. It is of environmental significance because heavy rains, such as those associated with Hurricane Agnes in 1972, could saturate these permeable deposits and trigger further downslope movement.

LAND RESOURCE ANALYSES

Multidisciplinary efforts of the USGS in 1973 produced maps and reports of principal use to planners, land-use managers, and others concerned with land-use decisionmaking. These reports generally were specially designed to be readily understandable to nongeologist users, while maintaining the traditionally high standards of scientific accuracy of the USGS. Areas of studies ranged from a few hectares to a model of the conterminous United States.

Systems-dynamics modeling of the United States

On the national scale, R. R. Doell has simulated a model of selected dynamic factors of the United States that analyzed relationships between energy use and resources, demographic factors, general economic or productive strength, pollution, and food supplies. Parameters were adjusted so that the model would follow changes in U.S. population, gross national product (GNP), and energy-supply use between 1900 and 1970. The model apparently shows correlations between the growth of the GNP and of energy use, but it indicates that population growth was for the most part independent of the other modeled factors. Further indications from the model are that a rise in overall cost of energy supplies, not a restriction in supplies, may limit the rate of growth of the GNP.

Natural-geologic-landmark program

The USGS, cooperating with the NPS, is engaged in a program to contribute proposed sites of great geologic value to the Registry of Natural Landmarks. L. L. Ray is conducting an inventory and assessment of such features on the Atlantic Coastal Plain. Rapid industrial development and expansion of urban and recreational land use on Coastal Plain is endangering such geologic environments as coastal lands, wetlands, offshore islands, barrier beaches, lagoons, and unusual rock formations. Selections from the inventory, described and appraised geologically, will be nominated for designation as Natural Landmarks.

R. L. Detterman has selected 88 potential sites as candidates for Natural-Landmark designation in the Arctic Lowland of northern Alaska. Many of the sites include geologic and geomorphic features in delicate environmental balance, such as muskeg, tundra, permafrost, and low, ice-cored hills called pingoes. Many of these features do not occur elsewhere in the United States.

D. E. Trimble, T. A. Steven, and P. L. Williams made onsite evaluations of 20 proposed sites for Natural Landmarks in Colorado, Idaho, and Oregon. The evaluations were done at the request of the NPS and resulted in recommendation of five sites for designation in the landmark program.

Interpretative maps for land-use-capability planning

In response to an urgent request from the county commissioners of Routt County in northwestern Colorado, G. L. Snyder developed a map, based on his geologic mapping in the northern part of that county, showing general physical characteristics of geologic units. The map contains units appropriate for land-use planners. For example, one unit of interest in construction is derived from degree of surface slope and relative bearing strength of the geologic materials, combined with excavatibility; another, appropriate for hydrologic engineering, is based on relative porosity, permeability, and pollution potential for ground and surface water combined with slope-failure susceptibility. As many as four ratings (best, good, fair, and poor) of each unit are shown on the map. The map has evoked an enthusiastic response from the county commissioners.

Land reclamation after mining

Open-pit mining has been under attack as thoroughly damaging to the environment. Mined-out land can be unsightly and may contribute to pollution of surface- and ground-water supplies, contaminate both air and water, and upset wildlife balances. J. B. Cathcart spent part of 1973 appraising the results of mined-land reclamation in Florida. Mining companies have reclaimed much of the land mined in the past and are reclaiming all current mining areas. Reclaimed land is being used for agricultural and recreational purposes (lakes for swimming, boating, and fishing; land for parks and golf courses), as well as for bird and wildlife sanctuaries, for housing developments, and for industrial sites. Land after mining and reclamation may be better farmland than it was prior to mining: some phosphate and clay and organic material that occurs in the reclaimed surficial material is not present in the unmined, natural surficial cover of quartz sand. Surface-water supplies are neither depleted nor permanently polluted by mining: the ponds formed as a result of reclamation are used for livestock water and for recreation with no known adverse results, and the addition of more lakes may actually increase the amount of water retained at the surface.

Land-resource-analysis maps seen as effective planning tools

Since publication of the Hartford North folio in 1972, it has become clear to Fred Pessl, Jr., and colleagues that maps depicting the physical and chemical characteristics of the land and water resources are enthusiastically received as products which can serve as effective planning tools for a wide variety of decisionmakers. Interdisciplinary USGS projects such as the Connecticut Valley Urban Area Project have developed new ways in which technical information can be presented to people not necessarily trained in the Earth sciences, but who are engaged in formulating policy and developing regulations that relate to land and water use. Partly as a result of USGS leadership in this field, an awareness of the importance and effectiveness of using natural-resource information as an aid in making land-use decisions has increased sharply. The ability of planners to use natural-resource information grows as the personal contact between the planning community and the geotechnical community increases, and so does the geologist's understanding of those natural-resource parameters which bear most directly on planning problems. The result of this interaction is an increase in requests from a broad sector of the general public for understandable, readily available, pertinent information about our land and water resources.

During 1973, R. B. Morrison used ERTS–1 multispectral imagery to map various features that have resulted from the modern (post-1890) episode of accelerated erosion in southern Arizona, during which arroyos, gullies, and sheet-eroded areas were formed. Maps also were prepared from these images, showing intensity of erosion, types of streams, and potential erodibility (of soils and other earth materials) for a 442,000-km^2 area.

A team of scientists and engineers produced computer maps of Yellowstone National Park and vicinity. The work was supervised and conducted by H. W. Smedes under contracts with NASA and in collaboration with investigators from Colorado State University, the Environmental Resources Institute of Michigan, and the NPS. The map covers about 125,000 km^2 of wild land terrain and depicts 12 ground-cover classes. To evaluate whether such applications are economically feasible and competitive with conventional mapping techniques, the studies included the determination of the minimum amount of "ground truth" required for training the computer, and the minimum amount of testing required to establish the accuracy of mapping for each class. Accuracies ranged from about 70 to 95 percent. The units mapped by computer techniques were selected on the basis of (1) natural terrain-association units, (2) units that could most likely be mapped on the basis of their spectral reflectance, (3) units having ecologic significance, and (4) units significant to land-use planners and managers (for example, for inventory, for monitoring changes, for management decisions related to wildlife—via the habitat that supports that life, and for wildfire potential).

The potential users were involved in the selection of map units that were important to them; some of these units had not previously been mapped. For the latter reason, and because the selected units were mapped faster, more accurately, and (or) cheaper than by conventional techniques, the computer map has been demonstrated to be a cost-effective and feasible technique of wide application. ERTS multispectral scanner imagery was used for the study, which produced a colored map. The map units range from water to bare rock, with various combinations of rock and vegetative cover between.

B. H. Bryant, T. W. Offield, and P. W. Schmidt statistically compared the faults, foliations, and joints observed during geologic mapping of a Precambrian terrane in the Evergreen, Colo., quadrangle with thermal, photographic, and topographic linears. Results of the comparison suggested that topographic linears are indicators of mappable faults and fractures; photographic linears are less useful in interpretation of any one structural element; and thermal linears, believed to represent zones of moisture concentration, are parallel to faults, foliations, and a statistically minor but more open joint set. Those structures form the ground-water reservoirs and zones of permeability in the igneous and metamorphic rocks of the area.

INVESTIGATIONS RELATED TO NUCLEAR ENERGY

UNDERGROUND NUCLEAR EXPLOSIONS

The USGS, through interagency agreements with the AEC and the DOD, investigates the geologic and hydrologic environment of each site where underground nuclear explosions are conducted. Most of these sites are at the Nevada Test Site. Geologic and hydrologic data are needed to evaluate the safety, engineering feasibility, and environmental effects of nuclear explosions.

At the Nevada Test Site, two ground-water systems have been identified—the Ash Meadows system and the Pahute Mesa system. Radiocarbon dating indicates that water presently being discharged from the Ash Meadows system ranges in age from 15,000 to 30,000 yr (L. J. Schroder, W. A. Beetem, H. C. Claassen, and R. L. Emerson, 1973). Geologic and hydraulic studies of the Ash Meadows discharge area confirm the complexity of ground-water flow in this interbasin carbonate system.

For some underground explosions it is necessary to excavate underground chambers below the zone of water saturation. In order to predict the water inflow to such chambers in advance of mining, W. W. Dudley, Jr., and R. K. Blankennagel have developed a correlation between transmissivity, storage coefficient, and relative specific capacity (a nonequilibrium parameter having the dimensions of specific capacity). Relative specific capacity integrates both transmissivity and storage coefficient and thereby allows empirical estimates to be made of the inflow into underground chambers.

At several explosion sites at the Nevada Test Site, postexplosion test holes have been instrumented to monitor ground-water inflow into explosion cavities at temperatures above the boiling temperature of water. H. C. Claassen and D. D. Gonzales have devised systems to sample water from the radioactive explosion cavities, so that the source of potential contamination to aquifers can be studied. They also have completed a two-well recirculating-tracer test using tritium. This test provides calibration for other tracers that can be used at locations where the introduction of tritium to aquifers is undesirable.

Project Rio Blanco, an experiment to study the effect of nuclear explosions on the productivity of gas-bearing formations in the Piceance Creek basin in Colorado, had varying effects on water levels in boreholes in the basin. According to J. E. Weir, Jr., and Gonzalez, anomalous changes in water levels were manifested as declines of as much as 9.14 m and rises of as much as 6.10 m. These net changes occurred during the period 1 to 2 mo after the detonation. The data suggest that storage coefficients may have been altered in the aquifers near the Rio Blanco site.

On Amchitka Island, Alaska, L. J. Schroder and W. C. Ballance (1973) have monitored the surface and ground waters following the Cannikin nuclear explosion. Minor chemical changes in the water of streams and lakes were noted a few days after the detonation, but the quality of the water returned to normal within 1 mo after detonation. The radiochemical quality of the water, as monitored by gross alpha, gross beta-gamma, and tritium analyses, was not affected by the Cannikin event. Tritium analyses of the ocean water around Amchitka Island are typical of normal seasonal variations in shallow ocean water.

Final water samples were recovered from the Cannikin reentry hole before it was plugged with cement in April 1973. Radiochemical analyses of water collected periodically from the hole are being studied to determine the processes of radionuclide distribution in nuclear-explosion cavities.

A bathymetric survey of Cannikin Lake, which was created by the collapse of the ground into the Cannikin explosion cavity, showed that the lake is the largest on the island, covers an area of 12.1 ha, and contains 401,000 m^3 of water.

Homomorphic deconvolution of teleseismic *P*-wave signals from underground nuclear explosions has been shown (Bakun and Johnson, 1973) to be a useful tool for studying characteristics of explosive sources. Application of the method to the study of earthquake-source characteristics and to discrimination of secondary arrivals in seismic profiling appears to hold promise.

At the Nevada Test Site in tunnels where nuclear tests are conducted, J. R. Ege, C. H. Miller, and J. D. Kibler have installed three-component hydraulic-cell (flatjack) stress-measuring probes. A set of three probes has been continuously recording stress changes since June 1972. The data show a cyclic stress-change pattern varying about 13.8 bars relative to the time of emplacement. The relative stress is greatest during spring and summer and least during fall and winter. Rock-temperature changes at the measuring points do not vary more than 1°C throughout the year. A measurement, in 1971, of the absolute stress measured by a borehole-deformation gage revealed an excess horizontal stress of 38.6 bars along a bearing of N. 28° E. The greatest secular-stress changes apparently occur along this direction.

A team of geologists (Jack Rachlin, W. J. Dempsey, P. J. Ruane, and Salih Faizi) has been studying the geology and hydrology of sites where the Soviet Union has used nuclear explosions for peaceful engineering purposes. The Soviet program has included experiments involving canal construction, construction of underground storage cavities, petroleum stimulation, extinguishing runaway gas-well fires, and metal mining. Additionally, the Soviets have expressed interest in using underground nuclear explosions in a program of seismic research involving study of the Earth's crust and upper mantle. This team uses data from the published scientific literature and data supplied by the Soviets at joint U.S. and U.S.S.R. conferences. The Soviet Union appears to be more active than the United States in applying nuclear explosives to engineering problems, and it is hoped that this country can learn from the larger Soviet experience.

RELATION OF RADIOACTIVE WASTES TO THE HYDROLOGIC ENVIRONMENT

Low-level solid and liquid radioactive wastes, generated by a wide variety of nuclear-energy facilities, are disposed of by burying or discharging the waste materials into surficial deposits in controlled areas at several locations. The AEC sponsors research on the identification of potential release mechanisms, pathways of movement, and traveltime of these wastes from the disposal areas. The research is also applicable to predicting the fate of accidentally released radioactive material and to many problems associated with determining geohydrological environments where high-level radioactive wastes may be safely stored. Part of the research is devoted to protecting the biosphere from disposed contaminating fluids, and part is related to developing new waste-disposal techniques and areas.

Columbia River Estuary

In order to define temporal variations in the amounts of radionuclides in the Columbia River Estuary, which are derived from the AEC's Hanford, Wash., reactor, D. W. Hubbell, H. H. Stevens, Jr., and J. L. Glenn developed models for determining the concentrations of radionuclides in solution and the concentrations of radionuclides associated with particulate material at Astoria, Oreg. The models use dimensionless relations and radionuclide concentrations determined from periodic sampling to establish for each flood and ebb the maximum and minimum concentrations and their times of occurrence. Mathematical functions generate the concentration distributions between adjacent maximum and minimum values. Radionuclide-transport rates determined by integrating over time the product of radionuclide concentration and discharge (water discharge is used in the computation of solute radionuclide transport, and sediment discharge is used for particulate radionuclide transport) show that the total transport rate (sum of solute- and particulate-radionuclide discharges) of most radionuclides is highest in the winter and spring and lowest in the late summer. Computations of radionuclide transport into and out of the reach between Astoria and the site of the former Beaver Army Terminal and of radionuclide decay within the reach indicate that the amount of radionuclides retained between river miles 14 and 53 varies seasonally. Levels of zinc-65, scandium-46, and manganese-54, which have moderately short half-lives and are transported mainly in association with sediments, diminished 60 percent or more between June 1965 and June 1970, despite the fact that their levels increased significantly during the fall and winter of 1967–68.

Hydrology of subsurface waste disposal, National Reactor Testing Station, Idaho

Liquid chemical and radioactive wastes have been discharged to ponds and wells at the National Reactor Testing Station in Idaho since 1952. These wastes are carried downgradient in the Snake River Plain aquifer. J. B. Robertson and J. T. Barraclough (1973) observed the behavior of these wastes to evaluate the various geohydrologic influences upon them and to assess their effects on the ground-water resources. Hydraulic dispersion has the most pronounced effect on the body of waste in the aquifer although sorption and radioactive decay have significant influences on some radionuclides. A study of the geohydrologic controls of possible downward migration of leachates from a solid-waste burial ground is continuing. Some of the sediment and water samples show trace amounts of waste radionuclides at various depths below the waste storage. Even though the drilling phase of the study was carefully performed, external contamination is believed to have caused some of the positive results for trace amounts of radionuclides. It appears that some of the waste detected could have been transported by natural water (Robertson, Schoen, and Barraclough, 1973).

Robertson and Barraclough (1973) developed and tested a numerical model which will simulate the transient migration of conservative and nonconservative solutes in ground water of the Snake River Plain aquifer (with transient hydraulics) at the National Reactor Testing Station, Idaho. The model (Robertson, 1974) uses a method of characteristics and includes the effects of two-dimensional dispersion, ion exchange (instantaneous, linear isotherm), radioactive decay, and convective influences. The model has successfully simulated the historically observed behavior of several radioactive- and chemical-waste products in the aquifer, including strontium-90, which is subject to all of the influences listed above. The model has been used to predict the future distribution of waste chloride, tritium, and strontium-90 to the year 2000. It is probably the first field-documented model to include all of the parameters indicated.

Siting a pilot-plant repository for radioactive waste

Harley Barnes (1974) reported that the USGS provided AEC with the geologic and hydrologic background data required for choosing the most promising site in bedded salt in the conterminous United States for their pilot-plant repository for solid high-level radioactive waste. Aided by positive findings for the Permian salt basin and Carlsbad potash mines and by less favorable findings for other areas, AEC chose a target area in southeastern New Mexico as the best potential site for the pilot-plant repository.

The rock types selected for investigation were salt and impermeable argillaceous rocks. The areas investigated included the Permian salt basin (especially in southeastern New Mexico), the bedded salt deposits in the Paradox basin in Utah and Colorado, the Supai salt basin and Luke salt body in Arizona, and the northern Gulf Coast salt-dome province. The argillaceous formations of the conterminous United States were also reviewed briefly but were considered less promising than bedded salt deposits. Aside from the Permian basin, the Paradox basin seemed to offer the most promising site for a repository.

RADIOACTIVE WASTE EMPLACEMENT IN SALT

Geologic studies continued in the Permian basin of southeastern New Mexico to provide data to the AEC for evaluating sites for a pilot-plant repository for solid high-level radioactive waste. Recent studies by A. L. Brokaw, C. L. Jones, G. O. Bachman, M. E. Cooley, and L. M. Gard, Jr., in the Pecos Valley and surrounding areas of southeastern New Mexico have added considerably to the known history of subrosion and deformation of salt and other soluble rocks in the northern Delaware basin and adjoining shelf area. Salient aspects in this history include the following sequential events:

1. Erosion and removal of Ochoan evaporite deposits and red beds from the Guadalupe Ridge during Early and Middle Triassic time, and the eastward migration of the eroded edge of Salado Formation into the Pecos Valley to the general longitude of Carlsbad, N. Mex., or beyond by early Late Triassic time.
2. Extensive solution, subsidence of the surface, and formation of a karst landscape with sinkholes, linear valleys, and caverns in the limestone terrane of the Guadalupe Ridge and in the evaporite terrane of the Gypsum Plains, Rustler Hills, and Pecos Valley south of Carlsbad, N. Mex., during Jurassic time.
3. Peneplanation and filling of sinkholes and other solution features with clays, sands, and coarse rubble by encroaching seas during Early Cretaceous time.
4. Eastward tilting of the Delaware basin during Late Cretaceous or early Tertiary time, resulting in some salt flowage in the lower part of the Ochoan evaporite series and intraformational movement of salt into elongate pillows or mounds which uplifted the overburden into anticlinal ridges near the eastern margin of the basin.
5. Solution and land subsidence during early Tertiary time, extending eastward across the Pecos Valley into the San Simon swale and other sections of eastern New Mexico along the courses of pre-Ogallala valleys.
6. Solution and land subsidence during much of late Tertiary and Quaternary time in areas of pre-Ogallala salt removal. Insofar as it has been determined, there has been no extension of the subrosional processes beyond the limits of the areas of pre-Ogallala salt removal.

SITES FOR NUCLEAR POWER REACTORS

Technical investigations and reviews of geologic and seismologic aspects of license applications to the AEC for nuclear power reactors were continued. The reviews evaluate regional and local geologic structure, seismology, and geologic foundation conditions that are related to the safety of nuclear facilities. The reviews result in reports to the AEC that become part of the public record of the licensing proceedings of the Commission.

During the year, F. N. Houser, F. A. McKeown, R. H. Morris, J. O. Maberry II, D. D. Dickey, W. V. Mickey, and S. R. Bockman prepared reviews on geologic and seismologic aspects of 33 sites for nuclear power reactors. The multidisciplinary nature of this work required consultation with other members of the USGS on specialized aspects of geophysics, marine geology and geophysics, petrology, and geochronology. The continuing experience indicates that regional and local geologic and seismologic knowledge, applied to evaluations of specific sites, provides a basis for closely adapting engineering-design criteria to the environment.

FLOODS

Three major categories of floods studied by the USGS are (1) measurement of stage and discharge, (2) definition of the relation between the magnitude of floods and their frequency of occurrence, and (3) delineation of the extent of inundation of flood plains by specific floods or by floods having specific recurrence intervals.

OUTSTANDING FLOODS

March 1973 flood in Southeastern States

Severe flooding caused by torrential rains March 15–18, 1973, occurred in basins of the Cumberland, Tennessee, and Mobile Rivers in Alabama, Georgia, Mississippi, and Tennessee.

March rainfall averaged 282 mm over the Tennessee River basin. Normal rainfall in March is 132 mm. As much as 406 mm of rain in a 48-h period in Wayne County in south-central Tennessee was reported by the SCS. Several areas recorded 203 to 254 mm in 48 h.

V. J. May reported that recurrence intervals of peak discharges exceeded 100 yr at 28 gaging stations and exceeded 50 yr at 25 other stations. Peak discharges of the Elk River near Pelham, Tenn., and the Flint River near Chase, Ala., were both greater than twice those of a 100-yr flood. Magnitudes of peak flows were determined at 449 gaging stations. Reservoir storage and discharge releases through flood-control dams were regulated by the Tennessee Valley Authority and the U.S. Army Corps of Engineers to minimize flood damages.

In the Tennessee River valley, seven lives were lost. Hundreds of people were evacuated from their homes and businesses, and more than 2,000 people were temporarily out of work in Chattanooga, alone.

Property damage was estimated at $100 million in Tennessee, $20 million in Alabama, and nearly $6 million in Georgia. Damage was severe and widespread, affecting homes, schools, industries, railroads, highways, and vehicles. The municipal airport of Chattanooga, Tenn., was inundated when levees were overtopped.

Spring floods of 1973 in the Mississippi River basin

John Skelton reported that maximum main-stem stages during the 1973 spring floods in the Mississippi River basin were the highest ever observed in a reach extending from about 80 to 675 km upstream from the Mississippi's confluence with the Ohio River. In most other reaches of the river, the 1973 stages were among the five highest ever observed.

The outstanding facet of the 1973 flood was the volume of flow in the Mississippi River. At St. Louis, Mo., the river remained above flood stage for 77 consecutive days, eclipsing the record of 58 consecutive days set in 1844. At Vicksburg, Miss., the river remained above flood stage for 89 consecutive days and set new records for volumes of flow.

Backwater flooding in some portions of the lower Mississippi River basin caused extreme hardship for agricultural interests. Eighty percent of some counties in the rich agricultural region of northwestern Mississippi were inundated during the height of the flooding.

Flood of August 1973 in New Jersey

S. J. Stankowski and A. J. Velnich (1974) reported that intense frontal rainfall caused flooding in four highly urbanized counties of north-central New Jersey on August 2, 1973. Rainfall intensities up to 102 mm/h were reported in Plainfield, with a maximum recorded precipitation of 210 mm in a 5-h period at Watchung. Peak flows in excess of 21.8 $m^3s^{-1}km^{-2}$ were determined in the upper Stony Brook basin near Watchung. New peaks of record were established at three gaging stations in the area, all of which had over 35 yr of record. The floods took six lives and caused an estimated $67 million in damage.

Record-breaking floods of October 1973 in north-central Oklahoma

Rainfall totaling more than 250 mm fell on an area of about 1,300 km^2 extending from Enid, Okla., northeastward to the Kansas border. An area of about 260 km^2 received rainfall amounts of 380 to 510 mm. The maximum amount occurred in Enid where about 510 mm of rain fell between 4:00 p.m. and 5:00 a.m. on October 10–11, 1973. Indirect discharge measurements show that runoff from small basins within the storm area reached a maximum of 18.1 $m^3s^{-1}km^{-2}$, according to R. H. Bingham, D. L. Bergman, and W. O. Thomas.

Flooding was most severe in Enid where peak discharges ranged from about 1.75 to 3.0 times the discharge of the estimated 100-yr flood.

The flood caused the loss of nine lives. In addition, thousands of hectares of topsoil and winter-wheat crops were lost by erosion. Highways, railroads, city streets, small businesses, and residential areas were also damaged considerably. Property damage caused by the October flood was $78 million, according to the Oklahoma Civil Defense Agency. The city of Enid and parts of Garfield, Grant, Kay, Kingfisher, and Noble Counties were declared disaster areas because of residential and agricultural damage, and parts of Osage and Pawnee Counties were declared disaster areas because of agricultural damage.

FLOOD-FREQUENCY STUDIES

Channel flood surveys in Alaska

Channel surveys at nine sites in south-central Alaska were used to compute bankfull discharge and maximum-evident-flood discharge. The results were compared with flood-discharge characteristics estimated from gaging-station records and regional multiple-regression equations. J. M. Childers reported that bankfull discharge was found to be a fair estimate of the 50-yr flood (average recurrence interval of 50 yr). The maximum-evident-flood discharge in northern Alaska was found to be the bankfull discharge.

Flood hydrology of Butte Basin, California

A streamflow and stream-stage network has been operated by R. G. Simpson in Butte Basin in northern California since October 1972. Data obtained will be used to describe the flood hydrology of the basin; collection and analyses of data are continuing and are scheduled to be completed in 1977.

Flooding was minor during the 1973 water year. The flood of January 17–19, 1974, of the Sacramento River caused significant overflow into the basin. Total Butte Basin overflow from the Sacramento River (measured near Butte City) was about 1,130 m^3/s.

Relation between 10-year floods and channel width for streams in Idaho

Relations between flow characteristics and channel characteristics show considerable promise in developing methods of defining flow characteristics at ungaged sites. The annual maximum peak flow, Q_{10}, that will be exceeded once every 10 yr, on the average, has been determined by C. A. Thomas at many gaging stations in Idaho, using the log-Pearson type III method. At many of these sites, measurements at or near the stage of the Q_{10} have been obtained from cableways spanning natural channels at which W, the width of channel at the Q_{10} discharge, can readily be obtained.

A regression of Q_{10} with W by computer, using data for 109 gaging stations, gives the following equation: $Q_{10}=0.496W^{1.90}$.

The correlation coefficient is 0.965, and the average standard error of the estimate is 55 percent (+70 percent and −40 percent). If further study establishes a suitable method to determine W, the use of this relation will provide a practical means of estimating Q_{10} at ungaged sites.

Basin effects on flood discharges in North Dakota

Attempts by O. A. Crosby to relate flood peaks to various climatic variables in individual basins resulted in standard errors of estimate ranging from 35 to 128 percent. Rainfall records were collected manually on a 3- to 5-km grid spacing interspersed with recording rain gages. The large standard errors appear to be due to an oversimplification of the storm parameters as well as a varying influence of these parameters on peak discharges with changes in overall storm magnitudes.

After the effects of climatic variables were evaluated, attempts were made to relate peak magnitudes to basin characteristics by linear regression. The basin parameters—area, shape, length, slope, and percent of cultivation—appear to have a significant effect on peak magnitude, but the data were insufficient to quantify these effects.

Small-area flood-frequency study in North Dakota

Available flood data on small areas are being analyzed by O. A. Crosby to develop relations for estimating the magnitude of floods in small basins in North Dakota. The relations are being defined by regional regression analyses of flood records at 126 sites. Preliminary investigations indicate that the major independent variables that affect flood-frequency relations for small basins are drainage area, slope of the stream, storage, soil index, and stream density. The relations developed may be used for any site in North Dakota in a drainage area ranging between 0.2 and 1,000 km^2 and where the flood flow is unregulated.

FLOOD MAPPING

Flood mapping in Glenn and Butte Counties, California

J. C. Blodgett and P. L. Stiehr have investigated the inundation of State Highway 162 across the 11-km-wide flood plain in Butte Basin, at the latitude of Butte City, which results from overland flow from the Sacramento River and from flooding on Butte

Creek. Flooding of Butte Basin by the Sacramento River will occur whenever flow in the main channel at Butte City exceeds a discharge of 2,500 m^3/s, a recurrence interval of about 3 yr. Characteristics of flooding, such as frequency, areas subject to inundation, flood profiles, and distribution of flow, were determined for floods that occurred between 1940 and 1973. The distribution of floodflow across the basin is not uniform. During the flood of January 24, 1970, 78 percent of the total discharge resulted from overland flow from the Sacramento River and 12 percent from flooding on Butte Creek; water-surface elevations differed across the flood plain by as much as 1.37 m.

Results of an analysis of the present roadway and bridge geometry indicate that backwater effects were less than 0.2 m during the January 24, 1970, flood. Maximum velocity of flows at the bridges was 2.1 m/s. At many locations adjacent to the roadway, ground elevations are higher than the road crown. If the roadway embankment were raised to prevent overtopping, backwater effects greater than 0.152 m would result upstream from 7 of the 15 bridges on State Highway 162. Additional bridge openings to discharge a total of 1,100 m^3/s would be required for at least six locations if backwater effects and velocities were to be kept to tolerable levels for flows similar to those observed during the January 24, 1970, flood.

During the flood of November 12, 1973, higher water-surface elevations were recorded on Butte Creek and its overflow channels for a discharge lower than that observed during the January 1970 flood, probably because of vegetation in the channels and consequent reduction in the capacity of the channel to carry floodflows.

Flood-prone areas of the Boulder-Fort Collins-Greeley area, Colorado

A map showing flood-prone areas along principal streams in the Boulder-Fort Collins-Greeley area of the Colorado Front Range urban corridor has been prepared. J. F. McCain and W. R. Hotchkiss reported that almost 340 km^2, about 7 percent of the study area, is subject to inundation by the 100-yr flood. The map will be useful in regional land-use planning, especially as an index to more detailed flood-plain information contained in referenced reports.

Florida flood mapping by step-backwater techniques in basins having little slope

Profiles computed by step-backwater methods are nearing completion for Brooker Creek between Island Fork Lake and Lake Tarpon, Hillsborough and Pinellas Counties, Fla. The creek spills from swamp to swamp. Parts of the channel are not identified on the 7½-min quadrangle topographic maps nor on aerial-photograph-base topographic maps at a scale of 1:400 having a 0.61-m contour interval. Extensive field work has been of only limited usefulness for estimating roughness values. However, W. R. Murphy, Jr., has estimated roughness values satisfactorily from large-scale, aerial-photograph-base, topographic maps. Roughness values were adjusted to obtain profiles comparable to those obtained from data based on stage-discharge relations at gaging stations.

Flood profiles of Iowa streams

A. J. Heinitz (1973) completed water-surface profiles and tabulated discharges of floods on 214 km of streams in the Rock River basin. The streams include the Rock and Little Rock Rivers up to the Minnesota State line and Otter Creek to about 1.6 km south of Sibley. Profiles include the outstanding flood of 1969 and those computed for the 25- and 50-yr floods. Flood-frequency and magnitude data are based on recent flood-frequency analyses (Lara, 1973).

Flood-prone-area mapping in Livingston County, Michigan

L. E. Stoimenoff identified areas that would be inundated by the 100-yr flood on portions of two streams in Livingston County, Mich. Using photogrammetric and step-backwater techniques, flood-prone areas were defined along 3 km of the South Branch Shiawassee River upstream from highway I–94 and along 8 km of the Portage River from Little Portage Lake to Hiland Lake. Maps were prepared showing the flood-prone areas and land-surface contours at 0.61-m intervals. Computed water-surface elevations of the 100-yr flood along the South Branch Shiawassee River are 1.2 to 2.4 m higher than normal low-water elevations. Elevations for the Portage River are 0.6 to 1.8 m higher than normal low-water elevations. In addition to the 100-yr-flood elevations, elevations for the 10-, 25,- 50-, and 500-yr floods were determined.

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. About 12,000 such maps have been completed for all of the States, the District of Columbia, and Puerto Rico.

The program has progressed in two phases. The first phase, beginning in 1969, was directed toward defining flood limits in populated areas where significant flood problems were known and flood information was urgently needed. The second phase, implemented during 1972, expanded the areal coverage to include areas in which future development was envisioned.

Inundation maps of urban areas

Maps showing areas inundated by major floods, flood profiles, discharge-frequency relations, and stage-frequency relations were published during the current year as Hydrologic Investigations Atlases for the following areas: Harvard, Ill. (H. E. Allen, Jr., and A. W. Noehre, 1973b) ; Marengo North, Ill. (H. E. Allen, Jr., and A. W. Noehre, 1973a) ; Norristown, Pa. (W. F. Busch and L. C. Shaw, 1973) ; Bellevelle, Ill. (J. D. Camp, 1972) ; Corning, N.Y. (K. I. Darmer and L. A. Wagner, 1973b) ; Elmira, N.Y. (K. I. Darmer and L. A. Wagner, 1973a) ; Wilkes-Barre, Pa. (H. N. Flippo, Jr., and L. W. Lenfest, Jr., 1973) ; Capron, Ill. (R. S. Grant and M. D. Duerk, 1973) ; Rio Guanajibo Valley, P.R. (W. J. Haire, 1972) ; Aguadilla-Aguada, P.R. (K. G. Johnson, 1972) ; Petersburg and Colonial Heights, Va. (E. M. Miller and P. N. Walker, 1973) ; Big Rock, Ill. (R. T. Mycyk, G. L. Walter, and B. L. McDonald, 1973) ; Garden Prairie, Ill. (R. T. Mycyk and R. S. Grant, 1973) ; Harrisburg, Pa. (L. V. Page and L. C. Shaw, 1973) ; Martinsburg, W. Va. (G. S. Runner and E. A. Fried, 1973) ; and Punaluu-Hauula, Oahu, Hawaii (T. M. Ushijimi and C. J. Ewart, 1973).

WATER QUALITY AND CONTAMINATION

Arsenic concentrations in the Tulpehocken Creek basin, Pennsylvania

Results of a study by C. R. Wood (1973) indicate that at least 23,000 kg of soluble arsenic compounds are still present near a disposal site in the Tulpehocken Creek basin, Pennsylvania. During the 7-yr period prior to 1964, industrial wastes containing more than 450,000 kg of arsenic were placed in industrial lagoons overlying a carbonate aquifer in the basin. The lagoons are near the Tulpehocken Creek and lie within the drainage area for the proposed Blue Marsh Lake. In 1964, arsenic concentrations as high as 17 million $\mu g/l$ were measured in the ground water near the lagoons. Between December 1964 and April 1971, 200,000 kg of arsenic were removed from the ground water near the construction site. A comparison of analyses of soil samples collected in 1965 and in 1973 showed that the bulk of the arsenic present in the soil in 1965 was not removed during the recovery operation. Arsenic concentrations in the ground water and in Tulpehocken Creek have continued to decline since recovery operations stopped in 1971, although large seasonal fluctuations occur. The highest concentration of arsenic measured since recovery operations stopped was 240,000 $\mu g/l$ on August 1, 1973. The area along Tulpehocken Creek from the lagoons to Myerstown, 1.6 km downstream, is underlain by ground water that contains arsenic.

Sources of arsenic in water in Long Valley, California

The largest reservoir in the Los Angeles water-supply network is Lake Crowley, in Long Valley; approximately 50 percent of the water entering the aqueduct flows through Lake Crowley. Water from many of Long Valley's hot springs with high arsenic content is also entering the lake. The springs yield enough arsenic to intermittently drive the concentration in Lake Crowley above the 50 $\mu g/l$ permissible in a drinking-water supply. Water leaving Lake Crowley is diluted with other water downstream, which subsequently reduces the arsenic concentration.

The sources of arsenic in Long Valley were isolated and their contributions were calculated. According to L. A. Eccles, the largest source of arsenic was attributable to the hot springs in Hot Creek Gorge; they alone accounted for 60 percent of the arsenic entering Lake Crowley. The other sources were inventoried, but individually they were relatively insignificant. There are two large springs in the gorge that account for most of the arsenic from that area; however, they are submerged in the channel of Hot Creek.

Mercury in the Carson River basin of Nevada

According to A. S. Van Denburgh (1973), the upper 2.5 to 7.5 cm of sand- to clay-sized sediment downstream from the pre-1900 ore-milling sites of Nevada's Comstock Lode contains as much as 20 $\mu g/g$ of mercury. (In contrast, background concentrations are less than 0.1 $\mu g/g$) in stream- and lake-bottom sediment of the Carson River basin, east of Carson City.) The mercury apparently is present as a sulfide or as a component of one or more nonmethyl organic compounds. The total mercury content of stream waters is related to the abundance of bottom-sediment mercury and the rate of streamflow. The maximum measured concentration was 25 $\mu g/l$, at a flow of 83 m^3/s and a suspended-sediment concentration of about 1,500 mg/l. At the higher concentrations, almost all of the mercury is associated with the suspended sediment rather than with the liquid phase.

Studies of ground-water microbial ecology

G. G. Ehrlich and E. E. Lory have continued their studies of the anaerobic bacterial populations of ground water. Using a special glass-bead-filled probe, samples were collected from wells in California. Preliminary results suggest that there is no correlation between the chemistry of the natural water body and the bacterial species present, but the total population appears to increase with increasing total organic-carbon concentration.

Attempts to achieve bacterial growth on unmodified ground-water culture media have been uniformly unsuccessful. Therefore, the influence of the organisms studied on water quality is uncertain. Growth can be achieved on standard laboratory media, however. Reasons for the failure of growth under simulated natural conditions are being sought.

Bacterial contamination of ground water

Samples from a well in the Niagara Dolomite, Door County, Wis., contained relatively high concentrations of total coliform colonies in the spring recharge periods of March–April 1972 and January–June 1973, and during the fall recharge period of September–October 1972. Above-normal fecal concentrations were restricted to the late summer-early fall recharge periods. Both total and fecal coliform populations decreased during periods of falling ground-water levels. M. G. Sherrill was able to correlate total and fecal coliform concentrations with seasonal ground-water recharge periods.

New method for map display of sources of acid mine drainage in effluent streams

As a part of studies sponsored by the Appalachian Regional Commission, McLaughlin Run and Painters Run, Allegheny County, Pa., were selected as typifying effluent streams in which water from abandoned and flooded coal mines is an environmental concern. During a period of optimum base-flow conditions, pH and specific conductance were measured at 38 sites on these streams. Seymour Subitzky developed a graphic method that presents the water-quality parameters at each site. On a map of suitable scale, specific-conductance variation is shown by scaled-diameter circles around each site. Within each circle are tick marks indicating pH level, and a "clock" hand, running from the center to the circle, displays the pH at the site. The result is a map that quickly indicates sources of acid mine drainage. In the case of McLaughlin Run and Painters Run, this symbology also suggests stream-quality renewal by interaction of the acid water with calcareous rubble in the stream channels.

Degradation of ground water is indicated in mountainous area

W. E. Hofstra and D. C. Hall (J. E. Biesecker, Hofstra, and Hall, 1973) reported a general chemical and bacteriological degradation of ground water in the fractured Precambrian aquifer of the Front Range in Jefferson County, Colo. About 20 percent of the 800 domestic wells sampled had more than 1 coliform bacteria per 100 ml of water. About 3 percent of wells sampled contained fecal coliform bacteria, and 5 percent had nitrate concentrations greater than 45 mg/l nitrate (NO_3), the level set by the USPHS for drinking water. Preliminary data analysis indicated that crowding of wells and septic tanks, age of the facilities, and geologic setting were major factors in the degradation of the ground water.

The effect of urban population density on phenols in water

Using a continuous liquid-liquid extractor for the collection and concentration of organic materials in water, M. C. Goldberg separated and concentrated 23 separate phenols from the waters of the South Platte River. Most of these materials were below practical limits of detection, but several phenols were found in major concentrations. Paracresol, a soap additive, was one of the most prevalent compounds. This material was observed on the sediment, but the major distribution was in the water.

The South Platte River rises in mountainous country and flows through the city of Denver, Colo. From the Denver city limits, it is approximately 30 km to the next town downstream. The sewage plant for Denver is located near the downstream side of the city. The highest concentrations of paracresol were found near the sewage plant and up to 8 km downstream. Lesser concentrations were found in the river where it flowed through the city proper, and negligible concentrations were found in the upper reaches of the river, especially in areas not densely populated.

Surface-water monitoring of oil-exploration sites in the Big Cypress area, Florida

E. T. Wimberly (1974a) found that surface-water samples from the Sunniland oil field in Sunniland, Fla., showed no detrimental effects attributable to the oil field. Later, Wimberly (1974b) sampled surface water from oil-exploration sites in the Big Cypress area prior to exploration and again several times after exploration had begun. Of the parameters investigated, only chloride showed any noticeable difference after exploration. Chloride in water from one site was about 445 times that of the background sample. Chloride content of the background samples averaged 23 mg/l. At a number of the sites sampled in the dry season, chloride had increased, but it returned to background level in the following wet season.

Nutrients in the Kissimee River, Florida

A water-quality investigation by A. G. Lamonds, Jr., indicates that about 50 percent of the nitrogen and 85 percent of the phosphorus contributed to Lake Okeechobee by the Kissimmee River, its largest tributary, originates in the lower, agricultural part of the basin and not in the upper, urban part of the basin. Analyses of nutrient samples collected monthly during the 2-yr investigation indicate that the concentration of phosphorus increases in a downstream direction, particularly during periods of low discharge. A comparison of average concentrations of nutrients in samples collected above and below water-control structures indicates that ammonia and phosphorus concentrations are often slightly higher on the downstream side of the structure. This increase in the concentration of ammonia and phosphorus appears to be due to the bottom release of water from the impoundment. At high discharges, when gate openings are relatively large, the differences between the concentrations of these constituents above and below the structure are small.

Mass-balance model for Everglades, Florida

B. G. Waller analyzed total-nitrogen and total-phosphorus loads entering and leaving the Everglades water-conservation areas in surface water and bulk precipitation (rainfall and dry fallout). It was found that most of the total nitrogen (78 percent) and total phosphorus (90 percent) entered these areas as bulk precipitation. Calculated loads of these nutrients in the bulk precipitation were 4.1×10^{-3} t km^{-2} d^{-1} for the total nitrogen and 0.16×10^{-3} t km^{-2} d^{-1} for the total phosphorus. Most surface-water discharge (89 percent) flows out of the conservation areas southward to Everglades National Park. Because of the flow characteristics from these areas, most of the total nitrogen (1.9 t/d) and total phosphorus (1.4×10^{-2} t/d) enter the park.

Insecticides in surface waters of southern Florida

H. C. Mattraw, Jr., observed several regional trends in the distribution of insecticides in southern Florida. The incidence of slightly soluble, chlorinated-hydrocarbon insecticides in surface-water samples has decreased steadily between 1968 and 1973. The organic-rich sediments of the study area have retained these compounds. Concentrations of DDD, DDE, and Dieldrin in sediments reflect land-use patterns.

Detergents in ground water, Elizabethtown area, Kentucky

T. W. Lambert found that detergents (as methylene-blue-active substance) in 54 water samples collected from wells and springs in the Elizabethtown, Ky., area ranged from less than 0.05 mg/l to 0.70 mg/l. Only six samples had concentrations of more than 0.10 mg/l, and only two samples exceeded the 0.5 mg/l-limit suggested by the USPHS. No relation between the detergent and nitrate occurs even in samples collected from the same site. Detergents have not yet seriously affected ground-water quality in the Elizabethtown area.

Water-quality modeling in Plantation Canal, Florida

T. N. Russo and R. S. McQuivey used the QUAL–1 mathematical-model system to calculate spatial and temporal distribution of DO and BOD in Plantation Canal, Fla. Calibration of seasonal-flow and no-flow models, using data from the period 1971–73, showed that photosynthesis, rather than atmospheric reaeration, is the primary means by which the water replaces its oxygen. Verification of the summer-flow model, using data for 1973–74, provided a good fit of the model predictions to observed field values. Model simulations indicated that the flow required to reach a prespecified DO level in the canal increased as the quality of the headwater decreased. These simulations also indicated that any flow-augmentation program should be designed to allow the photosynthetic communities to produce as much oxygen as possible.

Effect of highway salting on ground water in New Hampshire

Two sites in sandy aquifers along the Everett Turnpike in south-central New Hampshire are monitored as part of a continuing program on ground-water contamination by highway-deicing salts. J. E. Cotton reported that by the end of 1973, chloride concentrations in water from the monitor wells had not reflected the substantial decrease of deicing salts applied during the winters of 1971–72 and 1972–73. Use of salts on this highway had increased annually through the 1960's, reaching a peak of 90 t/km for the winter of 1970–71. Application was reduced to 68 t/km the next winter and 57 t/km during the winter of 1972–73. At the Nashua monitoring site, the chloride front just below the water table is migrating down hydraulic gradient at an estimated rate of 6 m/yr. The well nearest the highway is 17 m from the edge of the pavement. Chloride concentration of water from this well was still increasing at the end of 1973, presumably reflecting the cumulative effects of salt application through the winter of 1969–70.

Tritium in the municipal water supply of Broomfield, Colorado

On September 18, 1973, the Colorado Department of Public Health released information that Great Western Reservoir and Walnut Creek flowing into the reservoir were contaminated with tritium. The reservoir is the public water supply for Broomfield, Colo. Walnut Creek, which feeds Great Western Reservoir, flows from the area of the AEC Rocky Flats plant. Tritium levels in Walnut Creek ranged from 5,000 pCi/l on May 4, 1973, to 2,900,000 pCi/l on May 24, 1973. From June 1 through June 21, 1973, the tritium concentration was greater than 80,000 pCi/l. The reservoir water was reported to contain about 10,000 pCi/l tritium.

Areally distributed samples were collected by USGS scientists, beginning on September 21, 1973. The samples were from waters in lakes, reservoirs, streams, ditches, seeps, and springs upgradient, downgradient, and laterally adjacent to the plant site. Particular attention was focused on sources of water in the Walnut Creek drainage. This sampling program established that background tritium levels are less than 480 pCi/l for ground water and from 560 to 770 pCi/l for surface water. Preliminary interpretation of the data by R. T. Hurr indicates two, and possibly three, sources for the tritium. Higher than normal tritium levels in seeps and surface flow in Walnut Creek (2,600 pCi/l and 7,900 pCi/l, respectively) on the north side of the plant and in surface flow in South Walnut Creek (3,600 pCi/l) draining the central part of the plant indicate a common source affecting both creeks, although two or more sources are possible. The third source is a landfill operation north of the plant in an unnamed tributary to Walnut Creek. The effluent from the landfill, though having a flow of only about 0.1 l/s, was visible and had a tritium level of 35,000 pCi/l. At the time of sample collection, all the effluent seeped into the ground within about 100 m downstream from the landfill, and there was no surface flow into Walnut Creek.

Landfill-induced changes in stream biology

Invertebrate populations in a stream adjacent to a sanitary landfill, in Greene County, N.Y., vary significantly both upstream and downstream from the point where leachate from the landfill enters the stream, according to T. A. Ehlke. In addition to significant differences in invertebrate populations, changes in stream quality are shown by an increase in organic carbon from an average of 1.0 mg/l upstream from the landfill to 2.5 mg/l below the landfill, and by reddish-brown precipitates of metallic compounds downstream from the landfill.

Effects of sludge disposal on ground-water quality in Ocean County, New Jersey

Waste-water-solids utilization on land is being studied by William Kam and J. J. Murphy in Ocean County, N.J. It is assumed that the controlled application of anaerobic-digested domestic sludge (5 percent solids) could be beneficial in the reclaiming of almost barren land by building up the organic content of the soil, supplying nutrients for vegetated areas, and by increasing the moisture-retaining capabilities of the leached sandy soils without adversely affecting ground-water quality. The sludge is distributed to three separate sites. Each site is of a different soil character common to the eastern seaboard. Each site consists of five 1,012-m^2 plots. Three of the plots were cleared for crops; one plot remains in the natural vegetated state; and the fifth plot acts as a control. The depth to the water table ranges from 2 m to 4 m below land surface. The rate of application of sludge on the plots varies from 2.3 to 9.0 kg $m^{-2}yr^{-1}$.

Background data collected from 66 monitoring wells shows that the ground-water dissolved-solids content ranges from 8 to 16 mg/l; there are no coliforms, and levels of nitrate are low, varying from <1 to 90 μg/l. In most cases, only very small quantities of heavy metals were observed. Most of the wells contained copper and aluminum, ranging as high as 0.5 mg/l to 1.9 mg/l, respectively. As much as 0.4 mg/l Ni was also found in some wells. Lead, chromium, mercury, and cadmium were not detected. Ground-water monitoring after one season of sludge application indicates no significant difference in the values except for a slight increase in both hardness and calcium. Nitrate appeared to increase in some wells, including a control well, which suggests natural fluctuations in nitrate levels.

Ground-water pollution in the Pine Bend area in Minnesota

From a hydrogeologic reconnaissance of groundwater pollution in the Pine Bend area, Dakota County, Minn., H. O. Reeder and R. F. Norvitch determined that within about 5.2 km^2 of the Pine Bend industrial area, degradation of ground-water quality due to waste disposal had occurred. Increased dissolved solids, low pH values, and presence of phenols were detected. Specific conductance of water at 25°C ranged from 330 to 660 μmho/cm in nonpolluted water and from 840 to 2,300 μmho/cm in polluted water. Pollutants have invaded the surficial glacial-drift aquifer and the deeper Prairie du Chien-Jordan aquifer, but they do not necessarily occur in both aquifers at the same places. Major pollutant spread is in the direction of hydraulic gradients in the two aquifers. These gradients slope eastward and northeastward in the industrial area, and the ground water discharges into the Mississippi River.

Assuming no great changes in development or waste-disposal practices, it is unlikely that subsurface pollution will spread much farther areally. Deeper penetration of pollutants is probable, however. Ground-water quality can be restored by: (1) natural flushing, (2) artificial flushing, and (3) withdrawal wells.

Trace elements in ground water from spilling of industrial waste

T. W. Lambert reported that liquid waste, spilled into a sinkhole on the east side of Elizabethtown, Hardin County, Ky., was traced to a spring some 580 m away. The spring is along the left valley wall of Valley Creek. The pH of the raw spring water was 5.3. The water contains Fe, 630,000 μg/l; Mn, 69,000 μg/l; Zn, 160,000 μg/l; Cr, 50 μg/l; Cu, 85 μg/l; Ni, 63 μg/l; and Pb, 200 μg/l. Cadmium was not detected. A white precipitate had formed at the spring, which had an estimated flow of 2.8 l/s.

Hydrobiochemical aspects of sewage effluent applied to a grassed plot

At the St. Petersburg, Fla., Northwest Sewage Treatment Plant, tests are underway to evaluate the effectiveness of grass plots and the underlying mixed layers of sand and sandy clay to renovate sprinkler-applied secondary-treated sewage effluent. The effluent is applied to a 1.6 ha grassed plot underlain by 14 m of fine sand, an organic-stained spodic horizon, and alternating layers of clean fine sand and clayey sand.

During a 12-week period, commencing August 1, 1973, effluent was applied at a rate of 51 mm per week. Nitrogen and phosphorus in the chlorinated effluent averaged 10.5 mg/l and 1.4 mg/l, respectively. R. C. Reichenbaugh and D. P. Brown reported that preliminary analyses of ground-water samples collected after 15, 45, and 75 d from different depths in the plot reveal total nitrogen content of about 3 mg/l, a 60- to 70-percent reduction of total nitrogen compared with that of the effluent. Ground-water samples collected upgradient and outside of the plot also contain about 3 mg/l total nitrogen. Total phosphorus in samples collected from depths to 3.0 m is greater than that of the applied effluent. Below 3.0 m, the concentrations of total phosphorus decrease to about 0.6 mg/l, about that of background samples collected upgradient and outside of the plot.

Determinations of nitrifying and denitrifying bacteria show high numbers of both in the soil and ground water at the plot, compared with background numbers from samples collected outside of the plot. Coliform and streptococci bacteria found in samples from several wells, a few as deep as 6.1 m below land surface, indicate that these bacteria are being transported to depth in the sand aquifer. Results of virus research conducted by epidemiologists from the Florida Department of Health and Rehabilitative Services, Epidemiology Research Center, show that viruses are also being transported as deep as 6.1 m in some wells in the site.

Sulfate-chloride ratios indicate subsurface-waste migration

Observations by M. I. Kaufman (Kaufman and others, 1973) and D. J. McKenzie of geochemical changes in waters in an industrial deep-well waste-injection system southeast of Lake Okeechobee, Fla., revealed decreased sulfate concentrations concomitant with increased hydrogen sulfide, a process associated with oxidation of the injected organic waste by anaerobic bacteria. The sulfate-chloride ratio decreased from 0.38 to 0.005, and hydrogen sulfide, accompanied by significant amounts of carbon dioxide and methane, increased from 3.4 to 87 mg/l in waste fluids backflushed from an injection well. If one uses chloride as a conservative parameter, subtle decreases in the sulfate-chloride ratio suggest that the waste migrated upward to a shallow monitor well about 27 mo after waste injection initially began, and again within 15 mo of the resumption of waste injection following deepening of the injection well. The decreased sulfate-chloride ratios appear to be sensitive indicators of waste migration.

Pollution in Fountain Creek, Colorado

Municipal wastes from various sewage-discharge points in the Colorado Springs, Colo., area cause noticeable degradation of water quality in Fountain Creek. Downstream profiles of DO in Fountain Creek indicate that during hot summer days DO decreases from saturation above sewage-discharge points to concentrations of less than 2 mg/l downstream from the major sewage-inflow points, according to J. M. Klein. Below the last sewage-discharge point, the stream slowly recovers; approximately 40 river miles below Colorado Springs, DO is generally at saturation. Where the stream cannot immediately assimilate the pollution load imposed upon it, fish and macrobiological forms are nonexistent, and the water is dark and odoriferous. During the summer months, the largest BOD concentrations occur near the sewage-discharge points; however, during the cold winter months, BOD is suppressed until farther downstream.

A mathematical model is being calibrated to predict the effect of pollution loading on DO concentrations in the stream for various stream discharges, stream temperatures, and BOD loading.

ENVIRONMENTAL GEOCHEMISTRY

Geochemical pollution

U.S. Geological Survey Professional Paper 807, entitled, "Geochemical anomalies of a claypit area, Callaway County, Mo., and related metabolic imbalance in beef cattle," published in 1973, constitutes the central evidence in a civil suit pending in U.S. district court in Kansas City, Mo. This report concluded that the mining referred to in the title has demonstrably altered the trace-metal environment of a downstream pasture and probably caused metabolic imbalances noted in cattle using that pasture. The report was coauthored by R. J. Ebens, J. A. Erdman, and G. L. Feder (USGS) and A. A. Case and L. A. Selby (Univ. of Missouri). Ebens, Erdman, and Feder have given depositions concerning points raised in the report.

Geochemical pollution of the environment adjacent to coal-fired electric-generating plants has been demonstrated at one such plant in the northern Great Plains region. Elemental analysis of samples of sagebrush (*Artemisia tridentata*) or its ash collected at geometric intervals from the stack suggests that stack emissions are introducing measurable amounts of trace metals into the environment. J. J. Connor, J. R. Keith, and B. M. Anderson used linear-regression techniques to demonstrate statistically significant reductions of Se, Sr, V, Co, Ti, and Zn in sagebrush downwind. Strontium and cobalt appear to be accumulating in plant tissue up to 30 km downwind; selenium, vanadium, and titanium, up to 15 km; and zinc, up to 3 km. Accumulation of such metals as Cd, Cr, Cu, Li, Mo, Ni, and Pb cannot be demonstrated in these samples.

A novel approach to the assessment of trace-metal pollution in coastal environments is being investigated by R. W. Rowland. A preliminary study of copper and zinc levels in samples of mantle tissue of the mollusk *Mytilus edulis* collected in the yacht harbor at Santa Cruz, Calif., and at a point about 1 km eastward indicates that the harbor specimens exhibit the higher concentrations; this suggests the presence of greater pollution effects in the harbor.

Trace-metal accumulations due to urbanization in the Denver, Colo., area are being investigated by H. A. Tourtelot as an extension of his preliminary work around Longmont, Colo. (U.S. Geol. Survey, 1973, p. 228). Samples of surficial materials containing 100 or more ppm Cu or Pb, 200 or more ppm Zn, and detectable amounts of silver, molybdenum, and tin are found mostly in a band extending east from Golden along I–70 into the industrial and residential areas of northeast Denver. Metal-rich samples are also found in the Platte River valley northeast of Denver. The metals are thought to represent additions to the local surficial environment from urban technological activities because there is no evident geologic basis for these occurrences.

Geochemistry and health

The Pima Indians of Arizona, when compared with the white population, exhibit a higher average incidence of diabetes mellitus, obesity, cholesterol, gallstones, and cirrhosis of the liver but a lower incidence of duodenal ulcer, atherosclerosis, and carcinoma of the lung and breast. In a study of the geochemical environment in which the Indians live, H. L. Cannon (USGS) and M. L. Sievers (USPHS) found that water used for domestic purposes appears to be high in Na, Cl, Ca, Mg, SO_4, Sr, B, and Li and has an unusually low copper-molybdenum ratio.

Plant foodstuffs contain low concentrations of most trace elements, but beans appear to be high in strontium and molybdenum, cabbage is high in sulfate (SO_4), and wolfberry is high in lithium. Cannon and Sievers are investigating the possibility that the infrequency of atherosclerosis, hypertension, and myocardial infarction in the tribe is at least partly controlled by the hardness of the drinking water or the relatively high lithium content of water and some plants, or both.

Trace elements in soils

H. T. Shacklette, J. G. Boerngen, and J. R. Keith (1974), in a continuing study of trace metals in soils and other surficial materials of the conterminous United States, reported the following geometric mean concentrations in parts per million:

	Selenium	*Fluorine*	*Arsenic*
Entire U.S.	0.31	180	5.8
Eastern U.S.	.39	115	5.4
Western U.S.	.25	250	6.1

These results are based on a collection of over 900 samples from sites approximately 80 km apart. This work brings the number of elements studied in this program to 40 (Shacklette and others, 1971, 1973; Shacklette, Boerngen, and Turner, 1971).

R. R. Tidball reported that *Q*-mode factor analysis of the geochemistry of 1,140 samples of agricultural soils from Missouri demonstrates that the samples may be viewed as simple mixtures of three end-members, each reflecting an important parent material. They are (1) clay-rich shale or alluvium, (2) clay residuum of carbonate rocks, and (3) silica-rich alluvial terraces of the Mississippi and Missouri River valleys. In a follow-up study, Tidball found statistically significant differences for 25 of 32 elements among soils derived from different parent materials in Missouri.

The anticipated development of a coal-based electric-power industry in the Powder River basin requires the establishment of regional trace-element baselines, particularly for soils and vegetation, which can be used to assess potential changes. The establishment of such baselines requires, in turn, some knowledge of the character of the natural regional variation of trace elements in landscape units of the basin. R. J. Ebens, Tidball, and J. A. Erdman reported that soils in the basin are derived from a variety of parent materials, including sandstone, shale, aeolian, colluvial, and alluvial materials. These conditions are expected to produce considerable geochemical variation in soil composition at local scales. On regional scales, however, the basin consists largely of treeless, generally rolling terrain, and the landscape in one part strongly resembles the landscape in other parts. Thus, the geochemical variation in soil composition at regional scales should be small compared with variation at smaller scales. This hypothesis was confirmed in a preliminary study based on a hierarchical analysis of variance-sampling design. Of 22 trace metals studied in surface soil, none exhibit statistically significant variation at scales larger than about 10 km. In particular, such metals as B, Co, Cr, Cu, Ni, Pb, and V display less than 10 percent of their total variability at such scales.

Trace-element characteristics of plant foodstuffs

Largely on basis of field studies in Georgia, Missouri, and Wisconsin, H. T. Shacklette, J. A. Erdman, and J. R. Keith concluded that the greatest observed differences in trace-element content of unprocessed foodstuffs of plant origin occur among species and are most likely genetically controlled. Different organs of plants appear to concentrate different kinds and amounts of trace elements; for example, zinc appears to concentrate in seeds, titanium in vegetative parts. The elements Al, Ba, Cd, Ca, Cr, Pb, Mn, Sr, and Ti generally are more concentrated in tissues of such nonfood plants as trees and shrubs than in herbaceous plants such as vegetables. The potentially hazardous elements cadmium, lead, and selenium are commonly found in unprocessed food plants but in amounts equal to or much less than the concentrations found in native plant species. If the trace elements occur in ordinary or normal concentrations in soil, analyses of plant parts do not in general reflect the point-to-point trace-metal variation of the soil.

LAND SUBSIDENCE

Studies of land subsidence caused by the intensive withdrawal of ground water are continuing in Arizona, California, Louisiana, Nevada, and Texas. Multiple-depth extensometers to measure changes in thickness of aquifer systems subject to stresses exceeding preconsolidation stress are being installed in Texas and in Baton Rouge, La.; the deepest extensometer wells will be about 900 m deep and will utilize free pipes rather than anchored cables. The stress-strain records from these sites together with those from extensometers in Arizona, California, and Nevada that have been operating from 5 to 15 yr should add considerably to knowledge of the mechanical and hydrologic properties of compressible aquifer systems and the storage characteristics of the interbedded clayey aquitards and confining beds.

Rate of subsidence increasing in the Houston, Texas, area

A redetermination of elevations of bench marks in the greater Houston area was completed by the National Geodetic Survey in the spring of 1973. According to R. K. Gabrysch (1973), analysis of the data shows that the rate of subsidence increased from a maximum of about 0.073 m/yr during the period 1959–64 to a maximum of about 0.11 m/yr during the period 1964–69. Maximum subsidence between 1900 and 1973 has been about 3 m. Importation of surface water to the center of the area of ground-water withdrawals is scheduled for 1975. Use of the imported surface water will reduce the draft of ground water and will decrease the rate of subsidence. Site studies of subsidence at Seabrook and Texas City have begun with the drilling of test wells and the collection of undisturbed clay samples. The purpose of this part of the project is to predict the rates and amount of subsidence during the next 50 yr.

Horizontal and vertical ground movement measured near earth fissures in central Arizona

Recent surveys across major earth fissures near Picacho, Pinal County, Ariz., confirmed that significant horizontal and vertical ground movement is occurring on the perimeter of this heavily pumped ground-water basin, according to B. E. Lofgren. From 1964 to 1974, 0.75 m of vertical subsidence and 0.15 m of basinward ground movement in the vicinity of the fissures were measured by the U.S. Bureau of Reclamation. These movements are attributed to gravitational and seepage stresses in the basin. Although the correlation between subsidence and vertical seepage stresses has been recognized for many years, a similar correlation between horizontal ground movement toward centers of heavy drawdown and horizontal seepage stresses has only recently been recognized.

The USGS is continuing to monitor the relative ground movement across several dozen grabenlike earth fissures and rotational slump blocks forming on the margins of numerous overpumped ground-water basins of the arid areas in the West.

Land subsidence in Sacramento Valley, California, due to ground-water pumping

A preliminary investigation of possible land subsidence in the Sacramento Valley indicates that several extensive agricultural areas have subsided 0.1 m during the period 1935–40 and 0.3 m during the period 1941–64. Local subsidence exceeded 0.6 m in at least two areas of overdraft—east of Zamora and west of Arbuckle—according to B. E. Lofgren and R. L. Ireland (1973).

Although numerous surveys have been made in the valley, few areas have adequate vertical control to determine the magnitude or extent of subsidence. In several areas, the long-term water-level decline has been 20 to 30 m. A comparison of maps showing these water-level declines and average annual ground-water pumpage suggests areas of probable subsidence which do not have leveling control. In two areas of most intensive pumping, no long-term water-level declines have occurred and no subsidence is indicated.

Water imports have nearly arrested subsidence on the west side of the San Joaquin Valley

In western Fresno County, Calif., surface-water imports through the Federal-State California Aqueduct to the San Luis service area, which began in 1967, had reached 1,060 hm^3/yr in 1972 and 1973, according to J. F. Poland (1974). Consequently, by 1973 use of ground water had decreased to about a quarter of the 1,110 hm^3 pumped in 1967. As a result, the artesian head of the principal confined system has recovered 45 m or more along a 65-to-80-km reach of the aqueduct, nearly stopping the land subsidence. At the Cantua site adjacent to the aqueduct, USGS extensometers recorded compaction of 3.3 m in the 0-to-610-m depth interval from 1959 to 1972. During 1973, however, net compaction in this same depth interval was only 9 mm, and the depth interval between 153 and 610 m below land surface (most of the principal confined system) expanded 6 mm.

TELEGEOLOGY

ASTROGEOLOGY

PLANETARY INVESTIGATIONS

The Martian surface

In 1973, the main emphasis of planetary studies was further interpretation of the Mariner 9 data on Mars. One of the most surprising results of the mission was the discovery of channellike features on the Martian surface. D. J. Milton extended his earlier interpretation of these channels by comparing them with the channeled scablands of eastern Washington. The comparison shows many similarities in detail, such as longitudinal flow lines, transverse cataracts, and streamlined bars. Milton hypothesized that floods, comparable in magnitude to that which formed the scablands, occurred repeatedly on Mars to form the enormous channels that are observed. He tentatively suggested that large volumes of water could occur close to the surface in the form of ground ice. However, because of the CO_2 atmosphere, the water will not occur as pure-water ice but as a clathrate, a CO_2-H_2O compound which has a melting temperature that is pressure dependent. At temperatures of 0° to 10°C, clathrate is in an unstable situation, in which a sudden release of pressure, as a tectonic event, can trigger the dissociation of the clathrate and cause the sudden release of large volumes of water. This mechanism requires a mean annual temperature near the surface of 1° to 10°C and implies that past climatic conditions were considerably warmer than those at present.

Liquid water cannot exist at the Martian surface under the present temperature and pressure conditions; therefore, M. H. Carr explored the possibility that the channels could form by the thermal incision of liquid lava. A sustained flow of lava within a channel could heat the wallrocks causing them to flow and ultimately be incorporated into the lava stream. In this manner, a flow could cut a channel and form many of the features that resemble water-eroded forms. Modeling of the mechanism in the computer and comparison with terrestrial examples suggest that thermal incision of lava is a plausible means of making the large lunar and Martian sinous rille. However, the more fluviallike Martian channels do appear to be unlikely candidates for formation by lava flows.

L. A. Soderblom systematized the Mars crater counts and assembled a computer file of all observable craters categorized by size. The high midlatitudes and polar regions are deficient in craters less than 4 km in diameter, and it is suggested that these areas are probably mantled with debris carried by winds from the polar regions. Soderblom showed that a dichotomy occurs in the Martian crater counts similar to that for the Moon. The surface is either densely cratered or sparsely cratered, with relatively few areas of intermediate crater densities. From this observation, it is concluded that the cratering history of Mars and the Moon are very similar, with an early torrential phase followed by an extended period of low flux. This conclusion has an important implication regarding the use of craters for absolute dating, because it implies that the lunar flux curve is a good approximation of the Mars flux curve and can be used to date Martian surfaces.

D. E. Wilhelms also made a detailed comparison of Mars and the Moon, to explore similarities and differences in their cratering histories. While the general similarity pointed out by Soderblom holds true, Wilhelms showed that significant differences do occur between Mars and the Moon. There are more surfaces on Mars with intermediate crater densities between typical lunar mare and lunar upland. Wilhelms tentatively suggests that these intermediate surfaces on Mars may have formed volcanically during the waning phases of the early torrential impact flux.

S. S. C. Wu has found that an appropriate topographic datum for elevations is a 6.1 mb surface of fourth order and degree, which has a mean radius of 3,382.92 km. Elevation data from terrestrial radar, occultations, the ultraviolet spectrometer, and photogrammetry were integrated to produce a preliminary contour map of the entire planet.

Mars cartography

A 16-inch globe of Mars, showing topography, albedo, and provisional nomenclature supplied by USGS, JPL, and NASA, was completed and published in 1973 by Denoyer-Geppert Co., Chicago, Ill. Also using USGS compilations, NASA completed three 1:5,000,000 shaded-relief maps and 10 controlled mosaics, and four 1:5,000,000, two 1:100,000, and four 1:250,000 semicontrolled mosaics were made in support of Russian landing-site studies.

LUNAR INVESTIGATIONS

Lunar surface processes

D. E. Wilhelms (1973) reexamined the geology of the Crisium basin with Apollo 17 data to produce a simple evolutionary picture. Crisium basin is a typical large lunar impact, modified by smaller impacts, subsidence, infilling by plains and mantles of impact origin, mass wasting, and basaltic volcanism. Modification processes were much more intensive during the first third of lunar history than during the two-thirds following mare formation. No evidence for terra volcanism exists in the Crisium basin region.

G. G. Schaber (1973) evaluated the lava flows in southwestern Mare Imbrium. Eruption of these flood basalts apparently took place in at least three major episodes with suggested dates of 3.0 ± 0.4 b.y. (phase I), 2.7 ± 0.3 b.y. (phase II), and 2.5 ± 0.3 b.y. (phase III); the dates were determined by using the mare age-dating method of Soderblom and are supported by the relative mare ages of J. M. Boyce and A. L. Dial, Jr., (1973). The youngest lavas (phase III) have been traced to a possible source fissure at lat 22° 50′ N., long 31° 20′ W. A very low albedo linear cinder-cone complex on the southeastern end of the island Euler trends northeast-southwest and may be structurally related to the inferred eruptive vent.

H. J. Moore has derived an equation for the flow of a lava that has the properties of a Bingham plastic. The equations show little difference between velocities calculated for Bingham plastic flow and Newtonian flow on steep lunar slopes, but the yield strength of the Bingham plastic causes flowage to stop on gentle gradients. This result is in contrast with the Newtonian flow equations which predict flowage on all gradients. Application of the equation for the phase III flow of G. G. Schaber in Mare Imbrium indicates the yield strength of the flow was near 10^3 to 5×10^3 dyn/cm^2. This value is comparable to values estimated for terrestrial lava flow by D. L. Shaw which are 0.7×10^3 to 1.2×10^3 dyn/cm^2. Slightly higher values of yield strength for the lunar flows are commensurate with their thickness (<30 m). Gradients for the calculations were obtained from a very old map and were near 10^{-3} to 3×10^{-3}.

J. M. Boyce and A. L. Dial, Jr., extended the estimates of lunar surface ages using the Soderblom technique. The results show that light plains deposits (that is, Cayley Formation) predate the emplacement of the maria, and in general, the mare basalts decrease in age westward. The oldest mare is Mare Tranquillitatis, but the southern dark edges of Serenitatis are also old. Mare Imbrium, Serenitatis, and Humorum have basalts in them that formed during the interval between 3.3 to 3.5 b.y. ago. Finally, a series of young flows (approximately 2.5 b.y. old) invaded western maria (Oceanus Procellarum), and a few patches were superposed on southwestern Mare Imbrium, northern Mare Humorum, and northwestern Mare Serenitatis. Some of the younger units may have crystallized as recently as 2.0 b.y. ago.

R. J. Pike (1973) conducted morphometric analysis of 25 far-side craters. The results are: (1) Far-side lunar craters do not differ in shape from near-side craters, (2) the shapes of far-side craters are more consistent with an impact origin than with a volcanic origin, and (3) the inner slopes of crater rims are much gentler in craters more than 17.5 km in diameter than they are in smaller craters.

Pike has also made a preliminary estimate of the heights of central peaks (R_{ep}, in km) of lunar craters between 15 and 200 km across as a function of the crater rim diameter (D_r, in km). Unlike equations which imply geometric similitude, this exponential expression,

$$R_{ep} = 0.044 D_r^{0.81},$$

does not have a slope of 1.0.

LUNAR GEOLOGIC MAPPING

A new lunar time-stratigraphic system

Continued mapping of the limbs, poles, and far side of the Moon has demonstrated the desirability of subdividing the pre-Imbrian rocks. On the eastern limb and far side is a convenient datum, the Janssen Formation, which is the ejecta blanket of the Nectaris basin. A new system, named the Nectarian System, extends from the base of the Janssen Formation up to, but not including, the Fra Mauro Formation which is the ejecta blanket of the Imbrium System. All units older than the Janssen Formation are informally called pre-Nectarian, so that the name pre-

Imbrian is superseded by Nectarian and pre-Nectarian.

1:5,000,000 mapping

The first-draft manuscript of a reconnaissance map of the north pole area of the Moon by B. K. Lucchitta (1973c) has been completed. The lunar near-side part was mapped during 1972; the far-side part, during 1973. First-draft manuscripts of the west limb of the Moon by D. H. Scott and of the far side by D. E. Stuart-Alexander and D. E. Wilhelms have also been completed. The smooth facies of the Orientale ejecta blanket (the Hevelius Formation) is indistinguishable from material mapped elsewhere as smooth-plains deposits. Prior to the Apollo 16 mission to the Moon, the smooth plains were regarded as being composed chiefly of volcanic material and being similar to the mare basalts. The Apollo 16 samples indicated that the smooth plains at Descartes 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.

1:1,000,000 mapping

The following lunar maps were published in 1973 as miscellaneous geological investigations maps:

Cleomedes quadrangle	I–707 (LAC 44)	C. J. Cassella and A. B. Binder.
Fracastorius quadrangle	I–720 (LAC 97)	D. E. Stuart-Alexander and R. W. Tabor.
Taruntius quadrangle	I–722 (LAC 61)	D. E. Wilhelms.
Langrenus quadrangle	I–739 (LAC 80)	C. A. Hodges.
Grimaldi quadrangle	I–740 (LAC 74)	J. F. McCauley.
Byrguis quadrangle	I–755 (LAC 92)	H. G. Wilshire.
Petavius quadrangle	I–794 (LAC 98)	C. A. Hodges.

Geologic mapping of lunar science sites

Several areas of the Moon have been designated for preparation of geologic maps at a scale of 1:250,000 permitting portrayal and discussion of more detail than was possible in the 1:1,000,000-scale series. A final-draft manuscript map of the Copernicus region by K. A. Howard depicts the feature which generally is accepted as the type example of a lunar impact crater. All of the map units can be attributed to an impact origin, although some of the floor material may be endogenic. T. J. Kreidler, D. H. Scott, and G. W. Colton placed in open file a preliminary geologic map of part of crater Le Monnier.

REMOTE SENSING

G. G. Schaber has compared his photogeology of the western two-thirds of Mare Imbrium with Earth-based mapping of color and radar reflectivity. There is a general correlation between very weak 70-cm-wavelength depolarized radar echoes and blue mare deposits of Eratosthenian and Imbrian age. A similar but weaker correlation of 3.8 cm depolarized echoes and blue mare exists.

Anomalously low backscatter of depolarized echoes may result from: (1) low surface roughness and slopes of various scales, (2) regolith and basalt substrate chemistry leading to high attenuation, (3) low crater and rock frequency distributions, and (4) a thick attenuating regolith. The present investigations, when combined with results that indicate the blue maria have high TiO_2 contents, suggest the chemistry of the materials may contribute to the low depolarized echoes.

Correlation of imagery and photogeologic map units with remote-sensing data along the Bistatic-radar ground track of Apollo 14 reveal that:

1. Bistatic-radar estimates of surface roughness at S-band and VHF wavelengths correlate well with visual appraisal of surface roughness of surfaces seen in Lunar Orbiter IV imagery.
2. Bistatic-radar estimates of surface roughness at S-band and VHF wavelengths correlate well with the expectations of roughness for geologic map units.
3. Depolarized 70-cm terrestrial radar backscattered echos correlate directly with depolarized 3.8-cm terrestrial radar backscattered echos.
4. Infrared eclipse temperatures correlate negatively with albedos of various geologic map units.

APOLLO 16 SITE STUDIES

The predominance of breccias in the samples returned from the Apollo 16 site suggest that the Descartes highlands materials as well as the plains-forming materials (Cayley Formation) at the landing site are ejecta from large multiring basins. The problems of what materials are derived from which basins and to what extent the collected samples represent distant basin sources, as opposed to local materials reworked by secondary impact processes, remain unresolved. One stratigraphic sequence proposed by C. A. Hodges, W. R. Muehlberger, and G. E. Ulrich (1973) places an uppermost blanket of Orientale ejecta over Imbrium and possible Nectaris ejecta in that order. The mountainous terrain is inferred to be mainly distal hummocky ejecta from the Imbrium basin as proposed in 1962 by R. E. Eggleton and C. H. Marshall, with local subdued remnants of Nectaris ejecta showing through. On the basis of stratigraphic implications of lithologic variations in the breccias and crystalline rocks excavated by two kilometre-sized fresh young craters in the landing site, Ulrich (1973) suggested a slightly different model. He considered the sequence to be primarily a depositional product of the Imbrium basin-forming event. In this model, the ejecta were segregated gravitationally and thermally into light-matrix dry breccias concentrated in the highlands, and dark-matrix melt-rich breccias settled primarily in the plains with local pockets of molten material that crystallized to igneous textures at depths of 50 m and greater.

H. G. Wilshire, D. E. Stuart-Alexander, and E. D. Jackson (1973, 1974) likewise have shown that the Apollo 16 rocks are breccias most likely derived from one or more major impact basins. These rocks appear to represent both the hilly and furrowed Descartes highlands and the Cayley Formation. The source rocks are an anorthosite-norite-troctolite suite and are similar to those interpreted for Luna 20 on the southern rim of the Crisium basin. The terra breccias that have survived multiple reworking by small impacts indicate derivation from a plutonic environment in which sufficient time was available for extensive igneous fractionation and a lengthy post-consolidation history involving formation of coarse unmixing and recrystallization textures (Wilshire, 1974).

The presence of Orientale ejecta at Descartes is a reasonable inference, in light of work by L. A. Soderblom and J. M. Boyce (1972). They illustrated the similarity of age estimates between the plains-forming Helvelius Formation, recognized as unambiguous Orientale ejecta, and material on other terra plains including the Descartes area. Calculations by Hodges, Muehlberger, and Ulrich (1973) indicated that the volume of material available from Orientale is sufficient to deposit some tens of metres of material at Descartes. D. H. Scott, H. J. Moore, and C. A. Hodges (1974) inferred that nearly 10 m of Orientale is a reasonable value at the distance (3,000 km) from the Apollo 16 site.

APOLLO 17 SITE STUDIES

Summary reports of the geology of the Apollo 17 site have been published by W. R. Muehlberger, principal investigator, and members of the Apollo Field Geology Investigations Team (AFGIT, 1973; W. R. Muehlberger and others, 1973; W. R. Muehlberger and E. W. Wolfe, 1973). Since publication of "Geological Survey research 1973" (U.S. Geol. Survey, 1973, p. 230), a more detailed interpretation of the structural development of the Taurus-Littrow area, the basalt stratigraphy of the landing site region, and the origin of the dark mantle has been made.

Structure

Following the Serenitatis impact, an uplift of the massifs around the Apollo 17 site was probably rapid and occurred along high-angle faults. Thus, the graben walls are thought to have stood at angles steeper than the angle of repose. Rapid reduction of slope angles by accumulation of thick talus wedges on the lower slopes and of mass-movement deposits on the graben floor must have occurred. After subfloor basalt extrusion was completed, warping around the Serenitatis margin produced a broad anticlinal arch with the Taurus-Littrow Valley and Littrow Crater on its eastern limb. Long narrow grabens such as Rima Littrow I formed along the Serenitatis basin side of the crest of the arch, which was eventually overlapped by younger mare basalts of the Serenitatis basin.

Relatively young deformational events that took place during the long period of regolith formation include a slight eastward tilting of the Serenitatis basin and the development of wrinkle ridges in Mare Serenitatis and the Lee-Lincoln scarp in the landing area. Very recent deformation is suggested by the occurrence of small grabens on the surface of the light mantle and by the apparent youth of parts of the Lee-Lincoln scarp. The flowlike margins of this wrinkle ridge are interpreted by K. A. Howard and W. R. Muehlberger (1973) as anticlines and thrust faults that resulted from sliding on a décollement surface. D. H. Scott (1973) interpreted the same feature to be lava extrusions from fractures and fissures with little associated faulting or folding. C. A. Hodges (1973) suggested that some mare ridges, not including the Lee-Lincoln scarp, formed as squeezeups and autointrusions in tension fractures over buried topography within the crusts of lava lakes.

Basalt stratigraphy

K. A. Howard, M. H. Carr, and W. R. Muehlberger (1973) have revised the stratigraphic sequence of mare basalts for the Serenitatis basin, and the correlations have been carried into Taurus-Littrow valley by Muehlberger and E. W. Wolfe (1973). The darkest maria, previously assumed to be the youngest, now appears to be the oldest of the mare units. The basalt stratigraphy now recognized around the margin of Mare Serenitatis suggests that the dark mantle is associated with the second of three distinct periods of basalt eruption. The earliest period is represented by the titanium-rich basalt of the Apollo 17 valley floor. The second period includes the generation of the dark mantle that covers this region. One of these first two periods may be represented by the basalts collected from the Apollo 11 landing site. The third episode of volcanism in this region is restricted to Mare Serenitatis and is characterized by a variety of basalt that is lighter colored.

The dark mantle

B. K. Lucchitta (1973a) reduced the possible interpretations of the dark mantle at Taurus-Littrow to four: (1) A thick regolith on old mare material, (2) dark ejecta material, (3) a pyroclastic deposit or ashflow tuff, and (4) a different origin in different places. Muehlberger and Wolfe (1973) reported modifications to these hypotheses, including fire-fountaining and impact into molten lava, either of which might produce the quenched orange glass beads and the crystalline black beads which are similar in composition and typical of the dark-mantle samples.

TERRESTRIAL ANALOG AND EXPERIMENTAL STUDIES

Missile impact investigation

The impact of missiles traveling along oblique trajectories forms craters about 2 to 10 m across in natural materials at White Sands Missile Range, N. Mex. The missiles have kinetic energies between 2.1 and 81×10^{14} ergs. The oblique impacts produce craters whose shapes are bilaterally symmetrical with respect to the plane of the missile trajectory. Ejecta blankets have the same symmetry, crater rims are high, and the amount of ejecta is large down-trajectory. Crater rims are low and the ejecta blanket is thin to absent in the up-trajectory direction. Symmetry development is a function of the angle of impact, but modifications are caused by variations in target material and local topography.

Possible meteorite craters in Nevada

A cluster of more than 175 rimmed craters was discovered by K. A. Ketner in Tertiary alluvium in northern Nevada. The craters form a pattern 1.5 km wide and 20 km long that extends from the Dinner Station Ranch on Nevada State Highway 51, 40 km northeast of Elko. Crater rims are composed of lag gravel of pebbles and boulders derived from subsoil beds, and the flat crater floors are composed of fine sediment washed into the craters from the rims. Most craters are circular, but where two or more circular craters coalesce, irregular or lobate compound craters have been formed. Circular craters range up to 135 m in diameter, and one compound crater is 255 m long. The probable cause of the craters is a meteorite shower, and the age, estimated from geomorphic evidence, is a few hundred to a few thousand years. No meteoritic material has yet been recognized.

Peruvian desert studies

J. F. McCauley, M. J. Grolier, and G. E. Ericksen completed a survey of the windforms of the coastal desert of Peru, in an area from Tumbes at the northern end of Peru to the vicinity of Ocari in the south. A total of 6,054 pictures was taken during the survey.

North of Lima, emphasis was placed on the transition zone between the arid and semiarid desert from Talara to Tumbes, the yardangs in the Talara region originally described by Bosworth, the parabolic coastal dunes in the region of Trujillo, and the various dune forms and deflational features of the Sechura Desert as described by H. T. U. Smith, among others. South of Lima, emphasis was on the wind eroded and selectively deflated Tertiary rocks of the Paracas Peninsula near Pisco, the curving dune and draa sheets to the north and south of Nazca, and the aerodynamically sculptured Tertiary rocks of the Ica Valley. Numerous new windforms were discovered, and the transition was documented from a pure-wind environment to a more complicated regime where the erosional effects of running water dominate the topography (as in the Southwest United States).

Deep-seated inclusions

Studies of xenoliths in basalts from the Western United States by H. G. Wilshire, C. E. Meyer, E. L. Schwarzman, and L. C. Calk have shown that the two common types of ultramafic inclusions—chromium-diopside and aluminum-augite groups—each consist of olivine-rich and pyroxene-rich members. Structural and textural relations of these extreme lithologies in xenoliths containing both pyroxenite and peridotite, suggest that the pyroxenites are igneous segregations and the peridotites are their wallrocks. Members of both main groups have systematic changes of mineral compositions across pyroxinite-peridotite contacts. These variations show the long-term preservation of small-scale chemical heterogeneities in the mantle and offer the possibility of tracing changes in composition of the mantle with time.

Radar reflectivity

Substantial progress has been made by G. G. Schaber on geologic evaluation of 25-cm-wavelength side-looking radar images of Death Valley, Calif., undertaken as a feasibility study for interpretation of proposed Venus-orbiting imaging radar.

Detailed field investigations and laboratory analysis of the radar-film photometric properties have resulted in an excellent correlation between surface (vertical and horizontal) relief and backscatter radar power. Virtually all of the mapped geologic units within the valley floor and adjacent gravel fans can be recognized on the radar images by variations in gray tone (backscatter power). All surfaces with vertical relief under 2 to 3 cm (one-tenth wavelength) appear nearly black, whereas those with relief between 3 and 45 cm increase the backscattered power in a remarkably predictable manner.

Considerable progress has also been made on geologic evaluation of 3.8-cm and 70-cm Earth-based radar images of Mare Imbrium. Extremely low levels of backscatter from individual lava-flow sequences within the basin have been traced to possible decreased radar-absorption lengths within anomalously thick regoliths developed on high titanium and iron basalt lavas with elevated volatile contents. Preliminary indications are that the titanium and iron contents of individual lava surfaces may be measured by their backscatter-power levels.

This study will have significant value toward understanding the geologic and geochemical implications of the Earth-based Venus radar maps currently being produced at higher resolutions.

Computerized image development

Techniques have been developed by L. A. Soderblom for handling Mariner spacecraft imagery beginning with raw data and producing final cartographic computerized mosaics. These techniques apply specifically to Mariner 9 imagery of Mars and Mariner 10 imagery of Mercury; they include finding and removing reseaus, automatically measuring internal distortions, removal of random and coherent noise, and removal of photometric errors introduced in the TV camera. Programs have been further developed to complete the mosaicing of these processed images within the computer.

Programs have also been developed to provide special enhancements of ERTS images for a variety of geologic and cartographic applications. These include programs to enhance high-frequency detail, to produce false-color-enhanced imagery to aid in mapping specific color units, and to produce a simulated-color version that more readily enables a geologist to interpret an ERTS image.

LUNAR SAMPLE INVESTIGATIONS

Petrology of lunar breccias

A large proportion of the rocks returned from the Moon are complex breccias. Many different types are recognized and these differ greatly in their mechanisms of formation, source materials, and histories after formation. For example, some breccias originated as consolidated lunar surface debris; others may represent ejecta deposits from large impact events; and still others are rocks crushed by shock-induced deformation (O. B. James, unpub. data, 1974). Most of these breccias contain suites of fragments derived from multiple sources, and the fragments may have had complex deformational and metamorphic histories prior to their incorporation in the breccia. It requires a coordinated attack utilizing many methods to unravel the origin and history of these rocks and the fragments they contain. Multidisciplinary consortia of scientists, drawn from the entire community of lunar-sample investigators, have been organized to perform this type of study on single significant samples or critical suites of samples. E. C. T. Chao, O. B. James, and Edwin Roedder have accepted the responsibility for coordinating three such consortia and for providing petrologic data for the rocks being investigated. Following is a brief account of the samples studied by each of these three consortia and the early results of the petrologic investigations.

E. C. T. Chao is leading consortium studies of a suite of four samples collected from a boulder at Apollo 17 station 7. A large clast of noritic-troctolitic microbreccia is the oldest material in the boulder (represented by sample 77215). Blue-gray matrix-rich breccia (77115) encloses this clast, and the clast is cut by dark veinlets (77075) continuous with the blue-gray breccia. The blue-gray breccia is in turn enclosed by vesicular feldspathic basalt (77135). Chao and J. A. Minkin have presented the results of preliminary studies of the first three (1974a) and detailed studies of the last one (1974b) of these samples. They found that clast 77215 is a sheared and granulated microbreccia consisting of juxtaposed fragments and patches of crushed norite, granulated troctolite, and shattered, devitrified fragment-laden glass. Sample 77115 consists of a very fine grained fragment-laden microsubophitic crystalline rock which encloses a recrystallized aggregate of angular olivine and plagioclase fragments. Sample 77075 is similar to the microsubophitic lithology of 77115. Sample 77135 is a fine-grained fragment-laden poikilitic crystalline rock with texture that indicates it crystallized from a melt. Chao and Minkin (1974b) consider 77135 to be of special significance because rocks with similar compositions may represent one of the major rock types of the lunar highlands.

O. B. James is leading consortium studies of two light-gray breccias picked up as hand samples from the light mantle avalanche deposit at Apollo 17 station 3. Four other breccias of this type were collected from a boulder that was systematically sampled at station 2. From albedo considerations, it appears that both the avalanche and the station 2 boulder were derived from a layer of rock that caps South Massif (AFGIT, 1973). Comparisons of these light-gray breccias with terrestrial-impact breccias suggest that the layer from which they were derived may represent suevitelike ejecta deposited during a major impact event, possibly one of the basin-forming impacts (O. B. James, unpub. data, 1974). The James consortium breccias are 73255 and 73215. Sample 73255 is a vesicular, fragment-laden devitrified glass and may be the lunar equivalent of an impactite glass bomb. Sample 73215 contains a matrix of devitrified glass and a suite of fragmental materials like those in 73255; this rock differs from 73255, however, in that it is more heterogeneous, is not vesicular, was strongly sheared during or after consolidation, and was recrystallized after shearing (O. B. James, unpub. data, 1974).

Edwin Roedder is leading a consortium study of several samples collected from a large boulder at Apollo 16 station 11. The boulder is of breccia excavated by the impact event that produced North Ray Crater. Studies to date have been concentrated on 67915, a breccia that probably represents the matrix of the boulder. Roedder and P. W. Weiblen (Univ. of Minnesota) have examined 42 probe mounts from 67915. They found that most clasts are less than 1 mm across and are set in a fine-grained matrix of mineral fragments probably derived from the same parent rocks as the larger clasts (Weiblen and Roedder, 1973; Roedder and Weiblen, 1974a). About 95 percent of the clasts are gabbroic to troctolitic anorthosite in composition; the remaining 5 percent are of a wide variety of rock types, including peridotite and sodic ferrogabbro. A few clasts show igneous textures (especially noteworthy is a type, possibly of cumulus origin, in which subhedral plagioclase crystals of An_{95} composition are set in a matrix of olivine of Fo_{56} composition). Most clasts, however, are themselves breccias and show a wide range of textures reflecting diverse deformational and thermal histories.

Weiblen and Roedder (1973) have also made a detailed study of unusual shock-glass veinlets in the breccia 67915. These veinlets show no preferred orientation, and they are apparently of several generations (though emplacement of all may actually have occurred over a very brief time span). They are generally less than 0.1 mm thick and in part occupy planes along which lateral offset has occurred. Plagioclase cut by these veins is isotropic within 20 μm of the glass; mafic minerals cut by the veins are unaffected, however. Analyses by Weiblen show that the bulk of the glass in the veinlets contains 75 to 85 percent normative plagioclase, but the wall of each veinlet shows a very thin layer (1–5 μm thick) of the composition of an iron-rich pyroxene. The inferred genesis of the veinlets is as follows: (1) The breccia was fractured by shock, (2) hot vapor of pyroxene composition entered the fractures and condensed on the walls, and (3) hot plagioclase-rich melt entered the fractures and was quenched.

Petrology of lunar igneous and metamorphic rocks

Roedder and Weiblen (1974b) have found that compositions of silicate-melt inclusions in igneous-textured spinel troctolite 62295 trace the liquid line of descent of the parent melt of this rock. The sample contains the most complete suite of silicate-melt inclusions found to date in any lunar igneous rock. Microprobe analyses show that these inclusions have silica contents ranging in weight percent from 46.9 to 66.9; atomic Fe/Fe+Mg, from 0.16 to 0.64; and CIPW normative quartz contents from 2 to 39.7. Petrologic mixing calculations using the compositions of the bulk rock, minerals, and melt inclusions (after the method of T. L. Wright and P. C. Doherty (1970)) suggest that the crystallization sequence was as follows: spinel, olivine, minor titanium-rich phase, plagioclase. The mixing calculations also permit estimates of the amount of melt of the composition of any given inclusion that can be generated by fractional crystallization of the parent melt. These studies of the crystallization of 62295 suggest that spinel-olivine cumulates could have been formed during differentiation of the plagioclase-rich lunar highlands; thus they are a possible highlands rock type.

An unusual barred olivine chondrule in spinel troctolite 62295 has been studied in detail by Roedder and Weiblen (1974b). The chondrule consists of 91.2 percent olivine (Fo_{87-92}) and 8.8 percent plagioclase (about An_{90}). The olivine is a single crystal, almost perfectly circular in outline, and the plagioclase occurs within it, forming thin subparallel bifurcating stringers that separate the olivine into a series of bars. Some grains of plagioclase and olivine in the immediately adjacent rock matrix have crystallographically parallel orientations with the minerals in the chondrule. Zoning of the olivine in the chondrule is unusual: the core is $Fo_{88.5}$; there is an intermediate zone of Fo_{92}; and the rim is Fo_{87}. Three possible modes of origin for this particle are: (1) It represents a droplet of impact melt that crystallized in flight and was then incorporated in the 62295 melt, (2) it is an unusual type of phenocryst, or (3) it is a meteoritic xenolith. None of these alternatives for genesis is entirely satisfactory, as all require very special and unlikely conditions. It is hoped that further studies of such structures in lunar rocks will eventually shed some light on the origin of meteoritic chondrules.

D. B. Stewart is currently investigating the conditions of metamorphism of the lunar rocks that show evidence of having been crystallized at great depths and over long periods of time. These rocks show many characteristics produced by extensive intercrystalline diffusion. They have polygonal textures. Their pyroxenes are orthopyroxene and diopsidic augite with limited solid solution, and pigeonite is very rare; each type of pyroxene has constant composition over cubic centimetres of rock, is only rarely zoned, and shows extensive cation order. Their plagioclase is homogeneous, has low iron contents, and has very extensive long range Al:Si order. These characteristics indicate that intercrystalline diffusion took place by prolonged thermal annealing in the subsolidus temperature range 700° to 1,100°C. In the nearly anhydrous environment that likely prevailed in the lunar crust, such annealing would have required tens of millions of years or longer. Cooling rates associated with magmatic crystallization within a few kilometres of the lunar surface, or with any impact process, are too rapid for the rocks affected to develop such characteristics. These observations prompt the hypothesis that such rocks represent magmatic rocks crystallized early in the development of the lunar crust, and subsequently annealed for long times at depths of up to tens of kilometres. Stewart has proposed the term "Apollonian metamorphism" to distinguish this process of deep, long-term annealing from metamorphic processes related to impact events. It is possible that studies of equilibration in Apollonian rocks may be used to indicate the depth at which the metamorphism took place, and an attempt is being made by Stewart to develop a depth gage based on such studies and known values of thermal and chemical diffusivities.

Lunar glasses and lunar fines

The Apollo 17 mission returned an unusual sample that was composed almost entirely of spherules and broken spherules of orange glass and its devitrified equivalent. This glass is extremely homogeneous, free of bubbles and inclusions of meteoritic metal, and contains sparse olivine phenocrysts (McKay and Heiken, 1973; Prinz and others, 1973; Reid and others, 1973a, b; Roedder and Weiblen, 1973). Surfaces of the spherules show splatters of glass of similar composition and low velocity impact features (Carter and others, 1973; McKay and Heiken, 1973), but no obvious high-velocity impact features have been observed. The modes of origin that have been proposed by various investigators for this glass are (1) condensation from vapor, (2) impact melting of solid rock, and (3) volcanic fire fountaining. However, none of these suggestions is an entirely satisfactory explanation of all the characteristics of the glass. Roedder and Weiblen (1973) have proposed an alternative mode of origin that explains many of these characteristics. They have suggested that the particles formed during meteor impact into a body of liquid lava, and the resulting lava splash broke up into tiny droplets that were quenched to form the orange glass spherules.

Magnetic susceptibility in glass spherules from the fines of Apollo 15, 16, and 17 missions has been studied by F. E. Senftle, A. N. Thorpe, and C. C. Alexander. Almost all the particles show the presence of antiferromagnetic inclusions, but the nature of these inclusions has not yet been resolved. Closely spaced temperature measurements of the magnetic susceptibility below 77 K show a number of transitions that do not correspond to transitions of any known antiferromagnetic minerals.

More than 2,500 individual particles from the sub-37-μm size fraction of 10 Apollo 14 fines samples were analyzed by R. B. Finkelman. He found: (1) A pyroxene- and olivine-rich component that contributes considerably to this ultrafine size fraction, (2) particles of what may be a new mineral, consisting of 60 percent SiO_2, 34 percent FeO, and several percent each of MnO and CaO, and (3) colorless glass particles that may have formed by vapor fractionation during condensation of anorthosite vaporized by impact.

Lunar sample ages and isotopic characteristics

The U-Th-Pb and Rb-Sr systems of some Apollo 16 and 17 samples have been studied for primary dating purposes by Mitsunobu Tatsumoto, P. D. Nunes, R. J. Knight, D. M. Unruh, C. E. Hedge, and B. R. Doe (Nunes and others, 1974a, b). They found that all Apollo 16 fines are enriched in old lead with high $^{207}Pb/^{206}Pb$ ratios and that this lead enrichment may be related to some sort of volatilization process (Tatsumoto, 1970). They also found that data from a group of the Apollo 16 rocks fall on a 4.47- to 3.99-b.y. discordia line, when plotted on a U-Pb concordia diagram. (These samples are igneous-textured rock 68415, poikilitic rocks 60315 and 65015, clasts and matrix of feldspathic breccia 67015, "Rusty Rock" 66095, and North Ray Crater soil 67701.) The investigators interpret the lower intercept age of 3.99 b.y. as the age of the Imbrian event. All but the two poikilitic rocks contain an old lead component which reflects an earlier event at about 4.47 b.y. This event may have been a major crustal differentiation episode on a global or regional scale, with associated enrichment of lithophile elements, such as U, Th, and K. Tatsumoto and his coworkers continue to believe that 4.65 b.y. is a reasonable estimate for the formation age of the Moon, particularly since ages of 4.65 to 4.66 b.y. are apparently characteristic of many meteorites (Tatsumoto and others, 1973) and the Earth as well. South Ray Carter fines have U-Pb systematics that define a third event, at about 2.2 b.y.; this event may be the formation of South Ray Crater.

The δO^{18} and δD in samples of water extracted from lunar "Rusty Rock" 66095 were determined by Irving Friedman, K. G. Hardcastle, and J. D. Gleason. This rock is significant because it contains goethite, a hydrated iron oxide, and the question of whether the water in the goethite is of lunar or terrestrial origin is highly controversial. The amount of water released below 400°C ranges from 140 to 1,000 ppm. It has a δD similar to that of Earth water, but the δO^{18} is like that in lunar silicate minerals. Earth rust has a δO^{18} that is light and very different from that of the water extracted from 66095. Therefore, Irving Friedman and his coworkers believe that the water in 66095 is of lunar origin.

Chemistry of lunar samples

H. J. Rose, Jr., Frank Cuttitta, C. S. Annell, Sol Berman, R. P. Christian, E. J. Dwornik, and D. T. Ligon, Jr., have analyzed 21 Apollo 15 and 23 Apollo 16 rocks and soils for major and minor constituents. Methods used were chemical, X-ray fluorescence, and optical emission spectroscopy. Evaluation of the Apollo 15 data suggests the following: (1) Mare basalts collected at the Appenine Front and Hadley Rille stations are derived from at least two compositionally distinct units, (2) highland fines samples have smaller KREEP and meteoritic components than mare fines samples, and (3) selective volatilization could not have been an important factor in producing the low alkali concentrations in lunar lavas. Evaluation of the Apollo 16 data shows that: (1) The major variations of the trace elements in the analyzed rocks appear to be correlated with their pyroxene-plagioclase ratios, and (2) the breccias are richer in plagioclase than are the crystalline rocks.

Motoaki Sato has advanced a theory to explain the highly reduced state of lunar basalts; the theory is based on experimental studies of the effects of loss of gas-forming elements other than oxygen on the oxygen fugacity of basaltic magmas. He and his coworkers have proposed that reduction is due to the presence of reduced carbon and sulfur, coupled with scarcity of water, in the lunar interior (Sato and others, 1973). If water is absent in an ascending magma, the carbon and carbides that are present could start reducing dissolved ferrous oxide to the metallic state when the magma ascends to within 3 km of the lunar surface. Simultaneously the carbon and carbides would be converted to carbon monoxide gas that could have been the gas that formed the vesicles and vugs observed in the basalts that crystallized near the lunar surface. If such a magma is extruded, sulfur could also escape as S_2 or COS gas and cause precipitation of metallic iron. The scarcity of water would prevent oxidation of the magma by eliminating preferential escape of hydrogen, which Sato regards as the most common cause of oxidation in terrestrial magmas. The experimental studies also indicate that significant amounts of alkalis have not been volatilized from the lunar magmas: at the relevant oxygen fugacities, alkalis should volatilize as metallic vapor; if this volatilization had occurred, the magmas would have been substantially oxidized, but such oxidation is not observed.

REMOTE SENSING AND ADVANCED TECHNIQUES

EARTH RESOURCES OBSERVATION SYSTEMS (EROS) PROGRAM

The EROS program has continued to support and coordinate the applications research involved in ERTS–1 and Skylab experiments and remote-sensing applications demonstrations within various Bureaus and Offices of the Department of Interior. Special emphasis, however, has been placed on making the service functions of the program more responsive to users' needs. With the move of the EROS Data Center into its permanent facility, about 25 km northeast of Sioux Falls, S. Dak., in 1973, production scheduling and reproduction quality of remote-sensing data have improved. Increased staff to assist users in application problems, and equipment for data manipulation are available. The EROS library is also now housed at the Data Center.

User-assistance centers, with varying degrees of services available, are being developed. The most comprehensive services, including direct computer linkage to the EROS Data Center for search of the data base, assistance in ordering data, data manipulation equipment, basic remote-sensing reference library, and training geared to local area needs are at the EROS Applications Assistance Facility, Bay St. Louis, Miss., and U.S. Geological Survey offices, Menlo Park, Calif.

The EROS program is monitoring and supporting an intensive study of the costs and benefits of operational Earth resources survey systems feasible in the near term by the Earth Satellite Corp. and Booz, Allen Applied Research. The objective is to evaluate the utility of alternative Earth resources survey systems employing technology developed for ERTS–1. The results of ERTS–1 experiments are used to project the capabilities of ERTS-type systems to provide Earth resources information of value. A series of case studies are being performed in applications areas showing high potential benefit. An interim case study in crop surveying was published (Earth Satellite Corp., 1973). Others underway include: snow surveying, rangeland inventory, land-use mapping, environmental monitoring, and forest surveying. Using the results of the case studies and additional analyses of broad applications areas, the national costs and benefits are expressed in terms of economic efficiency, economic distribution, environmental quality, social impacts, and international impacts.

Remote-sensing technology and ERTS data in general have been found to have considerable potential for ground-water investigations and management. G. K. Moore and Morris Deutsch have demonstrated its use in locating unmapped aquifers, to study aquifer recharge and discharge, to estimate ground-water pumpage for irrigation, to predict the location and type of aquifer management problems, and to locate and monitor strip-mine sources of acid mine drainage.

Deutsch has also demonstrated how anomalies in vegetation, lithology, soils, moisture, and their patterns of distribution, all detectable by ERTS, may be indicative of underlying ground-water conditions.

The ERTS DCS has been shown to be a powerful tool for collecting environmental data from remotely located sensors in large geographic areas. Data collected from remote DCP's in Alaska, Arizona, California, Louisiana, New Jersey, Oregon, Pennsylvania, and Tennessee by the ERTS system have been processed and distributed by the existing USGS national telecomputing network. It is an attempt to simulate an operational satellite data collection, processing, and distribution system through which DCS users could conveniently receive data from their own DCP's. Potential applications of such a system include the provision of data to resources managers in real time, the monitoring of the health of environmental data collection systems, and the automatic updating of environmental computer data files.

At Guelph University, Ontario, Canada, Allen Falconer and others reported on a number of significant results from studies of ERTS data as they apply to the hydrology, geology, physiography, and water quality of the Lake Ontario basin. ERTS MSS band 4 was used to provide indications of the internal dynamics of Lake Ontario. Band 6 indicates the relative amount of particulate matter in the lake water. There is considerable definition of geological and soils phenomena on the ERTS imagery and appropriate thematic maps of the Lake Ontario basin are in preparation.

Graham Harris at McMaster University has related ERTS data to detailed chlorophyll readings made from the surface. Multiple classification of chlorophyll signatures from ERTS digital tapes is in progress. Preliminary results show that detail available from ERTS exceeds the classification capability of the standard computer program in use at the Canada Centre for Inland Waters.

WESTERN REGION

P. M. Merrifield and D. L. Lamar, California Earth Science Corp., together with Carl Gazley, Jr., Roy Stratton, and Jeannine Lamar, of the Rand Corp., and F. C. Billingsley of Jet Propulsion Laboratory have begun a study of the application of ERTS imagery to analysis of fault tectonics and earthquake hazards in California, using both optical and computer enhancement and manipulative techniques. The results of this EROS contract will be coordinated with the work of the Earthquake Research Center, USGS, Menlo Park, Calif.

Paul Tueller reported that preliminary results of a multidisciplinary study under EROS contract to the University of Nevada suggest that colorimetric analysis of infrared aircraft imagery and densitometric analysis of ERTS imagery may be used to measure chlorophyll A concentrations and biomass population in lakes. The densities of ERTS images, bands 4 and 7, were ratioed, and the resultant ratio corresponds to chlorophyll A and biomass contents with a coefficient correlation of 1.884.

At the University of Washington, John Sherman, Geography Department, has nearly completed compilation of an atlas demonstrating the numerous modes in which ERTS data can be analyzed for resource and environmental studies. Final publication material for the atlas will be completed by August 1, 1974. Arthur Gray, Urban Planning Department, and his staff have completed a detailed land-use analysis of the SeaTac Airport and environs, of San Juan Island, and of the proposed Skagit River nuclear powerplant site, utilizing both ERTS and aircraft data. Joseph Colcord, Department of Civil Engineering, continued to provide photogrammetric and engineering support to all contract work at the University. Results to date show that cartographic mapping of water bodies from ERTS at 1:250,000 scale compares favorably with mapping from aircraft photography at 1:120,000 scale; there is less than a 3-percent error in positions of known points.

Robert Scott, Department of Natural Resources, State of Washington reported that ERTS analyses are being added to airborne remote sensing to manage the State's timber and food-crop resources. This results in crop identification, monitoring of timber cutting, and monitoring of tussock-moth infestation using ERTS imagery under EROS contract. Visual analysis of ERTS imagery did not reveal tussock-moth infestations. However, computer analysis, using tapes of all four bands and a clustering method similar to LARSYS, produced a distinctive spectral signature for vegetation damaged by tussock moth.

CENTRAL REGION

The Geological Survey of Iowa, supported by an EROS grant, reported that land-use analysis of 11 counties in southern Iowa shows that the spatial resolution and spectral characteristics in ERTS–1 imagery are sufficient to provide for regional planning purposes. An environmental atlas has been prepared for publication which shows the distribution of soils, cultivated and natural vegetation, and drainage patterns. It also shows the distribution of population centers, access routes, and mineral resources. Information on ground-water distribution, depths to water tables, and relative production are also provided for this relatively depressed part of the State. This demonstration project shows the compatibility of information derived from satellite images and supporting aircraft photography from various altitudes and periods in time.

A research project by South Dakota State University, under a partly EROS funded Bureau of Reclamation contract, was directed toward the application of remote-sensing techniques to delineate high water table in Republic County, Kans. (Ryland and others, 1973). Data analysis consisted of visual interpretation of aerial photography and statistical analysis of film densities and water-table depths. The study revealed that visual inspection of remote-sensing imagery could be used to delineate existing high water-table problem areas. Linear correlation between film densities and water-table depths over the entire project area showed significant results at the 5-percent level; linear correlation analyses on a within-field basis resulted in significance at the 1-percent level; multiple regression equations significant at the 1-percent level were developed for corn and fallow fields; and a nonparametric-analysis procedure yielded as much as 91-percent-correct classification of water-table depth occurrences. Preliminary investigation of ERTS–1 data showed within-field reflectance patterns similar to those on the aircraft data.

The EROS Applications Assistance Facility at Bay St. Louis, Miss., is cooperating with the Bureau of Sport Fisheries and Wildlife in a study of Atchafalaya Basin, La., for the U.S. Army Corps of Engineers. The EROS office is providing a vegetation trend analysis using aerial photographs acquired in

1930, 1952, and 1973, to determine species and changes over time. The distribution of species, by population per species and by area, within this swampy basin reflects several variables of the hydrologic environment: average land elevation, average depth of inundation, average number of days inundated, and average land elevation resulting from sediment deposition accrued from flooding. These data are being entered into several analog and statistical hydrological models being developed by the USGS.

The EROS program funded a remote-sensing applications demonstration through the Bureau of Indian Affairs to use ERTS imagery and high-altitude photography (black and white at 1:80,000 scale and color infrared at 1:40,000 scale) to develop resource data for environmental impact statements and overall reservation planning for the Crow and Northern Cheyenne Reservations in south-central Montana. The USGS produced 108 orthophotoquads at 1:24,000 scale and orthophotomosaics at 1:125,000 scale covering the 1,250,000 ha of both reservations from the high-altitude photography. Raytheon Co. then prepared resource overlays to the orthophotomosaics from interpretation of ERTS imagery, interpretation reports, and guidelines on how to use these materials for both reservations. The overlays and supporting data were prepared of general vegetation type and condition; forest stratification by size or volume, overstory density, and vigor classifications; landforms; and hydrology. The contract called for an 85-percent accuracy of interpretation of a minimum unit of 73 ha using level 1 of the Anderson, Hardy, and Roach (1972) land-use classification, which was more than achieved in every case.

South Dakota State University, under an EROS-funded Bureau of Indian Affairs contract, analyzed ERTS–1 imagery of south-central South Dakota to determine whether it could be used to map soils and to determine whether conservation farming practices, such as wind-strip cropping, contour farming, terracing, and other related features, could be identified and monitored. General soil areas, delineated by photographic characteristics such as drainage patterns, drainage densities, tone, land-use patterns, and color, were found to have different range sites and soil-suitability classes and subclasses, indicating that the interpretations were in fact unique soil-resource areas. Some of the farming practices and features (wind-strip-cropped fields, stock ponds, reservoirs, and cropland boundaries) could be identified, but the others could not. Where little resource information is available, this type of inventory and mapping can be a significant and useful tool.

Under an EROS-funded contract, the IBM Corp. prepared for the Bureau of Land Management a digitally processed color-composite mosaic of eight ERTS MSS scenes from two passes over Wyoming (Ferneyhough and Murphrey, 1974). Digital image processing removed geometric errors and corrected the data to a UTM projection. Ground control points used to determine external geometry of the sensor were detected and located using computer algorithms. The resulting mosaic was an excellent-quality image with high geometric accuracy, retaining full sensor data radiometry and resolution. The computer time necessary to process one MSS scene of four wavelength bands was approximately 10 min.

Also, under a contract cooperatively supported by both the EROS program and the Bureau of Land Management, the Computer Research Corp., Arvada, Colo., used an ERTS–1 computer compatible tape and cadastral information to produce an image map of 935 km^2 of Sheridan County, Wyo., and Big Horn County, Mont., showing delineation of township, range, and section boundaries. The map was produced at scales of both 1:63,360 and 1:253,440 and is expected to facilitate recording changes in land ownership and land use on a pictorial base.

EASTERN REGION

G. K. Moore and G. W. North (1974) compared panchromatic black-and-white, color, and color-infrared photography and thermal imagery from aircraft and ERTS imagery for delineation of flood boundaries, drawing on data acquired from January through May 1973 over floods in Alabama, Mississippi, Louisiana, and Tennessee. In open agricultural and urban areas, boundaries were easily defined on all types of film and imagery, particularly thermal imagery. Wooded areas posed a problem even when trees were leafless, because the limbs obscured the ground. Color-infrared aircraft photography and satellite imagery, however, could be interpreted for flood boundaries. Seasonal development of the tree canopy prevented interpretation on both ERTS and aircraft imagery, except thermal imagery.

Morris Deutsch and F. H. Ruggles, Jr. (USGS), Philip Guss (Lockwood, Kessler, and Bartlett, Inc.), and Edward Yost (Long Island Univ.) (1973) used multispectral ERTS imagery obtained on March 31, 1973, and May 4–5, 1973, over the Mississippi River below St. Louis, Mo., to map the extent of flooding at the time the imagery was obtained. The ERTS data provided the first opportunity to map regionally this 1,200-river-mile reach of the river and some of its tributaries. The flood data were compared with imagery collected by ERTS on October 1–2, 1972, when the rivers were confined to their normal channels. The data were analyzed by additive-color techniques, and special enhancements were prepared to aid in the interpretation. The extent of the flooding was delineated by additive-color temporal composites of MSS band 7 infrared images from the fall and spring dates. The result was a vivid portrayal on a single scene of the flooded area in relation to the normal channel.

Employing ERTS data collected on May 24, 1973—the date the Mississippi River receded to bankfull stage, 26 days after the all-time flood peak was recorded at St. Louis—the investigators were able to delineate the area from which the flood waters receded, including delineations of areas still containing ponded water. The results are highly significant since they demonstrated that postflood data can be used to detect flooded areas and that it is not always necessary to image the flood peak or to collect data immediately following the flood.

Analysis of ERTS–1 imagery of the Middle Atlantic area by C. F. Withington (1974) has shown numerous previously unrecognized lineaments in the Coastal Plain and neighboring physiographic provinces. These lineaments are oriented in three main directions: N. 5° to 10° W., N. 20° to 40° E., and N. 50° to 75° E. Each can be traced more than 65 km; some, as much as 240 km. The lineaments range in width from less than 0.5 km to more than 8 km. That some of these lineaments are the surface traces of faults is confirmed by the work of M. W. Higgins, Isidore Zietz, and G. W. Fisher (1974) who have interpreted aeromagnetic anomalies over the upper Chesapeake Bay as representing a steep northeast-trending fault. The postulated fault coincides with one of the lineaments plotted on the ERTS imagery. The presence of these lineaments suggest that faulting on the Coastal Plain is much more prevalent than previously mapped.

One lineament, which may represent the trace of a fault that extends southward from Pennsylvania through the eastern part of Maryland, separates well-drained soil to the west from poorly drained soil to the east. The east side of the fault is thought to have been down dropped, causing the drainage to be ponded. In places, it is offset by northeast-trending lineaments. Spores from organic-bearing clay east of the lineament have been dated at not older than 12,000 yr. An earthquake reported from the Eastern Shore of Maryland occurred in 1906 near the southern part of the lineament. Movement along this possible fault is thought to have taken place sometime within the last 12,000 yr and may perhaps have taken place within the last 70 yr.

F. R. Brown, Bureau of Mines, in an EROS-funded investigation, reported that ERTS imagery can be used for the detection of specific point sources of pollution if the plume emitted is of sufficient size and, more importantly, if the plume can be contrasted with its background. Water vapor in ambient air is not a pollutant, but when present in the quantities emitted from the cooling towers of powerplants, some environmental impact may occur. Under particular conditions, the water vapor can condense to form ice, fog, or snow. The particulates and pollutants emitted from the stacks can be entrained in this plume and carried with the water particles over great distances. Detection of condensed water-vapor plumes is easily accomplished from ERTS against a background of either land or water. Water vapor will more readily condense out of the air if the absolute humidity of the air is low and the relative humidity is high. Detection of plumes consisting primarily of solid material is more difficult; when contrasted against a background which has a uniform spectral response such as water, the detection is greatly facilitated. When the background does not provide a uniform response (the typical situation when the background consists of contoured land structures), detection from ERTS becomes difficult at best unless the plume is very large.

FOREIGN AREAS

R. S. Williams, Jr. (unpub. data, 1974), principal investigator of a multidisciplinary ERTS experiment in Iceland, reported that ERTS imagery has sufficient resolution to map, from MSS color composites, areas of altered ground caused by high-temperature geothermal activity at the Námafjall, Torfajökull, and Reykjanes geothermal areas. A small area of intense thermal emission on the east side of the Námafjall geothermal area could also be mapped because of the snowmelt pattern. The major axes of the fallout pattern of tephra from the May–July 1970 volcanic eruption from Hekla Volcano can be mapped where sufficient depth of deposition destroyed the normal vegetation. It was possible to delineate lava flows from the 1961 volcanic eruption at Askja, some of the lava flows from the 1947–48 eruption and all of the lava flows from the 1970 eruption at Hekla, and the areas covered by tephra and lava from the 1973 eruption on Heimaey. Low sun-angle imagery ($<10°$) of snow-covered terrain has been particularly valuable in mapping new structural and volcanic features previously concealed beneath glacial ice in the active zones of Iceland. Such imagery has also shown the marked differences in volcanic geomorphology from a regional standpoint within the active zones. Enlargements from standard (3d generation) negatives enabled planimetric revisions to be made to the 1:100,000-scale maps of the islands of Surtsey and Heimaey; a change in the former is the result of erosion, and a change in the latter is the result of new land created by the 1973 volcanic eruption. Changes in extent of snow cover with time can be monitored on successive images. The change in size of sediment plumes from the many glacial rivers which discharge into the sea along the south coast can be monitored, and these size changes give a qualitative indication of seasonal changes in melting rates of glaciers. Changes in area of lakes, particularly glacier-margin lakes because of their powder-blue color, can be mapped most easily on MSS false-color composites. The increase in surface area of an ice-dammed lake was monitored until the occurrence of a jökulhlaup, after which the surface area of the lake was reduced considerably. ERTS imagery is especially amenable to showing the entire areal extent of Iceland's glaciers and icecaps at a point in time. New planimetric maps are under preparation at 1:500,000 and 1:250,000 scales which will accurately show the 90 percent of the area of Iceland covered by glacial ice. Recently deglaciated terrain can be distinguished on MSS false-color composites because of the absence of vegetation when compared with older deglaciated terrain. ERTS imagery, acquired about 1 yr apart, shows that the Eyjabakkajökull glacier, an outlet glacier on the northeast part of Vatnajökull, has surged nearly 2 km. Some of the effects of subglacial geothermal and volcanic activity under Vatnajökull can be seen in the form of collapse features in the surface of the icecap, after the occurrence of two jökulhlaups. MSS false-color composites permit the mapping of at least five distinct vegetation types (forested areas, cultivated areas, grasslands, reclaimed areas, and lichen-covered bedrock) and barren areas (absence of color). The high latitude of Iceland permits considerable stereoscopic coverage on sidelapping ERTS imagery. Features with relief as little as 100 m can be discerned. This ability to study stereoscopically landforms, vegetation distribution, occurrence of snow cover, glaciers, and geologic structure generally permits a more precise analysis to be made of these phenomena.

W. D. Carter (1974), whose ERTS experiment is coordinating the evaluation of ERTS–1 data applications to geologic mapping, structural analysis, and mineral resource inventory of South America with special emphasis on the Andes Mountain region, reported that the tectolinear interpretation of the ERTS–1 mosaic of the La Paz area is complete. The La Paz mosaic, parts of 22 ERTS band 6 images, scale 1:1,000,000, covering southwest Bolivia, southeast Peru, and northern Chile, was compiled as a model to establish systematic procedures for regional small-scale geologic mapping and mineral investigations in lesser developed countries. An interpretation of linear features, most of which are considered to be faults, fractures, and folds, indicates that the dominant structural trend is north-northwest to northwest. This trend is probably due largely to orogenic forces resulting from subduction along the western margin of the South American continent. Between La Paz and the Salar de Coipasa, Bolivia, there is a strong secondary set trending nearly east-west. This set may be related to transverse movement between the northern and southern parts of the South American plate. A tertiary set of linears of lesser abundance trends northeast. All of the linears are at least 5 km long, and the longest is more than 500 km. The tectolinear interpretation is now being tested to determine its utility as an exploration tool by comparing it with existing geologic maps, mineral-deposit and oilfield-location maps, and seismic-epicenter maps.

ERTS EXPERIMENTS BY OTHER BUREAUS

Departmental participation in NASA's ERTS–1 experiment, coordinated by and in some cases financially supported by the EROS program, is drawing to a close. Most of the investigations were programed on the basis of an assumed 1-yr life of the satellite. The fact that the satellite has provided data for 2 yr has served to extend some experiments, particularly those which have direct operational impact even in the experimental stage. The following is a summary of results of experiments undertaken by Bureaus other than the USGS.

A. M. Kahan, Bureau of Reclamation, in a Department of the Interior ERTS investigation, has successfully demonstrated the value of the DCS as a near real-time tool for monitoring mountain precipitation as part of a cloud-seeding operation (Kahan, 1974). Seven platforms in the San Juan Mountains of Colorado transmit weather data, relayed via ERTS, to ground stations where they enter a time-share computer system for use in control of cloud-seeding operations and for verification of weather forecasts. Data are available to the users within 3 to 8 h of original transmission. The DCP's have proved to be reliable weather-resistant systems for use in mountain environments.

A. M. Woll, Bureau of Indian Affairs, in an ERTS–1 experiment, is involving multiagency participation in an attempt to incorporate ERTS–1 imagery as a monitoring tool for solving complex forest management problems in the high-quality forest of the Pacific Northwest. Established natural-resource management units on the Quinault Indian Reservation in the State of Washington that could be identified and delineated on ERTS include clear cut, forest reproduction, conifer old growth, and hardwood. The State of Washington Department of Natural Resources could interpret the same cover-type groups on a sample grid established and compared to their more detailed forest inventory in western Washington. The State's comparative analysis between their ERTS interpretations and their previous survey is being compiled. Better spatial resolution is needed to fulfill the requirements of an adequate monitoring tool to show road-construction update, soil-moisture data, vigor by species, and more exact location of clear cutting lines. The investigators are recommending automated interpretation from the computer-compatible digital tapes of ERTS data as a possible means to achieve optimum spatial resolution and to obtain some of the data not available by standard photointerpretation methods.

R. G. Bentley, Jr., Bureau of Land Management, conducted an ERTS investigation designed to test the application of satellite imagery to predicting ephemeral and perennial range quantity and quality. He reported that by analyzing a dry fall-season image and a wet late-winter image of south-central Arizona, he has been able to differentiate three broad vegetative classes (perennial, ephemeral, and perennial-ephemeral); distinguish between areas producing light, moderate, and heavy ephemeral forage stands; and tentatively map areas of varying potential to produce ephemeral forage. Imagery of southern California has been used to delineate polygons, based on varying shades of gray, which correspond to broad soil types and plant communities. Testing of this method is continuing to see if, when combined with extensive field checks, it will provide the means to make accurate regional maps of the soils and vegetation of the California desert.

The ERTS–1 investigation by H. K. Nelson (1974), Bureau of Sport Fisheries and Wildlife, is concerned with mapping surface-water ponds in a continental migratory-bird habitat in North Dakota in May and July by adaptation of satellite data techniques previously developed for use with aircraft scanner data. The May and July data are elements of a predictive wildlife-production model used to establish hunting regulations. Using a computer technique called proportion estimation, which is basically a method for performing fractional-pixel (picture element) recognition as contrasted to whole-pixel recognition, a more accurate determination of the existence of smaller ponds and improved size estimates of larger ones is possible from the ERTS data. It is becoming clear that joint use of satellite and aircraft data in a properly designed multistage sampling plan, incorporating the proportion-estimation method, would take best advantage of the detailed information provided by aircraft sensors and the synoptic and more economically obtained satellite data.

APPLICATIONS TO GEOLOGIC STUDIES

Use of computer-enhanced ERTS images to discriminate hydrothermally altered rock types

Computer enhancement and color compositing of ERTS MSS data were used by L. C. Rowan, P. H. Wetlaufer, and J. H. Stewart (USGS) and A. F. Goetz and F. C. Billingsley (JPL) to map and discriminate hydrothermally altered rocks in south-central Nevada. The MSS bands were contrast stretched and ratioed to enhance spectral differences and to reduce radiance variations due to albedo and topography. Two or more of the enhanced black-and-white images, showing various ratio results, were used to make color composites for further enhancement of subtle spectral reflectance differences. In the most useful color composite, felsic rocks are rendered in pink, and mafic rocks, mainly basalt and andesite, are rendered in white. In normal photographs, the felsic rocks commonly appear as dark as the mafic rocks.

Distinctive colors also indicate areas in which hydrothermal alteration (primarily limonitic, but also argillitic or silicic) has affected the exposed rock; these areas notably coincide with mining districts. Particularly good agreement is found between the color pattern and geologic maps of altered ground in the Goldfield mining district.

Production of a global magnetic-anomaly map

R. D. Regan and W. M. Davis (USGS) and J. C. Cain (NASA, Goddard Space Flight Center) have produced a global magnetic-anomaly map by analyzing a suitably constructed subset of the POGO (Polar Orbiting Geophysical Observatory) satellite data. Verification of the anomalies was obtained by examining individual satellite profiles and Project Magnet data. The persistence of the anomalies on all satellite passes, independent of local time, demonstrates that they are real and not the effect of any magnetospheric or ionospheric disturbance. The rate of decay of the anomalies with altitude, as observed in the aircraft and satellite data, implies an internal origin for these anomalies. A limited analysis of the Cosmos satellite data reveals a similar global distribution of more intense anomalies. This pattern is consistent with an internal origin because the Cosmos 49 satellite recorded at a lower mean elevation than the POGO satellites.

A revised thermal model for interpretation of data from infrared scanners

The iterative model used in analysis of thermal infrared images has been simplified by Kenneth Watson, using a linear approximation to the Stefan radiation law. The resulting expression for the surface-heat flux leads directly to a Fourier-series solution for surface temperature rather than to an initial guess and iteration as required by the old model. There are advantages to this new method in concept and in considerable saving of computer time for modeling and thermal-inertia mapping.

Thermal-inertia mapping involves using the day-night temperature difference of the diurnal cycle; the new model yields a single variable dependence: the ratio of co-albedo to temperature difference. The average temperature of the diurnal cycle is directly calculated from the model as a single term which is independent of thermal properties. Topographic effects are now more easily determined, and the model has been used to determine topographic corrections using calibrated reflectance data acquired at three times in the day. The model is currently being evaluated using Nimbus satellite data and data acquired with a new dual-channel scanner.

The effect of voids or inclusions upon microwave radiometric temperatures.

Voids or inclusions in low-loss dielectric materials such as snow, ice, or a lunar regolith scatter the internal radiation and greatly suppress the effective microwave emissivity. For example, consider filling a tenth of the available volume in a dry snowpack with ice spheres. If the sphere diameter is one-tenth of the microwave wavelength, the microwave darkening will exceed 30°; if the ratio of diameter to wavelength is 0.2, the darkening will exceed 70°. A comparable effect will be caused by pebbles in the lunar regolith or by voids in sea ice. Therefore, for low-loss dielectrics, the microwave radiometric temperature may tell little about either the dielectric constant or the thermal temperature, but it may instead be an expression of either the dielectric loss or the concentration of voids or inclusions. A. W. England suggests that these parameters may be used to infer the age of sea ice, the degree of metamorphism in snow, the wetness of snow, the particle-size distribution in a planetary regolith, or the vesicularity of an igneous extrusion.

Geothermal reconnaissance from thermal infrared images

A thermal model, developed by Kenneth Watson for analysis of aerial infrared images and satellite data, is currently being applied in geothermal reconnaissance. The model is used to determine the appropriate times to acquire the images and to map the geothermal flux variations.

Thermal-scanner data, acquired by aircraft, have been successfully used to detect areas of intensive geothermal heating such as hot springs and steaming ground (McLerran and Morgan, 1965; Friedman and Williams, 1968; Moxham, 1969). Estimates of the minimum detectable geothermal fluxes have been based on interpretation of these thermal data acquired at only one time in the diurnal cycle (predawn for example) (White and Miller, 1969; Friedman, 1970; Hase, 1971). These data are limited by geologic and topographic effects which are a serious noise factor. Topographic slope, albedo, emissivity, and thermal-property differences all produce ground-temperature differences equivalent to geothermal heat fluxes of several hundred heat-flow units.

One means to overcome some of these noise effects is to use information from the diurnal cycle to model out the variations due to nongeothermal causes. An approach currently being investigated is to use repetitive calibrated imagery to estimate the mean diurnal temperature (dc) of the ground. This dc temperature can be readily corrected for albedo and topographic-slope effects using our thermal model. A resulting map of the corrected dc temperature provides a realistic assessment of geothermal-flux variations which can be detected by quantitative analysis of thermal images. Additional improvements could be achievable by making thermal measurements in two wavelength regions of the 8- to 14-μm window to correct for emissivity variations. However, in soil-covered areas the spectral contrast will be low, thus making emissivity correction difficult; fortunately in these cases emissivity has a second-order effect on the dc temperature.

Scientists of the USGS have made a theoretical analysis of the error in estimating the dc temperature from repetitive sampling of the diurnal variations. A significant improvement is obtained when the sampling rate is increased from two to three times a day; a more frequent sampling does not extend the improvement. Thus, from a practical and theoretical viewpoint, it appears that sampling three times a day is probably adequate.

Thermal emission and reflection images were acquired of the Raft River, Idaho, area in early November. A variety of interesting features were observed by T. W. Offield. An area known to be warm at 1-m depth appears, in the thermal images, to be warmer than the surrounding ground. The images defined other apparently warm ground in the vicinity of a gravel lens through which hot water rises to the surface. Thermal linears which might indicate near-surface moisture concentration along fractures buried by valley alluvium were rarer than expected, possibly because the images were obtained in the dry season.

A new hypothesis on the relationship of ore bodies and lineaments in Alaska

Studies of Nimbus and ERTS images by E. H. Lathram resulted in the formulation of a hypothesis that mineralized areas in Alaska may be spatially related to regional sets of northeast- and northwest-trending linears—many previously unrecognized—that may be the surface expressions of crustal fractures (Lathram and Gryc, 1973; Lathram and others, 1973). Linears representative of these sets are clearly apparent on an ERTS mosaic of the Yukon-Tanana Upland east of Fairbanks.

According to the conventional metallogenic hypothesis, ore deposits in southern and central Alaska are believed to be localized along arcuate belts which conform to stratigraphy and orogenic and orographic features. The new hypothesis postulates that favorable areas are parallel to major northwest- and northeast-trending fractures and are especially likely where such fractures cross. For example, according to the conventional concept, one would expect to find copper-molybdenum porphyry deposits in an arcuate belt south of the Denali fault; according to the new hypothesis, such deposits should be found in two northeast-trending belts that could extend northeast of the Denali fault. The latter prediction has recently been substantiated by independent sources (E. R. Chipp, written commun., 1973). Using northeast and northwest fracture systems as a guide, independent mineral exploration in the Tanacross quadrangle in the Yukon-Tanana Upland in 1970 and 1971 resulted in the discovery of a number of copper-molybdenum deposits, two of which are currently being explored by drilling. These deposits lie northeast of the Denali fault.

Although these deposits were not found directly by use of ERTS images, their discovery supports the new hypothesis developed solely through use of ERTS images, and leads to two important conclusions:

1. The new hypothesis can be used as an additional exploration rationale by the mineral-resource industry.
2. ERTS images can be employed effectively to map large-scale fracture systems that may be important in controlling the distribution of ore deposits.

An investigation of major sand seas in desert areas throughout the world

A principal aim of this ERTS-image study by E. D. McKee and C. S. Breed has been to develop an objective classification of major eolian sand deposits. A preliminary classification, based on dune forms recognized in ERTS images thus far examined, encompasses the following five basic types: (1) Parallel straight or linear, (2) parallel wavy or crescentic, (3) star or radial, (4) parabolic or U-shaped, and (5) sheets or stringers.

Factors believed to control and to determine the size and form of dune bodies are direction, variability, and strength of wind, underlying topography, vegetation, moisture, distance from source, and amount of sediment available. Of these factors, the wind regime is by far the most important. The relations of wind strength and direction to dune form must necessarily be established from meteorological data where these are available. The data are plotted on sheets as overlays to the ERTS-image mosaics that display the dune patterns. Such overlays have been completed, in part, for South-West Africa and for White Sands, N. Mex., with air-current information shown in the form of wind-rose diagrams.

Interpretation of playa surfaces using ERTS–1 images

The repetitive coverage of ERTS–1 has been used in Iran by D. B. Krinsley to map and compare the seasonal changes that occur in the surface hydrology and in the areal extent and morphology of playas. Hydrologic inventories were made in interior basins that had not been measured previously because of their inaccessibility. During the period August 1972 to August 1973, the overall driest ground conditions occurred in late September 1972, and the overall wettest conditions occurred from March through May 1973. It was found that other characteristics of playas may also be determined by using ERTS images. Bearing strengths of playa soils can be inferred from changing hydrologic conditions (in conjunction with field data), and slight differences in salt-crust morphology can be detected or greatly enhanced by using false-color composites of ratioed and stretched transparencies generated by computer-compatible tapes of ERTS–1.

Thermal surveillance of Cascade Range volcanoes

J. D. Friedman reported preliminary results of ERTS–1 experiment 251 data: During the early winter period of 1972–73, at Devil's Kitchen, Lassen Volcanic National Park, temperatures at 15-cm depth in this active geothermal area showed a 68-percent correlation with fluctuations of anomalous surface temperatures, and temperatures at 50-cm depth showed an 8-percent correlation with surface-temperature fluctuations. Temperatures were measured by thermister arrays and transmitted by DCP's through the ERTS–1 satellite. A preliminary estimate of the anomalous heat flow at Devil's Kitchen infrared thermal anomaly, is 0.75×10^6 cal/s over an area of 41,600 m^2. At the Boiling Springs Lake anomaly, controlled by the same system of faults, thermal radiation from the lake surface alone (not considering evaporative heat loss) was calculated to be 0.71×10^6 cal/s.

Forty-eight pinpoint radiation anomalies on the upper flanks of Mount Rainier between elevations of 3,050 and 3,965 m, discovered and recorded by aerial infrared scanner in April 1973, may represent locations of fumarolic-vapor emission or warm ground considerably below the summit crater.

The RS–7 and RS–14 aerial infrared scanner missions, flown for the USGS by the U.S. Forest Service and Johnson Spacecraft Center, NASA, during 1973, completed coverage of surface thermal anomalies in the Cascade Range volcanoes. Cartographic plots of these anomalous areas, in conjunction with surface temperature and other data compiled as a result of experiment SR 251, permit estimation of radiation heat loss from these areas during the repose periods of the host volcanoes.

By the end of 1973, aerial infrared thermographic surveys were completed as the first sequence of surveys of the distribution and relative intensity of thermal activity on Mount Baker. The surveys show that thermal emission, characterized by solfataric activity and warm ground, is concentrated within the crater south of the main summit. Clusters of strong infrared anomalies coincide with glacier-perforation features near the east and west breaches of this crater and suggest that much of the thermal activity is subglacial. The outgoing radiative flux from the east-breach anomalies is estimated at 7,780 μcal cm^{-2} sec^{-1}, and is sufficient to account for the volume of ice melted to form the glacier perforations. Infrared anomalies were also recorded near the head of Mazama Glacier midway down the north slope of the volcano. This latter site was monitored for temperature by thermistor array and the ERTS–1 Data Communications System. The distribution of thermal and solfataric activity confirms historical observations that this crater was a major site of eruptive activity in the 19th century. Moreover, the present thermal activity accounts for continuing hydrothermal alteration in this crater and recurrent debris avalanches from Sherman Peak on its south rim.

Near-infrared reflectance anomalies of andesites and basalts in southern California and Nevada

In late 1972, the multichannel scanner of the Environmental Resources Institute of Michigan was flown over a number of sites in southern California. H. A. Pohn reported that the data from these flights showed numerous high-reflectivity anomalies in the 1.0 to 2.6 μm channels for some outcrops which were later identified as andesites and more mafic rocks. In the past year, laboratory research was initiated in an attempt to find the cause of these anomalies. Spectroradiometer measurements were made of rocks collected from the anomalous areas, but these proved unsatisfactory owing to the restricted spectral range of the radiometer. More recently, a spectral curve of cinders collected at one site was run by A. F. Goetz (Jet Propulsion Lab); results show anomalous spectral reflectance beyond 1 μm which bore out the anomalous nature of the material.

A comparison of the anomalous spectral curves, derived from the scanner images using the gray-scale calibration and the known spectral reflectivity of common geologic materials, with measured laboratory spectra was made by Pohn. It is tentatively concluded that the anomalies are caused by a coating of limonite or hematite particles on the rocks. The particles are smaller than 5 μm and probably less than 1 μm; they may have been deposited by post-eruptive fumarolic activity in the anomalous areas.

ERTS images improve geologic mapping in Alaska

ERTS images are being used by E. H. Lathram to complete a revised 1:1,000,000-scale map of northern Alaska. In the earlier compilation (Lathram, 1965), the lowland area of the Ipewik and Kukpuk Rivers were shown to be largely devoid of structural data. Several seasons of exploration in this area by private companies and by the USGS failed to provide data on the distribution of structural elements mainly because of tundra cover and paucity of outcrops along streams and rivers. Interpretation of conventional aerial photographs revealed little additional data. ERTS images, however, display a clear and detailed representation of the regional structural pattern (Lathram and others, 1973, fig. 2). The new map compilation of this area shows clearly the complexity of structure revealed by the ERTS image and the pronounced difference between the structural pattern in this area and that in the area of strata of comparable age to the north and east. The difference in structural complexity may be due to oroclinal bending around an axis trending northeast through the lowlands (Tailleur and Brosgé, 1970) or, more probably, to the superimposition of a western and younger belt of east-directed thrust faults upon an older, eastern belt of north-directed thrust faults (Grantz and others, 1970). Recognition of the structural complexity and determination of its cause are critically important in determining the potential for petroleum accumulations at depth in the area.

Enlargements of ERTS images to a scale of 1:250,000 are also being used in geologic mapping. In the Kukpuk-Ipewik Rivers area of northern Alaska, compilation of known geology on the ERTS images has facilitated extrapolation of data into unmapped areas and has led to recognition of structural and stratigraphic anomalies that suggest new interpretations of the geology (Tailleur, *in* Gryc and Lathram, 1973).

ERTS images were successfully used in field mapping in 1973, by W. P. Brosgé, I. L. Tailleur, and others to determine the location of lithologic contacts between field stations (I. L. Tailleur, oral commun., 1973). George Plafker, R. L. Detterman, and others employed ERTS images in field studies of the location and continuity of major faults in southern Alaska, as a part of the Earthquake Hazards Reduction Program of the USGS. The images were particularly useful for mapping in the snowfield areas bordering the Gulf of Alaska; not only are field observations more easily and accurately located on the ERTS image than on the most recent topographic map, but the distribution of perennial snow is more accurately figured on the image than on the more than 10 yr-old map (George Plafker, oral commun., 1973).

Possible new oil target in Alaska

Examination of ERTS image 1004–21395 by W. A. Fischer and E. H. Lathram has revealed hitherto unrecognized east-trending alinements of coastal plain lakes north of Umiat, Alaska. Comparison of the trends of these alinements with available geologic, magnetic, and gravity data suggests the presence of concealed structures which may be favorable for concentrations of gas in shallow strata and of oil in strata at or near the basement (Fischer and Lathram, 1973).

Study of more recent ERTS images of northern Alaska (acquired in 1973) not only substantiates observations made of the Umiat area but also shows that the main east-trending alinement is prominent throughout the coastal plain to the east, extending as far as the Canning River (E. H. Lathram, unpub. data, 1974). This area includes Prudhoe Bay and other recently discovered oil fields. The recognition of the lineament in the coastal plain between the Colville and Canning Rivers substantially increases the area suitable for oil exploration.

Use of *x*-band radar images to interpret certain bedrock, morphologic, and cultural features in southern New England

Analysis by P. T. Banks, Jr., of *x*-band radar images covering Massachusetts, Connecticut, and Rhode Island suggests that the geomorphic features of most of southern New England are controlled by bedrock structure. Structure visible in the images includes primarily linear elements which are interpreted to be faults or morphologic forms controlled by joints, cleavage, bedding, or foliation. Glacial (Pleistocene) drift is rarely thick enough to obscure these features at the observed scale, except in eastern Massachusetts.

Although lithologies cannot be determined, the relative resistances of certain areas to erosion is obvious, and is probably directly related to lithology; boundaries between these areas are inferred to be lithologic contacts. The differential resistance to erosion accounts for virtually all of the observable features on the images.

A computer program to facilitate comparison of computer-made terrain maps with control data

Digital data supplied by multispectral scanners are readily handled and interpreted by computer.

However, the statistical-decision rules used in the computer program are such that the maps produced must be checked for accuracy. This is done by comparing the computer-produced maps with control data compiled in map format from studies of aerial photographs and ground surveys.

K. J. Ranson and R. R. Root, graduate students at Colorado State University, working on a grant supervised by H. W. Smedes of the USGS, have written a computer program to perform this accuracy check. Two recognition maps produced from ERTS–1 four-channel MSS data of two NASA test sites were used to test and verify this program. The sites are Yellowstone National Park in Wyoming and the Cripple Creek region in Colorado.

Three basic methods are used to compare computer recognition maps with the control data. First, a point-by-point comparison relates each cell in a test area on the recognition map with the corresponding data. Second, areas of each map unit, such as forest cover, grassland, rock type, and water, shown on the computer map are matched with comparable areas shown on the control map. Third, a pairwise array generated from the point comparison data indicates the frequency and location of errors of omission and commission for each unit.

Data, supplied to the computer on punched cards, describe the size of the test areas, the number and designation of map units, and the cell-by-cell data derived from recognition and control maps for each test area. On the basis of the control area, the classification accuracy of a computer-made recognition map can be determined from the computer output of this program.

A point-classification map shows the spatial distribution of misclassified recognition map cells. Three displays are produced, one on a line printer and two on 35-mm microfilm. The line-printer map and one of the microfilm maps are bordered by specified line and column numbers designating the location of the test area. Misclassified cells are designated by the appropriate map-unit symbols as identified on the recognition map. The other microfilm display has light and dark point clusters representing incorrectly and correctly classified cells respectively, and is projected onto a photo or map of the test area to illuminate optically the spatial misclassification pattern.

A point classification table summarizes the cell-by-cell comparison of control and recognition map data. The total number of correctly identified cells, total number of equivalent ground-truth cells, the percentage of correctly identified cells, and the 90-percent confidence limits for each map unit are presented in the table.

An area-classification table displays the percentage area of equivalent control classes (input as data), percentage area of each map unit on the recognition map, and the percentage area of each map unit correctly identified. The area data serve as an independent check on the point-classification results in the event of misregistration between control and recognition maps.

Even though this automated comparison technique was designed specifically for comparing recognition maps with corresponding ground-truth data, it has potential applications wherever experimental and control data need to be compared.

Geophotogrammetry, a new solution to an old problem

The old problem of transferring geologic field data accurately from aerial photographs to a base map now has a ready solution. Two PG–2 optical-mechanical photogrammetric plotters have been put into use for this purpose by C. L. Pillmore in the Denver Field Center's joint-use photogrammetry lab. The PG–2's are complex high-accuracy instruments that offer an excellent stereoscopic system for viewing and interpreting aerial photographs, coupled with high-order transferring or mapping capability. After the lab photogrammetrist sets up a stereoscopic model in one of the instruments, adjusts it for scale, and levels it to a base map (a matter of minutes, normally), the machine is ready for use and is much less difficult to operate than a microscope; it requires only a little practice before actual transfer of geologic data can begin. Film or glass transparencies or paper prints of aerial photographs in color, color infrared, black and white infrared, or standard black and white can be used with equal ease. Magnifications ranging from × 2 to × 10 allow detailed stereoscopic inspection of about any scale photograph. Annotations or marks on the photographs can be readily identified and traced in the stereo model and compiled or transferred directly to a base map.

Identification of vehicular scars on Arctic tundra from ERTS images

Study of ERTS images by E. H. Lathram (unpub. data, 1973) resulted in identification of pronounced vehicular scars in the tundra near Umiat, Alaska, dating from the 1945–52 period of exploration. This study suggests that if such scars are of high contrast with surroundings and larger than about 20 m, they can be identified and their state monitored by the use of ERTS images.

The extent of scarring depends on the season of occurrence, condition of substrate (particularly with respect to water content, that is, ice-wedge occurrence), degree of vegetation removal, and slope. Trails made by small tracked vehicles such as weasels and bombardiers have left little trace. Cattracks, with little or no blading, and used only in winter, do not cause extensive scars. Light vehicle trails are most intensely scarred. The principal indicator of trails is the presence in the tracks of grasses distinctly greener than adjacent vegetation. Field review of the state of vehicular scars in the Umiat area by R. L. Detterman (USGS) and John Koranda (Lawrence Livermore Laboratory) indicates that all are revegetating at varying rates and are approaching a stable state. Old trails are difficult to see on the ground at present and in 5 to 10 yr will probably not be visible.

The most striking example of scarring, noted on band 5 ERTS images, occurs on the ridge north of Umiat. Here a heavily used trail, bladed bare of vegetation, leads up a 10° slope to the site of several drill holes. This trail was used in summer and winter during the 1945–52 period and crosses the exposed area of a bentonitic shale formation. Erosion of the trail has formed a depression on the slope about 45.7 m wide and 4.6 m deep. Revegetation is proceeding, with felt-leaf willow, equisetum, and a grass (stipa) not noted elsewhere, indicating the onset of healing.

Visual study of images of the area to the south and east of Umiat, where exploration activity has occurred since 1960, indicates that younger scars are more apparent on ERTS images than the older scars in the Umiat area.

Precambrian fracture and lineament systems of central and northern Arizona

Remnants of Paleozoic rocks found south of the physiographic margin of the Colorado Plateau (Mogollon rim) indicate that part of this region belongs structurally to the Colorado Plateau. The undisturbed nature of the Plateau strata indicate that Precambrian rocks in this region have been structurally little modified since Precambrian time.

Faults that have been mapped in central and north-central Arizona, and lineaments observed in ERTS–1 images, have been compiled by D. P. Elston for an area that lies across the physiographic boundary of the Colorado Plateau. The pattern seen in Precambrian rocks in the southern part of the area is also seen in Paleozoic rocks to the north and also occurs in plateau basalts and thick valley-fill deposits of Miocene and Pliocene age. A number of extrusive centers of the San Francisco volcanic field on the Colorado Plateau are apparently localized along northeast- and north-trending lineament systems, similar in trend to strongly developed northeast- and north-trending systems exposed in Precambrian rocks to the south. The regional relationships indicate that fracture systems developed during Precambrian time have served to localize much later structural adjustments and that the broad pattern of simple faults and folds in Paleozoic rocks on the Plateau apparently reflects a pattern of ancient major faults and fractures in the basement.

Linear structural features determined from ERTS–1 images

Linear structural features in Arizona, parts of adjacent States, and northern Mexico have been mapped at a scale of 1:1,000,000 using ERTS–1 images. Special attention was paid to the differences between linear features in the Colorado Plateau and the Basin and Range province. Considering only distribution and orientation of the features, M. E. Cooley has formed the following tentative conclusions: The linear features generally trend northwest and northeast throughout the area, except possibly near Yuma where they tend to be parallel with the San Andreas fault system along the east side of the Gulf of California embayment. The linear features are apparent in both the slightly consolidated alluvium and the consolidated rocks, which range in age from Holocene to late Pleistocene. The alinement of linear features follows the trends of faults such as the Hurricane fault and the trends of monoclines, such as the East Kaibab monocline. The orientations of the linear features are consistent in rocks of all ages in the area. It is concluded from studying the ERTS–1 images that the regional fracture pattern was formed during Precambrian time and has been imposed on the younger rocks.

Analysis of Skylab images of Puerto Rico

Initial interpretation by J. V. A. Trumbull of photographs taken during Skylab Mission 2 over western Puerto Rico recognizes a wide variety of phenomena in the coastal waters. Desecheo Island, west of Puerto Rico, shows a definite wake pattern indicating that surface-water currents were flowing southwestward into Mona Passage. This movement is rather surprising, because the net flow through the passage is northward. Bottom topography is clearly visible at depths of at least 30 m. Plumes of turbid water issuing from rivers are obvious and show the direction of coastal currents. The little-studied belt of turbid water along the coasts is clearly shown. Wind-slick patterns, which seem to be turbidity patterns in offshore waters, and other visible phenomena will require considerable further investigation if the full information content of the satellite images is to be utilized.

Coastal currents off California and Oregon

The ERTS–1 images used in conjunction with surface-drift cards by P. R. Carlson and D. R. Harden indicated a southerly flow direction of near-surface coastal currents off central California during mid-June 1973. Near-surface currents off northern California and southern Oregon were more complex. Some drift cards were recovered north and some south of their release points, but the prevalent direction of flow was northerly. General agreement in flow direction of coastal currents obtained from ERTS–1 images and drift-card data reinforces the image interpretation. Results indicate that complete seasonal coverage of nearshore circulation interpreted from ERTS–1 images should provide information necessary for proper coastal zone management.

APPLICATIONS TO HYDROLOGIC STUDIES

ERTS imagery detects glacier change

ERTS imagery of glacier regions in Western North America and a few other scattered areas have been analyzed to find significant glacier features (M. F. Meier, 1973). Long-term surface velocities are readily determined by comparison of recent ERTS imagery to maps that have been produced from earlier data, and some short-term fluctuations are large enough to be seen on sequential images. According to R. M. Krimmel, short-term fluctuations have given an indication of the magnitude of seasonal ice loss due to calving. Surging glaciers are readily identifiable on imagery. Glaciers in the process of surging have been monitored, and a prediction has been made as to the time and magnitude of the next surge of a Soviet glacier. ERTS imagery of large glaciers obtained under conditions of low sun angle and complete snow cover show previously undetected subtle tone changes which have been interpreted as dynamic flow features or reflections of subglacial topography.

Hydrologic applications of ERTS–1 Data Collection System in central Arizona

H. H. Schumann (1974) and J. W. H. Blee reported that ERTS–1 was used to relay hydrologic data (streamflow rates, precipitation amounts, soil temperature, air temperature, and snow-moisture content) from remote sites in central Arizona. Three streamflow gaging stations, one meteorological station, and two installations for measuring the moisture content of snow were equipped with ERTS–1 DCP's.

By mid-March 1973, the high moisture levels on the Salt River and Verde River watersheds reduced reserve reservoir storage capacity, and a large potential for flooding in the Salt River valley presented a critical water-management situation. Between March 15 and May 22, 1973, the ERTS–1 DCS was utilized to furnish near-real-time information on snow-moisture content and streamflow rates for use in the Salt River Project's management and operation of reservoirs on the Salt and Verde Rivers. Data from both microwave and ERTS–1 telemetry were used successfully to predict the volume of runoff into the reservoirs, and serious flooding of the Phoenix metropolitan area was prevented.

Remote-sensing research in wetlands

V. P. Carter (1974a) reported that available remotely sensed data—NASA high-altitude color-infrared photographs, USGS black-and-white orthophotos, and ERTS data—were used in the Dismal Swamp Study authorized by Congress (Public Law 92–478). The data were used for (1) overall study-area selection, (2) location of intensive study area, (3) hydrologic studies, (4) vegetation mapping, and (5) field studies, including identification of special-interest areas.

Possible future applications of remote sensing to the Dismal Swamp (Carter, 1974b; Carter and D. G. Smith, 1973) include: (1) Using ERTS data or thermal imagery as an aid in making a detailed hydrologic study, (2) monitoring the effects of water-level management by the use of repetitive satellite data, (3) detecting vegetation changes with additional high-altitude color-infrared photographs or ERTS data, and (4) making detailed ecological studies by the use of low-altitude aircraft coverage of selected sites. Thematic extraction of surface-water areas, vegetation associations, and burned or clear-cut areas from satellite data on a repetitive basis could provide timely and useful information for resource management.

Carter and other USGS scientists produced

1:10,000-scale experimental orthophotoquads of the Doboy Sound 7½-min quadrangle, Sapelo Island, Ga. The maps show the upper wetland boundary and generalized species composition within the wetland.

A study of species progression in fresh to moderately brackish tidal marshes on the central Atlantic coast has been completed. The purpose of this study was to examine seasonal changes in major plant species as they may affect remotely sensed data for the area.

Jane Schubert (NASA) and Carter developed a look-up table for use with the ERTS_ANALYSIS System, developed at Goddard Space Flight Center for analyses of coastal wetlands vegetation and other features, using ERTS MSS data (Carter and Schubert, 1973). This look-up table is partly based on extensive ground investigations and field spectral-reflectance measurements.

Skylab Earth Resources Experiment Package (EREP)

A. L. Higer and A. E. Coker reported that Skylab EREP S–192 high-density digital tapes were processed at Bendix Aerospace Systems Division to automatically classify land-cover types, wetlands, and pine-covered areas for land-use mapping in the Green Swamp test site in central Florida. Also, ERTS–1 digital tapes have been processed on General Electric's Image 100 processor at Daytona Beach, Fla. The feasibility of automatic land-use mapping in Florida by the use of Skylab and ERTS digital data has been established, according to Higer and Coker.

Remote sensing of ocean water

Large plumes develop as the freshwater from the Connecticut, Housatonic, and Thames Rivers flows southward from Connecticut into the salty ocean water of Long Island Sound. F. H. Ruggles, Jr., reported that plumes from the largest stream, the Connecticut River, have been identified as far as 22 km from shore, whereas plumes from the Housatonic and Thames Rivers have not been recognized beyond 11 km from the shoreline.

Seven ERTS images have been analyzed and the plumes delineated by use of the Stanford Research Institute's ESIAC. These seven images cover a range of conditions from springtide to ebbtide. The best results were obtained by insertion of MSS band 5 into the ESIAC. Color-additive viewing, using band 6 positive transparency as red and band 5 negative transparency as green, facilitated visual viewing.

Thermal characteristics of Ozarks stream valleys

E. J. Harvey (USGS) and J. H. Williams (Missouri Div. Geol. Survey and Water Resources) reported that, as part of a continuing study, additional predawn flights were made in the summer of 1973 in which a radiation thermometer was used to sense emitted radiation from the land surface in the valleys of gaining and losing streams. The temperature level of the gaining stream valley was lower than that of the losing stream valley. On March 7–8, 1972, and June 21–22, 1973, thermal imagery was obtained of the gaining and losing reaches of Logan Creek valley in Reynolds County, Mo. Both flights were made after periods of several days without rain. The March imagery did not show a visual difference in the level of emitted radiation as might be expected at the time of the spring equinox. However, the June imagery showed a marked cooling in the gaining reach in both the postsunset and the predawn flights. The imagery for the midday flight showed a smaller difference. Also, the tributary valleys in the gaining reach were cooler than the tributary valleys in the losing reach.

Ground-water levels in the gaining reach of the valley are near the level of the flood plain, whereas in the losing reach they are as much as 76 m below the level of the flood plain.

ERTS imagery for ground-water studies

Some present and potential uses of ERTS imagery are to locate new aquifers, to study aquifer recharge and discharge, to estimate ground-water pumpage for irrigation, to predict the location and type of aquifer-management problems, and to locate and monitor strip mines, which commonly are sources for acid mine drainage. In many cases, boundaries that are gradational on the ground appear to be sharp on ERTS imagery. These applications were demonstrated in a recent study by G. K. Moore and Morris Deutsch.

Evapotranspiration calculated using color-infrared photography to measure vegetation

J. E. Jones developed a method of interpreting color-infrared photography as a relative radiometer to provide a description of vegetation which was related to evapotranspiration. A densitometric analysis of the positive transparencies was adjusted to define relative irradiance in three spectral bands which were functionally related to spectral regions indicative of plant quantity and activity. Film from 38 aerial color-infrared photographic missions flown from 1967 to 1971 over the Gila River in southeastern Arizona provided the photographic data. Water-budget data provided the monthly evapotranspiration rates. The photographic interpretation of 13 flights in 1968 defined the seasonal variability of the consumptive-use coefficient in the Blaney-Criddle evapotranspiration equation for 890 ha of phreatophyte-covered land and for 696 ha of cleared land. The coefficients of correlation between measured and computed evapotranspiration were 0.86 for the phreatophyte-covered area and 0.88 for the cleared area. Depth to ground water and moisture content of soil could not be determined by the interpretation, but plant stress due to moisture content was detectable. Discrimination between eight different plant communities was also possible. The cost of one color-infrared photographic mission and densitometric analysis of the photographic data was about one-tenth of the cost of conventional species classification and canopy measurements.

Thermal-infrared imagery used in Montana

Thermal-infrared imagery has been used in Montana to detect ground-water inflow and to determine reservoir flow patterns. Several aircraft flights utilizing a temperature-calibrated thermal-infrared scanner were made over Noxson and Cabinet Gorge Reservoirs and Lake Koocanusa to detect inflow from bank storage and reservoir leakage. A. J. Boettcher reported that because the areas of interest are fairly long (more than 80 km each) and because many data are gathered during a flight, the scanner data are recorded on magnetic tape in the aircraft and later converted to a computer-compatible form. The computer can then output the data in symbols, contours, or patterns showing 0.5°C differences in water temperature. Ground data are utilized to maintain high standards of accuracy.

Niagara River turbidity plume

One of the most important factors governing the size and shape of turbidity plumes in large quiescent water bodies is wind speed and direction. E. J. Pluhowski reported that the importance of the ambient wind field is illustrated by ERTS–1 satellite imagery of western Lake Ontario on April 29, 1973, and September 3, 1973.

On April 29, 1973, brisk west-northwest winds caused a strong eastward-moving longshore current along the southern boundary of the lake. The shearing effect of this current on the northward-moving Niagara River plume is portrayed in ERTS image 1280–15302–4, 5. The plume extended only 3.2 km offshore; however, it was identifiable for a distance of at least 13 km downwind along the New York shoreline. The total surface area of the plume on April 29, 1973, was 34 km^2.

Gentle offshore winds on September 3, 1973, on the other hand, greatly expanded the size of the Niagara River plume. The southerly winds on that day reinforced the northward-flowing Niagara River jet. The offshore winds pushed the leading edge of the Niagara plume about 30 km into the lake. As shown in ERTS image 1407–15343–4, 5, a large clear-water (dark) plume developed which covered 514 km^2 of lake surface.

The utility of high-altitude aircraft and spacecraft imagery in reconnaissance hydrologic studies of arid and semiarid regions

In Montana, New Mexico, Wyoming, and Utah, L. M. Shown and J. R. Owen, Jr., are investigating the use of high-altitude aircraft, 1:120,000-scale photography and ERTS imagery for inventorying surficial geology, relief, drainage density, vegetation, channel types, and land use as indicators of water and sediment yield, chemical water quality, and occurrence of ground water. These indicators can be discerned on false-color ERTS images, and drainage density is one indicator that can be readily measured. The ERTS images are best for defining areal and regional hydrologic systems and identifying areas that need additional investigation in order to understand and evaluate hydrologic processes. False-color infrared photographs taken from high-altitude aircraft are entirely adequate for mapping source areas of water and sediment and for evaluating their conveyance through the drainage network. Conveyance is determined by the presence and magnitude of (1) upland rilling, (2) upland deposits such as fans and bahadas, (3) channel deposits such as fans, bars, and flood plains, (4) channel conditions such as raw banks (stable or healed), and (5) the permeability of alluvium as indicated by channel width and cover. The easy detection of phreatophytes on infrared photographs facilitates the assessment of ground-water occurrence, and different spectral signatures for different species provide information about the chemical quality of the ground water.

APPLICATIONS TO CARTOGRAPHIC STUDIES

During fiscal year 1974, the Topographic Division was funded by NASA and the EROS program of the Department of the Interior to investigate specific cartographic applications of space and high-altitude aircraft photographs. The principal emphasis was placed on data from ERTS with secondary emphasis on Skylab missions SL–2 thru SL–4.

ERTS investigations, begun with the satellite launch in 1972, have evolved into definitions of proposed investigations for ERTS–B, to be launched in 1974–75, and have culminated in recommended specifications for an improved ERTS–C. Skylab was launched early in fiscal year 1974, and experiments are continuing with data from the S–190–A, S–190–B, and S–192 sensors.

ERTS image maps

Prototype image maps have been prepared from ERTS images at scales ranging from 1:250,000 to 1:1,000,000 and in a wide variety of formats and modes. Within the United States, these include quadrangles at 1:250,000, 1:500,000, and 1:1,000,000 scale and State image maps at 1:500,000 and 1:1,000,000 scale—all monochromatic and all bearing the UTM grid for geodetic reference. Prototype image maps of Antarctica have also been produced. ERTS is in many ways ideally suited for mapping the polar regions with the exception of the 8.2°-radius circle surrounding each pole.

Selected image-format and State base maps in color at 1:500,000 scale have been duplicated and placed on public sale. The first 1:500,000-scale image-format map, Upper Chesapeake Bay, meets NMAS as determined from the UTM grid and is printed in false (infrared) colors. The State base map of New Jersey in similar form is significant in that it is the first colored mosaic in map form that maintains uniformly high image quality. The mosaic was laid in film rather than paper-print form, a departure from conventional practice made possible by the high geometric fidelity of ERTS. The scale, format, and mode of the Upper Chesapeake Bay image map are considered optimum as the prototype for a potential national or worldwide series of maps based on the ERTS image format.

Map revision applications

Selective experimental revision of smaller scale line maps and the delineation of areas that will require revision from other source material are being accomplished with ERTS imagery. For the conterminous United States, source material suitable for map revision is generally available, and thus ERTS imagery is of limited value in this application. However, ERTS imagery was used as one source in the revision of the Virginia State base map and also indicated changes to be made to the Arizona State base map (both 1:500,000 scale). For Alaska, the imagery is considered suitable for revising part of the 1:250,000-scale map series, but this application has not been effected to date. Another promising application of ERTS in map revision is to indicate areas where map updating is needed—large-scale as well as small-scale maps—even though other source material may be needed for the actual revision. In Antarctica, ERTS images have been found to be extremely valuable for revising such features as coastlines, ice shelves, and ice tongues and has even led to the discovery of uncharted mountain ranges.

Other ERTS applications

The aeronautical and nautical charting potential of ERTS has been investigated. Imagery from both Apollo and ERTS has been used to demonstrate the advantages of small-scale imagery as a base for aeronautical charts. Pilots who have evaluated the experimental space-image bases indicate that they offer some advantage over existing line base maps. The potential of ERTS imagery for nautical charting has not been determined. MSS band 4 indicates underwater features as deep as 10 m. By using both bands 4 and 5, actual depths down to about 5 m can be determined with reasonable accuracy under suitable conditions. ERTS also has the potential for positioning isolated reefs and islets within 1 km of true position, but this application is only now being fully investigated. Considering the inadequacy of nautical charts in many areas of the world and the fact that coastal areas are constantly changing, ERTS may well have practical application to nautical charting.

Geometry of ERTS imagery

Geometric analyses of RBV and MSS imagery have been performed. A sizable number of MSS and RBV images and image-derived products have been precisely analyzed through measurement of photo-identified control points or the reseaus on the RBV's. The ERTS MSS positional accuracy is summarized as follows:

Mode and form	*Error range (rms)*
Raw—referenced to lat/long indicators	1–8 km
Bulk—referenced to ground control:	
Best fit to UTM projection	150–350 m
UTM grid fitted to single-band image	50–100 m
UTM grid fitted to single-band mosaic of 2 to 4 images	100–150 m
UTM grid fitted to multiband (colored) single image (lithographed)	150 m [1]
UTM grid fitted to multiband (colored) mosaic of 2 to 4 images (lithographed)	240 m [1]
Precision processed to UTM projection	125–150 m

[1] Based on the few products so far produced.

Methodology for measurement and analysis of ERTS image products has been developed and is in various stages of documentation.

Processing modifications

MSS-image processing has been modified to improve the cartographic aspects of ERTS imagery. On the basis of both geometric and photometric analyses of ERTS imagery, several changes have been adopted by either NASA or USGS. Some of the more important are:

1. Removal by NASA of the MSS line-scan anomaly, which resulted from insufficient sampling and changes in the Earth-rotation effect.
2. Removal of the along-track scale variation, which alters the uniformity of MSS imagery. (To be implemented for ERTS–B)
3. Changes in image processing to improve density range and contrast. Although recommended changes have not been implemented by NASA, they have been applied by USGS in preparing cartographic products.
4. Changes in color-composite preparation. Tests indicate that, with current NASA processing, color composites from bands 5 and 7 are superior for general purposes to those from bands 4, 5, and 7. The two-band method simplifies cartographic processing and is being used by USGS. However, any change in basic processing of the bands may call for further change in the preparation of color composites.

A comprehensive set of specifications based on cartographic requirements, including recommended changes, has been prepared for an improved ERTS satellite. Many of these changes should be adopted for ERTS–C.

ERTS projection

A map projection and precision processing have been defined which will permit the cartographic processing of ERTS imagery to be automated. The investigation of MSS imagery indicates that it can be recorded in system-corrected (bulk) form on a defined cylindrical map projection. Several variations of cylindrical projections were considered, and the conformal Space Oblique Mercator (SOM) was selected as the most suitable. The SOM projection is described fully in other reports; its most important characteristics are that it is uniform and continuous and that it develops distortion of only about 1 part in 10,000. Defined processing procedures based on this projection provide for the automated production of cartographic products. These procedures could replace the scene-corrected (precision-processed) system of ERTS–1 and result in products available in a matter of days when justified.

In summary, from the mapping viewpoint ERTS has exceeded expectations. It gives mapmakers a new source from which image maps of small scale can be produced efficiently and accurately. Moreover, ERTS points the way toward a revolutionary concept—automated mapping of the Earth.

Gridding of ERTS images

The normal method of converting an image to a map is to rectify the image to fit the map projection. However, the transformation of ERTS images to fit a projection results in an unacceptable reduction in image quality. Therefore, a computer program developed by Ohio State University under contract to USGS is used to fit the grid to the image. The process relates image details to the ground coordinate system with no loss of image quality and is now standard in the production of ERTS-image maps.

ERTS image format series

Investigations of the geographic repeatability of ERTS–1 images indicated that orbits and along-track image centers have been maintained within approximately 15 km and 5 km; if requested, NASA could maintain orbit control within 5 km, that is, within half the 10-percent overlap along track and half the 14-percent sidelap at the Equator. A computer-generated plot of nominal-scene centers is available for the United States, with latitude and longitude assigned to each nominal scene. The group of gridded ERTS-image maps thus far produced includes Upper Chesapeake Bay, Lake George, Fla., the Everglades, Fla., and Lake Okeechobee, Fla.

Stereocapability of convergent RBV on ERTS

An examination of the ERTS system disclosed that it is feasible for two RBV cameras to be tilted 5.1° from nadir to produce a full stereopair from each exposure station, or a 10.2° angle would provide a stereopair from exposures at every other station. With a convergent RBV system of 0.36 base-height ratio, relief differences as small as 25 m can be detected under ideal conditions. Relief of 50 to 100 m should be generally detected, and relative elevation differences of 100 to 200 m could be measured. These characteristics should be of value in interpretation.

Skylab investigations

The Skylab sensors for cartographic applications were: S–190–A, an assembly of six 153-mm focal-length cameras recording on various 70-mm films and film-filter combinations; S–190–B, a 457-mm focal-length frame camera recording on 12.5-cm film; and S–192, a 13-channel (0.4 to 12.4 μm) multispectral scanner.

Evaluations of Skylab data for cartographic applications included an image-quality analysis of various film and spectral-band combinations of selected S–190–A and S–190–B images. Image resolution proved to be close to predicted values, except when loss of platen vacuum at exposure and use of lower resolution second-generation duplicate copies caused undue degradation. Resolution values ranged from 41 m/lp (metres per line pair) to 82 m/lp for the S–190–A and from 14 m/lp to 27 m/lp for the S–190–B camera. Further evaluations are planned with direct enlargements from first-generation SL–4 images.

Experiments to determine map-revision applications of S–190–A photographs indicate suitability for scales of 1:250,000 to 1:1,000,000. Further studies of map revision are being undertaken with the S–190–B photographs. The limited ground coverage of Skylab photographs restricts the areas for potential test sites.

Skylab photographs are being used to prepare experimental image maps at 1:100,000, 1:250,000, 1:500,000, and 1:1,000,000 scale. It is estimated that 1:100,000 is the optimum scale for photomaps from S–190–B photographs and that 1:500,000 is optimum for S–190–A photographs. Practical applications are marginal at best because all Skylab photographs have already been taken.

The experiment to evaluate the S–192 MSS for cartographic applications awaits imagery. Preliminary inspection of imagery made available by NASA indicates that additional ground information can be acquired in detecting water-land interfaces and in penetrating haze and thin clouds.

APPLICATIONS TO GEOGRAPHIC STUDIES

LAND USE AND OTHER GEOGRAPHIC STUDIES

A land-use classification system for use with remote-sensor data

A land-use classification system, described in U.S. Geological Survey Circular 671 (Anderson, Hardy, and Roach, 1972), has been developed to meet the needs of Federal and State agencies for an up-to-date overview of land use throughout the country on a basis that is uniform in date, scale, and categorization at the more generalized first and second levels. This classification system utilizes the best features of existing widely used classification systems to the extent that they are amenable to use with remote sensing, and it is open ended so that regional, State, and local agencies may develop more detailed land-use classification systems at third and fourth levels to meet their particular needs and at the same time remain compatible with the national system.

The approach to land-use classification proposed by the USGS is resource oriented in contrast to the people-oriented system developed in the mid-1960's by the Urban Renewal Administration and the Bureau of Public Roads. In the people-oriented system, seven of the nine more generalized first-level categories involve urban uses of land which accounts for less than 5 percent of the total area of the United States. This 5 percent of the area has, however, about 95 percent of the total population, demonstrating the real need for an urban-oriented land-use classification system.

It has, however, become increasingly apparent that a resource-oriented land-use classification system is also needed. The USGS classification system has been developed to meet this need. Eight of the proposed nine level I categories are associated with the 95 percent of the area of the United States not in urban and built-up uses. A considerable degree of compatibility between the people- and resource-oriented systems of classification can be achieved at the more generalized levels. It is probably impossible, however, to achieve complete compatibility between land-use data collected from ground observation and enumeration and that compiled from remote-sensor data, particularly at the more detailed levels of categorization.

In developing a land-use data system with a resource orientation, several basic assumptions, needs, and requirements have been recognized. Federal and State agencies engaged in land management and planning activities need comparable land-use data in order to carry out various interagency activities effectively. Although probably no ideal land-use classification system will ever be developed, provision has been made to provide for flexibility in the USGS classification and, at the same time, make it possible to summarize and generalize on a reasonably uniform basis. Thus, each Federal and State agency will be able to develop more detailed levels of classification appropriate to its specific needs. The more generalized levels I and II of the USGS classification, utilizing remote-sensor data, offer the most efficient and least costly means of compiling land-use data over extensive areas.

After many consultations with representatives from Federal and State agencies, a proposed revision of categories of land use for levels I and II has been completed. A revised edition of Circular 671 is scheduled to be issued at the end of fiscal year 1974, and will be distributed to all interested Federal and State agencies as well as inquirers from various other groups such as regional and local planners and river-basin commissions.

Phoenix and southern Arizona land-use mapping project

During fiscal year 1974, final reports are being written on the two primary investigations involving 1:250,000-scale mapping of land use in southern Arizona. One of these was the NASA-sponsored test of the utility of ERTS film-type images to update a land-use map of the Phoenix quadrangle which had been previously compiled from high-altitude aerial photographs. The second was an EROS-sponsored pilot project to develop procedures for land-use mapping and analysis for large regions.

The findings from the ERTS interpretation of the Phoenix quadrangle showed that residential growth could be monitored using ERTS imagery with more than 80-percent accuracy in terms of total area of change, although many small areas of change were missed. New cropland and new water were detected with better than 95-percent accuracy, possibly better accuracy than is achievable from aerial photographs taken only once per year because ERTS imagery can show seasonal changes. Certain types of land use or land-cover classes are delimited better using ERTS imagery because of characteristic seasonal vegetation changes; for example, fallow fields on the edge of the desert. It is evident that ERTS imagery and high-altitude aerial photographs complement each other. For example, ERTS images quickly show areas that are changing rapidly and for which aerial photographs or other more detailed information should be obtained.

The data on changes of land use between 1970 and 1972 in the Phoenix quadrangle were introduced to the computer data bank by card input. Some analysis was performed on the change data, relating them to other data in the bank such as land ownership, soils, and drainage. Maps of land use before and after ERTS became operational have been plotted automatically.

Progress on the EROS-sponsored development of procedures for nationwide land-use mapping and analysis at a scale of 1:250,000 consisted of completion of the two-by-two matrix of four quadrangles making up the heart of the Arizona Regional Ecological Test Site (ARETS). For each of the four quadrangles, data now recorded in digital form in the computer data bank involve land use land ownership, soils, drainage basin, and census-county and tract codes. For the Mesa, Tucson, and Ajo quadrangles, the information was read in by a new procedure for digitizing, using the Faul-Coradi digitizer in the USGS Denver Mapping Center. Arc segments recorded in this manner had to be collected into polygons for plotting as maps that are more accurate geographically than the cellular plots used previously for the Phoenix quadrangle. Crosshatching in color or other form of symbolic representation is also possible with the new form of map output.

In order to make the new data compatible with the computer programs being used to analyze the Phoenix quadrangle data, it was necessary to convert all 18 polygonal sheets—6 factors for each of 3 quadrangles—to cells. A computer program to do this was written by the USGS Geographic Information Systems Group. It is now possible to analyze the land use of all four quadrangles in one step, and these quadrangles contain nearly all of the intensively used land and over 80 percent of the population in Arizona.

Central Atlantic Regional Ecological Test Site (CARETS) project

The CARETS investigation is testing the applicability of ERTS data as input to an environmental information system for the multistate mid-Atlantic region surrounding Chesapeake and Delaware Bays. The information-system framework encompasses a flow of data through several stages from sensor to user and involves evaluation and feedback from several potential users. The basic assumption of the CARETS project is that there is a measurable environmental impact associated with land use and land-use change as determined with remote-sensor data; therefore, properly calibrated ERTS-derived land-use data sets may provide regional planners and administrators with a shortcut to an understanding of the environmental changes occurring in their areas. The CARETS research design involves three interrelated program steps or subtasks:

1. Land-use analysis: Maps and data sets on land use for the 70,000-km^2 region have been prepared in final form and approved by the USGS for placement on open file in USGS libraries. Level I 1972 land use of the

CARETS area has been compiled from ERTS imagery and formatted to eight 1:250,000 topographic sheets. Area measurements of forest and agricultural land uses in the Norfolk metropolitan area compared favorably to those obtained from land-use maps based on aerial photographs.

Parts of Virginia, Maryland, Delaware, New Jersey, and Pennsylvania were field checked, resulting in greater map accuracy, a further test of the USGS land-use classification scheme presented in Circular 671, and input to the proposed classification revision. Experiments in accuracy determination were also conducted in parts of rural Virginia.

A comprehensive report on the Norfolk prototype test site, based on the results of several CARETS research efforts, analyzes land use and land-use changes between 1959 and 1972, discusses land-use-related environmental problems, and demonstrates the use of the CARETS data base.

The computerization of the CARETS data sets is of high importance to the land-use-analysis subtask. Investigation of the best methods of measuring areas and of digitizing, retrieving, and plotting land-use data in polygon form have been supported by the CARETS project. Level II land use of the Norfolk-Portsmouth Standard Metropolitan Statistical Area (SMSA) has been digitized using the Canadian Geographic Information System, and data summaries have been produced. Also, the Geography Program's Geographic Information Systems Group has conducted several successful experiments in digitizing land-use and related data for portions of CARETS and is now reviewing proposals for the operational digitizing of the CARETS data base.

2. Environmental-impact assessment: The objective of the environmental-impact-assessment subtask is to perform sample interpretations and analyses of land-use data sets in terms of the environmental impact of land-use patterns and land-use changes. W. E. Davis is compiling a series of surficial geology and slope maps for the CARETS region which will be of great value to planners in delimiting areas where surficial geology poses restraints upon development. H. P. Guy and E. J. Pluhowski are using levels I and II land-use categories in evaluating the effectiveness of CARETS land-use data in improving estimates of streamflow parameters in selected Maryland drainage basins. John Lewis (Univ. of Maryland) has investigated the relationship between land use and air quality in the Norfolk-Portsmouth SMSA and has submitted a report identifying types of land-use information needed to evaluate air quality, strategies available for air-quality control, and applications of this information to Norfolk area air-quality planning. Finally, Robert Dolan (Univ. of Virginia) has mapped land use and land cover of the Atlantic coast barrier islands and fringing wetlands; he has classified land-use categories with respect to their vulnerability to natural processes and suitability or risk for development, and has made recommendations concerning the remote-sensor monitoring of these very fragile environments.
3. User evaluation: A user-evaluation program has been developed and is being employed to receive feedback concerning the value of CARETS-data products; the program involves the introduction of the products to potential users, a time interval for user examination of the data, and a followup interview utilizing a series of questionnaires designed to elicit required information. Besides numerous contacts with individual users, the CARETS user-evaluation program held user meetings with planners in southeastern Virginia and in Fredericksburg, conducted a land-use data workshop for planners from the Washington, D.C., metropolitan area, and worked closely with planners in the Metropolitan Washington Council of Governments. Presently plans are being developed for user evaluation by State planners and representatives of Federal agencies interested in land-use information.

Comparative urban studies

One project of the Geography Program is a comparative study of land use and land-use change in a rank-size sample of U.S. urban areas, using remote sensors aboard aircraft as well as ERTS and Skylab satellites. Closely related to this is development of a procedural manual, an urban spatial-growth model, and techniques for mapping land use from ERTS MSS data in digital format.

During 1973, the mapping and analysis of land-use change from 1970–1972 NASA aircraft imagery was completed for Phoenix and Tucson, Ariz., San Francisco, Calif., New Haven, Conn., Cedar Rapids, Iowa, Boston, Mass., Pontiac, Mich., and Washington, D.C. This work was carried out by staff personnel plus planners or university researchers at Dartmouth College, Sonoma County (Calif.) Planning Commission, Oakland County (Mich.) Planning Commission, University of Arizona, and California State University at San Jose. Land-use maps for San Francisco and Washington, D.C., were published or placed on open file in USGS libraries.

With contract support from the Association of American Geographers (AAG), work was begun on construction of an urban spatial model. This project attempts to correlate 1970 land-use information for the urban test sites with contemporaneous data from the 1970 census. The spatial model and knowledge of land-use changes in 1970–72 gained from remote-sensor data are being used to assess the significance of land-use change and other environmental impacts.

A user's procedural manual is also being prepared with contract support from the AAG. It describes and illustrates steps in land-use interpretation and in preparation and maintenance of a data base for use with sensor data from aircraft and satellites. Besides documenting many of the Geography Program's recent research procedures, the manual will serve as a text and training aid for State and other user groups establishing their own land-use monitoring systems.

At the request of the Appalachian Regional Commission, the USGS Geography Program has undertaken land-use studies in Lycoming County, Pa., the Pittsburgh metropolitan area (an integral part of the USGS Greater Pittsburgh Regional Study), and the Kentucky River Area Development District, Ky. The Southwestern Pennsylvania Regional Planning Commission is also sharing in this effort. For the USGS study, NASA aircraft acquired high-altitude color-infrared photographs of the Pittsburgh area on March 23, 1973. The next day, the NASA ERTS–1 satellite acquired excellent cloud-free MSS imagery of the same area. The USGS land-use studies of Pittsburgh, done in collaboration with local planners, afford an exceptional opportunity for use of remote-sensor data, coordinated with Earth science studies, for use in regional planning.

Geography Program scientists continue to work with colleagues at the Purdue University Laboratory for Applications of Remote Sensing to apply ERTS MSS data in digital format to the challenge of inventorying land use and monitoring land-use change. Computer digital maps of approximately level II and level III detail were produced at a scale of 1:24,000 for the Washington, D.C., San Francisco, and Phoenix test sites. These maps use all ERTS data in all spectral bands. More generalized digital maps at smaller scales were produced by using one-fourth and one-ninth samples of the data or by other data-reduction techniques. Digital data from two contrasting seasonal scenes were successfully overlaid to produce a more detailed classification and also to use seasonal spectral differences as a classification aid (not a hindrance) in separating functional classes that are spectrally similar at some time of the year.

One byproduct of this approach is the actual mapping of land recently disturbed by man. The Phoenix map, for example, shows extensive urban expansion on the urban perimeter. In addition, the USGS geographers successfully overlaid digitized boundaries of coordinate grid cells and census statistical areas in the computer. Once the ERTS pixels (picture elements) were classified, aggregations and area measurements were immediately available by user jurisdiction. Computer preparation of map reproducibles for land-use-class areas was also demonstrated. User interest in the ERTS computer maps and information system is keen.

Geographic Information System (GIS) development

Developmental work continued during fiscal year 1974 on the establishment of a geographic information system necessary to provide the capability for computer-assisted storage, editing, manipulation, and retrieval of a geographic data base in support of major projects of the Geography Program. This system includes (1) digitization of maps of land-use and other environmental data, (2) editing and updating of the computer-stored data base, and (3) manipulation of that data base in order to perform area measurements, map-overlay analyses, and statistical and other computer-aided operations.

Procurement and implementation of the Advanced Interactive Digitization program (DIGIT), Computer Aided Map Compilation (CAMAC), and the Minicomputer Geographic Information System (IMAGE) of the University of Saskatchewan have progressed subject to unavoidable procurement problems. Sole-source procurement of the PDP–8e and Tektronix graphic-storage devices necessary for implementing the programs has been completed. Training of Geography Program staff members in operation of the minicomputer and peripherals is nearly completed.

Regarding Raytheon's Natural Resources Information System (NRIS), funded by the EROS program, through the Bureaus of Indian Affairs and Land Management, the Geographic Information System review determined that considerable continued work by the GIS programing staff was necessary to install and operationally test the system on USGS computers. After errors were discovered in the software delivered by Raytheon in November 1973, a GIS programer consulted with Raytheon programers in Waltham, Mass. Updates of the system have been completed for 25 of the 37 programs used in 12 special processing procedures.

The Graphic Input Procedure (GIP), developed earlier in the project period, has been undergoing operational tests on EROS- and ERTS-funded projects in the Geography Program. When operationally tested and proven, the GIP will be available for editing and correcting digitized maps for further manipulation and information retrieval using the NRIS or the IMAGE and CAMAC programs. Programing is 90 percent complete on a procedure to transform maps and overlays digitized via the GIP programs into grid cells of whatever size is required by users.

Negotiations were initiated and are being completed to digitize, process, manipulate, and retrieve land-use and related data through the Canada Geographic Information System by arrangement with Environment Canada and the Canadian Government.

An advisory group of the IGU Commission on Geographical Data Sensing and Processing has also provided continuing advice and guidance during the year on problems relating to the development of a geographic information system in the USGS Geography Program.

Cooperative land-use-data projects

The Geography Program has recently been involved in two test and demonstration programs with the Ozarks Regional Commission, whose jurisdiction includes portions of Arkansas, Kansas, Louisiana, Missouri, and Oklahoma.

The first program concerned the cooperative development of a computerized land-use data base. The first results of this project, consisting of land-use maps and data for approximately 180,000 km^2 in the Ozarks region, have been turned over to the Commission. Prior to the start of compilation, a year was spent in planning directed toward user implementation. Various agencies of the States within the commission area were consulted on the specification of the data base as well as the minimum content required to satisfy initial planning efforts. The final concept was developed to provide the user agencies with a minimum data base of information which also could be easily and economically expanded to include additional needed data. Provisions were made to provide assistance in the development of updating techniques and procedures.

The data base now contains the following overlays of information, compiled at a scale of approximately 1:125,000 but keyed to the standard 1:250,000-scale topographic map series: (1) land use, delineated in compliance with U.S. Geological Survey Circular 671 level II categories; (2) political boundaries (the lowest level shown is county); (3) public land ownership (all Federal and State land in units as small as 16.2 ha is shown by administering agency); and (4) drainage areas, as published in the Catalog of Information of Water Data, issued by the USGS' Office of Water Data Coordination. In addition to these individual overlays, the deliverable items included computer plots of the land use for each sheet and a statistical analysis of the land use by counties covered by the sheet. The statistical analysis showed the amount of each type of land use within each county as well as the percentage of each land use relative to all others within the county. Computer tapes which contain all of the data on the compiled overlays were produced so that other types of statistical data can be provided; these include land use by amount or percentage, by drainage area within counties or sheet, by ownership within counties or sheet, or by other combinations of these parameters.

The second project consisted of the development of planning-data overlays for 100-yr flood-plain, mineral deposits, surface transportation, utilities, fish and wildlife, and park areas for the counties bordering the Arkansas River from its junction with the Mississippi River to Tulsa, Okla. Since both cooperative land-use-data projects are keyed to the same data base, all of the aforementioned data-base information is being used also by the Arkansas River Corporation in its final report.

To insure utilization of the data base and to make access to the information available to the greatest number of possible users, the USGS Geography Program and the Ozarks Regional Commission are cooperating on the development of an implementation effort, part of which consists of working with Federal, State, and county agencies to provide statistical data and graphics for problem solving.

INTERNATIONAL COOPERATION IN THE EARTH SCIENCES

The USGS conducts a wide variety of programs in the international sector, in which most of the USGS Divisions participate in varying degree. Present-day programs have grown from or been influenced by the international work of the USGS in technical assistance over the last 34 yr. The programs may be divided into major categories, as follows:

1. Technical assistance to developing countries at the request of other governments and agencies.
2. Scientific and technical cooperation on subjects of mutual interest.
3. Participation in international commissions and scientific programs.
4. Natural disaster response.

These programs involve studies in areas scattered from the Antarctic to Europe, Asia, Africa, and Latin America.

Technical assistance to developing countries has been a major part of the international program of the USGS. Most of this assistance has been sponsored by the Department of State's AID and predecessor agencies at the invitation of the host countries. The assistance has been provided by working through host-country resources agencies, in close collaboration with counterpart scientists, in geologic and topographic mapping, mineral and water-resources investigations, geophysical and geochemical surveys, and related analytical work. Training of Earth-science technical and professional personnel and development of local geologic, hydrologic, and cartographic organizations have been an integral part of the assistance projects.

In fiscal year 1974, the USGS was involved in continuing long-range multidisciplinary assistance in Brazil, Colombia, Indonesia, and Saudi Arabia, as well as in short-term assistance in 34 other countries. (See table 2.) Most of the long-range assistance is sponsored by AID; however, the work in Saudi Arabia is sponsored by the Kingdom of Saudi Arabia, under an agreement with the Saudi Arabian Ministry of Petroleum and Mineral Resources. Short-range investigations in Oman, Yemen, and Jordan were also sponsored by the respective host governments.

In fiscal year 1974, a substantial part of the USGS technical assistance was concerned with the application of remote-sensing techniques. On behalf of AID, the USGS continued its assistance to the Government of Thailand in establishing a national program for application of remote sensing in agricultural, forestry, land-use, water resource, and mineral-resource surveys. Also on behalf of AID, the USGS continued a study of the use of multispectral photography for natural-resources surveys, in cooperation with Indonesian agencies, and an experimental study of the possibilities for using remote sensing in the search for ore deposits in heavily vegetated areas in the tropics. The USGS also carried out an international remote-sensing training and demonstration program for AID, which included a 2-week seminar-workshop in Nairobi, Kenya; a pilot study of the possible use of remote-sensing techniques for water, range, and land-use surveys in the region of the Liptako-Gourma Authority (Niger, Mali, and Upper Volta) in West Africa; a pilot study of the application of earth-resources satellite data to geologic analysis in Afghanistan; a 9-week training program for 36 Latin American scientists at Inter-American Geodetic Survey headquarters in the Canal Zone; and a 4-week training course for 34 foreign nationals at the EROS Data Center at Sioux Falls, S. Dak.

At the request of AID, the USGS initiated a study of the possibilities for applying satellite data for early warning and damage assessment in areas of natural disaster.

Technical assistance is also provided by the USGS through international organizations. During fiscal year 1974, for example, A. D. Acuff served as consultant to countries in southeast Asia on pollution problems related to offshore prospecting and development activities, sponsored by the United Nations Development Program in support of the Coordinating Committee for Joint Prospecting of Mineral Resources in Asian Offshore Areas. The USGS provided the services of F. H. Wang to help the committee prepare and initiate regional offshore programs in southeast Asia.

In recent years, emphasis in the USGS international program has been gradually shifting from

TABLE 2.—*Technical assistance to other countries provided by the USGS during fiscal year 1974*

Country	USGS personnel assigned to other countries			Scientists from other countries trained in the United States	
	Number	Type	Type of activity [1]	Number	Field of training
Latin America					
Argentina				1	Water quality studies; pollution controls.
Bolivia				2	Remote sensing.
Brazil	20	Geologist	A, B, C, D	4	Do.
	9	Hydrologist	A, C	2	Surface water techniques.
	1	Geochemist	B	1	Water quality.
	3	Mathematician	D	2	Water resources.
	2	Chemist	A	3	Hydrologic techniques.
Chile	2	Geologist	A, C	--	
	1	Geophysicist	D	--	
Colombia	8	Geologist	A, B, C, D	7	Economic geology.
				1	Remote sensing.
Costa Rica	2	Geologist	D	--	
Guatemala	1	Hydrologist	D	--	
Honduras	1	Geologist	D	--	
Mexico	1	Geologist	D	1	Application of isotopes to hydrology tritium.
Nicaragua				1	Earthquake hazard reduction.
Peru	1	Geophysicist	D	--	
	1	Geologist	D	--	
Surinam				1	Hydrology.
Venezuela	1	Hydrologist	D	1	Hydrogeology.
	2	Geologist	D	1	Hydrology.
				2	Remote sensing.
Africa					
Algeria	2	Geologist	A	--	
Chad	1	Hydrologist	D	--	
Ethiopia				1	Hydrology.
Gambia				1	Remote sensing.
Ghana				1	Hydrology.
Kenya	6	Geologist	D	--	
	3	Hydrologist	A, C, D	--	
Liberia	1	Publication specialist	D	1	Analytical chemistry.
Libya				1	Hydrology.
Mali	2	Hydrologist	D	1	Remote sensing.
Niger	2	Hydrologist	D	--	
Nigeria				1	Do.
Sierra Leone				1	Stream gaging.
Somalia				1	Exploration for radioactive materials.
South Africa	1	Geologist	D	1	Analysis of igneous materials.
Tunisia				2	Aquifer artificial recharge methods.
				2	Remote sensing.
Upper Volta	2	Hydrologist	D	1	Do.
Near East–South Asia					
Afghanistan	1	Geologist	B	1	Hydrology.
Bangladesh				1	Remote sensing.
India	3	Hydrologist	A	3	Hydrologic techniques.
				2	Hydrology.
Iran	2	Geologist	B	2	Remote sensing.
Jordan	1	Geologist	D	2	Geological engineering.
				2	Petroleum resources.
Nepal	3	Hydrologist	A	3	Ground-water investigations.
Oman	5	Geologist	D	--	
Pakistan	3	Geologist	A, B, D	1	Geology.
	2	Hydrologist	C, D	2	Remote sensing.
Saudi Arabia	17	Geologist	A, B, C, D	2	Geophysics.
	2	Geophysicist	B	--	
	2	Civil engineer	B	--	
	3	Chemist	B	--	
	2	Mathematician	B	--	
	2	Publication editor	B	--	
	1	Publication specialist	B	--	
	2	Cartographic technician	B	--	
	1	Driller	B	--	
	1	Photographer	B	--	
	1	Electronics technician		--	
	1	Project assistant		--	
	1	Administrative officer		--	
	1	Field operations manager		--	
	1	Secretary		--	

[1] See footnote at end of table.

TABLE 2.—*Technical assistance to other countries provided by the USGS during fiscal year 1974*—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					
Turkey				2	Remote sensing.
Yemen	1	Hydrologist	A	--	
	2	Civil engineer	B	--	
	3	Cartographic technician	B	--	
Far East					
Indonesia	7	Geologist	A, B, D	1	Geological mapping.
	2	Cartographer	B	1	Geothermal power survey.
	1	Spectrographer	D	1	Ground-water resources evaluations.
	1	Photogeologist	D	1	Hydrography.
				2	Modern mineralogical techniques.
				2	Remote sensing.
Japan				1	Earthquake research.
				1	Geochemistry of ore deposits.
				1	Research on Alaskan Territory fossil plants.
Kmer Republic				2	Remote sensing.
Korea	1	Hydrologist	C	1	Hydrogeology.
Philippines	3	Geologist	D	--	
Thailand	8	Geologist	B, D	1	Hydrology.
				1	Remote sensing.
				3	Water resources engineering.
Other					
Australia	1	Geologist	D	--	
Finland	1	Geologist	D	--	
France	8	Geologist	D	1	Astrogeology.
	1	Chemist	D	--	
	2	Hydrologist	D	--	
Great Britain				1	Isotopic investigations of concretions from Pierre Shale.
Iceland	1	Geologist	D	--	
Italy	1	Geologist	D	--	
New Zealand				1	Geophysics; microearthquake and seismological studies.
Poland	2	Geologist	D	--	
	2	Hydrologist	D	--	
Spain	4	Hydrologist	D	1	Remote sensing.
				1	Volcanology.
Switzerland				1	Earthquake research.
Yugoslavia	3	Geophysicist	C	1	Quaternary studies.
	2	Geologist	D	--	
	1	Hydrologist	D	--	
Total countries, fiscal 1974				40	
Total participants, fiscal 1974				94	
Total countries, 1943–June 1974				94	
Total participants, 1943–June 1974				1,450	

[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.

technical assistance to scientific exchange and cooperative research. This is in part a result of the growing capability of Earth-science agencies in many developing countries and in part the growing recognition in both developed and developing countries of the importance of cooperative studies on problems of mutual concern.

The USGS participates in a wide range of cooperative scientific programs with other countries. For example, in Yugoslavia cooperative research projects on deep-crustal structure, rare-metal mineralization, karst permeability, and earthquake reconstruction are being carried out by local institutes on excess-currency funds, sponsored by the USGS. Research projects on mining hydrology and lead-zinc mineralization are being carried out in Poland under similar funding. The USGS recently initiated cooperative research projects in geochemical exploration and in hydrology with Mexican counterpart agencies under the auspices of the National Science Foundation and the Mexican Consejo Nacional de Ciencia y Technologia. The USGS participates in scientific exchange with the U.S.S.R. related to earthquake studies, environmental pollution, and remote sensing under intergovernmental agreements signed in 1972. The USGS also cooperates with France in techniques of Earth-resources data processing and petroleum-resource evaluation.

USGS scientists have conducted studies of the application of ERTS–1 satellite systems in cooperation with scientists in more than 40 countries. Most of this cooperation is in the form of experimental projects to apply satellite imagery for Earth-resource studies, under the auspices of NASA. The USGS has recently intensified its study of sea ice by means of satellite imagery and aircraft surveillance in cooperation with the U.S. Army, Coast Guard, NASA, Office of Naval Research, and Canadian Polar Continental Shelf Project, through AIDJEX. AIDJEX has cooperated with Russian scientists in gathering data in the Bering Sea. Pilot experiments have demonstrated the ability to distinguish first-year ice from multiyear ice by remote sensing and to measure ice deformation.

USGS scientists have also been active in many international conferences and scientific programs on behalf of the United States. Among the conferences in which USGS representatives have participated are the Colloquium on Recycling of Materials held in Orleans, France; Committee on Space Applications Research (COSPAR) held in 1973 in Konstanz, Federal Republic of Germany, and in 1974 in São Paulo, Brazil; Continental Meeting on Science and Man held in Mexico City; Economic Commission for Asia and the Far East (ECAFE) Regional Conference on Mineral Resources Development at Kuala Lumpur, Malaysia; Coordinating Committee for Joint Prospecting of Mineral Resources in Asian Offshore Areas (CCOP) in Bangkok, Thailand; Central Treaty Organization (CENTO) Advisory Group on Minerals Development at Karachi, Pakistan, and several CENTO Working Group meetings in Turkey, Iran, and Pakistan; and Workshop on Earth Science Aid to Developing Countries and NATO Advanced Studies Institute Seminar on Metallogeny and Plate Tectonics in Newfoundland. Among the continuing programs of the international scientific unions in which USGS scientists participate are the Commission for the Geological Map of the World, the International Hydrological Decade, the International Geological Correlations Program, and the International Geodynamics Project. The Survey has also taken a leading part in helping plan a Circum-pacific Energy and Mineral Resources Conference, held in Honolulu in August 1974 under the auspices of the American Association of Petroleum Geologists (AAPG), the CCOP, and the Pacific Science Association.

As part of its support for the United States' response to natural disasters abroad, the USGS also carries out geological, geophysical, and hydrological studies to assess disaster effects and evaluate possible dangers. In cooperation with agencies in Guatemala, El Salvador, and Costa Rica, the USGS has initiated an experimental program of monitoring seismic events that may precede volcanic eruptions, transmitting data from ground sensors via the ERTS–1 satellite. As a consequence of the 1972 earthquake at Managua, the USGS is undertaking a project to develop a seismic-monitoring and earthquake-assessment capability in Nicaragua. The USGS has responsibility for the operation of the worldwide standard seismograph network, which collects information on the location and magnitude of earthquakes throughout the world and provides data of fundamental importance for crustal studies and disaster response.

As part of the USGS technical assistance and cooperative programs abroad, 94 earth scientists and engineers from 40 countries pursued academic or intern experience in the United States during fiscal year 1974. Types of assistance to, or exchange of scientific experience with, each country during the fiscal year are summarized in table 2. Under USGS guidance, 1,450 participants from 94 countries have completed research, observation, academic, or intern-training programs in the United States as of June 1974.

Since the technical assistance work began in 1940, more than 2,088 technical and administrative documents authored by USGS personnel have been issued. During calendar 1973, 110 administrative and (or) technical documents were prepared, and 62 reports or maps were published or released in open files. (See table 3.)

TABLE 3.—*Technical and administrative documents issued in calendar year 1973 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	Published in technical journals	Published or released by USGS
Afghanistan	1	2	--	--
Africa	1	--	--	--
Bolivia	1	--	--	--
Brazil	10	1	2	1
Colombia	2	6	1	2
Costa Rica	1	--	--	2
Ethiopia	--	--	--	1
India	--	--	--	1
Indonesia	6	2	1	1
Iran	1	--	--	--
Kenya	1	--	--	--
Liberia	4	3	--	11
Nepal	1	--	--	1
Nicaragua	3	2	--	2
Nigeria	--	--	--	1
Pakistan	2	17	--	16
Peru	--	1	--	--
Philippines	--	1	--	1
Saudi Arabia	10	18	8	5
South America	1	4	--	--
Thailand	--	1	--	--
Turkey	1	2	1	1
General	3	1	3	--
Total	49	61	16	46

SUMMARY BY COUNTRIES

BOLIVIA, PERU, AND CHILE

A cooperative remote-sensing program of information exchange has been established between W. D. Carter and geologists in Bolivia, Peru, and Chile, using ERTS–1 images. A mosaic of 22 images covering the area between lat 16°–20° S. and long 66°–72° W., called LaPaz, was compiled for lineation and structural geologic studies to determine the relationship between such features and the distribution of ore deposits. The linear features have been compiled by several geologists and compared with each other and existing published data. Correlation has been excellent, and preliminary field studies have already discovered a mineralized fault zone that has an estimated extent of 20 km. Plans for detailed sampling along this trend have been developed and are underway in Bolivia. Mosaics for other selected areas of the Andes are now being compiled.

BRAZIL

Technical cooperation in natural-resource assessment

As the major element in a restructured program of technical cooperation with Brazil, during calendar year 1973 the USGS conducted 20 formal training courses and symposia for about 250 young Brazilian scientists. Twenty-five USGS specialists were involved in these courses, which included studies in photogeology, hydrology, geophysics, field geology, statistical methods, geochemistry, economic geology, computer programing, and remote sensing. The USGS staff was assisted by an equal number of Brazilian senior scientists. In addition, 14 Brazilian geologists and hydrologists received formal training at universities in the United States and in laboratory and field programs of the USGS.

Specific short-term advisory assistance also was provided to counterpart Brazilian agenices by specialists of the USGS and the USBM. These activities included help in planning a Mineral Technological Center, planning a network of stream-gaging stations for hydroelectric power development, developing a hydrologic information system at the Computer Center of the Ministry of Mines and Energy, organizing remote-sensing projects, studying evaporite resources, and operating mobile laboratory units.

CENTO

Training in geologic mapping

The seventh annual Central Treaty Organization (CENTO) Training Course in Geologic Mapping (including mineral exploration, mine appraisal, and geochemical exploration) was held from July 16 to September 22, 1973, at the Ravandj lead mine, Iran, under the direction of E. H. Bailey (USGS). Other instructors were J. W. Barnes (Univ. of Wales, College of Swansea, U. K.) and M. P. Nackowski (Univ. of Utah). The instructing staff also included regional instructors from each CENTO country: M. Valizadeh (Univ. of Teheran, Iran), S. H. Ali Shah (Geological Survey of Pakistan), and S. Derici (Maden Tetkik ve Arama Institusu, Turkey). Nineteen graduate geologists or mining engineers from Turkey, Iran, and Pakistan participated in the field training. The program was supported logistically by the Geological Survey of Iran and financially by the multilateral Technical Cooperation Fund of CENTO, the British Overseas Development Agency, and AID.

The group lived and studied at the Ravandj mine, 250 km south of Teheran. The postgraduate participants learned how to evaluate the mineral resources and potential of a mine area through application of modern field techniques of surface and underground mapping and reconnaissance, and detailed methods of geochemical exploration. The maps were of immediate value to the mining company; a more detailed report is being prepared for publication by CENTO.

COLOMBIA

Institutional development

During the period 1963–73, the Ministry of Mines and Petroleum has developed one of the most active and competent national geological surveys in Latin America, the Instituto Nacional de Investigaciones Geologico-Mineras (INGEOMINAS). The growth and strength of this institution, which now has a staff of 350, including 70 field geologists and 34 chemists, is in large part due to the cooperation program between the Ministry of Mines and Petroleum and the USGS, with the financial support of development loans from AID. These loans provided for the services of scientists of the USGS for scientific work and training in Colombia, scholarships and participant training of young Colombian geologists in the United States, and purchase of basic equipment and supplies needed for field and laboratory work. Many millions of tonnes of coal, phosphate rock, gypsum, limestone, and metalliferous ores have been discovered during the course of the cooperative geologic mapping and resources investigations.

Mineral deposits

J. B. Cathcart and Colombian colleagues completed the first phase of a several-year study of phosphates with the evaluation of one deposit estimated to have large tonnages of commercial-grade phosphate rock. This project, which is a part of the overall cooperative program, is expected to continue as a long-term project of INGEOMINAS.

D. L. Rossman (USGS), working with 10 Colombian geologists, is making a geochemical sampling survey of a 14,400 km^2 area in conjunction with geologic mapping. Two areas, one containing cinnibar and the other showing Cu, Au, Sb, Zn, and Hg, are being investigated in detail. Tectonics of the area are being studied in relation to continental drift.

INDIA

Water resources of the Kadur subbasin, Vedavathi River basin, Mysore State

N. E. McClymonds recently completed a reconnaissance geohydrologic study of the Kadur subbasin in cooperation with the Indian Central Groundwater Board. The 740-km^2 subbasin, which is underlain entirely by Precambrian crystalline rocks, receives an average of 650 million m^3 of precipitation annually. Annually, an average of about 50 million m^3 of water is diverted from streams, and about 14 million m^3 leaves the basin in streams. In 1973, 1.7 million m^3 was withdrawn from wells in the subbasin.

INDONESIA

Mapping program

Geologic mapping by A. C. Effendi, Nana Ratman, and Tjetje Apandi (Geological Survey of Indonesia), advised by D. E. Wolcott (USGS), has shown a pumiceous tuff of probable Quaternary age to be widely distributed over the northeastern tip of Sulawesi. The tuff may have been deposited during formation of the Tondano caldera. The tuff overlies andesitic breccias and is overlain in places by material from still-active andesitic volcanoes. Alteration of the tuff by solfataric action, still in progress, has produced kaolin deposits that are being mined on a small scale.

In central-west Sumatra, geologic mapping in the area of Mount Kerinci by Subardjio, Dan Djuri, and Budisantose (Geological Survey of Indonesia), advised by W. H. Nelson (USGS), suggests that granite rocks were emplaced at two different intervals near the close of the Paleozoic. Pink granite is unconformably overlain by rocks that have yielded Permian fossils, whereas nearby gray granodiorite intrudes metamorphic rocks that contain Permian fossils.

A tectonic map of Indonesia, compiled by W. B. Hamilton in the context of plate tectonics, indicates a continuity of tectonic belts of varying types and age and is useful in assessing different terranes for metallic-mineral or petroleum potential. The map shows, for example, that the oil-bearing deep Tertiary Sumatra basin does not continue eastward across the Sunda Shelf north of the west coast of Java; instead, it fans out eastward into several thinly filled basins.

Geothermal surveys

Analyses of geochemical samples from the Banggai and Sula Archipelagoes, east of Sulawesi, and far from the tin islands of Bangka and Biliton, showed anomalous concentrations of tin. During reconnaissance geologic mapping of the area in 1972 by Rab Sukamto, Tjarda, and Purwoto (Geological Survey of Indonesia) and D. E. Wolcott (USGS), 350 samples from stream sediment, panned heavy-mineral concentrates, and beach sands were collected for semiquantitative spectrographic analyses in USGS laboratories. Thirty-three samples from areas near Permian and Triassic granitic and volcanic rocks contained from 10 to $>1,000$ ppm Sn. Of 48 samples from granitic and volcanic rocks analyzed by spectrophotometric techniques in the laboratories of the Geological Survey of Indonesia, 8 samples contained 10 to 16 ppm Sn. Further investigations seem to be warranted in areas underlain by granitic rocks.

Studies of ERTS imagery

ERTS–1 imagery (MSS bands 4, 5, 6, and 7) of the island of Sumbawa was interpreted by Adjat Sudradjat (Geological Survey of Indonesia) in collaboration with D. E. Wolcott (USGS). Reefs north of Sumbawa, that do not appear on existing maps, were clearly seen on band 4. Also, the relative ages of Quaternary volcanoes were established more certainly, and the boundaries of volcanic rocks from different eruption centers were determined more accurately and quickly than with fieldwork alone.

Lineations (faults and joints) are prominently displayed on the imagery. Some lineaments that probably represent major faults, not traceable in the field beneath a volcanic rock cover, were easily detected on bands 5 and 6. More lineations were seen on color composites of bands 4, 5, and 7 than on black-and-white prints of any single band.

JORDAN

Mineral-resource evaluation

In the fall of 1973, A. H. Chidester spent a month in the Kingdom of Jordan where he made a preliminary evaluation of Jordan's Earth-resources programs and institutions. On the basis of field trips to key areas and mining operations, review of existing Earth-resources data and geologic maps, and discussions with officials of the Natural Resources Authority, Chidester was able to provide the Jordan Government with a realistic assessment of its natural-resources potential and recommendations for future programs.

MALI, UPPER VOLTA, AND NIGER

Remote-sensing applications to range-utilization and water-resource problems

Reconnaissance feasibility studies relating to the use of ERTS imagery for mapping and evaluating selected environmental features of parts of Mali, Upper Volta, and Niger were recently completed by R. M. Turner and M. E. Cooley in several areas near the towns of Bamako, Ouagadougou, and Niamey. Some of their studies were related to: (1) Detection of tsetse fly habitats, (2) location of "river-blindness" organism (*Simulium damnosum*) breeding sites, and (3) mapping of areas of brush burning for range improvement, areas of gully and sheet erosion, areas favorable for ground-water exploration, and areas appropriate for flood-retreat farming in the inland delta of the Niger River. Preliminary results indicate that ERTS imagery is a valuable tool for mapping certain geohydrologic features and for detecting sources of many environmental problems in the areas studied.

MEXICO

Cooperative study in exploration techniques

The Consejo de Recursos Naturales No Renovables of Mexico and the USGS initiated a project for investigation of techniques of geochemical and geophysical exploration in the Sonoran environment. This project is sponsored in part by the Consejo Nacional de Ciencia y Tecnologia of Mexico and the NSF. Project activities will involve four to six USGS scientists and an equal number of Mexican scientists on a part-time basis. Areas in northern Mexico and the Southwestern United States are being studied jointly.

Project objectives are to develop improved methods for mineral exploration in the desert environment through onsite reviews of methods already tested in Arizona and northern Sonora, and the testing of untried procedures, particularly those utilizing soil gases and (or) vegetation. Special emphasis will be given to methods suitable for exploration for hidden ore bodies in regions covered by alluvium in areas near exposed sulfide deposits or along structural trends where deposits are known.

NEPAL

Ground-water investigation in the Lumbini Zone, western Tarai

G. C. Tibbitts, Jr., and William Ogilbee reported that a ground-water exploration project in the Lumbini Zone of the western Tarai of Nepal, in cooperation with the Nepalese Department of Irrigation, Hydrology, and Meteorology, had been completed. They noted that an artesian area covering about 200,000 ha had been identified from 99 test wells requiring 12,700 m of drilling. High artesian pressures of up to 12.2 m above land surface and high transmissivities averaging 2,000 m^2/d coincide in an area of about 65,000 ha. Concentrations of dissolved solids in water from wells range from 90 to 490 mg/l. Most water analyses indicate a low to very low sodium hazard and a low salinity hazard for irrigation.

NICARAGUA

Earthquake hazard reduction studies

The USGS is providing technical support to the Government of Nicaragua for the establishment of a Center for Seismic Studies, in an effort to minimize the hazards of future earthquake disasters. Equipment for 14 short-period seismic stations and 16 accelerographs has been procured and prepared for installation under the supervision of P. L. Ward, who has also supervised the training of Nicaraguan personnel in the use and maintenance of the equipment. The main objective of this program is to provide a scientific basis for determining the seismic and volcanic risk in western Nicaragua and to provide information for use in regional planning.

OMAN

Mineral-resource investigation

At the request of the Government of Oman, R. G. Coleman and E. H. Bailey completed a geologic reconnaissance of Oman, with emphasis on evaluating potential for mineral resources.

PAKISTAN

Genesis of hydrochemical facies of ground water in the Punjab region of Pakistan

An analysis of the origin of the hydrogeochemical facies of ground water in a selected area of the Punjab region was recently completed by P. R. Seaber, William Back, C. T. Rightmire, and R. N. Cherry (1973). They concluded that the distribution of the deuterium and oxygen isotopic composition permits delineation of areas in Rechna Doab in which either the Ravi River or the Chenab River contributes to the ground water today, on the basis of the Ravi River water being isotopically heavier. Mid-Doab waters show the results of mixing and evaporation of the two river waters. Carbon–14 concentrations show the waters to be of modern age.

Most of the ground water is recycled irrigation water, and the chemical reactions resulting from transpiration and evaporation exert a major control over its chemical composition. Calcium has three sources: (1) River water draining calcareous rocks at higher elevations, (2) solution of calcareous minerals, and (3) original evaporites in the Punjab Alluvium of the Indus Plain. Sodium is derived chiefly from solution of evaporites and secondarily from dissolution of silicates. The major source of magnesium is the dissolution of calcite and dolomite. Chloride is derived primarily from solution of evaporites, evaporite dust particles, and rainfall. Bicarbonate is derived from five major sources: (1) Infiltration of river water, (2) dissolution of secondary soil evaporites, (3) dissolution of calcareous minerals, (4) sulfate reduction, and (5) silicate buffering. Sulfate is derived almost entirely from the solution of gypsum and anhydrite.

An understanding of the origin and distribution of the chemical character of the ground water in the Punjab region should be helpful in evaluating the potential effectiveness of reclamation schemes and in the long-term management of water quality.

Chemical quality of ground water in an area of the Punjab region

H. A. Shah (Pakistan Water and Power Development Authority) and P. R. Seaber (USGS) (1972) concluded that measurable and significant changes have occurred since 1964 in ground-water quality in the Mona area of Chaj Doab and are still in progress. Introduced calcium bicarbonate or magnesium bicarbonate water, especially where it is adjacent to a canal, is changed to sodium bicarbonate water. Probably the chief cause of this change is the movement of sodium water from depth. Other causes may be leaching of salts from the land surface, precipitation of calcium carbonate, ion exchange, decline in the water table, and ground-water inflow from adjacent areas.

PERU

Desert features study

J. F. McCauley, M. J. Grolier, and G. E. Ericksen completed investigations of the desert features of coastal Peru, a NASA-sponsored comparative planetary study. This project, undertaken in collaboration with several Peruvian agencies, was started with a field study in 1971 that resulted in publication of a preliminary photographic atlas (Grolier, Ericksen, McCauley, and E. C. Morris, 1974). Features observed in Peru are similar to features observed on Mariner 9 imagery of Mars, and the study has helped to interpret probable eolian features on the surface of Mars.

Engineering geology related to earthquakes

G. E. Ericksen, Arthur Grantz, and George Plafker (1974) contributed to the final report of an AID-sponsored National Bureau of Standards project, entitled "Design, siting, and construction of low-cost housing and community buildings to better withstand earthquakes and windstorms." The work done by the USGS personnel focused on siting considerations.

SAUDI ARABIA

Geologic history of the Precambrian shield

The rocks of the Precambrian shield of the southern part of Saudi Arabia are divided into four major tectono-stratigraphic assemblages, according to

W. R. Greenwood, D. G. Hadley, D. L. Schmidt, and R. E. Anderson: an early assemblage of older Precambrian crustal rocks, a middle assemblage of oceanic rocks, a late assemblage of upper Precambrian orogenic rocks, and a postorogenic assemblage of uppermost Precambrian and Phanerozoic cratonic rocks (Greenwood and others, 1973).

The assemblage of crustal rocks consists of orthogneiss (Khamis Mushayt Gneiss) and paragneiss and schist (Hali Group) that were highly deformed and metamorphosed to amphibolite facies during the Asir orogeny. The oceanic assemblage consists of basaltic pillow lava, tuff and breccia, graywacke, graphitic shale, and chert (Baish and Bahah Groups) that were deposited in a marine basin most probably adjacent to the gneissic continental crust. This oceanic assemblage was recumbently folded, metamorphosed to greenschist facies, and thrust over the crustal rocks during the Tihama orogeny.

The orogenic assemblage consists of predominantly andesitic volcanic rocks (Jiddah, Halaban, and Murdama Groups) that were deposited on the continental crust in a marine and subaerial environment. This threefold volcano-orogenic assemblage comprises the Hijaz tectonic cycle, consisting of three orogenic pulses marked by major unconformities at the tops of the Jiddah, Halaban, and Murdama Groups. Rhyolitic volcanism is significant in the uppermost Halaban and Murdama. Batholiths of diorite and quartz diorite intrude the Jiddah Group and are dated about 960 m.y. by R. J. Fleck. Gray granodiorite batholiths, dated between 760 and 800 m.y. by Fleck, intrude the Halaban, as do plutons of red granite and quartz monzonite, dated at about 600 m.y. by Fleck, that are unconformably overlain by the Murdama Group. Strong, commonly isoclinal, north-trending folds and faults and greenschist-facies metamorphism characterize the Hijaz tectonic cycle.

Formation of the postorogenic assemblage encompassed the latest cratonic and postcratonic events. The latest cratonic event in the southern shield area was formation of the prominent northwest-trending left-lateral Najd fault system, possibly active as late as 520 m.y., according to Fleck. In the northern shield area, upper cratonic volcanic rocks of the Shammar Group and sedimentary-volcanic rocks of the Jubaylah Group were deposited as the Najd fault formed (D. G. Hadley, 1973). Postcratonic events include deposition of the Nubian-type Wajid Sandstone of early Paleozoic age, the overlying sedimentary rocks of late Palezoic and Mesozoic age, and epeirogenic movements within the shield.

Precambrian layered gabbro

Layered gabbroic bodies are abundant in the Precambrian shield of the southern part of Saudi Arabia. R. G. Coleman, G. F. Brown, and T. E. C. Keith (1972) reported on nine such bodies that are characteristically vertical cylindrical masses that have steep inward-dipping layers. Some are single circular intrusions, whereas the lobate form of others indicates multiple coalescing intrusions; they range from 1 km to 8 km in diameter, but larger bodies are known. The gabbro bodies commonly intrude the central area of synforms developed in north-trending mobile metamorphic belts. The rocks are primarily clinopyroxene gabbros, some containing olivine and orthopyroxene. Although no major ultramafic zones have been discovered, some layers approach 80 percent clinopyroxene or olivine. Magnetite, ilmenite, and pyrrhotite, with some exsolved pentlandite, are common as disseminated minerals, but oxide and sulfide layers have not been found. Potassium-argon ages on six different bodies range from 415 to 769 m.y. and, as with the granitic rocks of the southern shield, were variously reset at least during the Pan-African event.

Wajid Sandstone (lower Paleozoic)

Conglomerate beds in the upper part of the widespread Wajid Sandstone of the eastern and southern part of the Precambrian shield area of Saudi Arabia have previously been interpreted as Gondwana glacial deposits. These conglomerate beds, examined by D. L. Schmidt and D. G. Hadley (1973) in the Bani Khatmah area of the western Ar Rubʻ al Khālī area, contain normally graded polymictic conglomerate, commonly in fluvial channels cut in mature quartz sandstone. None of the features observed suggest deposition in a glacial environment. Whereas the age of the Wajid was previously considered to be Permian and older(?), it is now considered Cambrian or Ordovician in age.

Magnetic study of the development of the Red Sea

An analysis of all available total-intensity magnetic data of the Red Sea rift valley and environs shows that magnetic lineations are present over the coastal margins. The anomalies are of smaller amplitude and longer wavelength than those observed over the axial trough. Coast-to-coast magnetic profiles, when compared to a sea floor model, clearly show a distinctive anomaly—due to a long period of reversal—on each profile. This reversal is considered to have occurred between 35.00 and 37.61 m.y. ago. Two other candidates for long reversal exist but were dismissed because of poor correlation of adjacent anomalies. A two-phase opening, therefore, was assumed: the first phase between 40 and 33 m.y., and the second phase between 4.5 to 5.0 m.y. and present. Feature-to-feature correlation of observed profiles to the model gives a spreading rate for the first phase of 1.34 ± 0.5 cm/yr, whereas the second phase of spreading is 0.88 ± 0.02 cm/yr.

Seismic and drilling results show the upper surface of the sea floor beneath the trough to be approximately 2.0 ± 0.2 km. If the axial anomaly is produced by a body 2 km below sea level, an intensity of magnetization of 0.003 ± 0.001 emu/cm^3 is required to produce the observed amplitudes. Using the value for the causative body underlying the margins yields depths of between 4 and 5 km to account for the anomaly amplitudes.

Economic geology

Copper and copper-zinc massive sulfide deposits at Wadi Bidah were remapped by W. R. Greenwood, R. J. Roberts, T. H. Kiilsgaard, and R. G. Worl during 1973 to determine the relationship of metallization to stratigraphy and structure. The ore bodies are steeply dipping tabular replacement deposits in shear zones that cut volcaniclastic and sedimentary rock units of the Baish and Bahah Groups of Precambrian age. The ore bodies in some places were localized in sheared anticlines of sheared calcareous tuff units and in other places in sheared limbs of folded quartz porphyry sills.

Pyrite and chalcopyrite are the principal ore minerals, accompanied locally by sphalerite. Some sphaleritic zones contain significant amounts of gold.

Exploration by diamond drilling in three deposits has shown that the massive sulfide ore bodies are as much as several hundred metres long, 20 m wide, and extend to at least 225 m deep. Layers within the deposits contain as much as 6-percent copper; the copper content of Rabathan—the principal deposit—averages 2.14 percent. The zinc content locally is as much as 5 percent; the gold content, as much as 10 ppm.

Many other exploration targets have been identified in the district and the potential for further discoveries is good.

R. W. Luce, R. J. Roberts, and Abdulaziz Bagdady completed mapping of the Mahd adh Dhahab mine in the central Arabian Shield. The mine was first operated about 3,000 yr ago during the reign of King Solomon (961–922 B.C.) and possibly may have been the fabulous Ophir mine of the Book of Kings of the Bible. Subsequently it was operated during the Abassid Caliphate (A.D. 750–1258) and during 1939–54 by the Saudi Arabian Mining Syndicate (SAMS). Production during the first two periods is conjectural; assuming the Biblical reference is correct, the mine may have produced from 23,327,625 to 46,655,250 g during King Solomon's time. Production during the period 1939–65 by SAMS totaled 23,818,065 g fine gold and 31,166,609 g silver. Reserves in dumps, tailings, and old stopes have a gross value of about $18,800,000 at metal prices prevailing in early 1974 (Au, $4.50/g; Ag, $0.16/g; Cu, $1.88/kg).

Geologic mapping at a scale of 1:2,500 in the district disclosed altered zones south and southwest of the principal productive area, which were geochemically sampled along a series of traverses that cut mineralized zones. A total of 814 samples were analyzed for Au, Ag, Cu, Pb, and Zn. The mean metal contents in parts per million are as follows: Au, 2.6; Ag, 6.7; Cu, 1,394; Pb, 902; and Zn, 1,560. An exploratory program designed to test the downdip extensions of these mineralized zones began in late 1973.

Detailed mapping and intensive sampling by F. C. W. Dodge and A. M. Helaby of molybdenite-bearing quartz veins associated with the Uyaijah ring structure in the Al Kushaymiyah region indicates that the grade and quantity are probably inadequate to permit present-day mining; however, the veins represent a potential future resource. Oxidation, which has altered and consequently resulted in removal of virtually all the pyrite in the veins, has affected molybdenite to a lesser extent. Unaltered molybdenite is present in most of the veins, as well as powellite which may in part represent an alteration product of the sulfide. Powellite is rarely present in host rocks and molybdenum content is low, indicating little migration of molybdenum outside the veins. Consequently, significant enrichment of molybdenum beneath the zone of oxidation is not likely.

Although four ancient mines that were studied by Helaby and Dodge in the Al Kushaymiyah area have no current economic potential, the study provides information on mineralization controls in this region of the Arabian Shield. Silver, lead, zinc, and molybdenum metallization are dominant. Mineralization took place late in the geologic history of the region, and structural controls rather than lithologic controls are of prime importance. The deposits were apparently formed in fairly shallow environments, probably at depths not exceeding 10 km.

THAILAND

Remote sensing

In early 1973, five U.S. instructors (including T. W. Offield and G. K. Moore), a project coordinator (I. O. Morgan), and project director (M. D. Kleinkopf), conducted an in-country training program in remote sensing, in Thailand, principally on the use of ERTS imagery by the USGS. The project was sponsored jointly by the AID and the Thai National Research Council (NRC), and was attended by 72 participants—60 from Thailand and 12 from ECAFE and Mekong Secretariat countries. The course included 6 weeks of intensive classroom instruction in fundamentals of remote sensing and applications of ERTS data to problems in agriculture, forestry, land development, hydrology, geology, and oceanography. After the instruction period, the participants returned to their respective organizations and successfully established applications-research programs. Four members of the U.S. team returned in May 1973 to provide further consultation, to evaluate progress of ongoing programs, and to brief authorities in the Royal Thai Government about the project status. In addition to training, the program provided equipment including a multispectral aircraft camera, a viewer-projector for interpretive studies, and a microdensitometer for quantizing tonal variations in the imagery. Computer processing of ERTS tapes was introduced to demonstrate the use and limitations of data-enhancement techniques.

Mineral-resources appraisal

Working in cooperation with counterparts in the Royal Thai Department of Mineral Resources, D. R. Shawe and R. J. Hite investigated potential areas for the discovery of uranium minerals and potash deposits. Uranium-copper deposits found in Jurassic sedimentary beds on the plateau suggest that the plateau may have significant potential for discovery of uranium minerals. In structure and stratigraphy the Khorat Plateau is similar to the Colorado Plateau of the Western United States.

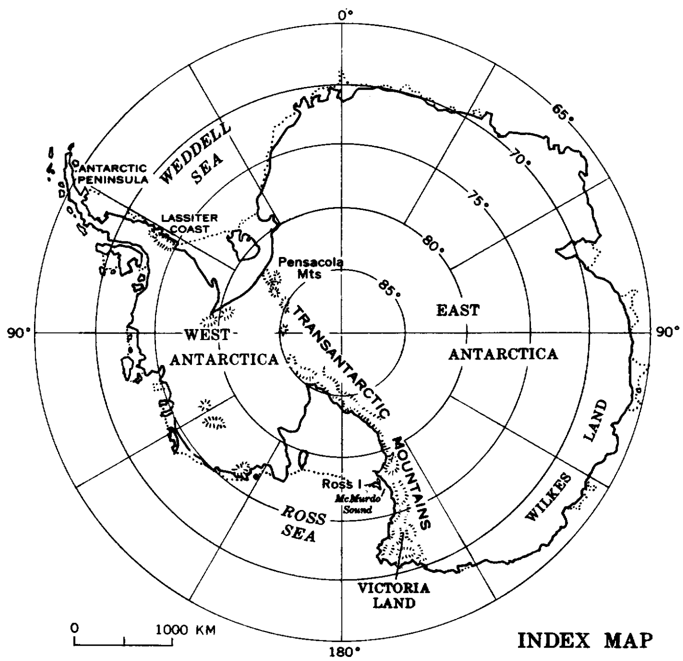
ANTARCTICA

During the 1973–74 austral summer, USGS personnel carried out geologic field studies in the Dry Valleys of southern Victoria Land near McMurdo Sound and in the Pensacola Mountains near the southern end of the Weddell Sea. (See index map.) Work in the Dry Valleys was part of Northern Illinois University's Dry Valley Drilling Project, and the Pensacola Mountains investigations were made in conjunction with a survey by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) of blue-ice surfaces that are potential runways for landing wheeled aircraft. These field activities, as well as laboratory studies in petrology, geochemistry, geophysics, and paleontology on Antarctic material collected during previous expeditions, are part of the U.S. Antarctic Research Program (USARP) sponsored by the Office of Polar Programs of NSF. The fieldwork is supported by the U.S. Navy's Operation Deep Freeze. Progress in Antarctic aerial photography and topographic mapping, which are functions of the USGS, is reported in the section "Mapping in Antarctica."

Solar energy in the Antarctic

Temperature measurements by Irving Friedman and G. I. Smith were made on cores recovered from the bottom of Lake Vanda, Wright Valley, Antarctica. These show that the high-temperature (about 25° to 28°C) brine in the lower part of the lake cannot be heated by a source below the lake bottom. The theory of solar heating of Antarctic lakes in the Dry Valleys of Victoria Land, first expounded by Wilson and Wellman (1962), would seem to be proved by these findings.

Outcrops of lacustrine silt and clay from around the edges of Lake Vanda and Don Juan Pond, a small salt lake in another part of the same valley, were also studied by Smith and Friedman. The deposits are



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related to earlier high stands of lakes in the area, which has been inferred by others on the basis of exposed erosional shorelines and fossil algal mats that provide C^{14} dates indicating them to be a few thousand years old. The lack of an apparent break in sediment deposition suggests that only one expansion episode occurred. Enlargement of these lakes was probably the result of a warmer climatic cycle rather than a colder one as is generally inferred for similar events in temperate climates and as has been inferred for these Antarctic events; warmer periods in the Antarctic increase the amount of melt-water runoff into lakes markedly, whereas colder periods only decrease the amount of water lost from lakes by a small amount because it is mostly by the process of sublimation rather than evaporation.

The Antarctic Peninsula, an extension of the Andean porphyry copper province

Laboratory studies were completed by P. D. Rowley, P. L. Williams, and D. L. Schmidt on a disseminated copper deposit mapped by the USGS during the 1970–71 field season in the central Lassiter Coast, southern Antarctic Peninsula. Mineralization followed after a complex igneous history. Emplacement of a 105-m.y.-old batholith of fine- to medium-grained homogeneous granodiorite with late-stage dacite dikes was accompanied by pyrite mineralization (K-Ar dates by A. H. Clark, Edward Farrar, and S. L. McBride of Queen's Univ., Ontario). The granodiorite was intruded by a 95-m.y.-old concentrically-zoned stock(?) of medium- to coarse-grained mostly porphyritic quartz monzonite. These rocks were then cut by steep dikes, generally 10 to 20 m wide, of fine- to medium-grained granodiorite porphyry which is also dated as 95 m.y. in age. These igneous rocks are similar to rocks mapped elsewhere in the Lassiter Coast and to the calc-alkalic Andean plutonic rocks of other parts of the Antarctic Peninsula.

Hydrothermal alteration of phyllic and argillic grades closely (?) following the porphyry dike injection is confined to the immediate vicinity of northwest-trending shear zones of altered propylitic rock. Porphyry-type mineralization accompanied hydrothermal alteration and produced disseminations of mostly pyrite and chalcopyrite and quartz veins containing chalcopyrite, pyrite, molybdenite, malachite, and magnetite. This deposit would be noneconomic even if it were located in the United States, but it is the richest so far reported in the Antarctic Peninsula. About two dozen sightings of copper or molybdenum minerals have been made elsewhere in the Lassiter Coast, and sketchy published reports of numerous areas farther north in the Antarctic Peninsula and South Shetland Islands make frequent mention of pyrite, copper minerals, molybdenite, and localized hydrothermal alteration. The numerous copper occurrences indicate that the Antarctic Peninsula is part of the circumpacific porphyry copper province.

Chemical weathering of the Lassiter Coast

Chemical weathering in Antarctica is widely believed to be insignificant or nonexistent under present climatic conditions. Using X-ray powder diffraction analysis of heat-treated samples, S. J. Boyer (Univ. of Colorado) has identified illite, mixed-layer chlorite, vermiculite, montmorillonite, and mixed-layer illite-montmorillonite from thin, immature soils of the Lassiter Coast. The soils occur as small, widely scattered patches that were developed on middle Cretaceous plutonic rocks probably following rather recent (Quaternary?) deglaciation of the surfaces. The identified minerals are interpreted to have formed by slow chemical weathering of primary chlorite and micas under conditions as presently existing in the area.

Antarctic Peninsula shows little southerly drift since middle Cretaceous

K. S. Kellogg and R. L. Reynolds (Univ. of Colorado) conclude on the basis of a paleomagnetic study that the southern Antarctic Peninsula has undergone little latitudinal drift since middle Cretaceous time. The analyzed rocks are from plutons and dikes sampled during the 1972–73 field season in the northern Lassiter Coast. The mean Virtual Geomagnetic Pole (VGP) is at lat 82° S., long 100° E. for two stable localities in plutons, and at lat 89° S., long 105° E. for nine stable localities in dikes. Nearby plutons and two dikes similar to the ones sampled have yielded eight K–Ar age dates on biotite and hornblende ranging between 95 and 119 m.y. (work by A. H. Clark, Edward Farrar, and S. L. McBride of Queen's Univ., Ontario, and by H. H. Mehnert). The paleomagnetic data are supported by the results of work in progress by Reynolds on samples from the central Lassiter Coast. These mean VGP's are similar to those of the northern Antarctic Peninsula that have been reported by other workers. In contrast, the calculated VGP's reported for Lower Cretaceous plutons and younger dikes from Marie Byrd Land diverge widely from the present geographic pole. Thus West Antarctica seems to be composed of at least two continental blocks of different drift histories.

Magnetic surveys in Transantarctic Mountains and adjacent glacierized area

All available aeromagnetic data in the Transantarctic Mountains and adjacent area of Cape Hallett to long 105° W. have been compiled by J. C. Behrendt. A residual contour map of long-wavelength anomalies shows a generally lower field over the Transantarctic Mountains than the Ross Sea and Ross Ice Shelf area north of lat 84° S. South of this latitude, a broad positive anomaly crosses the mountains and extends over the Ross Ice Shelf. Residual profiles show short-wavelength anomalies that can be correlated with known geologic outcrops and allow mapping of the extension of the magnetic rock units beneath the ice-covered area. Estimates of depth to magnetic basement were compiled and contoured and reveal relief on magnetic basement of about 8 km. One interesting result is the suggestion or presence of a thick sedimentary rock section, up to 8 km in thickness, beneath the Ross Sea and Ross Ice Shelf. This area therefore may have a petroleum-resource potential.

A parent magma of the differentiated Dufek intrusion

Field study by A. B. Ford (unpub. data, 1974) of the single small exposure of the steep border zone of the layered mafic Dufek intrusion in the Pensacola Mountains shows that fine-grained gabbro and diabase at the contact have been contaminated to some extent by Paleozoic quartzite. Although small blocks of embayed quartzite are common along the wall, their virtual absence more than a few metres toward the interior of the body suggests that contamination is local. However, this contamination as well as their highly iron enriched compositions probably rule out use of the chilled contact rocks to infer original magma compositions. Basaltic rocks of a small dike swarm in the nearby Cordiner Peaks probably are better candidates for approximating parent Dufek magma compositions. These dikes were extensively sampled during the 1973–74 field season. Preliminary studies suggest that the dike basalts are silica-oversaturated tholeiites probably similar to Jurassic basaltic rocks of the Ferrar Dolerite found throughout the Transantarctic Mountains.

Pyroxenes of the Dufek intrusion

Electron-microprobe analysis of bulk compositions of pyroxenes representative of the entire layered series, including granophyre cap, have been completed by G. R. Himmelberg (Univ. of Missouri). This work shows that cumulus pyroxenes form coexisting calcium-poor and calcium-rich series through a large part of the exposed section of the differentiated mafic complex. Both series show Skaergaardlike iron-enrichment trends. The calcium-poor pyroxenes are in the series bronzite-inverted pigeonite and range upward from $Ca_{3.5}Mg_{69.1}Fe_{27.4}$ to $Ca_{11.4}Mg_{34.0}Fe_{54.6}$. Calcium-rich pyroxenes are in the series augite-ferroaugite and range upward from $Ca_{36.4}Mg_{48.7}Fe_{14.9}$ to $Ca_{30.0}Mg_{23.5}Fe_{46.5}$. The augitic series does not become as iron enriched as in the Skaergaard and Bushveld intrusions possibly owing to differences in P_{O_2} (partial pressure) during later stages of fractional crystallization.

TOPOGRAPHIC SURVEYS AND MAPPING

OBJECTIVES OF THE NATIONAL MAPPING 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

The Department of the Interior was assigned governmentwide responsibility for the coordination of federally funded domestic mapping activities by the Office of Management and Budget (OMB) in 1967. This responsibility, as described in OMB Circular A–16 Revised, was limited to mapping activities that could contribute to the national mapping program. The responsibility was delegated by the Department to the Geological Survey.

Channels of communication were established by the USGS with all interested Federal agencies in an effort to identify mapping needs, products, programs, and capabilities. Coordination identified only a few mapping programs of other Federal agencies that developed data appropriate for inclusion in the national mapping program. These programs had been well coordinated with the mapping program of the USGS. However, it was determined that many Federal, State, and local agencies depend on the products of the national topographic series for use as base maps upon which to add various information. Because there appeared to be considerable opportunity for duplication in the preparation of such special-purpose maps, the USGS recommended to OMB that Circular A–16 be amended to broaden coordination to include mapping activities beyond those which can contribute to the national mapping program.

The responsibilities of the USGS were expanded as a result of the findings published in the July 1973 report of the OMB Task Force on Mapping, Charting, Geodesy, and Surveying (MC&G). On the basis of a comprehensive study of civil-agency mapping and geodesy programs and related activities, the OMB task force recommended consolidation of MC&G activities in the Federal Government in one agency that would have the authority and responsibility to manage and coordinate national mapping and related programs. The report emphasized the need for greater efforts in activities that would identify, evaluate, and respond to national mapping needs effectively and economically.

In its response to OMB regarding this report, the Department of the Interior recognized its central role in the task force operational and organizational recommendations. The Department agreed to act, within the limits of its authority, on those issues that would contribute to the overall efficiency of Federal mapping activities. Accordingly the following additional responsibilities are to be assigned to the Geological Survey:

1. Departmentwide review and coordination of facility, cadastral, and mapping control surveys to optimize their usefulness.
2. Identification and evaluation of governmentwide domestic mapping requirements and development of the capability to respond to the variety of Federal mapping needs that are based on the national topographic map series. The USGS is to work with each Federal agency to assure that services consistent with the needs of that agency are provided.
3. Development of the National Cartographic Information Center to furnish expeditiously information on available cartographic data generated by Federal, State, and local government agencies and some private sources.
4. Evaluation and coordination of all MC&G research and development within the Department to avoid fragmentation and duplication.

Instructions for implementing these planned activities are being prepared and will be included in departmental release 757. A meeting to discuss these plans and related procedures was held with representatives of Department of Interior Bureaus and USGS Divisions.

During the past year, several activities were undertaken that are in consonance with these broader mapping coordination responsibilities. The USGS and the Bureau of Land Management (BLM) have undertaken a joint study of procedures to determine how best to use USGS standard topographic maps in the production of special-purpose maps required by BLM. Sample products are being prepared.

At the request of BLM, a USGS representative was assigned to a BLM task force to assist in the study of BLM mapping problems. Other USGS representatives attended BLM meetings held to develop policy and decide on BLM's mapping program for minerals management. The USGS also agreed to comply with a BLM request for the detail of USGS personnel to assist in field surveying to meet BLM's control requirements in Alaska.

To assist the Bureau of the Census in expediting preparation of maps of the Metropolitan Map Extension Series, arrangements have been made for the Bureau to receive copies of advance prints of all USGS quadrangles prepared in fiscal year 1974. Specially prepared orthophotographic products were forwarded to the Census Bureau for experimental compilations of metropolitan maps.

Eight hundred sections of the Dallas, Tex., experimental orthophotomap and 800 copies of the Mesa, Ariz., orthophotoquad were furnished to the Federal Highway Administration (FHWA) for use as illustrations in the FHWA's recently published "Highway Planning Map Manual."

The FHWA distributed experimental sample county maps prepared by the USGS to FHWA regional and district offices and to State highway departments for review and comment. Valuable feedback was received from 49 State highway departments and was made available to the USGS. Opinions submitted regarding the potential value and limitations of county-format maps will influence further development of these types of maps. In response to a request by the Mississippi State highway department, transmitted through the FHWA, the USGS agreed to send representatives to FHWA Region IV Workshop in Jackson, Miss., where orthophotomapping, county-format maps, and urban mapping requirements are to be discussed.

Several map coordination meetings have been held with SCS representatives to discuss ways in which USGS map products can be applied effectively in the production of soil survey graphics. As a result of these meetings, the USGS and the SCS have agreed to share costs in preparation of orthophotoquads in seven States for use in soil survey publications.

Considerable progress has been made in an urban mapping study aimed at determining how the functions of various agencies concerned with problems of metropolitan areas can be better served by additional or different cartographic data. Information has been exchanged in meetings with officials of San Diego and San Francisco, Calif., Atlanta, Ga., Fort Wayne, Ind., Frederick, Md., and Norman, Okla. Contracts have been negotiated with private mapping firms to prepare, to USGS specifications, experimental large-scale orthophotographic maps at 1:1,200 scale for Fort Wayne, Ind., and Charleston, S.C. The work is in progress. Specifications for experimental mapping in San Francisco, Calif., and Frederick, Md., have been prepared. Arrangements have been made for followup interviews with officials of these four cities after they have had opportunities to apply and evaluate these map products in their activities.

NATIONAL CARTOGRAPHIC INFORMATION CENTER

The National Cartographic Information Center (NCIC) has been established to provide users with one-stop access for acquiring information about maps, charts, geodetic control, aerial and space imagery, and related cartographic data generated by Federal, and ultimately State, local, and private sources. The NCIC usually does not hold the data for which it provides information and access, but it manages a system that provides a link between the user and the data. The center enables customers to find out what cartographic information and materials are available, to place an order, to pay or submit a purchase order, and to receive copies of the information or materials in a reasonable time. The NCIC, located at the USGS National Center in Reston, Va., is both an active information office and the management center of a network of linked data repositories, including those not administratively part of NCIC.

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 91 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 5 percent of the total area which is not yet published but which is available as advance manuscript prints.

During fiscal year 1974, 1,622 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, 423 new maps at a scale of 1:24,000, equivalent to about 0.7 percent of the total area, were published to replace 15-min quadrangle maps (1:62,500 scale) which did not meet present needs. Figure 6 shows the extent and location of the current topographic map coverage.

Map revision and maintenance

As maps become out of date, revision is necessary to show changes in the terrain and changes and additions to manmade features, such as roads, buildings, and reservoirs. During fiscal year 1974, 954 general-purpose quadrangle maps of the 7½-min series (1:24,000 scale) were revised. Most of these revised maps are in large metropolitan areas and their expanding suburbs and in States that are completely mapped in the 7½-min series which have cooperative programs for a regular updating. About 58 percent of the 1,880 maps currently in the revision program (fig. 7) are being updated by photorevision—a low-cost rapid production method that relies primarily on photointerpretation. Recent aerial photographs of the areas to be revised are inspected, and changes in cultural and other planimetric features are mapped and printed in purple on the revised map.

An inspection program, initiated in fiscal year 1972, has contributed substantially to reduction of the revision backlog. About 50 percent of the quadrangles inspected did not need revision and thus receive only the inspection date note on the map at the time of reprint.

The maps in the revision program which are not photorevised will receive a more complete overhaul, which will include a field check and revision of some or all of the color-separation drawings.

In fiscal year 1974, approximately 1,750 general-purpose quadrangle maps were reprinted to replenish stock.

1:250,000-scale map series

The 48 conterminous States and Hawaii are completely covered by 473 topographic maps at 1:250,000 scale. Originally prepared as military editions by the Defense Mapping Agency, formerly the U.S. Army Map Service, the series is now maintained by the USGS. The Alaska reconnaissance map series is being replaced with an improved series based on larger scale source material and on new photogrammetric compilation. An active revision program has been established to maintain the currency of the Alaska series. Figure 8 shows revision in progress on 1:250,000-scale maps.

State base map series

State base maps are published at scales of 1:500,000 and 1:1,000,000 for all States except Alaska. State base maps of Alaska are published at scales of 1:1,584,000, 1:2,500,000, 1:5,000,000, and 1:12,000,000. A State base map of Connecticut is also available at a scale of 1:125,000. The maps are generally prepared in three editions—base, topographic, and shaded relief—and show urban areas, major communications routes, major hydrographic features, and county boundaries. The series, compiled according to modern standards, consists of 46 maps covering the 50 States and the District of Columbia. Eleven of the maps are being revised, and new topographic maps are being prepared for Indiana and Oklahoma. Figure 9 shows revision in progress on State base maps.

National park map series

Special topographic maps have been prepared for 44 of the approximately 120 national parks, monuments, historic sites, and other areas administered by the NPS which are large enough to require separate editions. They are usually made by combining the existing quadrangle maps of the area into one map sheet, but occasionally surveys are made covering only the park area. Most of these maps are also available in a shaded-relief edition. Most other parks, monuments, and historic sites are shown on maps in the general-purpose quadrangle series. New or revised maps in preparation include:

Big Bend National Park, Tex.
Canyonlands National Park, Utah
Channel Islands National Monument, Calif.
Death Valley National Monument, Calif.-Nev.
Glacier National Park, Mont.
Great Smoky Mountains National Park, N.C.-Tenn.
Mammoth Cave National Park, Ky.
Mesa Verde National Park, Colo.
Mount McKinley National Park, Alaska
Mount Rainier National Park, Wash.
Point Reyes National Seashore, Calif.
Theodore Roosevelt National Memorial Park, N. Dak.

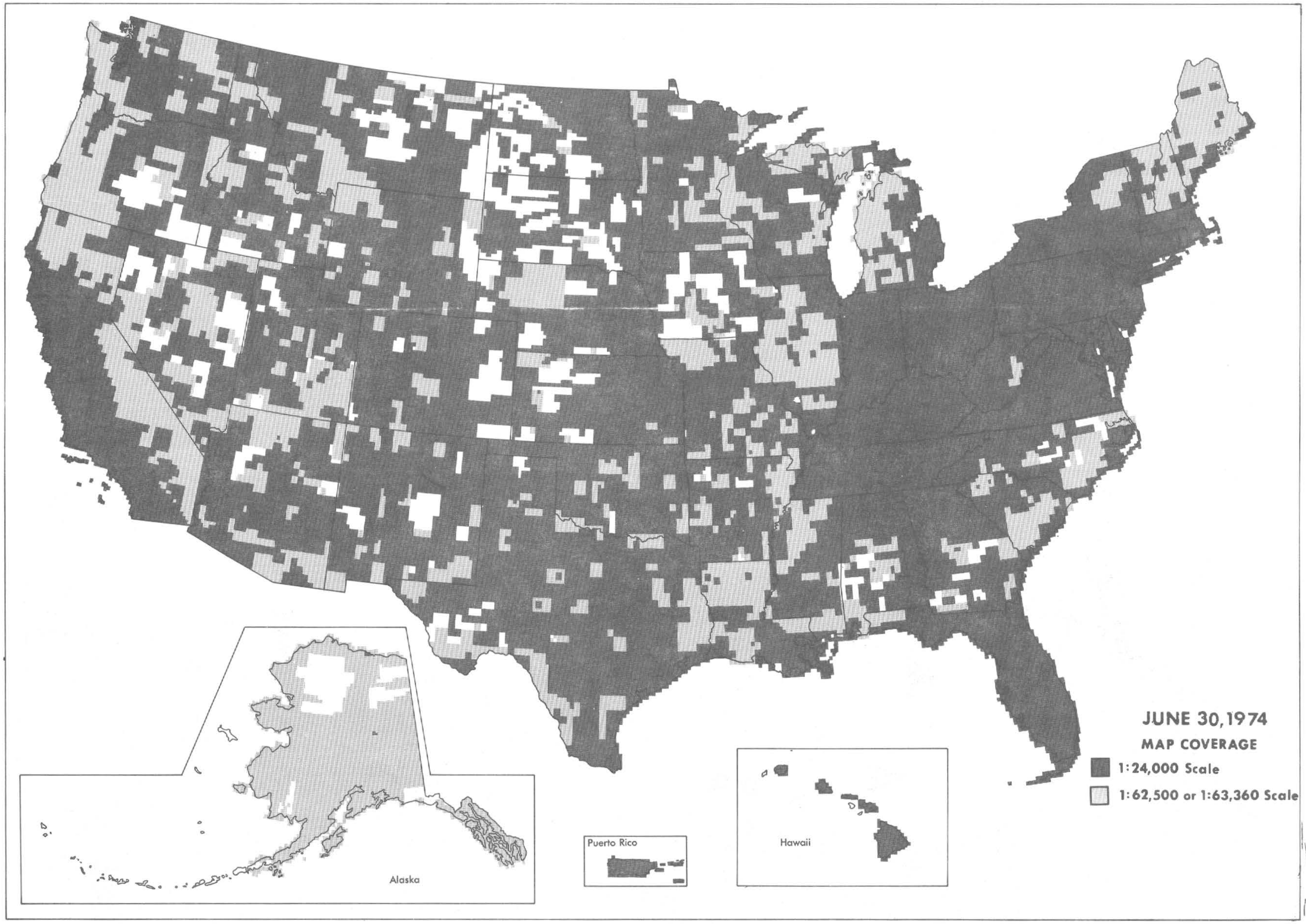

FIGURE 6.—Status of 1:24,000- and 1:62,500-scale mapping.

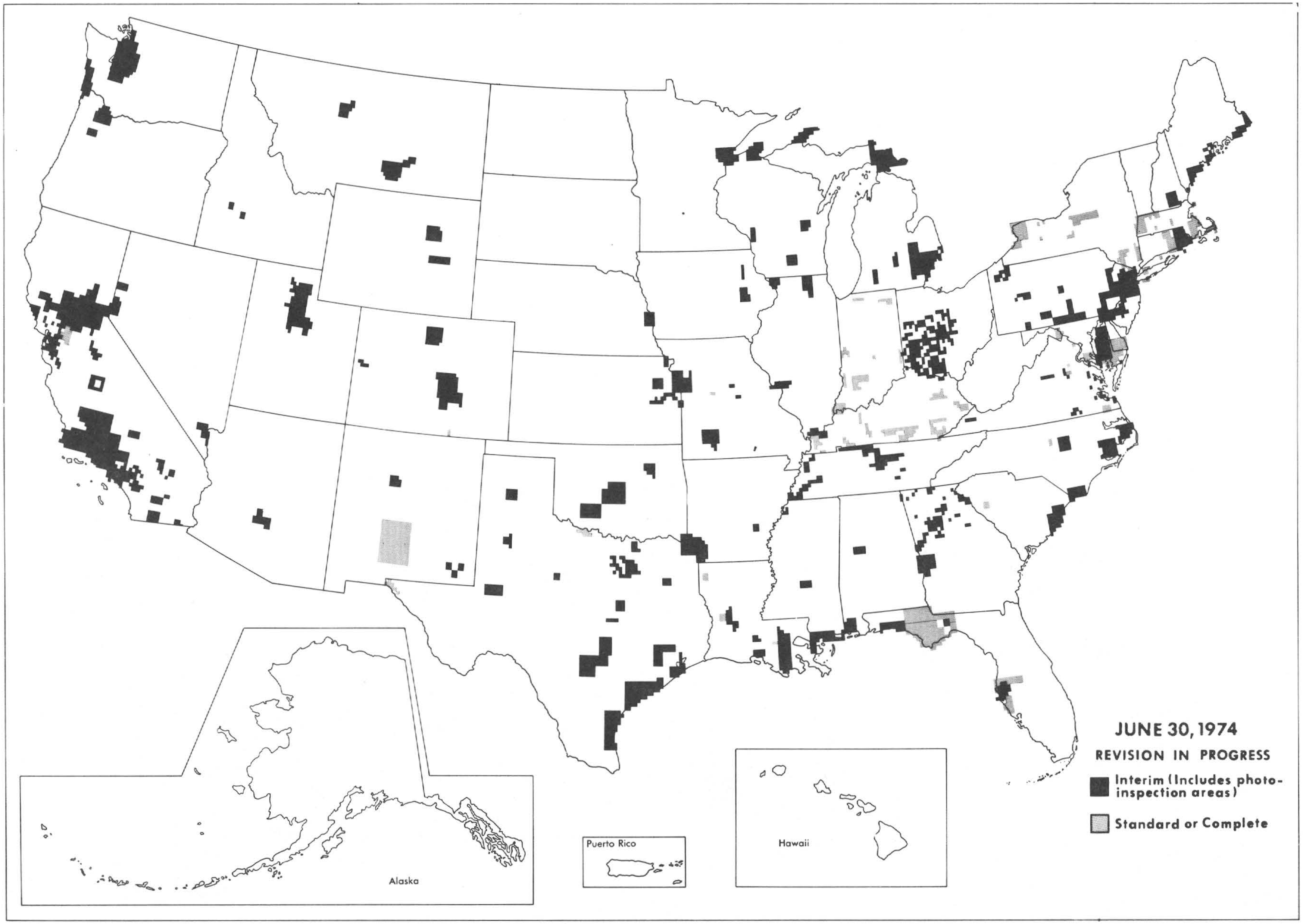

FIGURE 7.—Revision in progress, 1:24,000-scale topographic maps.

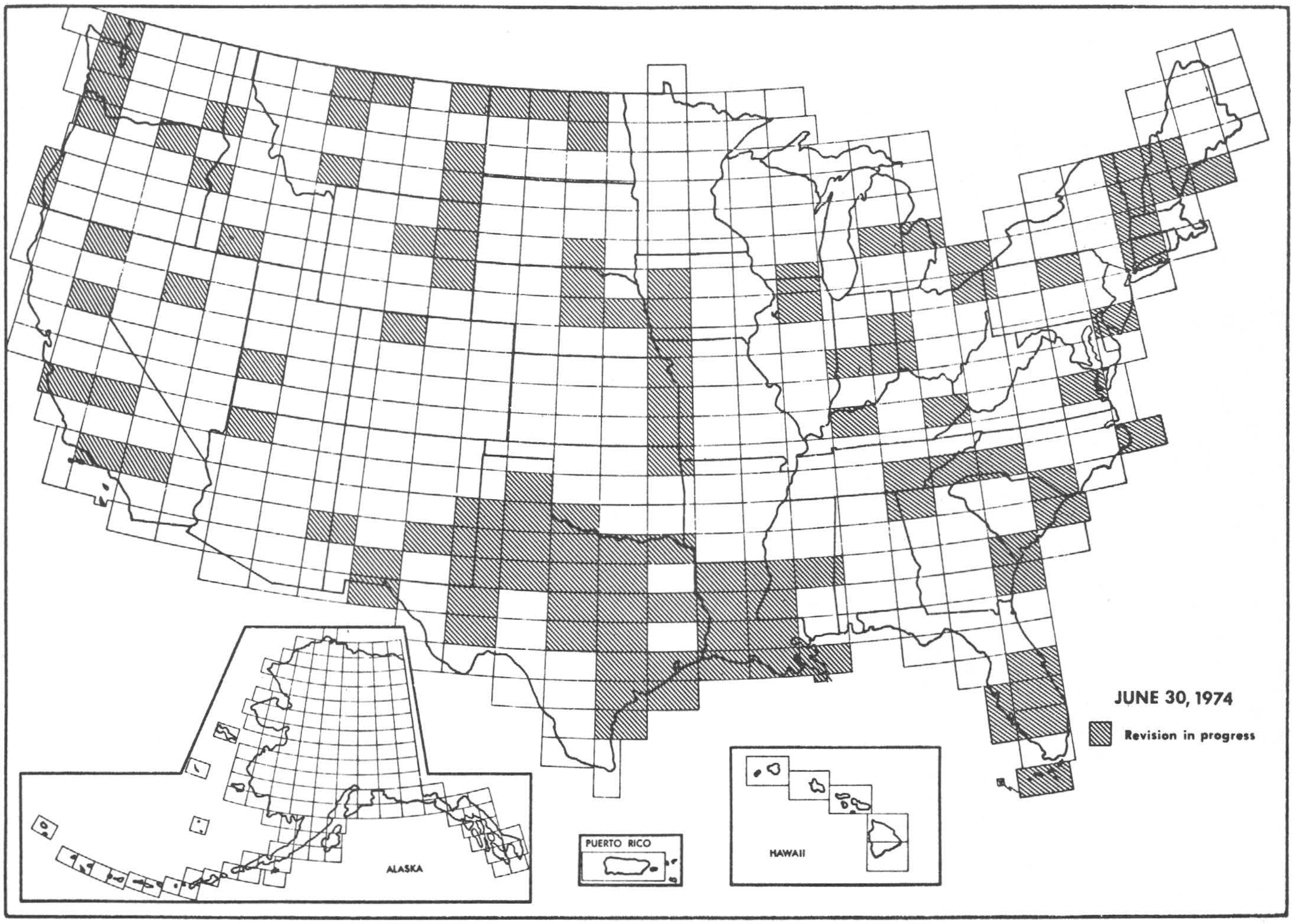

FIGURE 8.—Revision of 1:250,000-scale topographic maps.

Small-scale map series

The International Map of the World (IMW) series at the scale of 1:1,000,000 is part of an international program to attain worldwide coverage at a uniform scale and format. The maps are published in accordance with technical agreements and specifications adopted at the United Nation conferences held in 1962 and 1964.

Twenty-eight of the 54 IMW maps required to cover the conterminous United States and Hawaii have been published. Twenty-one additional maps of the conterminous States and 13 maps of Alaska were published by the Army Map Service (now the Defense Mapping Agency, Topographic Center) from 1955 to 1959 in a military series at 1:1,000,000 scale. Although these maps do not meet the IMW specifications in all respects, they are recognized by the United Nations Cartographic Office as provisional editions in the IMW series (fig. 10).

Work in progress includes six new maps—Andreanoff Islands, Attu Island, Blue Ridge, Cold Bay, Hawaii, and Ozark Plateau—and five revisions—Cascade Range, Chicago, Hudson River, Lake Erie, and Savannah.

Orthophotographic products

Orthophotomaps have become the standard 1:24,000-scale publication for many areas where conventional cartographic symbolization cannot adequately portray featureless terrain such as swamps and deserts. About 177 orthophotomaps have been published at 1:24,000 scale, with more than 400 quadrangles in the current orthophotomapping program.

Orthophotoquads are orthophotographs or orthophotomosaics in 7½-min quadrangle format with little or no 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 line map. Approximately

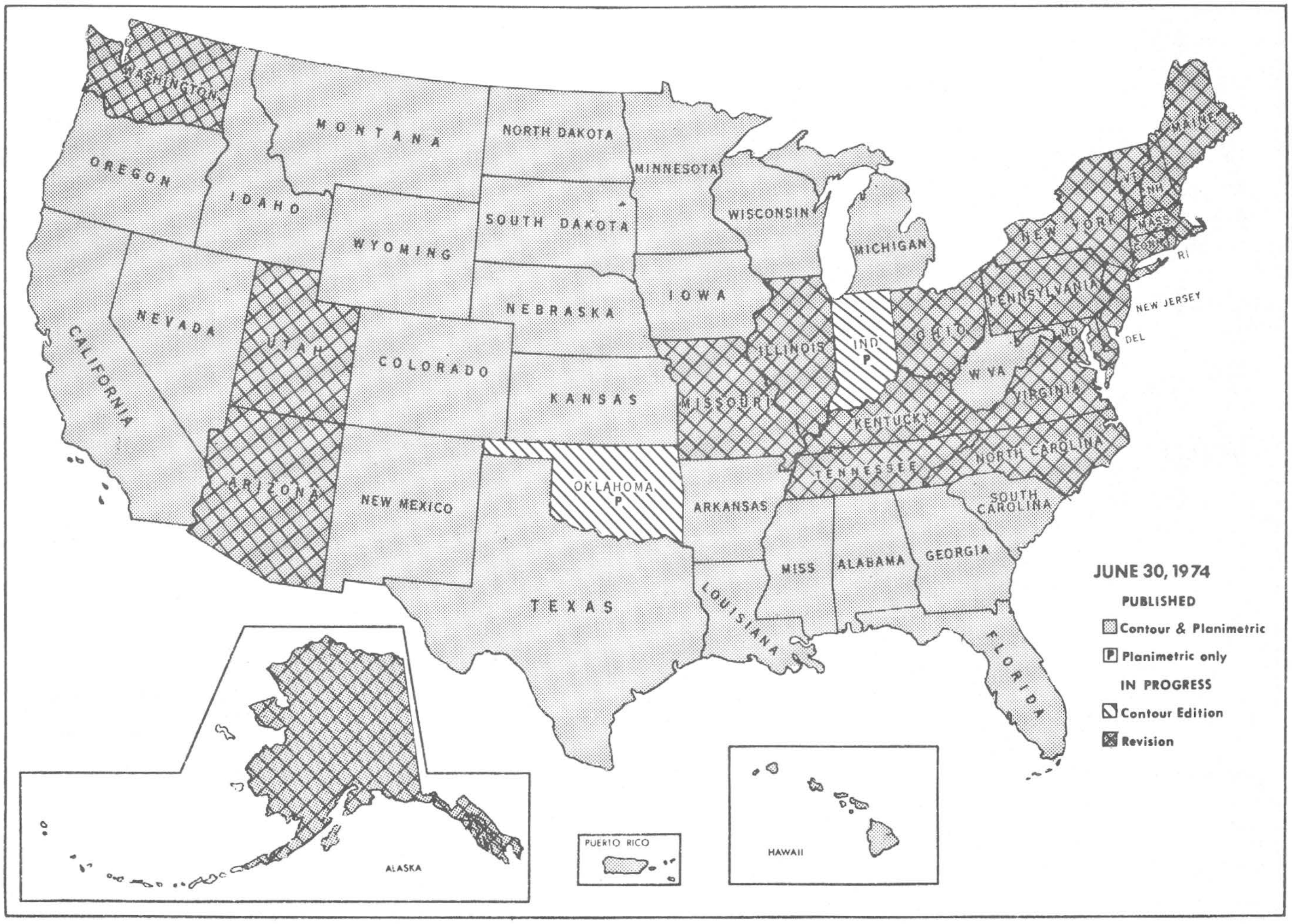

FIGURE 9.—Status of State base maps.

1,400 orthophotoquads were produced by the USGS in fiscal year 1974.

Intermediate-scale map series

There is a definite need for an intermediate-scale map series between the 1:24,000- and the 1:250,000-scale series. Experiments have been conducted to evaluate various scales and formats.

A county map series was recently established as an element of the national mapping program to meet the urgent needs of Federal, State, and local agencies engaged in comprehensive planning. Maps in this series are planned for production at 1:50,000 scale or 1:100,000 scale for larger western counties. A uniform scale will be maintained within each State to insure county-to-county compatibility. Completed or programed work includes Sonoma County, Calif.; Morris County, Kans.; Stafford County, Va.; 30 counties in Pennsylvania; and all counties in Colorado and Connecticut.

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 multicolor maps and an index with more than 41,000 entries. The following individual map sheets are available as separate sales items:

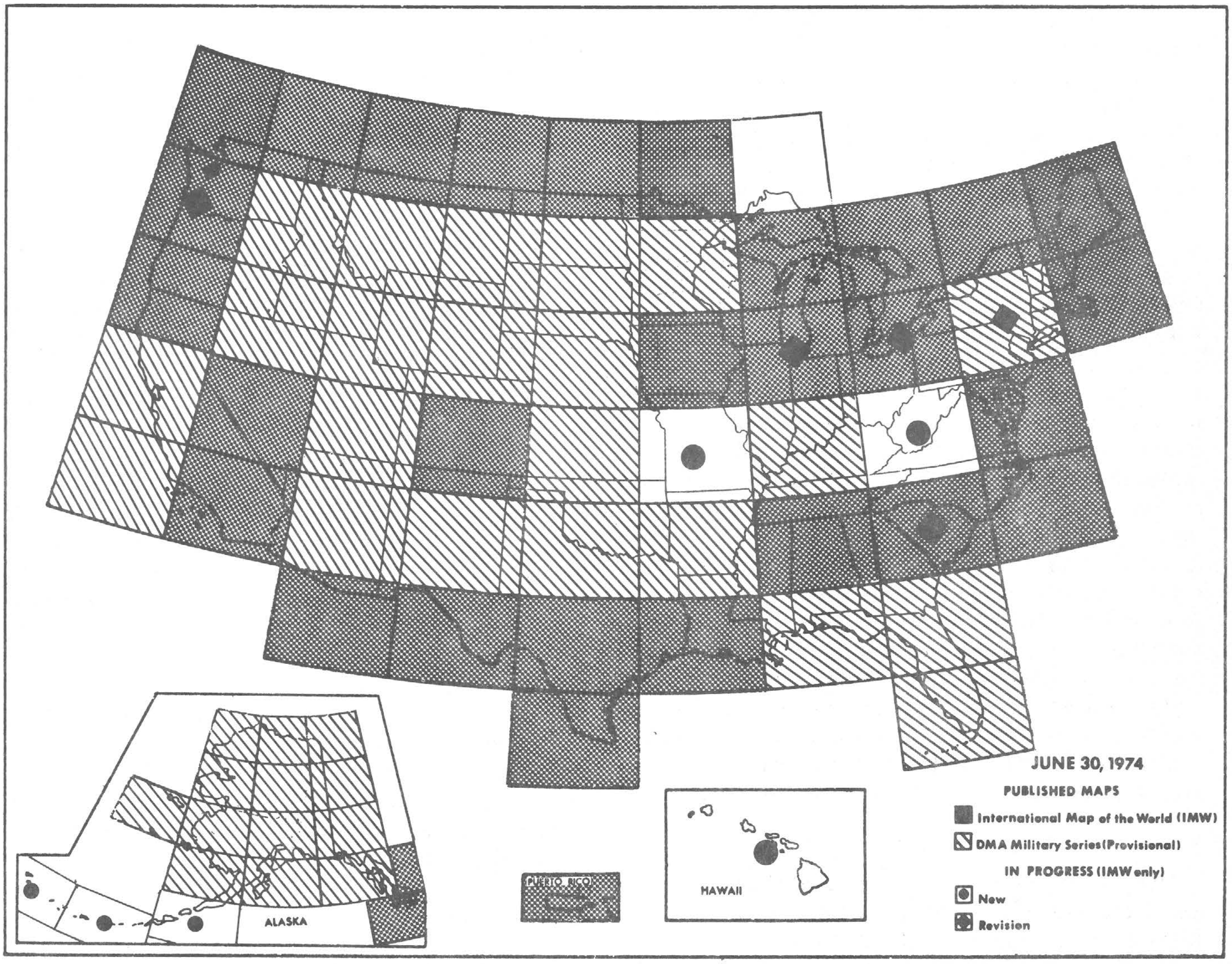

FIGURE. 10.—Status of publication of 1:1,000,000-scale topographic maps. Work in progress is being done by the USGS.

United States general reference
Regional general reference
Northeastern States
Florida
Southeastern Alaska
Southwestern Alaska
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, 1970
Federal lands
Population trends: changes, density, and urban-rural
Congressional districts for the 91st Congress
Shaded relief (conterminous United States)
Shaded relief (Alaska)

MAPPING IN ANTARCTICA

The U.S. Antarctic Research Program (USARP) is administered and funded by the Office of Polar Programs, National Science Foundation. The USGS participates in this program by administering the topographic field operations, winterover Doppler research programs, and cartographic programs.

Topographic field operations

The major austral-summer project was the operation of the Geoceiver with specially designed interface equipment for obtaining real-time, Doppler-satellite-derived geodetic positions (longitude and latitude) for geophysical study sites. The USGS engineer, J. W. Schoonmaker, Jr., operated the equipment in support of the Ross Ice Shelf Glaciological and Geophysical Survey. Doppler data obtained with the Geoceiver by tracking Navy navigation satellites was computed instantaneously into latitude and longitude for 33 geophysical study sites. Absolute position accuracies from a real-time solution for a single satellite pass ranged from 100 to 200 m. Refined geodetic positions of specific satellite passes are expected to increase the accuracy by a factor of five. Real-time geodetic positions at base camp were used to aline the inertial navigation system of the Twin Otter aircraft, which was used for all travel between base camp and the remote study sites.

A second project, the Pine Island Bay survey on the Lindsey Islands, was cancelled owing to changes in the icebreaker schedule. Not enough time remained of the austral season for the ship to move into and out of the bay before winter ice conditions became too hazardous. However, the two USGS engineers, R. N. Gardner and E. G. Shirmacher, were flown to Pole Station where they tied in the Geoceiver locations at old Pole Station, new Pole Station, and the top of Pole Station's new geodesic dome with existing survey stations. In addition, Schirmacher surveyed a section of the boundary of Specially Protected Area No. 6 at Cape Crozier. Afterwards both men traveled by icebreaker to Palmer Station where they conducted a survey to tie the Doppler tracking station to existing stations.

Winterover Doppler research programs

Doppler research was conducted at Casey, Palmer, and Pole Stations. Palmer Station Doppler operations were terminated in March 1974.

D. W. Bennett and R. D. Worcester operated the Geoceiver at old Pole Station through the 1973 winterover period, and they were replaced by M. Y. Ellis and T. K. Meunier for the 1974–75 period. Satellite-derived geodetic positions have been computed at 5-d intervals. Preliminary analysis indicates that the Pole Station is moving approximately 9 to 10 m/yr in the direction N. 43° W. Before returning to the United States, Bennett and Worcester flew to Byrd Station for 4 d of satellite tracking. Project Hawkeye, a secondary but important assignment, was successfully carried out by Ellis and Meunier on June 3, 1974. The men obtained telemetry data for the fifth-stage motor burn of a NASA Scout rocket that was launched from Vandenberg Air Force Base. The scientific satellite was put in a polar orbit to study the radiation over the polar regions, especially the North Pole.

Operations of the Doppler research station established at Casey Station were conducted during the 1973 winterover period by Lyle Supp (Applied Research Laboratories (APL), Univ. of Texas), assisted by R. F. Wilson (USGS). Henry Edwards (APL) and D. L. Schneider (USGS) are stationed there for the 1974–75 period. The USGS engineers' primary assignment is to accompany the Australian field survey party as surveyors and Geoceiver operators on the traverse in support of the International Antarctic Glaciological Program. Satellite-derived geodetic positions have been computed for 14 geophysical sites. Two of these sites were established by Wilson at Perth and Melbourne, Australia, at the request of the Australian Division of National Mapping and in support of its National Geodetic Net.

ERTS experiments in polar regions

Investigations continue under the NASA-funded project SR–149, "The Cartographic Applications of ERTS–RBV Imagery in Polar Regions," principal investigator, W. R. MacDonald. Results to date demonstrate applications in small-scale mapping, small- and medium-scale map revision, and significant finds such as new geographic features in Antarctica and changes in ice fronts, glaciers, and coastal areas. Results have been documented in "The Cartographic and Scientific Applications of ERTS–1 Imagery in Polar Regions" by R. B. Southard and W. R. MacDonald (1974), and "New Space Technology Advances Knowledge of the Remote Polar Regions" by W. R. MacDonald (1974).

Cartographic activities

The status of USGS topographic mapping in Antarctica is shown in figure 11. Two 1:250,000-scale sheets, Cape Burks and Hull Glacier of the Hobbs Coast-Marie Byrd Land area, were completed and await printing, as are the Mount Berlin and Grant Island sheets.

ERTS–1 imagery was used as a current source to add new geographic features and to change coastal features to the 1:1,000,000-scale IMW sheet of McMurdo Sound area.

INTERNATIONAL ASSISTANCE PROGRAMS

Indonesia

F. S. Brownworth, Jr., left for Indonesia in April 1974 for a 3-mo temporary assignment in Jakarta. He is evaluating Indonesian mapping capabilities; assisting in the development of a national mapping plan to meet requirements for natural-resources ap-

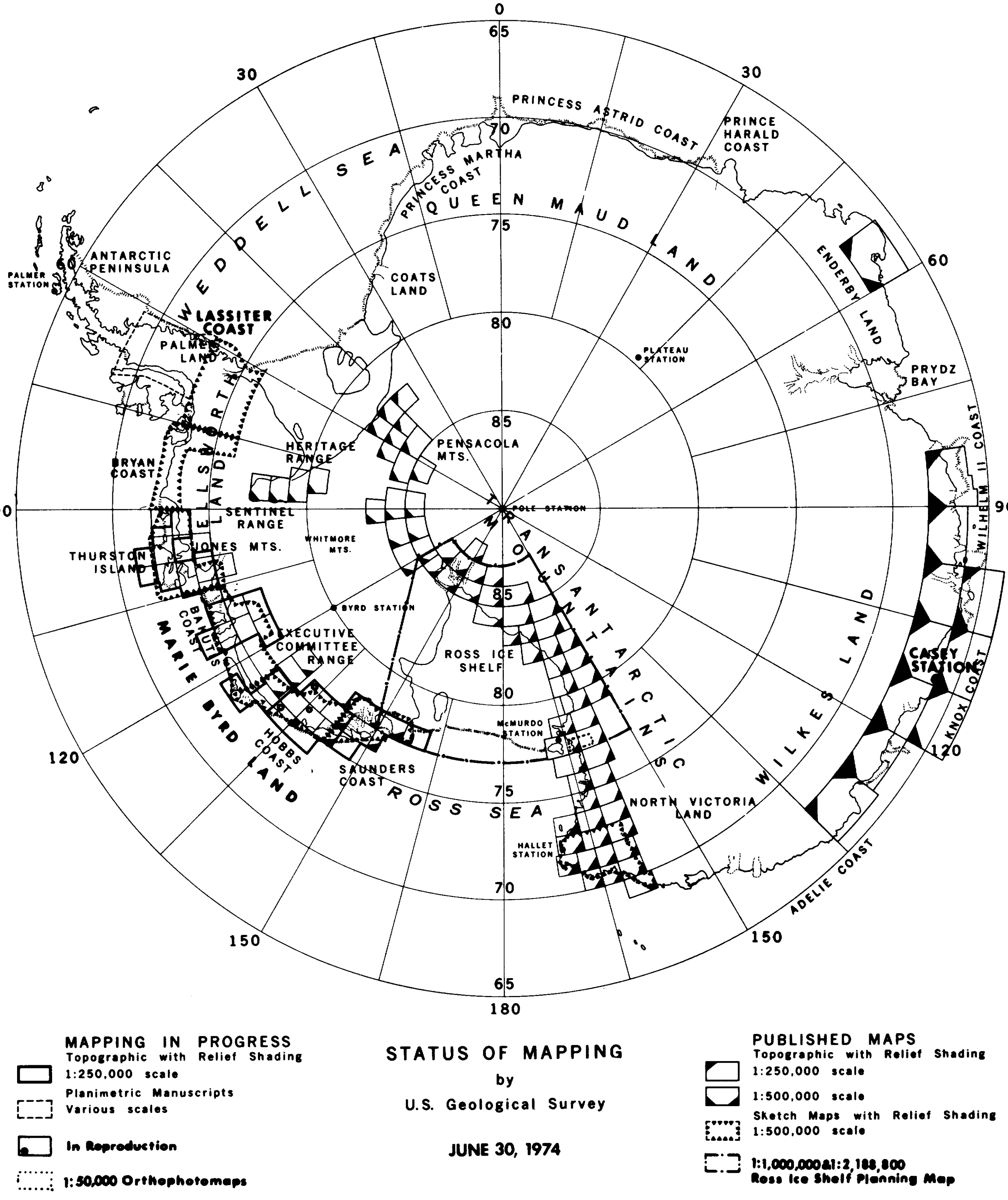

FIGURE 11.—Index map of Antarctica, showing status of topographic mapping.

praisal, development, and land-use studies; and identifying surveying and mapping priorities to meet short- and long-range objectives.

Liberia

The geological-exploration and resources-appraisal project in Liberia was completed on June 30, 1972. All ten 1:250,000-scale geographic shaded-relief base maps of Liberia were published in color during 1973. Copies were distributed to Liberia and other interested parties.

Mexico

Amendments and additions to the USGS-CETENAL (Comisión de Estudios del Territorio Nacional) agreement for the exchange of information and joint mapping of U.S.-Mexico border areas were approved by both agencies in May 1974. Several joint meetings have been held in Mexico City, Denver, and Washington, D.C., to maintain close coordination for the implementation of the agreement.

Pan American Institute of Geography and History (PAIGH)

The USGS continued to provide administrative and staff support for the U.S. member of the Commission on Cartography and for the chairman and U.S. member of the Committee on Topographic Maps and Aerophotogrammetry. Eight USGS personnel are actively participating in PAIGH activities.

The U.S. section of the Commission on Cartography held two meetings during this period. In December 1973, they met to consider the results from the General Assembly in Panama, to discuss and propose new programs and projects for the coming year, and to report on committee activities. In January 1974, they met to review the directing council's comments and reception of special project proposals submitted after the December meeting, and to discuss the Secretary General's proposal to recommend to the United Nations that a U.N. cartographic conference for the Americas be held every 4 yr, between the PAIGH general assemblies.

A supply of 10,000 copies of the USGS public-information leaflet "Seguridad y Sobrevivencia en Un Terremoto" (Safety and Survival in an Earthquake) was sent to the General Secretariat of PAIGH in Mexico City for distribution throughout Latin America.

Saudi Arabia

The USGS is continuing to assist the Ministry of Petroleum and Mineral Resources of the Kingdom of Saudi Arabia in assessing the mineral potential of the Precambrian Shield area of central and western Saudi Arabia. A photogrammetric specialist and a geodetic specialist are assigned to this program. Maps of special areas of geologic interest have been controlled in Saudi Arabia and compiled there and in the United States. They are used as base maps for geologic investigations and reports.

United Nations cartographic conference

R. H. Lyddan and W. R. MacDonald attended the VII United Nations Regional Cartographic Conference for Asia and the Far East in Tokyo, held October 15–27, 1973. En route to Japan, Lyddan stopped for several days in Alaska to consult State mapping officials and to visit USGS personnel.

Yemen Arab Republic

The USGS agreed to map an important irrigation and development area in the Tihama of the Yemen Arab Republic near the Red Sea. The maps will be 1:20,000-scale orthophoto bases with metric contours. T. K. Bray, F. L. Aschert, C. E. Morrison, T. A. Moye, and L. R. Reitz were assigned to the Wadi Mawr project in June 1973 to establish the horizontal and vertical field control for the mapping. They completed the assignment in the allotted time. The topographic manuscripts are being prepared under contract by a commercial mapping firm and should be completed by the end of July 1974.

Training programs and inquiries

Training and extended briefings in mapping operations are provided for participants and exchange scientists from other countries. Additionally, technical tours of the production and research facilities of USGS and other surveying and mapping agencies were arranged for more than 25 foreign visitors. Technical reports and publications, information on sources of equipment, instructions on new mapping techniques, and proposed solutions for mapping problems are provided to other countries on request.

RESEARCH AND DEVELOPMENT

FIELD SURVEYS

Inertial surveying

Two different inertial navigation systems, developed during the last few years by the Department of Defense for use on ships and aircraft, have possible application as map control surveying instruments. Recently, the accuracy of these systems has been improved substantially and is approaching that required of ground surveys.

The PADS (Position and Azimuth Determining System) was developed by the U.S. Army Engineer Topographic Laboratories for artillery control surveys. The system consists of an inertial platform and a laser velocimeter and is mounted on a Jeep. Litton Systems, Inc. is preparing to offer a civilian version of PADS. Map control accuracies in position can be met with this system over a distance of several kilometres, but the accuracy in elevation is marginal.

Another system being considered by the USGS will provide ground profiles by measurement from an aircraft. The aircraft's position and elevation will be determined by an inertial system and will be projected to the ground by a laser altimeter. Development work on this system is just beginning, and the desired accuracies are within 3 m in horizontal position and within 0.15 m in elevation.

Special surveys

A control test course is being established at the National Center in Reston. The course will be about 3,000 m long and will incorporate about 20 marks, consisting of driven rods, concrete posts, 1 aluminum post, and 2 marks set in permanent structures. Positions and elevations will be established on the marks, and the course will be used for testing new equipment and for training.

A project for establishing closely spaced bench marks across about 15 earthquake fault zones in Nevada and California was undertaken for the Center for Earthquake Research. The monitor lines, 15 to 30 km long, are to be periodically releveled in an effort to detect vertical fault creep as a tool for earthquake research. The fieldwork, computations, and associated graphic information, including profiles of elevation differences, are performed by the Western Mapping Center, and the assembled material is sent to the Center for Earthquake Research for analysis.

Releveling is being performed in two suspected subsidence zones, Isleton, Calif., and Bowie-Willcox, Ariz. The primary purpose of the leveling is to provide current elevations for mapping, but an important secondary purpose is to obtain subsidence information. The Isleton area, with a history of erratic subsidence, last releveled in 1967, is showing measurable subsidence of up to 0.3 m. The Bowie-Willcox area was a suspected subsidence zone, but only limited releveling had previously been performed. Preliminary results indicate subsidence greater than 1 m in some parts of the area.

In support of geologic studies, repeated levelings have been undertaken within selected tectonic areas. The objective is to locate vertical crustal movements and to evaluate their significance. Vertical movements detected through repeated levelings are a potentially valuable index of accumulating crustal strain. Precise leveling data are available from the turn of the century, and comparative study of the data is an important element in the analysis of contemporary surface deformation. A secondary objective is to consider, as a part of the comparative elevation study, the possible development of a new vertical datum.

Equipment improvements

To meet the requirements of the Occupational Safety and Health Act of 1970, USGS towers are to be equipped with safety devices for climbing ladders. Three basic types are commercially available: (1) a cage around the ladder with a platform every 10 m; (2) a steel rail with locking notches at 15-cm intervals; and (3) a wire cable or Dacron rope incorporating life belt, friction brake, and sliding attachment. The wire-cable type appears to be the most feasible for surveying towers. However, the available devices are manufactured for steel-rung ladders, and modifications are needed for installation on USGS aluminum towers. The cable will be extended and attached 1.4 m above the platform level to allow the climber to be on the platform before disengaging himself from the safety belt.

Plans are underway to equip a ¾-ton van with a built-in light-table and stereoscope assembly to provide a mobile work station for field parties engaged in revision and photointerpretation mapping operations. The table will have an embedded steel strip and a magnetic strip to hold a map sheet or photos in place. A chair will be mounted on rails for easy adjustment.

Conventional tripods were modified with extension legs to satisfy an immediate demand along the Georgia coast for a higher-than-normal instrument height for the corner prisms used in electrooptical distance measurements. The upper dowel sections of the legs attached to the tripod head were replaced with dowels 1.8 m long to allow instrument heights of up to 2.7 m.

PHOTOGRAMMETRY

Advanced mapping techniques

Analytical plotters and advanced techniques developed by the military are being applied to standard topographic mapping in an effort to increase mapping capability and reduce the time required for making a map. The Defense Mapping Agency (DMA) has loaned USGS two improved AS–11A plotters for an indefinite period and has trained operators and maintenance technicians to work with these plotters. In addition to DMA furnishing equipment, software, training, and maintenance, the Rome Air Development Center (RADC), Griffiss Air Force Base, N.Y., has offered facilities for researching digital approaches with advanced techniques. If successful, several mapping operations now being done sequentially will be accomplished concurrently, thus significantly shortening the map cycle.

The AS–11A is a first-order stereoplotter consisting of a Bendix computer, a Nistri stereoviewer, and a Nistri coordinatograph. The ability to use the computer to adjust for systematic errors in real time is one of the important advantages of the analytical plotters over mechanical types. Unfortunately, the computer is an outdated, delay-line-memory type, and preparing any new programs is slow, tedious, and expensive. During 1974 both AS–11A's will be updated with minicomputers large enough to compile FORTRAN programs.

The first 1:24,000-scale mapping projects with the AS–11A's are well underway. One is the Estrella, Ariz., project consisting of quadrangles with a 40-ft (12-m) contour interval; compilation has been completed. The other is the Escalante, Utah, project consisting of 33 quadrangles covering a portion of the Grand Canyon, with a 40-ft contour interval. These two mapping projects are resurveys of areas covered by outdated maps. The AS–11A map manuscripts will be field tested for accuracy and completeness.

For the research project planned at RADC, an AS–11B–1 plotter will be used both to extract digital terrain data automatically and later to extract planimetric data manually. (In practice, the data would be extracted simultaneously using two plotters.) Any field surveys needed are to be performed with the aid of whatever aerial photographs are available for the area. Cartographic operations will commence with project authorization and will consist of digitizing the base-sheet graticule and complete collar information. The planimetric and generated contour data will be edited, combined on magnetic tape with base-sheet data, and finally plotted automatically on scribecoat sheets. This first project using automatic modes will involve some unusual manipulations requiring modifications of existing computer programs to fit the various operations into a workable sequence. While the primary objective is to prove the approach feasible for reducing the routine map-production time by 50 percent, the ultimate objective is to be able to respond to important map users' urgent needs in a matter of hours for emergency charts, and in a matter of days for standard quadrangle maps.

Quality control for aerial photographs

A study was conducted to determine the usefulness of the Itek Visual Edge Match Comparator (IVEMC) for photographic resolution determinations and quality analysis. Briefly, the IVEMC method involves the use of a split-field microscope to subjectively match image edges to edges on a reference matrix card. The matrix consists of columns of elements with edges of constant sharpness but varying contrast, and rows of elements with edges of varying sharpness but constant contrast. After locating the matching element in the matrix, the interpreter obtains the photo resolution value from a companion table.

Resolution values determined from readings on bar-target images were compared with IVEMC resolution values. Data for the study were obtained by measuring and evaluating image edges on 13 photos. Results indicated that sufficiently accurate photo resolution values can be determined with the IVEMC system, as the largest discrepancy amounted to 14 percent of the bar-target values.

Mapping from high-altitude photographs

This research explored the practicality of compiling 1:24,000-scale standard line maps from 1:72,000-scale high-resolution photographs. First-generation color film positives of selected stereomodels of an area near Gillette, Wyo., were set up in a Kern PG 2 stereoplotter for delineation of the planimetric and contour details. The *C*-factor (ratio of flight height to contour interval) for the standard compilation was 840 as compared with the *C*-factor of 1800 for the 20-ft (6-m) contour interval (CI) research compilation. The planimetry was compared with the field-checked standard compilation and found to be essentially complete and accurate. The contours were tested against withheld field elevations. The study indicated that the use of small-scale, high-resolution photographs would be practical for compiling

1:24,000-scale, 20-ft (6 m) CI maps, especially with a slightly lower *C*-factor of 1600.

Digitization

Specifications were developed for three-axis digitizing components for a Kern PG 2 stereoplotter. The entire system is intended for use as a research tool to provide capability for measuring and recording on magnetic tape the *x*, *y*, and *z* coordinates of both point and linear data in static and dynamic modes respectively. The least count of recorded data for all axes will be 0.005 mm. A visual display of the coordinate data will be provided along with controls for presetting other necessary data. Online monitoring of linear data will be provided with a cathode-ray tube. Further research projects planned for the digitized stereoplotter include profiling, computerized contouring, and digitizing terrain models.

A new technique for digitizing shorelines, fathometer-line end points, and fathometric traces of lakes has been developed in response to a need for data on lakes in the State of Washington. Where multiple photocoverage existed, photoscale was unified by treating each photo as a strip and assembling the photos into a block by simultaneous strip adjustment. A coordinatograph was used to digitize 17,500 shore points and 25,000 fathometer trace points on 111 lakes. The photogrammetrically derived data were transformed into computer graphics of shorelines and bathometric curves.

Optical calibration laboratory

On April 1, 1973, the calibration services, with associated equipment, for aerial cameras and lenses provided by the National Bureau of Standards (NBS) were transferred to USGS at McLean, Va. All equipment has now been moved to the USGS National Center at Reston to form one of the most complete optical calibration laboratories in the United States.

During the transition period, a number of modifications were made in both NBS and USGS calibration instruments. The four main arrays of the camera calibrator now have complete angular coverage from 0° to 54.5° off axis. The visual optical bench is now equipped with a 30-cm aperture, 3-m focal-length parabolic mirror which provides a collimated beam that will enable lenses up to 180-cm focal length to be measured at full aperture. Several special camera mounts were designed, and are now in service, to assure greater accuracy and stability in positioning and holding cameras during tests.

Fully analytical aerotriangulation

Research continued in the use of superwide-angle photographs, taken at higher-than-normal flight heights, and fully analytical aerotriangulation to effect a reduction in vertical ground control needed for mapping. The test project (Louisburg, N.C.) comprised eight 7½-min quadrangles with 10-ft (3-m) CI. An abundance of control was identified on 3 sets of photographs—2,900-m wide-angle and 3,350-m and 6,700-m superwide-angle. Photocoordinates were first measured on image points on the 6,700-m photographs with a Mann monocomparator. The direct geodetic constraint solution did not meet vertical accuracy requirements for 10-ft CI mapping, with a 7.75-ft (2.36-m) rms residual. The image points were measured on the 3,350-m photographs with a Nistri TA3/P stereocomparator, and the adjustment also failed to meet vertical accuracy requirements, with a 3.8-ft (1.15-m) rms residual. In both solutions, numerous points exhibited position and elevation ambiguities between photographs and (or) between strips, indicating unsatisfactory point transfer. Therefore, for a third trial, all untargeted points have been drilled on the plates with a Wild PUG 2, and the photocoordinates will again be measured with a Nistri TA3/P.

Aerotriangulation system evaluation

New aerotriangulation systems developed in-house, by other foreign and domestic agencies, and by private industry are continually being tested. A recent series of tests was performed on a block consisting of 50 photographs taken in 4 strips. In all tests, 4 horizontal control points and 27 vertical control points were treated as held points, while 21 horizontal and 49 vertical control points were withheld to test the solution. All control points were targeted. The basic input data consisted of plate coordinates and, therefore, where model or strip data were required, the data were first processed. The results showed that a less complicated adjustment produced comparable accuracy at significantly lower computer cost.

Aerotriangulation for orthophotomapping

Tests were conducted to determine the accuracy of a semianalytical aerotriangulation solution for various configurations and sources of control input. In the first series of tests, the measured photographic data were adjusted to (1) all available horizontal ground control, (2) control spaced externally and internally at 15-min intervals, (3) 15-min perimeter control only, and (4) well-defined map points spaced at 7½-min and 15-min intervals. In the second series of tests, pass points and control points were measured on the orthonegatives with a coordinatograph, and the data were adjusted to (1) all ground control, (2) 15-min perimeter ground control, and (3) map control spaced at 7½- and 15-min intervals. The results indicated that, with careful photogrammetric measurement and field identification, ground control at 15-min intervals externally and internally will produce satisfactory scale solutions for large blocks of aerial photographs. The results of solutions constrained to map control and to measurements from orthophotographs were unsatisfactory, mainly because interpreting pass points and control points on monoscopic imagery was difficult.

CARTOGRAPHY

New map symbology and formatting

A new design for standard topographic maps has the objective of promoting simplicity, clarity, and economy in content, construction, and reproduction for maps of the future. Experimental maps at 1:20,000 and 1:50,000 scale include such elements as (1) formatting on a rectangular metric grid block rather than the quasi-trapezoidal geographic quadrangle so that sheet size does not vary with latitude; (2) modifying currently standard symbols for compatibility with computer technology, especially in revision and maintenance; (3) providing feature-separation flexibility in construction so that the cartographer, through use or omission of mezzotint density screens, can emphasize features of greater importance and progressively eliminate lesser features in deriving maps of smaller scale; and (4) printing four sheets at a time from five combined negatives per sheet on a large five-color press.

Basic copy for the 1:20,000-scale map was derived from the Wausau West, Wis., 7½-min quadrangle map. For effective display of the range and variety of the revised symbolization, fictitious features were added at will. The map is formatted on the UTM grid with the grid lines at 5-cm intervals over an area of 45×60 cm, which represents a ground area of 9×12 km, longer in the east-west dimension—a decided change from the shape of the traditional quadrangles but one that favors the map user, who can handle a wide sheet better than a narrow and deep one. The 45×60-cm format could be a universal size for a coordinated set of map scales, with each 5-cm grid segment representing a convenient metric ground distance.

From the production point of view, the 45×60-cm format entails no change in cartographic materials or equipment now in use. The 60×76-cm format for scribecoat sheets and film sheets for 1:24,000-scale maps is a convenient size for the proposed metric format. From the reproduction point of view, the format enables printing a four-sheet layout with no wasted space in the north-south direction. In the east-west direction, a surplus of margin would permit the design of folded maps, a product often discussed favorably but not yet provided in the national mapping program.

Symbols and portrayal were simplified several ways: Symbols for obsolescent features and several minor features were omitted; all dots were eliminated from spot and linear symbols; the number of linear symbols with dashes was reduced; mezzotint screens were used extensively to subdue or enhance particular features and to obtain good color combinations; feature separation was provided as well as color separation; and the number of basic type faces was reduced. Thus, the experimental maps show solid-line roads instead of cased roads; solid transmission lines instead of the intricate dash-dot symbol now used; two lineweights to indicate perennial and intermittent drainage features; solid-line boundaries for such features as parks, cemeteries, and substations; banding for principal boundaries as an aid to clarity; landmark culture in black as distinguished from nonlandmark features that are screened to a subdued dark gray; supplementary contour lines screened rather than tediously dashed; index contours scribed separately for nearly direct use in preparing half-scale or smaller maps; and type faces that can be more easily read and reproduced.

The 1:50,000-scale experimental map was derived from the 1:20,000-scale version by photographic reduction to 40 percent. Lineweights were selectively held to 60 and 80 percent of original. Mezzotint screens of selected densities were interposed to make the five combined films from which the proof of the partial map was made.

Economical use of five-color map press

The printing plant at the National Center will include a new five-color Harris press that will print a maximum image format of about 110×145-cm on 112×147-cm paper. Normal procedure has been to make pressplates that contain four standard quadrangle maps (4-up). Because the maps vary considerably in width (east-west) with latitude, the 112-cm dimension for two map widths is critical, especially for the wider maps in the southern latitudes of the United States. A partial solution to the problem is to redesign the layout of marginal information so that maps of southern areas can still be printed 4-up.

A better solution might be to adopt a standard rectilinear metric grid format to replace the quasi-trapezoidal geographic quadrangle, so that sheet size does not vary with latitude. A format of this type has been designed and used for several experimental maps. In this format the mapped areas, regardless of scale, are contained within neatlines that measure 45 cm north-south and 60 cm east-west. These dimensions leave about 10 cm to be divided for the printing of supplementary information in the north and south margins of each map. In the east-west dimension there is a surplus of about 13 cm per map, a very comfortable amount, 3 cm for necessary supplementary data in one margin and the rest for necessary and contemplated additional data in the opposite margin.

Several years ago it was common practice to print the map linework in four colors, and features such as woodland, open water, and urban areas in three solid tints—a total of seven impressions per sheet. In recent practice, open water and urban areas have been printed in screened values of the blue used for drainage features and the red used for highway classification. Thus the five-color new press can be used most effectively to completely print four maps in a single run.

Current normal procedure is to print interim-revision maps in the five standard map colors plus purple for added features. Because printing in six colors is inefficient with the five-color press, we must design color schemes that will produce the full range of map colors with no more than five impressions. To illustrate the feasibility of a five-color scheme for printing interim-revision maps, a six-color composite proof of the North Miami, Fla., 7½-min map was prepared from the normal color-separation materials and a combination of five colors (magenta, yellow, cyan, brown, and black). Random-pattern mezzotint density screens were used to blend colors and obtain the desired variations in the basic colors. Although the desired effect was achieved with stud-registered contact photoprinting, it remains to be seen if the new press can hold register and satisfactorily reproduce fine-line features made up of multiple superimposed impressions.

Automated cartography

Recent advances in the state-of-the-art of automated digitizers have produced hardware that makes precise and cost-effective digitizing of map data a much more nearly practical operation than it was a year ago. Consequently, the USGS has recently carried out three map-data digitizing projects to test the hardware and aid in developing software for processing digital map data.

1. In a cooperative project with the RALI program, the contour plate of one of the Hartford, Conn., 7½-min quadrangles was digitized by manual line-following on the Bendix DataGrid Digitizer. The resultant digital contour data was set to use in software development.
2. A small portion of the Pembroke, N.C., 7½-min quadrangle was raster scanned on the NASA Optronics Photomation at Wallops Island, Va. The instrument does an excellent job of precision scanning, but it is extremely slow and highly sensitive to dust particles, scratches, light pinholes, and other film or image defects.
3. Experiments are currently underway in contour digitizing by automated line-following with a computer-controlled laser beam. The work is being done under contract by the Sweepnik digitizer of the i/o Metrics Company of Sunnyvale, Calif. Portions of the Block, Tenn., 7½-min contour plate have been digitized, and preliminary results were sufficiently encouraging to warrant extension of the research.

Equipment developments

In 1972, a design for a hand-operated scribecoat tester was obtained from the Defense Mapping Agency Topographic Center, where it was used to measure the pressure required to penetrate the engraving layer. The tester was redesigned for use as a scribing head on the Cartoplot. In its modified form, the tester can both control and indicate the pressure at the tip of a scribing point while it is guided automatically to scribe a line 5,080 cm long. For convenience, the line is compressed into an area of about 18×23 cm. A scribing pressure of 110 ± 15 g is maintained on an unsharpened Duotone steel phonograph needle. Once the test line is completed, an average lineweight is calculated from five measurements taken at selected intervals along the scribed line. Contrary to most expectations, point wear decreases rather than increases lineweight. A decrease of lineweight in excess of 5 μm over a test line of 5,080 cm is unacceptable.

A hand-operated precise point marker was fabricated for use on film or scribecoat. The instrument, similar to the electric pinprick of the Cartoplot, is 13 cm high and 6.4 cm in diameter and has an internal spring for automatic lifting of the needle after pricking. When viewing, the operator cannot see the needle. Magnification is adjustable from × 6 to × 12, changing the field of view from 18 to 10 mm. The base is made of clear plastic to admit external light and is padded with felt to prevent scratching the film.

Slope mapping

Important advances have been made in the development of techniques for making slope maps. An easel has been designed that eccentrically rotates the film under the projected image of a contour negative. The images of the contour lines are consequently spread by an amount that depends on the size of the orbit. The spread lines have a sharp, well-defined edge, and the amount of the spread is controlled with a high degree of precision.

Another technique uses an orbital lens device—an eccentric lens mount contained within a rotating disk —to widen contour lines photographically. During exposure, the disk rotates and the eccentricity is controlled simultaneously (by limit switches) as the lens sweeps from the preset eccentricity to center. The device can be fitted on a standard cartographic camera; interchanging the standard lens and the orbiting lens should require no more than 20 min.

In addition to the presentation of the slope zones in color, it is now possible to portray as many as eight zones in black and white by either of two new methods. One makes use of distinctive combinations of patterns and screens; the other uses a density-slicing technique to differentiate the slope zones by density contrast on continuous-tone film.

Land-use classification

Land-use classification in normal topographic mapping is a distinct possibility. The many possible scales, formats, and methods of classifying, either independently or as part of the mapping process, are under investigation. One project focused on photomaps at 1:24,000-scale; four available 7½-min orthophotoquads of the Fredericksburg, Va., area were selected for displaying level II classification as defined by Anderson, Hardy, and Roach (1972). Actual compilation of land-use lines was done by experienced personnel in the Geographic Applications Program and was depicted on the orthophotoquads as white dropout lines. A portion of the Fredericksburg orthophotoquad is being digitized by the i/o Metrics Sweepnik laser scanner. Approximately 60 samples of the land-use maps have been distributed for evaluation by interested users. In addition, the four orthophotoquads were combined photographically and reduced to 1:50,000 scale. Little information loss was noted by most reviewers.

In a similar effort, the Keefeton NE, Okla., quadrangle was selected for trying level I and II classification concurrently with compilation and scribing. Land-use lines were delineated on a 1:24,000-scale base prepared from an orthophotomosaic derived from 1:80,000-scale photos. The north half of the quadrangle was done monoscopically and stereoscopically with the aid of contact prints of 1:24,000-scale photos; the south half was done stereoscopically with the aid of the 1:80,000-scale photos cut into strips to provide stereo coverage. An informal field check of the completed land-use map indicated a high degree of accuracy.

Orthophoto projects

In view of the projected increase in the production of orthophotoquads—5,000 programed for fiscal year 1975—several important quality-control measures have been taken:

1. Specifications for aerial photography have been revised and will be modified further as more experience is gained.
2. Guidelines for controlling and improving image quality have been developed. Aimpoints for image density have been established but are tentative and will be changed as experience indicates.
3. Hardware is being procured for a research effort in monitoring and rating the image quality of orthophotoquads at each step of the photomapping process. The objective is to determine a threshold of image quality for each production phase. The analysis should indicate the losses through the system and operations needing more study.

New methods have been developed for the preparation and presentation of color orthophotomaps. Among these is a density-slicing technique that permits vegetative cover, for example, to be isolated and printed in green. Another innovation is the combination of random-dot negatives and mezzotint screens in such a way that all the features in a variety of colors can be printed from only five plates, thereby minimizing the number of press runs. The results of these methods are illustrated by the Saltair, Utah, orthophotomaps.

The USGS has developed specifications and is serving as technical monitor on four contract urban mapping projects:

1. Though somewhat set back by delays in obtaining the photographs, the Ft. Wayne, Ind., project is nearly completed. The contract calls for 440 1:2,400-scale monochromatic orthophotographic maps, a semicontrolled 1:15,840-scale photomosaic, and stereoplotted contour drawings of a 2-mi^2 area registered to the maps. The USGS will meet with potential map users to explain how the products can be obtained and used; 3 to 6 mo later, another meeting will be held to determine the suitability of the products applied to municipal operations, land management, surveys, and planning studies.
2. First delivery on the Charleston, S.C., contract for 590 1:2,400-scale monochromatic orthophotographic maps has been made, but the project is behind schedule because of delays in obtaining the photographs and lack of correspondence between photographs taken at different times.
3. A contract for large-scale orthophotographic maps of the San Francisco area will be awarded in 1974. The maps will cover a 140-km^2 area at 1:6,000 scale and selected areas at 1:1,200 scale. A 30-cm focal-length camera will take photographs at 7,900 m, 3,650 m, and 1,830 m.
4. A contract for sixty-four 1:2,400-scale monochromatic orthophotographic maps of the Frederick, Md., area will be awarded in 1974. The photographs for the project were obtained on contract, in April 1974, with a 30-cm focal-length camera at 3,650 m.

The USGS is also monitoring private mapping ventures in other cities and providing technical counsel to the cities as requested.

Slightly skewed north-south, 1:120,000-scale U–2 photographs of the Willamette River Basin were used to prepare the twenty-nine 1:24,000-scale orthophotoquads of the Forest Grove, Oreg., project. Some new techniques were applied which minimized costs —block adjustment of data derived from the orthonegatives and butt-joined and taped assembly of the orthophotoquads using Kodak Kind 1594 paper prints.

The Chicago experimental orthophotomap project was undertaken (1) to prepare a large-scale experimental orthophotomap of a densely populated urban area for use particularly in urban planning and development, (2) to further develop cartographic techniques, procedures, and symbolization, and (3) to determine the optimum flight height for urban orthophotomapping. Rectified 1:5,000-scale mosaics were prepared from the 3,650-m (15-cm focal length), 3,650-m (30-cm focal length), and 5,500-m (30-cm focal length) photographs. A thorough evaluation of each mosaic showed that the 3,650-m, 30-cm photographs offered the best photographic resolution. Simplicity, coupled with the requirement for minimal reproduction costs, was the motivating factor influencing the design of the map. Selected street names, identification of landmark features, route markers for highways, and available bench marks and elevations were shown. Type styles were chosen for legibility and compatibility with the scale of the map. A positive mask of the interior type was made to block out the imagery and at the same time provide a halo effect for the type on the finished maps. The halo made the type more legible and contributed to a pleasing overall impression of the map. Only the open-water features were enhanced cartographically, and this was done by screening. Two 2½-min, 1:5,000-scale monocolor orthophotomaps (Englewood C and Jackson Park A) were prepared. Twenty photographic copies of each map were sent to the Illinois State Geologist, who distributed copies to various city departments and planning commissioners in Chicago for evaluation.

To evaluate the quality of orthophotos produced by the Gigas-Zeiss Orthoprojector system, particularly its potential for scanning steep terrain models, arrangements were made to have a double-model orthophoto of part of the Lake Bonnie, Antarctica, quadrangle (Dry Valley project) prepared on the GZ–1 of the U.S. Forest Service. The quality of the resulting orthophoto was excellent, and the contour plot generated during the scanning showed that automatic contouring was worthy of additional experimentation. On the basis of the favorable first results, the entire Lake Bonnie quadrangle, comprising 21 models, will be completed on the GZ–1.

A research project in cooperation with the Water Resources Division is being conducted in the vicinity of Sapelo Island, Ga., to investigate procedures for interpreting, delineating, and mapping coastal wetlands by means of remote sensing and photogrammetric techniques. The study area contains a variety of coastal marsh conditions, ranging from saline to brackish and including some complicated transition zones, and it extends from a mainland river through sea island marshes to the Atlantic Ocean. Considerable background data on the region has been accumulated by the University of Georgia Marine Institute located on the island. Six black-and-white 1:10,000-scale orthophotoquads are being prepared for this project on a format of 2½ min of latitude by

$3\frac{3}{4}$ min of longitude, covering the same area as the Doboy Sound, Ga., $7\frac{1}{2}$-min quadrangle map. Vegetation was delineated on the orthophotoquads in conformance with the upper wetland boundary and major plant species associations stated in the relevant laws of Georgia, or proposed amendments to them. Major plant-species associations were interpreted and delineated on the orthophotoquads to provide a basis for accurately determining marsh boundaries and for evaluating the marshes for management and regulation. An upper wetland boundary line, dividing the marsh from the upland and based on vegetation and morphology, will be interpreted and mapped to meet the National Map Accuracy Standards.

To aid rectification of high-altitude photographs in the production of orthophotoquads, a method has been devised for using ink dots as control points. Eight small dots are marked with india ink on the aerial negative outside the quadrangle boundary. The marks are measured and carried through aerotriangulation but are not used in the solution. The coordinate values of the ink dots derived from aerotriangulation are plotted on the base sheets and used as control for rectification. The artificial points are clearly visible in the projected image of the rectifier and are much easier to fit to than natural image points, particularly if the aerial negatives are dark. Another aid to simple rectification lies in using du Pont CRN reversal film to produce a rectified and scaled negative in the Wild E 4 rectifier directly from the aerial film. In the production of an orthophotoquad, this procedure eliminates one photographic generation—a paper print or a positive film—and improves the image quality of the final product. A paper print is made as a byproduct to visually evaluate tone match and overall density distribution.

COMPUTER TECHNOLOGY

In order to meet the growing demands of the USGS, the Computer Center Division (CCD) continued to expand its facilities during fiscal year 1974. The ecological impact of dwindling natural resources created an urgent need in the Survey's scientific community for increased computer availability. Also, as a result of the Survey's relocation of its headquarters to Reston, additional administrative needs for computer technology were recognized.

RESTON COMPUTER SYSTEM

With the move to the National Center, an interim computer system was installed at Reston, Va. The system selected was an IBM 370/155, designed to increase the computing capacity available to CCD users. At the same time, the 370/155 system is similar to the 360/65 system in Washington, D.C., both of which are controlled by the same operating system, have the same software packages, and use the same cost accounting system.

The 370/155 has a main memory capacity of 4 million bytes, 31 disk drives, 10 tape drives, 2 line printers, and a card reader and punch. While the 370/155 system serves the immediate needs of the USGS computer-user community, it is anticipated that before the end of 1975 there will be a need for 4 to 6 times the capacity of the present 370/155 system. As a result, CCD is currently working on a request for proposal to procure a larger computer system for Reston, Va.

TELECOMMUNICATIONS

Telecommunications is a rapidly expanding field. Because of the frequent state-of-the-art changes in such technological areas as netting, front-ending, concentrating, and multiplexing, the communication system to the two Washington, D.C., metropolitan-area computers is expanding rapidly in size and complexity. There are currently more than 120 terminals supported by the computers in Reston and the Department of the Interior building.

NEW SOFTWARE SUPPORT

Easytrieve

An item that was added during 1974 was the Panosophic Systems, Inc., software package called "Easytrieve," a system that facilitates data retrieval and report generation. It can also sort files, compare two files, selectively reproduce new files, and generate mailing labels. One of the main advantages of the Easytrieve system is the minimum of coding requirements, allowing noncomputer professionals access to computerized data bases.

Time Sharing Option (TSO)

The CCD has implemented a time-sharing service, IBM's TSO, for Survey scientists and other users to communicate on a real-time basis with the Reston computer. TSO provides users from many different locations, who have a shared interest, instant access to a common body of stored information. It also helps fulfill the problem-solving and text-editing requirements of Survey computer users.

WORD PROCESSING

During 1974 the recent developments in word processing were investigated, and various classes of word-processing equipment were examined. Innovations include the development of complex text-editing equipment as well as sophisticated dictation systems.

After an evaluation of new equipment, an IBM Magnetic Card Selectric Typewriter II (MCST II) was demonstrated to personnel from various organizational units within the USGS. These demonstrations showed the capabilities of available word-processing systems. The MCST II, a general-purpose, stand-alone text-editing processor, is now in use at CCD.

NEW FACILITIES

The computer requirements of the CCD's branch offices were investigated during the last year. Consequently, three of the branch sites will have their computing capacities upgraded:

1. Menlo Park, Calif. The computing requirements are presently met by use of the National Center computer and by extensive contracting with local commercial or Government computer facilities. Much of the workload has for years been processed at local facilities such as NASA-Ames, Lawrence Berkeley Labs, and Stanford University, but it is doubtful that they will be able to handle the rapidly increasing workload. A large computer will be installed to meet the long-range needs of the Menlo Park users.
2. Rolla, Mo. An IBM 360/20 computer terminal has been in operation for a number of years, but a more flexible computer system is necessary for the continued improvement of the Midcontinent Mapping Center. Increased computer capacity will make possible the implementation of new methods of analytical aerotriangulation and more efficient operational procedures.
3. Sioux Falls, S. Dak. The present IBM 360/30 computer is used extensively to catalog the data of both EROS and ERTS, to answer requests and fill orders from the public, and to schedule the operation of the EROS Data Center. The workload has saturated the present system; a larger capacity computer will lessen the operational problems.

U.S. GEOLOGICAL SURVEY PUBLICATIONS

PUBLICATIONS PROGRAM

Books and maps

Results of research and investigations by the U.S. Geological Survey are made available to the public through professional papers, bulletins, water-supply papers, circulars, miscellaneous reports, and several map and atlas series, most of which are published by the Geological Survey. Of these reports, books are printed and sold by the U.S. Government Printing Office, and maps are printed and sold by the Survey.

All books, maps other than topographic quadrangle maps, and related Geological Survey publications are listed in the catalog "Publications of the Geological Survey, 1879–1961" and "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 (STOP 329), Reston, VA 22092.*

State list of publications on hydrology and geology

"Geologic and Water-Supply Reports and Maps, [State]," a series of booklets, provides a ready reference to these publications on a State basis. The booklets also list libraries in the subject State where 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-yr intervals. The first group of "Surface Water Supply" papers covers the water years 1961–65.

Publication of quality-of-water records began in the annual State series in 1964 as "Water Resources Data for [State]: Part 2, Water Quality Records." The annual publication in the 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. 302–304) 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, 1200 South Eads Street, Arlington, VA 22202.* 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 (STOP 435), Reston, VA 22092,* or to the Water Resources Division district offices listed on pages 302–304.

Open-file reports

Open-file reports, which consist of manuscript reports, maps, and other preliminary material, are made available for public consultation and use. Arrangements can generally be made to reproduce them at private expense. The date of release and places of availability for consultation are given in news releases or other forms of public announcement. Since May 1974, all reports and maps released only in the open files have been listed monthly in "New Publications of the Geological Survey." For reports issued before this date, a listing has been published annually in the circular series. Most open-file reports are placed in one or more of the three Geological Survey libraries: National Center, Reston, Va.; Building 25, Denver 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 298–304 and interested State agencies. Many open-file reports are superseded later by formally printed publications.

Journal of Research of the U.S. Geological Survey

The "Journal of Research of the U.S. Geological Survey" is a bimonthly periodical designed to provide relatively rapid publication of short scientific papers by Survey personnel. It replaces the short-papers chapters of the annual Geological Survey Research series of professional papers.

Earthquake Information Bulletin

The "Earthquake Information Bulletin" is published bimonthly by the Geological Survey to provide current information on earthquakes and seismological activities of interest to both general and specialized readers. It also lists pertinent publications and selected future professional meetings of earth science groups.

PUBLICATIONS ISSUED

During fiscal year 1974, the Geological Survey published 5,363 maps comprising some 19,962,751 copies, as follows:

Kind of map	1974
Topographic	4,774
Geologic and hydrologic	516
Maps for inclusion in book reports	33
Miscellaneous (including maps for other agencies)	40
Total	5,363

In addition, 6 issues of the Journal of Research comprising about 43,000 copies, 3 issues of the "Earthquake Information Bulletin" comprising about 30,000 copies, 145 technical book reports, and 3,746 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 9,903,350 copies of maps, including 505,425 index maps, were distributed. Approximately 7.3 million maps were sold, and $3,193,715 was deposited to Miscellaneous Receipts in the U.S. Treasury.

The Survey also distributed 399,250 copies of technical book reports, without charge and for official use, and 1,224,250 copies of booklets, free of charge, chiefly to the general public; 218,300 copies of the monthly publications announcements and 147,000 copies of a sheet showing topographic map symbols were sent out.

The total distribution resulted from receipt of 624,950 individual orders. The following table compares Survey map and book distribution (including booklets but excluding symbol sheets and monthly announcements) during fiscal years 1973 and 1974.

Distribution points	Fiscal year 1973	Fiscal year 1974	Change (percent)
Eastern (Arlington, Va.)	6,522,161	6,010,586	− 8
Central (Denver, Colo.)	5,614,462	4,598,479	−18
Alaska (Fairbanks)	128,205	123,317	− 4
12 other Survey offices	839,335	794,435	− 5
Total	13,104,163	11,526,817	−12

HOW TO OBTAIN PUBLICATIONS

OVER THE COUNTER

Book reports and periodicals

Book reports and issues of the journal and the bulletin currently in print (professional papers, bulletins, water-supply papers, "Topographic Instructions," "Techniques of Water-Resources Investigations," "Journal of Research of the U.S. Geological Survey," "Earthquake Information Bulletin," and some miscellaneous reports) can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C., and publications other than the periodicals can also be purchased from the Geological Survey Public Inquiries Offices listed on pages 301, 302.

Maps and charts

Maps and charts may be purchased at the following U.S. Geological Survey offices:

1200 South Eads St., Arlington, Va.

Room 1028, General Services Administration Bldg., 19th and F Sts., NW., Washington, D.C.

National Center (STOP 302), 12201 Sunrise Valley Dr., Reston, Va.

900 Pine St., Rolla, Mo.

Building 41, Denver Federal Center, Denver, Colo.

345 Middlefield Rd., Menlo Park, Calif.
Room 441, Federal Bldg., 710 West Ninth St., Juneau, Alaska
310 First Ave., Fairbanks, Alaska
Public Inquiries Offices listed on pages 301, 302.

Geological Survey maps are also sold by more than 1,400 authorized commercial dealers throughout the United States. Prices charged are generally higher than those charged by Geological Survey offices.

Indexes showing topographic maps published for each State, Puerto Rico, the Virgin Islands (U.S.), Guam, American Samoa, and Antarctica are available free on request. Publication of revised indexes to topographic mapping is announced in the monthly "New Publications of the Geological Survey." Each index also lists special and United States maps, as well as Geological Survey offices from which maps may be purchased and local dealers who sell the Survey's maps.

BY MAIL

Book reports

Technical book reports, certain leaflets in bulk quantity, and some miscellaneous reports can be ordered from the *Superintendent of Documents, Government Printing Office, Washington, DC 20402.* Prepayment is required and should be made by check or money order payable to the Superintendent of Documents. Postage stamps are not accepted; cash is sent at the sender's risk. On orders of 100 copies or more of the same report, a 25-percent discount is allowed. Circulars and some miscellaneous reports may be obtained free from the *U.S. Geological Survey, Branch of Distribution, 1200 South Eads Street, Arlington, VA 22202.*

Maps and charts

Maps and charts, including folios and hydrologic atlases, are sold by the Geological Survey. Address orders to *U.S. Geological Survey, Branch of Distribution, 1200 South Eads St., Arlington, VA 22202,* for maps of areas east of the Mississippi River, including Minnesota, Puerto Rico, and the Virgin Islands (U.S.), and to *U.S. Geological Survey, Branch of Distribution, Denver Federal Center, Denver, CO 80225,* for maps of areas west of the Mississippi, including Alaska, Hawaii, Louisiana, Guam, and American Samoa. Residents of Alaska may also order maps of their State from the *U.S. Geological Survey, Alaska Distribution Section, 310 First Ave., Fairbanks, AK 99701.*

Prepayment is required. Remittances should be by check or money order payable to the U.S. Geological Survey. Prices are quoted in lists of publications and, for topographic maps, in indexes to topographic mapping for individual States. Prices include the cost of surface transportation.

Advance material from mapping

Advance material available from current topographic mapping is indicated on individual State index maps which are issued quarterly. This material, which includes such items as aerial photography, geodetic control data, and maps in various stages of preparation and editing, is available for purchase. 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 *National Cartographic Information Center, U.S. Geological Survey, National Center (STOP 507), Reston, VA 22092.*

EROS Data Center materials

Geological Survey aerial photography, NASA aircraft photography and imagery, ERTS imagery, and Skylab imagery and photography are sold by the Geological Survey, as are copies of the photography and imagery produced on 16-mm browse film, which are designed to provide prepurchase evaluation. ERTS Standard Catalogs are also sold. Address requests for current price list, additional information, and orders to *U.S. Geological Survey, EROS Data Center, Sioux Falls, SD 57198.* Prepayment is required for orders. Remittances should be made payable to the U.S. Geological Survey.

National Technical Information Service

Some Geological Survey reports, including computer programs, data and information supplemental to map or book publications, and data files, are released through the National Technical Information Service. These reports, available either in paper copies or in microfiche, or sometimes on magnetic tapes, can be purchased only from *U.S. Department of Commerce, National Technical Information Service, Springfield, VA 22161.* Geological Survey reports that are released through NTIS, together with their NTIS order numbers and prices, are announced in the monthly "New Publications of the Geological Survey."

Journal of Research of the U.S. Geological Survey and Earthquake Information Bulletin

Subscriptions to the "Journal of Research of the U.S. Geological Survey" and the "Earthquake Information Bulletin" are by application to the *Superintendent of Documents, Government Printing Office, Washington, DC 20402*. Payment is by check payable to the Superintendent of Documents or by charge to your deposit account number. Single issues may also be purchased from the Superintendent of Documents.

PUBLICATIONS OUT OF PRINT

Book publications listed as out of print can no longer be obtained from the Superintendent of Documents, Washington, D.C. However, some books listed as out of print are available for purchase from these authorized agents: U.S. Geological Survey offices at 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 South State St., Salt Lake City, UT 84138; Room 1C45, 1100 Commerce St., Dallas, TX 75202; Room 7638, Federal Bldg., 300 North Los Angeles St., Los Angeles, CA 90012; Room 504, Customhouse, 555 Battery St., San Francisco, CA 94111; Room 678, U.S. Courthouse, West 920 Riverside Ave., Spokane, WA 99201; and Room 108, Skyline Bldg., 508 Second 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 1974

[Cooperators listed are those with whom the U.S. Geological Survey had a written agreement for fiscal cooperation in fiscal year 1974, 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:
- Albuquerque Operations Office
- Division of Applied Technology
- Division of Headquarters Services
- Division of Reactor Research and Development
- Idaho Operations Office
- Nevada Operations Office
- Oak Ridge Operations Office
- Richland Operations Office
- Rocky Flats Division
- 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
- Edwards Air Force Base
- Eglin Air Force Base
- Headquarters (AFTAC/AC)
- Homestead Air Force Base
- Office of Scientific Research
- Rocket Propulsion Laboratory
- Vandenburg Air Force Base

Department of the Army:
- Army Electronics Command
- Army Research Office
- Cold Regions Research and Engineering Laboratory
- Corps of Engineers
- White Sands Missile Range

Department of Commerce, National Oceanic and Atmospheric Administration:
- Buoy Office
- Environmental Research Laboratories
- National Marine Fisheries Service
- National Ocean Survey
- National Weather Service

Department of Defense:
- Advanced Research Projects Agency
- Defense Intelligence 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 Reclamation
- Bureau of Sport Fisheries and Wildlife
- National Park Service
- Office of Saline Water
- Office of Water Resources Research
- Water Resources Council

Department of the Navy:
- Key West Naval Station
- Marine Corps, Camp Pendleton
- Naval Weapons Center
- Office of Naval Petroleum and Oil Shale Reserves
- Office of Naval Research
- Public Works Center, Guam

Department of State:
- Agency for International Development
- International Boundary and Water Commission
- International Joint Commission

Department of Transportation:
- Federal Highway Administration
- Office of the Secretary

Environmental Protection Agency:
- Management Division
- National Environmental Research Center
- Office of Radiation Programs
- 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 Forestry Commission
- 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
- City of Seward
- 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 Nogales
- 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
- Pima County Board of Supervisors
- San Carlos Irrigation and Drainage District
- Show Low Irrigation Company
- University of Arizona

Arkansas:
- Arkansas Department of Pollution Control and Ecology
- Arkansas Division of Soil and Water Resources
- Arkansas Geological Commission
- Arkansas State Highway Commission

California:
- Alameda County Flood Control and Water Conservation District
- Alameda County Water District
- Antelope Valley-East Kern Water Agency
- Berrenda Mesa Water District
- Big Bear Lake Pest Abatement District
- California Department of Conservation, Division of Mines and Geology
- California Department of Fish and Game
- California Department of Water Resources
- California Division of Highways, Materials and Research Department
- California Water Resources Control Board

California—Continued
- Casitas Municipal Water District
- Chino Basin 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
- County of Fresno
- County of Madera
- County of Modoc
- County of Sacramento, Department of Public Works
- County of San Diego, Board of Supervisors
- County of San Mateo
- Desert Water Agency
- East Bay Municipal Utility District
- Fern Valley Water District
- Georgetown Divide Public Utility District
- Goleta County Water District
- Hoopa Valley Tribe
- Imperial Irrigation District
- Indian Wells Valley County Water District
- Kern County Water Agency
- Lake County Flood Control and Water Conservation District
- Livermore Amador Valley Water Management Agency
- Los Angeles County, Department of County Engineers
- Los Angeles County Flood Control District
- Los Angeles Department of Water and Power
- Madera Irrigation District
- Merced Irrigation District
- Metropolitan Water District of Southern California
- Mojave Water Agency
- Montecito County Water District
- Monterey County Flood Control and Water Conservation District
- Napa County Flood Control and Water Conservation District
- Orange County Flood Control District
- Orange County Water District
- Oroville-Wyandotte Irrigation District
- Pacheco Pass Water District
- Paradise Irrigation District
- Placer County Department of Public Works
- Riverside County Flood Control and Water Conservation District
- San Benito County Water Conservation and Flood Control District
- San Bernardino County Flood Control District
- San Bernardino Valley Municipal Water District
- San Luis Obispo County 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

California—Continued
- Santa Cruz County Flood Control and Water Conservation District
- Santa Cruz County Planning Department
- Santa Margarita and San Luis Rey Watershed Planning Agencies
- Santa Maria Valley Water Conservation District
- Santa Ynez River Water Conservation District
- Siskiyou County Flood Control and Water Conservation District
- Solano Irrigation District
- Tehachapi-Cummings County Water District
- Terra Bella Irrigation District
- Tulare County Flood Control District
- Turlock Irrigation District
- United Water Conservation District
- University of California:
  - Department of Engineering
  - School of Forestry and Conservation
- Valley Community Services District
- Valley Sanitary District
- Ventura County Flood Control District, Riverside County
- Western Municipal Water District
- Woodbridge Irrigation District
- Yolo County Flood Control and Water Conservation District

Colorado:
- Arkansas River Compact Administration
- Cherokee Water District
- City and County of Denver, Board of Water Commissioners
- City of Aspen
- City of Aurora, Department of Public Utilities
- City of Colorado Springs, Department of Public Utilities
- City of Fort Collins
- City of Pueblo
- Colorado City Water and Sanitation District
- Colorado Department of Natural Resources:
  - Division of Water Resources
  - Division of Wildlife
  - Geological Survey
- Colorado Department of Public Health, Water Pollution Control Commission
- Colorado River Water Conservation District
- Colorado Water Conservation Board
- Lower South Platte Water Conservation District
- Northern Colorado Water Conservation District
- Pikes Peak Area Council of Governments
- Rio Grande Water Conservation District
- San Luis Valley Water Conservation District
- Southeastern Colorado Water Conservancy District
- Southwestern Water Conservation District
- State of Colorado, Department of Highways
- Teller County
- Urban Drainage and Flood Control District

Connecticut:
- City of Hartford, Department of Public Works
- City of New Britain, Board of Water Commissioners
- City of Torrington
- Connecticut Geological and Natural History Survey
- Department of Environmental Protection
- Department of Transportation

Connecticut—Continued
- State of Connecticut, Office of State Planning
- Town of Fairfield

Delaware:
- Delaware Geological Survey, University of Delaware
- Department of Highways and Transporation, Division of Highways

District of Columbia:
- Department of Environmental Services

Florida:
- Brevard County
- Broward County
- Broward County Air and Water Pollution Control Board
- Central and Southern Florida Flood Control District
- City of Boca Raton
- City of Clearwater
- City of Cocoa
- City of Deerfield Beach
- City of Fort Lauderdale
- City of Fort Myers
- City of Gainesville
- City of Hallandale
- City of Hollywood
- City of Jacksonville
- City of Juno Beach
- City of Miami, Department of Water and Sewers
- City of Pensacola
- City of Perry
- City of Pompano Beach
- City of Riviera Beach
- City of St. Petersburg
- City of Sarasota
- City of Tallahassee
- City of Tampa
- City of Temple Terrace
- City of West Palm Beach
- Collier County
- Collier County Water Management District No. 1
- Collier County Water Management District No. 7
- Department of Pollution Control
- East Central Florida Regional Planning Council
- Englewood Water District
- Escambia County
- Florida Department of Natural Resources:
  - Bureau of Geology
  - Division of Parks and Recreation
- Florida Department of Transportation
- Hillsborough County
- Jacksonville Area Planning Board
- Lake County
- Lake Worth Drainage District
- Lee County
- Loxahatchee River Environmental Control District
- Marion County
- Martin County
- Metropolitan Dade County
- Orange County
- Osceola County
- Palm Beach County
- Pinellas County

Florida—Continued
- Reedy Creek Improvement District
- Sarasota County
- Seminole County
- Southwest Water Management District
- Suwanee River Authority
- Tampa Bay Regional Planning Commission
- Tampa Port Authority
- Volusia County
- Walton County

Georgia:
- Chatham County
- City of Brunswick
- Dekalb County
- Department of Natural Resources:
  - Earth and Water Division
  - Environmental Protection Division
- Department of Transportation

Hawaii:
- City and County of Honolulu
- Honolulu Board of Water Supply
- State Department of Land and Natural Resources
- State Department of Transportation

Idaho:
- City of Kellogg
- Idaho Bureau of Mines and Geology
- 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
- Environmental Protection Agency
- Fountain Head Drainage District
- Fulton County
- Illinois Institute of Environmental Quality
- Kane County
- Lake County
- McHenry County Regional Planning Commission
- Sanitary District of Bloom Township
- State Department of Registration and Education:
  - Illinois State Geological Survey
  - Illinois State Water Survey
- State Department of Transportation:
  - Division of Highways
  - Division of Water Resources Management
- The Metropolitan Sanitary District of Greater Chicago
- University of Illinois at Urbana-Champaign

Indiana:
- City of Indianapolis
- Indiana Board of Health
- Indiana Department of Natural Resources
- Indiana Highway Commission

Iowa:
- City of Cedar Rapids
- City of Des Moines
- City of Fort Dodge

Iowa—Continued
- Iowa Geological Survey
- Iowa Natural Resources Council
- Iowa State Highway Commission, Highway Research Board
- Iowa State University
- Iowa State University, Agricultural and Home Economics Experiment Station
- Linn County
- University of Iowa, Institute of Hydraulic Research

Kansas:
- City of Wichita
- Kansas State Department of Health
- Kansas 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
- Louisiana Office of State Planning
- Louisiana State University
- Sabine River Authority of Louisiana
- Sabine River Compact Administration

Maine:
- Maine Department of Economic Development
- Maine Department of Transportation
- Maine Geological Survey
- Maine Public Utilities 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 Natural Resources, Division of Mineral Resources
- Department of Public Works:
  - Division of Highways
  - Division of Waterways
- Metropolitan District Commission
- State Water Resources Commission:
  - Division of Water Pollution Control
  - Division of Water Resources

Michigan:
- Michigan Department of Agriculture, Soil and Water Conservation Division
- Michigan Department of Natural Resources:
  - Geological Survey Division
  - Water Resources Commission

Minnesota:
- Metropolitan Council of the Twin Cities Area
- Metropolitan Sewer Board of the Twin Cities Area
- Minnesota Department of Highways
- Minnesota Department of Natural Resources, Division of Waters, Soils, and Minerals
- Minnesota Pollution Control Agency
- Minnesota State Planning Agency
- Pelican River Watershed District

Mississippi:
- City of Jackson
- Harrison County Development Commission
- Jackson County Board of Supervisors
- Jackson County Port Authority
- Mississippi Air and Water Pollution Control Commission
- Mississippi Board of Water Commissioners
- Mississippi Geological Survey
- Mississippi Research and Development Center
- Mississippi State Highway Department
- Mississippi State University
- Pat Harrison Waterway District
- Pearl River Basin Development District
- Pearl River Valley Water Supply District
- Yellow Creek Port Authority

Missouri:
- Curators of the University of Missouri
- Metropolitan St. Louis Sewer District
- Missouri Department of Business and Administration, Division of Geological Survey and Water Resources
- Missouri State Highway Commission
- Missouri Water Pollution Board
- St. Louis County

Montana:
- Endowment and Research Foundation—Montana State University
- Lewis and Clark County, Board of County Commissioners
- Montana Bureau of Mines and Geology
- Montana Department of Health and Environmental Sciences
- Montana Department of Intergovernmental Relations
- Montana Department of Natural Resources
- Montana State Fish and Game Department
- Montana State Highway Commission

Nebraska:
- Clay County Ground Water Conservation District
- Hamilton County Ground Water Conservation District
- Kansas-Nebraska Big Blue River Compact Administration
- Lower Platte South Natural Resources District
- Nebraska Department of Environmental Control
- Nebraska Department of Water Resources
- Nebraska Game and Parks Commission
- Nebraska Natural Resources Commission
- Seward County Ground Water Conservation District
- State Department of Roads
- University of Nebraska, Conservation and Survey Division
- Upper Big Blue Natural Resources District
- York County Ground Water Conservation District

Nevada:
- Nevada Bureau of Mines

Nevada—Continued
- 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:
- Bergen County
- Camden County Board of Freeholders
- Delaware River Basin Commission
- New Jersey Department of Agriculture, State Soil Conservation Committee
- New Jersey Department of Environmental Protection
- New Jersey Department of Transportation
- North Jersey District Water Supply Commission
- Passaic Valley Water Commission
- Rutgers State University
- Township of Cranford

New Mexico:
- Albuquerque Metropolitan Arroyo Flood Control Authority
- City of Las Cruces
- Costilla Creek Compact Commission
- Elephant Butte Irrigation District
- Interstate Stream Commission
- New Mexico Bureau of Mines and Mineral Resources
- New Mexico State Engineer
- New Mexico State Highway Department
- Pecos River Commission
- Rio Grande Compact Commission
- University of New Mexico

New York:
- Board of Hudson River—Black River Regulating District
- Central New York State Parks Commission
- City of Albany
- City of Auburn
- City of New York:
  - Board of Water Supply
  - Environmental Protection Agency
- County of Chautauqua
- County of Cortland
- County of Dutchess:
  - Board of Supervisors
  - Department of Public Works
- County of Nassau, Department of Public Works
- County of Onondaga:
  - Department of Public Works
  - Water Authority
- County of Orange
- County of Suffolk:
  - Department of Environmental Control
  - Water Authority
- County of Ulster, Ulster County Legislature
- County of Westchester, Department of Public Works
- County of Wyoming
- Department of Environmental Conservation:
  - Environmental Management

New York—Continued
- Department of Environmental Conservation—Continued
  - 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 Middlebury
- Town of Warwick
- Village of Nyack

North Carolina:
- City of Asheville, Public Works Department
- City of Burlington
- City of Charlotte
- City of Durham, Department of Water Resources
- City of Greensboro
- City of Winston-Salem
- North Carolina Department of Conservation and Development, Division of Mineral Resources
- North Carolina Department of Natural and Economic Resources, Office of Earth Resources
- North Carolina Department of Water and Air Resources
- State Department of Transportation
- 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 Corvallis
- City of Eugene, Water and Electric Board
- City of McMinnville, Water and Light Department
- City of Portland, Bureau of Water Works
- City of The Dalles

Oregon—Continued
- 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

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 Office of State Planning and Development
- Susquehanna River Basin Commission

Rhode Island:
- City of Providence, Department of Public Works
- State Department of Natural Resources:
  - Division of Fish and Wildlife
  - Division of Planning and Development
- State Department of Transportation, Division of Roads and Bridges
- State Water Resources Board

South Carolina:
- Commissioners of Public Works, Spartanburg Water Works
- State Highway Department
- State Land Resources Conservation Commission
- State Pollution Control Authority
- State Public Service Authority
- State Water Resources Commission

South Dakota:
- Black Hills Conservancy Subdistrict
- City of Sioux Falls
- City of Watertown
- East Dakota Conservancy Subdistrict
- South Dakota Department of Natural Resource Development
- South Dakota Department of Transportation

Tennessee:
- City of Chattanooga
- City of Lawrenceburg
- City of Manchester
- City of Memphis, Board of Light, Gas, and Water Commissioners
- Lincoln County

Tennessee—Continued
- 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
- Tennessee State Planning Office

Texas:
- City of Dallas, Public Works Department
- City of Fort Worth
- City of Houston
- County of Dallas
- Sabine River Compact Administration
- Texas Highway Department
- Texas Water Development Board

Utah:
- Bear River Commission
- Salt Lake County
- State Department of Highways
- State Department of Natural Resources, Division of Water Rights
- Utah Geological and Mineralogical Survey
- Utah Legislative Council

Vermont:
- State Department of Highways
- State Department of Water Resources, Planning and Development Division
- Vermont Geological Survey

Virginia:
- City of Alexandria
- City of Newport News, Department of Public Utilities
- City of Norfolk:
  - Department of Utilities
  - Division of Water Supply
- City of Roanoke
- City of Staunton
- County of Chesterfield
- County of Fairfax
- Virginia Department of Conservation and Economic Development, Division of Mineral Resources
- Virginia Department of Highways
- Virginia Polytechnic Institute and State University
- Virginia State Water Control Board

Washington:
- City of Port Angeles
- City of Seattle, Department of Lighting
- City of Tacoma:
  - Department of Public Utilities
  - Department of Public Works
- Clark County Public Utility District
- Coleville Business Council
- Cowlitz County Public Utility District
- Municipality of Metropolitan Seattle
- Quinault Business Committee
- Squaxin Indian Tribe
- The Evergreen State College
- Washington State Department of Ecology

Washington—Continued
- Washington State Department of Fisheries
- Washington State Department of Game
- Washington State Department of Highways
- Washington State Department of Natural Resources, Division of Mines and Geology
- Yakima Tribal Council

West Virginia:
- Clarksburg Water Board
- Morgantown Water Commission
- West Virginia Department of Highways
- West Virginia Department of Natural Resources, Division of Water Resources
- West Virginia Geological and Economic Survey

Wisconsin:
- City of Madison
- City of Middleton
- Dane County
- Douglas County
- Madison Metropolitan Sewerage District
- Southeastern Wisconsin Regional Planning Commission
- State Department of Natural Resources
- State Department of Transportation, Division of Highways
- The University of Wisconsin-Extension, Geological and Natural History Survey

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 Department of Environmental Quality
- Wyoming State Engineer

OTHER COOPERATORS AND CONTRIBUTORS

Appalachian Regional Commission

Government of American Samoa

Government of Guam

Government of Jordan

Government of Oman

Government of Saudi Arabia

Government of Yemen

Ozarks Regional Commission

Permittees and licensees of the Federal Power Commission

Puerto Rico:
- Puerto Rico Department of Natural Resources
- Puerto Rico Environmental Quality Board

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: Denver Federal Center, Denver, Colo. 80225; 303 234-3131
Western Region: 345 Middlefield Road, Menlo Park, Calif. 94025; 415 323-8111

HEADQUARTERS OFFICES

Office	*Official in charge and telephone number*	*Address*
Administrative Division	Edmund J. Grant (703 860-7201)	National Center, STOP 201.
Computer Center Division	Carl E. Diesen (703 860-7106)	National Center, STOP 801.
Conservation Division	Russell G. Wayland (703 860-7524)	National Center, STOP 600.
Earth Resources Observation Systems Program.	John M. DeNoyer (703 860-7881)	1925 Newton Sq. East, Reston, Va. 22090.
Geographic Applications Program	James R. Anderson (703 860-6344)	National Center, STOP 115.
Geologic Division	Richard P. Sheldon (703 860-6531)	National Center, STOP 911.
Publications Division	Harry D. Wilson, Jr. (703 860-7181)	National Center, STOP 341.
Resource and Land Information Program.	J. Ronald Jones (703 860-7435)	National Center, STOP 105.
Topographic Division	R. H. Lyddan (703 860-6231)	National Center, STOP 516.
Water Resources Division	Joseph S. Cragwell, Jr. (703 860-6921).	National Center, STOP 409.

SELECTED FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices are not included; list is current as of July 1, 1974. Correspondence to the following offices should be addressed to the Post Office Box, if one is given]

COMPUTER CENTER DIVISION

Location	*Official in charge and telephone number*	*Address*
Arizona, Flagstaff 86001	James E. Crawforth (602 774-1312)	601 East Cedar Ave.
California, Menlo Park 94025	James L. Mueller (415 323-2661)	345 Middlefield Rd.
Colorado, Denver 80225	Frederick B. Sower (303 234-2551)	Rm. E2608, Bldg. 53, Denver Federal Center.
Missouri, Rolla 65401	Glenn A. Ridgeway (314 364-6985)	P.O. Box 41.
South Dakota, Sioux Falls 57198	Ralph J. Thompson (605 594-6555)	EROS Data Center.

CONSERVATION DIVISION

REGIONAL OFFICES

Location	*Official in charge and telephone number*	*Address*
Central Region: Denver, CO 80225	George H. Horn, Regional Conservation Manager (303 234-2855).	Bldg. 25, Denver Federal Center.
Eastern Region: Washington, DC 20006	George F. Brown, Regional Conservation Manager (202 343-4685).	Suite 316, 1825 K St., NW.
Gulf of Mexico Outer Continental Shelf Operations: Metairie, LA 70011	Robert F. Evans, Conservation Manager (504 589-3381).	P.O. Box 7944; 336 Imperial Office Bldg., 3301 North Causeway Blvd.
Western Region: Menlo Park, CA 94025	Willard C. Gere, Regional Conservation Manager (415 323-2108).	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; 212 Skyline Bldg., 218 E St.
Arizona, Phoenix 85004	Donal F. Ziehl (602 261-3766)	Rm. 208, 522 North Central Ave.
California, Los Angeles 90012	Fred J. Schambeck, Keith A. Yenne (213 688-2846).	Rm. 7744, Federal Bldg., 300 North Los Angeles St.
Bakersfield 93301	Donald F. Russell (805 861-4186)	Rm. 309, Federal Bldg., 800 Truxtun Ave.
Menlo Park 94025	Leo H. Saarela (415 323-2563). Henry L. Cullins, Jr., Reid T. Stone (415 323-2108).	345 Middlefield Rd.
Sacramento 95825	Robert D. Morgan, acting (916 484-4219).	Rm. W-2231, Federal Bldg., 2800 Cottage Way.
Colorado, Denver 80225	James A. Carter, acting (303 234-4435). John P. Storrs (303 234-3984). Sterling R. Osborne (303 234-5042). Daniel A. Jobin (303 234-4435).	Bldg. 25, Denver Federal Center.
Durango 81302	Jerry W. Long (303 247-5144)	P.O. Box 1809; 125 West 10th St.
Grand Junction 81501	Peter A. Rutledge, James W. Hager (303 242-0731).	P.O. Box 2939; Federal Bldg., 4th St. and Rood Ave.
Idaho, Pocatello 83201	John T. Skinner (208 235-6262)	P.O. Box 1610; Federal Bldg., 150 South Arthur St.
Louisiana, Houma 70360	John Borne (504 868-4033)	P.O. Box 1269.
Lafayette 70501	Elmo G. Hubble (318 232-6037)	P.O. Box 52289; 239 Bendel Rd.
Lake Charles 70601	Robert Darrow (318 478-6440)	P.O. Box 6088, Drew Station.
Metairie 70011	Harry McAndrews (504 589-3341). Donald W. Solanas (504 589-3333). Jake B. Lowenhaupt (504 589-3251).	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)	P.O. Box 1716; Federal Bldg., 114 South Halagueno St.

Location	Responsible officials and telephone numbers	Address
New Mexico—Continued		
Farmington 87401	J. E. Fassett, Philip T. McGrath (505 325-4572).	P.O. Box 959; Petroleum Club Plaza, 3535 East 30th St.
Hobbs 88240	Arthur R. Brown (505 393-3612)	P.O. Box 1157; 205 North Linam St.
Roswell 88201	N. O. Frederick, Donald M. VanSickle (505 622-9257).	Drawer 1857; Federal Bldg. and U.S. Courthouse, Richardson Ave. at 5th St.
Oklahoma, McAlester 74501	Alexander M. Dinsmore (918 423-5030).	P.O. Box 816; 509 South 3d St.
Oklahoma City 73118	Charley W. Nease (405 231-4806)	Suite 404, 50 Penn Pl.
Tulsa 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 3202, 830 NE. Holladay St.
Texas, Freeport 77541	George Kinsel (713 233-2604)	P.O. Box 2006.
Utah, Salt Lake City 84138	Howard F. Albee (801 524-5643). Edward Guynn (801 524-5650). Jackson W. Moffitt (801 524-5646).	Rm. 8422, 8426, and 8432, Federal Bldg., 125 South State St.
Washington, Tacoma 98401	Gordon C. Giles (206 593-6500)	P.O. Box 1152; Rm. 244, Federal Bldg.
Wyoming, Casper 82601	Charles J. Curtis (307 265-3247). Elmer M. Schell (307 265-3421).	P.O. Box 2859 and 2373; Rm. 2002 and 2001, Federal Bldg. and Post Office, 100 East B St.
Newcastle 82701	Glenn E. Worden (307 746-2737)	P.O. Box 219; Suite 201, 110½ West Main St.
Rock Springs 82901	John A. Fraher (307 362-6422). Arne A. Mattila (307 362-7350).	P.O. Box 1170; Rm. 201 and 204, First Security Bank Bldg., 502 South Front St.
Thermopolis 82443	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, National Space Technology Laboratories.
South Dakota, Sioux Falls 57198	Allen H. Watkins (605 594-6123)	EROS Data Center.

GEOLOGIC DIVISION

REGIONAL OFFICES

Location	Official in charge and telephone number	Address
Central Region:		
Denver, CO 80225	Ralph L. Erickson, Regional Geologist (303 234-3624).	Bldg. 25, Denver Federal Center.
Eastern Region:		
Reston, VA 22092	Eugene H. Roseboom, Jr., Regional Geologist (703 860-6631).	National Center, 12201 Sunrise Valley Dr., STOP 953.
Western Region:		
Menlo Park, CA 94025	David L. Jones, Regional Geologist (415 323-2214).	345 Middlefield Rd.

OFFICES

Location	Official in charge and telephone number	Address
Alaska, Anchorage 99501	Donald H. Richter (907 272-8228)	216 Skyline Bldg., 218 E St.

Location	Official in charge and telephone number	Address
Alaska–Continued		
College 99701	Florence R. Weber (907 479-7245)	P.O. Box 80586.
Arizona, Flagstaff 86001	Michael H. Carr (602 774-5261, ext. 1455).	601 East Cedar Ave.
Arkansas, Little Rock 72201	Boyd R. Haley (501 371-1616)	3815 West Roosevelt Rd.
California, La Jolla 92037	George W. Moore (714 453-2820, ext. 341).	P.O. Box 271; 8604 La Jolla Shores Dr.
San Francisco 94105	Ralph B. Matthiesen (415 556-7725)	Rm. 7067, 390 Main St.
Colorado, Boulder 80302	Sylvester T. Algermissen (303 499-6204).	R 10X4, RB3-A436.
Connecticut, Middletown 06457	Fred Pessl, Jr. (203 346-5542)	P.O. Box 470.
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 (617 548-3705)	U.S. Geological Survey, Woods Hole Oceanographic Institution.
New Mexico, Albuquerque 87115	Jon R. Peterson (505 264-4637)	Albuquerque Seismological Center, Kirtland AFB, East Bldg. 10002.
Ohio, Columbus 43210	James M. Schopf (614 421-2393)	Orton Hall, Ohio State Univ., 155 South Oval Dr.
Pennsylvania, Carnegie 15106	Reginald P. Briggs (412 644-2920)	P.O. Box 420.
Puerto Rico, San Juan 00936	John M. Aaron (809 766-5340)	GPO Drawer 2230.
Tennessee, Knoxville 37902	Robert A. Laurence (615 524-4011, 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, Seattle 98195	Thane H. McCulloh (206 543-5059)	Dept. of Oceanography, WB 10, Univ. of Washington.
Spokane 99201	Albert E. Weissenborn (509 456-4677).	West 920 Riverside Ave.
Wyoming, Laramie 82070	J. David Love (307 745-4495)	Box 3007, Univ. Station, Geology Hall, Univ. of Wyoming.

PUBLICATIONS DIVISION

PUBLIC INQUIRIES OFFICES

[Each of the following offices provides over-the-counter sales service for Survey book reports and geologic and topographic maps relating to its geographic area, and for selected Survey reports of general interest]

Location	Official in charge and telephone number	Address
Alaska, Anchorage 99501	Margaret I. Erwin (907 277-0577)	Rm. 108, Skyline Bldg., 508 2d Ave.
California, Los Angeles 90012	Lucy E. Birdsall (213 688-2850)	Rm. 7638, Federal Bldg., 300 North Los Angeles St.
San Francisco 94111	Jean V. Molleskog (415 556-5627)	Rm. 504, Customhouse, 555 Battery St.
Colorado, Denver 80202	Sylvia T. Huhta (303 837-4169)	Rm. 1012, Federal Bldg., 1961 Stout St.
District of Columbia, Washington 20244.	Bruce A. Hubbard (202 343-8073)	Rm. 1028, GSA Bldg., 19th and F Sts., NW.
Texas, Dallas 75202	Mildred V. Smith (214 749-3230)	Rm. 1C45, 1100 Commerce St.
Utah, Salt Lake City 84138	Wendy R. Hassibe (801 524-5652)	Rm. 8102, Federal Bldg., 125 South State St.
Virginia, Reston 22092[1]	A. Ernestine Jones (703 860-6167)	Rm. 1C402, National Center, 12201 Sunrise Valley Dr.

[1]Maps only.

Location	*Official in charge and telephone number*	*Address*
Washington, Spokane 99201	Eula M. Thune (509 456-2524)	Rm. 678, U.S. Courthouse, 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[2]	John J. Curry (703 557-2751)	1200 South Eads St.
Colorado, Denver 80225[3]	Dwight F. Canfield (303 234-3832)	Bldg. 41, Denver Federal Center.
Alaska, Fairbanks 99701[4]	Natalie A. Cornforth (907 452-1951, ext. 174).	310 First Ave.

TOPOGRAPHIC DIVISION

State	*Engineer in charge and telephone numbers*	*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, Denver Federal Center.
Missouri, Rolla 65401	A. Carroll McCutchen (314 364-3680).	P.O. Box 133; 9th and Pine Sts.
South Dakota, Sioux Falls 57198	Allen H. Watkins (605 594-6123)	EROS Data Center.
Virginia, Reston 22090	Roy E. Fordham (703 471-1711)	1925 Newton Sq. East.
Reston 22092	Peter F. Bermel (703 860-6352)	National Center, 12201 Sunrise Valley Dr., STOP 567.

WATER RESOURCES DIVISION

REGIONAL OFFICES

Location	*Official in charge and telephone number*	*Address*
Northeastern Region: Reston, VA 22092	Joseph T. Callahan, Regional Hydrologist (703 860-6985).	National Center, 12201 Sunrise Valley Dr., STOP 433.
Southeastern Region: Atlanta, GA 30309	Rolland W. Carter, Regional Hydrologist (404 526-5395).	Suite 200, 1459 Peachtree St. NE.
Central Region: Denver, CO 80225	Alfred Clebsch, Jr., Regional Hydrologist (303 234-3661).	Bldg. 25, Denver 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 (205 345-8257)	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.

[2]For maps of areas east of the Mississippi River (including Minnesota).
[3]For maps of areas west of the Mississippi River (including Louisiana).
[4]For residents of Alaska.

Location	*Official in charge and telephone number*	*Address*
Arkansas, Little Rock 72201	Richard T. Sniegocki (501 378-5246).	Rm. 2301, Federal Office Bldg., 700 West Capitol Ave.
California, Menlo Park 94025	Lee R. Peterson (415 323-8111, ext. 2326, 2327, 2465, 2466).	855 Oak Grove Ave.
Colorado, Denver 80225	James E. Biesecker (303 234-3815)	Bldg. 25, Denver Federal Center.
Connecticut, Hartford 06101	Frederick H. Ruggles, Jr. (203 244-2528).	P.O. Box 715; Rm. 235, Post Office Bldg., 135 High St.
Delaware	Walter F. White, Jr. (301 661-4664)	See Maryland District Office.
District of Columbia	do	Do.
Florida, Tallahassee 32303	Clyde S. Conover (904 377-4251)	Suite F-240, 325 John Knox Rd.
Georgia, Atlanta 30340	John R. George (404 526-4858)	Suite B, 6481 Peachtree Industrial Blvd.
Hawaii, Honolulu 96815	Frank T. Hidaka (808 955-0251).	1833 Kalakaua Ave.
Idaho, Boise 83724	Hal K. Hall (208 342-2538)	P.O. Box 036, FBUSCH; Rm. 365, Federal Bldg. and U.S. Courthouse, 550 West Fort St.
Illinois, Champaign 61820	Lawrence A. Martens (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.
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 Pl.
Louisiana, Baton Rouge 70806	Albert N. Cameron (504 348-4281)	P.O. Box 66492; 6554 Florida Blvd.
Maine, Augusta 04330	Gordon S. Hayes (207 622-6171)	State House Annex, Capitol Shopping Center.
Maryland, Parkville 21234	Walter F. White, Jr. (301 661-4664)	8809 Satyr Hill Rd.
Massachusetts, Boston 02114	John A. Baker (617 223-2822)	Suite 1001, 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	John A. Baker (617 223-2822)	See Massachusetts District Office.
New Jersey, Trenton 08607	John E. McCall (609 599-3511, ext. 212).	P.O. Box 1238; Rm. 420, Federal Bldg., 402 East State St.
New Mexico, Albuquerque 87106	William E. Hale (505 247-2246)	P.O. Box 4369; Geology Bldg., Univ. of New Mexico.
New York, Albany 12201	Robert J. Dingman (518 472-3107)	P.O. Box 1350; Rm. 343, U.S. Post Office and Courthouse.
North Carolina, Raleigh 27602	Ralph C. Heath (919 755-4510)	P.O. Box 2857; Rm. 440, Century Sta. Post Office Bldg.
North Dakota, Bismarck 58501	Quentin F. Paulson (701 255-4011, ext. 227, 228).	P.O. Box 778; Rm. 348, New Federal Bldg., 3d St. and Rosser Ave.
Ohio, Columbus 43212	James F. Blakey (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. Courthouse, 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	John A. Baker (617 223-2822)	See Massachusetts District Office.

Location	*Official in charge and telephone number*	*Address*
South Carolina, Columbia 29201	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	Stanley P. Sauer (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 84138	Theodore Arnow (801 524-5663)	Rm. 8002, Federal Bldg., 125 South State St.
Vermont	John A. Baker (617 223-2822)	See Massachusetts District Office.
Virginia, Richmond 23220	William E. Forrest (804 782-2427)	Rm. 304, 200 West Grace St.
Washington, Tacoma 98402	Leslie B. Laird (206 593-6510)	Rm. 300, 1305 Tacoma Ave., South.
West Virginia, Charleston 25301	Edwin E. Harris (304 343-1310, 1311).	Rm. 3303, Federal Bldg. and U.S. Courthouse, 500 Quarrier St., East.
Wisconsin, Madison 53706	Charles L. R. Holt, Jr. (608 262-2488).	Rm. 200, 1815 University Ave.
Wyoming, Cheyenne 82001	Samuel W. West (307 778-2111)	P.O. Box 2087; 4015 Warren Ave.

OFFICES IN OTHER COUNTRIES

GEOLOGIC DIVISION

Location	*Officer in charge*	*Address*
Brazil, Rio de Janerio	S. Anthony Stanin	U.S. Geological Survey, USAID/Rio de Janerio/ENGR, APO New York 09676.
Colombia, Bogotá	Maurice M. Brock	U.S. Geological Survey, USAID, c/o American Embassy, APO New York 09895.
Indonesia, Bandung	Paul W. Richards	U.S. Geological Survey, c/o American Embassy, USAID/ENGR, APO San Francisco 96356.
Saudi Arabia, Jiddah	Thor H. Kiilsgaard	U.S. Geological Survey, c/o American Embassy, APO New York 09697.
Thailand, Bangkok	Joseph O. Morgan	Office of Agricultural Development, USOM—Thailand, APO San Francisco 96346.

WATER RESOURCES DIVISION

Location	*Officer in charge*	*Address*
Brazil, Rio de Janerio	Don C. Perkins	U.S. Geological Survey, USAID/Rio de Janeiro/ENGR, APO New York 09676.
Kenya, Nairobi	Neal E. McClymonds	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.
Yemen, Sanaa	James R. Jones	U.S. Geological Survey, USAID/Sanaa, Agency for International Development, Washington, DC 20521.

INVESTIGATIONS IN PROGRESS IN THE GEOLOGICAL SURVEY

Investigations in progress during fiscal year 1974 are listed below, together with the names and headquarters of the individuals in charge of each. Headquarters at main centers are indicated by (NC) for the National Center in Reston, Va., (D) for Denver, Colo., and (M) for Menlo Park, Calif.; headquarters in other cities are indicated by name (see list of offices, p. 298, for addresses). Inquiries regarding projects for which no address is given in the list of offices should be directed to the appropriate Division of the Geological Survey, Reston, Va. 22092. The lowercase letter after the name of the project leader shows the Division technical responsibility: c, Conservation Division; e, EROS Program; g, Geographic Applications Program; w, Water Resources Division; no letter, Geologic Division.

The projects are classified by principal topic. Most geologic-mapping projects involve special studies of stratigraphy, petrology, geologic structure, or mineral deposits, but are listed only under "Geologic Mapping" unless a special topic or commodity is the primary justification for the project. A reader interested in investigations of volcanology, for example, should look under the heading "Geologic Mapping" for projects in areas of volcanic rocks, as well as under the heading "Volcanology." Likewise, most water-resources investigations involve special studies of several aspects of hydrology and geology, but are listed only under "Water Resources" unless a special topic—such as floods or sedimentation—is the primary justification for the project.

Areal geologic mapping is subdivided into mapping at scales smaller than 1:62,500 (for example, 1:250,000), and mapping at scales of 1:62,500, or larger (for example, 1:24,000).

Abstracts. *See* Bibliographies and abstracts.
Aluminum:
  Resources of the United States (S. A. Patterson, NC)
Analytical chemistry:
  Activation analysis (J. J. Rowe, NC)
  Analytical methods—water chemistry (M. W. Skougstad, w, D)
  Analytical services and research (J. I. Dinnin, NC; 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, NC)
  Mineral deposits, characteristic analysis (J. M. Botbol, NC)
  Natural organic, macromolecules in water (R. L. Wershaw, w, D)
  Organic geochemistry and infrared analysis (I. A. Breger, NC)
  Organic substances in water (D. F. Goerlitz, w, M)
  Plant laboratory support (J. J. Connor, D)
  Radioactivation and radiochemistry (H. T. Millard, D)
  Reactor support (L. L. Thatcher, w, D)
  Rock chemical analysis:
    General (D. R. Norton, D)
    Rapid (L. Shapiro, NC)
  Sample control (H. Bastron, M)
  Services (J. L. Ramisch, NC; L. B. Riley, D)
  Spectrochemistry (E. L. Mosier, D)
  Trace analysis methods, research (F. N. Ward, D)
  Ultratrace analysis (H. T. Millard, D)
  X-ray spectrometer for Viking lander (P. Toulmin, III, NC)
  See also Spectroscopy.
Arctic engineering geology (R. Kachadoorian, M)
Barite:
  Geology, geochemistry, and resources of barite (D. A. Brobst, NC)
Base metals. *See base-metal names.*
Bibliographies and abstracts:
  Geophysical abstracts (J. W. Clarke, NC)
  Lunar bibliography (J. H. Freeberg, M)
  Vanadium, geology and resources, bibliography (J. P. Ohl, D)
  Water-resources selected abstracts, bibliography, index, input to Water Resources Scientific Information Center (J. C. Kammerer, w, NC)
  State:
  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, NC)
  Bentonite, resource evaluation in Rocky Mountain region (C. A. Wolfbauer, D)
  State:
  Georgia, kaolin investigations (S. H. Patterson, NC)
Coal:
  Resources of the United States (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)
  Colorado:
    Brook Cliffs coal field (G. D. Fraser, c, D)
    Buckhorn Lakes quadrangle (R. G. Dickinson, c, D)
    Citadel Plateau (G. A. Izett, c, D)
    Courthouse Mountain quadrangle (R. G. Dickinson, c, D)
    Danforth Hills area (M. J. Reheis, c, D)

Coal—Continued
States—Continued
Colorado—Continued
- Denver basin, Tertiary coal zone (P. E. Soister, c, D)
- Disappointment Valley, eastern (D. E. Ward, D)
- Douglas Creek Arch area (B. E. Barnum, c, D)
- Little Snake River coal field (C. S. V. Barclay, c, D)
- Middle Park—North Park area (G. A. Izett, c, D)
- North Park area (D. Hill, c, D)
- Savery quadrangle (C. S. V. Barclay, c, D)
- Smizer Gulch and Rough Gulch quadrangles (W. J. Hail, D)
- Washboard Rock quadrangle (R. G. Dickinson, c, D)
- Watkins and Watkins SE quadrangles (P. E. Soister, c, D)
- Yampa coal field (M. E. Brownfield, c, D)

Montana:
- Decker quadrangle (B. E. Law, c, Casper, Wyo.)
- Hardy quadrangle (K. S. Soward, c, Casper, Wyo.)
- Jordan quadrangle (G. D. Mowat, c, Billings)
- Monarch quadrangle (B. E. Barnum, c, D)
- Pearl School quadrangle (G. L. Galyardt, c, Casper, Wyo.)
- Rocky Reef quadrangle (K. S. Soward, c, Casper, Wyo.)

New Mexico:
- Gallup East quadrangle (E. D. Patterson, c, Roswell)
- Gallup West quadrangle (J. E. Fassett, c, Farmington)
- Manuelito quadrangle (J. E. Fassett, c, Farmington)
- Samson Lake quadrangle (J. E. Fassett, c, Farmington)
- Twin Butte quadrangle (J. E. Fassett, c, Farmington)
- Western Raton field (C. L. Pillmore, D)

North Dakota:
- Clark Butte 15-minute quadrangle (G. D. Mowat, c, Billings, Mont.)
- Dengate quadrangle (C. S. V. Barclay, c, D)
- North Almont quadrangle (H. L. Smith, c, D)
- White Butte 15-minute quadrangle (K. S. Soward, c, Casper, Wyo.)

Pennsylvania:
- Northern anthracite field (M. J. Bergin, NC)
- Southern anthracite field (G. H. Wood, Jr., NC)

Utah:
- Alton coal field (W. E. Bowers, c, D)
- 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)
- Collet Top quadrangle (H. D. Zeller, c, D)
- East-of-the-Navajo quadrangle (F. Peterson, c, D)
- Fourmile Bench quadrangle (W. E. Bowers, c, D)
- Horse Mountain quadrangle (W. E. Bowers, c, D)
- Jessen Butte quadrangle (E. M. Schell, c, Casper, Wyo.)
- Kaiparowits Plateau area (H. D. Zeller, c, D)
- Needle Eye Point quadrangle (H. D. Zeller, c, D)
- Pete's Cove quadrangle (H. D. Zeller, 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)

Virginia and West Virginia:
- Central Appalachian Basin (K. J. Englund, NC)

Coal—Continued
States—Continued
Wyoming:
- Acme quadrangle (B. E. Law, c, Casper)
- Alpine quadrangle (H. F. Albee, c, Salt Lake City, Utah)
- 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)
- 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)
- Gillette Coal Field (W. L. Rohrer, c, Casper)
- Grieve Reservoir quadrangle (C. S. V. Barclay, c, D)
- Hanna Basin area (L. F. Blanchard, c, D)
- Hoback Peak quadrangle (D. A. Jobin, c, D)
- Kemmerer area (M. L. Schroeder, c, D)
- Ketchum Buttes quadrangle (C. S. V. Barclay, c, D)
- Little Snake River coal field (C. S. V. Barclay, c, D)
- Monarch quadrangle (B. E. Barnum, c, D)
- Oil Mountain quadrangle (W. H. Laraway, c, Casper)
- Pickle Pass quadrangle (D. A. Jobin, c, D)
- Poison Spider quadrangle (W. H. Laraway, c, Casper)
- Rawlins—Baggs area (G. M. Edson, c, D)
- Reid Canyon (W. H. Laraway, c, Casper)
- Riner quadrangle (R. B. Sanders, c, D)
- Rock Springs uplift (P. J. LaPoint, c, D)
- 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)

Construction and terrain problems
- Deformation research (S. P. Kanizay, D)
- Electronics instrumentation research for engineering geology (J. B. Bennetti, D)
- Engineering geology laboratory (R. A. Farrow, D)
- Plowshare special studies (F. W. Stead, D)
- Reactor-site investigations (F. N. Houser, D)
- Regional slope-stability studies, California and Pennsylvania (D. H. Radbruch-Hall, M)
- Research in rock mechanics (F. T. Lee, D)
- Sino-Soviet terrain (L. D. Bonham, NC)
- Soil engineering research (T. L. Youd, M)
- Special intelligence (L. D. Bonham, NC)
- Subsurface waste emplacement (H. Barnes, D)
- Veterans Administration Hospital site evaluations (T. C. Nichols, Jr., D)
- Volcanic hazards in the Cascade Range, California and Washington (D. R. Crandell, D)

States:
Alaska:
- Arctic engineering (G. Gryc, M)
- Geologic investigations, Amchitka Island (L. M. Gard, Jr., D)

California:
- Geologic environmental maps for land-use planning (E. H. Pampegan, Jr., M)
- San Francisco Bay sediments, engineering geology studies (D. R. Nichols, J. Schlocker, M)

Flood characteristics of streams at selected sites—Continued
- Oregon, flood profiles, Umpqua River and tributaries (D. D. Harris, w, Portland)
- Tennessee (W. J. Randolph, w, Nashville)

Flood discharge from small drainage areas:
- Colorado (G. L. Ducret, Jr., w, D)
- Connecticut (M. D. Thomas, w, Hartford)
- Delaware (R. H. Simmons, w, Dover)
- Florida (W. C. Bridges, w, Tallahassee)
- Illinois (J. W. Curtis, w, Champaign)
- Maryland (D. H. Carpenter, w, College Park)
- Massachusetts (C. G. Johnson, Jr., w, Boston)
- Minnesota (L. C. Guetzkow, w, St. Paul)
- Mississippi (J. W. Hudson, w, Jackson)
- North Dakota (O. A. Crosby, w, Bismarck)
- Rhode Island (C. G. Johnson, Jr., w, Boston, Mass.)
- South Carolina (B. H. Whetstone, w, Columbia)
- Virginia (E. M. Miller, w, Richmond)

Flood frequency:
- Alabama, flood frequency synthesis for small streams (C. O. Ming, w, Montgomery)
- Iowa (O. G. Lara, w, Iowa City)
- Kentucky, magnitude and frequency (C. H. Hannum, w, Louisville)
- New Jersey, magnitude and frequency and effect of basin characteristics (S. J. Stankowski, w, Trenton)
- North Carolina, flood frequency and high-flow studies (N. M. Jackson, Jr., w, Raleigh)

Flood hazard mapping:
- United States (E. J. Kennedy, w, NC)
- Alabama (J. R. Harkins, w, Tuscaloosa)
- Arkansas (M. S. Hines, w, Little Rock)
- California (J. R. Crippen, w, M)
- Colorado (R. U. Grozier, w, D)
- Connecticut (F. H. Ruggles, w, Hartford)
- Georgia (M. Price, w, Atlanta)
- Hawaii (C. J. Ewart, w, Honolulu)
- Idaho (W. A. Harenberg, w, Boise)
- Illinois (W. O. Thomas, Jr., w, Champaign)
- Indiana (R. E. Hoggatt, w, Indianapolis)
- Iowa (O. G. Lara, w, Iowa City)
- Kansas (D. B. Richards, w, Lawrence)
- Kentucky (C. H. Hannum, w, Louisville)
- Louisiana (A. S. Lowe, w, Baton Rouge)
- Maine (R. A. Morrill, w, Augusta)
- Maryland (W. B. Solley, w, Parkville)
- Michigan (R. L. Knutilla, w, Okemos)
- Minnesota (L. C. Guetzkow, w, St. Paul)
- Mississippi (K. V. Wilson, w, Jackson)
- Missouri (E. E. Gann, w, Rolla)
- Montana (M. V. Johnson, w, Helena)
- Nebraska (F. B. Shaffer, w, Lincoln)
- Nevada (D. O. Moore, w, Carson City)
- New Jersey (R. E. Gatton, Jr., w, Trenton)
- New Mexico (L. P. Denis, w, Albuquerque)
- New York (B. Dunn, w, Albany)
- North Carolina (K. L. Lindskov, w, Raleigh)
- North Dakota (O. A. Crosby, w, Bismarck)
- Ohio (D. K. Roth, w, Columbus)
- Oklahoma (W. B. Mills, w, Oklahoma City)
- Pennsylvania (L. V. Page, w, Harrisburg)
- South Carolina (B. H. Whetstone, w, Columbia)

Flood hazard mapping—Continued
- South Dakota (O. J. Larimer, w, Huron)
- Tennessee (C. R. Gamble, w, Nashville)
- Texas (J. D. Bohn, w, Austin)
- 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 (C. L. Lawrence, w, Madison)
- Wyoming (J. F. Wilson, Jr., w, Cheyenne)

Flood insurance studies:
- Alabama (J. R. Harkins, w, Tuscaloosa)
- Arizona (B. N. Aldridge, w, Tucson)
- California (J. R. Crippen, w, M)
- Connecticut (M. A. Cervione, w, Hartford)
- Florida (W. A. Pitt, w, Tallahassee)
- Illinois (R. T. Mycyk, w, Oak Park)
- Indiana (P. B. Rohne, Jr., w, Indianapolis)
- Kansas (D. B. Richards, w, Lawrence)
- Michigan (R. L. Knutilla, w, Okemos)
- Minnesota (L. C. Guetzkow, w, St. Paul)
- Missouri (E. E. Gann, w, Rolla)
- New Jersey (E. G. Miller, w, Trenton)
- New York (K. I. Darmer, w, Albany)
- Texas (J. D. Bohn, w, Austin)
- Wisconsin (W. B. Gannon, w, Madison)

Flood-inundation mapping:
- Idaho (W. A. Harenberg, w, Boise)
- Illinois, northeastern (A. W. Noehre, w, Oak Park)
- Minnesota, flood-plain mapping (L. C. Guetzkow, w, St. Paul)

Flood investigations:
- Documentation extreme floods (W. Hofmann, w, NC)

States:
- Arkansas (M. S. Hines, w, Little Rock)
- California, Lake-Playa Flood study (M. W. Busby, w, Garden Grove)
- Florida, flood investigations, Alafia basin (L. H. Motz, w, Tampa)
- 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)
  - Floods in Indiana, magnitude and frequency (P. B. Rohne, Jr., w, Indianapolis)
- Iowa:
  - 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)
- Maryland, floods of June 1972 (K. R. Taylor, w, Parkville)
- Minnesota, flood-plain studies (L. C. Guetzkow, w, St. Paul)
- Mississippi, special flood reports (C. H. Tate, w, Jackson)
- Nebraska, magnitude and frequency of floods (E. W. Beckman, w, Lincoln)
- Nevada:
  - Environmental study, western Nevada (P. A. Glancy, w, Carson City)
  - Flood investigations (L. Harmsen, w, Carson City)

Geochemistry, water—Continued
- Geochemical survey of waters of Missouri (G. L. Feder, w, D)
- Geochemistry of geothermal systems (I. Barnes, w, M)
- Geochemistry of San Francisco Bay waters and sediments (D. H. Peterson, w, M)
- Hydrologic applications of quantitative mineralogy (R. Schoen, w, NC)
- Hydrosolic metals and related constituents in natural water, chemistry (J. D. Hem, w, M)
- Hydrous metal oxides, their geochemistry and effect on water quality (E. A. Jenne, w, M)
- Interaction of minerals and water in saline environments (B. F. Jones, w, NC)
- Mineralogic controls of the chemistry of ground water (B. B. Hanshaw, w, D)
- Organic geochemistry (R. L. Malcolm, w, D)
- Radiochemical surveillance (V. J. Janzer, w, D)
- *See also* Quality of water.

Geochemistry and petrology, field studies:
- Basalt, genesis (T. L. Wright, NC)
- Basin and Range granites (D. E. Lee, D)
- Environmental geochemistry of western powerplant sites (J. R. Keith, D)
- Epithermal deposits (R. G. Worl, D)
- Geochemical halos, Utah-Nevada (R. L. Erickson, D)
- Geochemical studies in Southeastern States (H. Bell III, NC)
- Geochemistry of diagenesis (K. J. Murata, M)
- Geochemistry of sediments, San Francisco Bay, Calif. (D. S. McCulloch, M)
- Geochemistry of Tippecanoe Sequence, Western Craton (L. G. Schultz, D)
- Hawaiian ankaramites (M. H. Beeson, M)
- Humates, geology and geochemistry, Florida, New Mexico, and Wyoming (V. E. Swanson, D)
- Inclusions in basaltic rocks (E. D. Jackson, M)
- Layered Dufek intrusion, Antarctica (A. B. Ford, M)
- Layered intrusives (N. J Page, M)
- Mercury, geochemistry and occurrence (A. P. Pierce, D)
- Niobium and tantalum, distribution in igneous rocks (D. Gottfried, NC)
- Oil shale, organic geochemistry (R. E. Miller, D)
- Petrology of the Yellowstone Plateau volcanic field, Wyoming, Idaho, Montana (R. L. Christiansen, M)
- Rare-earth elements, resources and geochemistry (J. W. Adams, D)
- Regional metamorphic studies (H. L. James, M)
- Residual minor elements in igneous rocks and veins (G. Phair, NC)
- Services (P. H. Held, M; H. J. Miller, NC)
- Solution transport of heavy metals (G. K. Czamanske, M)
- Submarine volcanic rocks, properties (J. G. Moore, M)
- Tertiary-Laramide intrusives of Colorado (E. J. Young, D)
- Thermal waters, origin and characteristics (D. E. White, M)
- Titanium, geochemistry and occurrence (N. Herz, Athens, Ga.)
- Trondhjemites, major and minor elements, isotopes (F. Barker, D)
- Ultramafic rocks, petrology of alpine types (R. G. Coleman, M)
- Weathering, igneous rocks (R. W. White, D)

Geochemistry and petrology, field studies—Continued
- Western coal regions:
  - Geochemical survey of rocks (R. J. Ebens, D)
  - Geochemical survey of soils (R. R. Tidball, D)
  - Geochemical survey of vegetation (J. A. Erdman, D)
- *States:*
- Arizona:
  - Ray program:
    - Mineral Mountain (T. G. Theodore, M)
    - Silicate mineralogy—geochemistry (N. G. Banks, M)
  - Stocks (S. C. Creasey, M)
- California:
  - Kings Canyon National Park (J. G. Moore, M)
  - Long Valley caldera-Mono Craters volcanic rocks (R. A. Bailey, NC)
  - Ritter Range metavolcanic rocks (R. S. Fiske, NC)
  - Sierra Nevada metamorphism (B. A. Morgan III, NC)
  - Sierra Nevada xenoliths (J. P. Lockwood, M)
- Colorado:
  - Petrology of the Mt. Princeton igneous complex (P. Toulmin, III, NC)
  - Regional geochemistry—Denver urban area (H. A. Tourtelot, D)
  - San Juan volcanic field, east and central (P. W. Lipman, D)
- Idaho, Wood River district (W. E. Hall, M)
- Michigan, Sault St. Marie 2-degree quadrangle (J. W. Whitlow, NC)
- Missouri:
  - Geochemical survey of rocks (R. J. Ebens, D)
  - Geochemical survey of soils (R. R. Tidball, D)
  - Geochemical survey of vegetation (J. A. Erdman, D)
- Montana:
  - Boulder batholith, structure and petrology (R. I. Tilling, Hawaii National Park; H. W. Smedes, D)
  - Diatremes, Missouri River Breaks (B. C. Hearn, Jr., NC)
  - Geochronology, north-central Montana (B. C. Hearn Jr., NC; R. F. Marvin, R. E. Zartman, D)
  - Wolf Creek area, petrology (R. G. Schmidt, NC)
- Nevada, igneous rocks and related ore deposits (M. L. Silberman, M)
- New Mexico, Valles Mountains (R. L. Smith, NC)
- South Dakota, Keystone pegmatite area (J. J. Norton, Rapid City)
- Utah, Mule Ear (D. E. Stuart-Alexander, M)

Geochronological investigations:
- Carbon-14 method (M. Rubin, NC)
- Geochronology—Denver (C. E. Hedge, D)
- Geochronology and rock magnetism (G. B. Dalrymple, M)
- Igneous rocks and deformational periods (R. W. Kistler, M)
- Lead-uranium, lead-thorium, and lead-alpha methods (T. W. Stern, NC)
- Magnetic chronology, Colorado Plateau and environs (D. P. Elston, E. M. Shoemaker, Flagstaff, Ariz.)
- Radioactive-disequilibrium studies (J. N. Rosholt, D)
- *See also* Isotope and nuclear studies.

Geologic mapping:
- Geologic map of the United States (P. B. King, M)
- Map scale smaller than 1:62,500:
  - Antarctica:
    - Dufek Massif and Forrestal Range, Pensacola Mountains (A. B. Ford, M)

Geologic mapping—Continued
Map scale smaller than 1:62,500—Continued
Antarctica—Continued
Neptune and Patuxent ranges, Pensacola Mountains (D. L. Schmidt, D)
Belt basin study (J. E. Harrison, D)
Columbia River basalt (D. A. Swanson, Hawaii National Park, Hawaii)
States:
Alaska:
Charley River quadrangle (E. E. Brabb, M)
Compilations of Alaska geology (E. H. Lathram, M)
Craig quadrangle (G. D. Eberlein, M. Churkin, Jr., M)
Delong Mountains quadrangle (I. L. Tailleur, M)
Geologic map (H. M. Beikman, M)
Geology of Alaska (G. Gryc, M)
Glacier Bay National Monument (D. A. Brew, M)
Hughes-Shungnak area (W. W. Patton, Jr., M)
Iliamna quadrangle (R. L. Detterman, M)
Juneau and Taku River quadrangles (D. A. Brew, M)
Metamorphic facies map (D. A. Brew, M)
Natural landmarks investigation (R. L. Detterman, M)
Northern part, petroleum investigations (G. Gryc, M)
St. Lawrence Island (W. W. Patton, Jr., M)
Tracy Arm-Fords Terror (Thundering Fiords) Wilderness study area (D. A. Brew, M)
Arizona:
North-central part (D. P. Elston, Flagstaff)
Phoenix 2-degree quadrangle (T. N. V. Karlstrom)
Shivwits Plateau (I. Lucchitta, Flagstaff)
Arkansas (B. R. Haley, Little Rock)
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)
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, NC)
Spokane-Wallace region (A. B. Griggs, M)
Nevada:
Elko County (R. A. Hope, M)
Elko County, central (K. B. Ketner, D)
Elko County, western (R. R. Coats, M)
Geologic map (J. H. Stewart, M)
Nevada Test Site geologic investigations (P. P. Orkild, D)
New Mexico:
Socorro 2-degree quadrangle (G. O. Bachman, D)
West half of Santa Fe 2-degree quadrangle (R. B. Johnson, D)
North Carolina, Charlotte 2-degree quadrangle (J. B. Hadley, NC)

Geologic mapping—Continued
Map scale smaller than 1:62,500—Continued
States—Continued
Pennsylvania, Greater Pittsburgh region geology (W. R. Wagner, Carnegie)
South Carolina, Charlotte 2-degree quadrangle (J. B. Hadley, NC)
Utah:
Delta 2-degree quadrangle (H. T. Morris, M)
Glen Canyon Recreation Area (A. L. Brokaw, D)
Tooele 2-degree quadrangle (W. J. Moore, M)
Washington, Spokane-Wallace region (A. B. Griggs, M)
Wyoming:
Geologic map (J. D. Love, D)
Preston 2-degree quadrangle (S. S. Oriel, D)
Map scale 1:62,500, and larger:
States and territories:
Alaska:
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, NC)
Cochise County, southern part (P. T. Hayes, D)
Cummings Mesa quadrangle (F. Peterson, c, D)
Garnet Mountain quadrangle (P. M. Blacet, M)
Hackberry Mountain area (D. P. Elston, Flagstaff)
Mt. Wrightson quadrangle (H. Drewes, D)
Ray district, porphyry copper (H. R. Cornwall, M)
Sedona area (D. P. Elston, Flagstaff)
California:
Coast Range, ultramafic rocks (E. H. Bailey, M)
Condrey Mountain-Hornbrook quadrangle (P. E. Hotz, M)
Geysers-Clear Lake area (R. J. McLaughlin, M)
Long Valley caldera (R. A. Bailey, NC)
Malibu Beach and Topanga quadrangles (R. F. Yerkes, M)
Merced Peak quadrangle (D. L. Peck, NC)
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)
Searles Lake area (G. I. Smith, M)
Sierra Nevada batholith (P. C. Bateman, M)
Colorado:
Barcus Creek quadrangle (W. J. Hail, D)
Barcus Creek SE quadrangle (W. J. Hail, D)
Bonanza quadrangle (R. E. Van Alstine, NC)
Buckhorn Lakes quadrangle (R. G. Dickinson, c, D)
Central City area (R. B. Taylor, D)
Citadel Plateau (G. A. Izett, c, D)
Coal mine deformation studies, Somerset mining district (C. R. Dunrud, D)
Cochetopa area (J. C. Olson, D)

Geologic mapping—Continued
Map scale 1:62,500, and larger—Continued
States and territories—Continued
Colorado—Continued
Courthouse Mountain quadrangle (R. G. Dickinson, c, D)
Denver basin, Tertiary coal zone (P. E. Soister, c, D)
Denver metropolitan area (R. M. Lindvall, D)
Disappointment Valley, geology and coal resource (D. E. Ward, D)
Front Range, northeastern part, Fort Collins area (W. A. Braddock, D)
Indian Hills Precambrian (B. H. Bryant, D)
Lake City caldera (P. W. Lipman, D)
Middle Park—North Park area (G. A. Izett, c, D)
Northern Park Range (G. L. Snyder, D)
Philadelphia Creek quadrangle (B. E. Barnum, c, D)
Platoro caldera and related volcanic rocks, southeastern San Juan Mountains (P. W. Lipman, D)
Poncha Springs quadrangle (R. E. Van Alstine, NC)
Rangely NE quadrangle (H. L. Cullins, c, Metairie, La.)
Rough Gulch quadrangle (W. J. Hail, D)
San Juan mining area (R. G. Luedke, NC)
Savery quadrangle (C. S. V. Barclay, c, D)
Smizer Gulch quadrangle (W. J. Hail, D)
Strasburg SW quadrangle (P. E. Soister, c, D)
Thornburgh quadrangle (M. J. Reheis, c, D)
Ward and Gold Hill quadrangles (D. J. Gable, D)
Washboard Rock quadrangle (R. G. Dickinson, c, D)
Watkins and Watkins SE quadrangles (P. E. Soister, c, D)
Connecticut:
Cooperative mapping program (M. H. Pease, Jr., Boston, Mass.)
Taconic sequence (E-an Zen, NC)
Florida, Attapulgus-Thomasville area, fuller's earth deposits (S. H. Patterson, NC)
Idaho:
Alpine quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Bayhorse area (S. W. Hobbs, D)
Boulder Mountains (C. M. Tschanz, D)
Goat Mountain quadrangle (M. H. Staatz, D)
Grouse quadrangle (B. A. Skipp, D)
Hawley Mountain quadrangle (W. J. Mapel, D)
Malad southeast quadrangle (S. S. Oriel, D)
Montour quadrangle (H. E. Malde, D)
Palisades Dam quadrangle (D. A. Jobin, c, D)
Patterson quadrangle (E. T. Ruppel, D)
Poker Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Upper and Lower Red Rock Lakes quadrangles (I. J. Witkind, D)
Wood River district (W. E. Hall, M)
Yellow Pine quadrangle (B. F. Leonard, D)
Indiana:
Ohio River Quaternary (M. P. Weiss, DeKalb, Ill.)
Ohio River valley, Quaternary geology (L. L. Ray, NC)
Kentucky, cooperative mapping program (D. W. Olive, Lexington)
Maine:
Blue Hill quadrangle (D. B. Stewart, NC)

Geologic mapping—Continued
Map scale 1:62,500, and larger—Continued
States and territories—Continued
Maine—Continued
Castine quadrangle (D. B. Stewart, NC)
Chain Lakes area (E. L. Boudette, Flagstaff, Ariz.)
Orland quadrangle (D. R. Wones, NC)
Rumford quadrangle (R. H. Moench, D)
The Forks quadrangle (F. C. Canney, D)
Maryland:
Delmarva Peninsula (J. P. Owens, NC)
Northern Coastal Plain (J. P. Minard, NC)
Western Maryland Piedmont (M. W. Higgins, NC)
Massachusetts:
Boston and vicinity (C. A. Kaye, Boston)
Cooperative mapping program (M. H. Pease, Jr., Boston)
Taconic sequence (E-an Zen, NC)
Michigan:
Gogebic Range, western part (R. G. Schmidt, NC)
Wakefield quadrangle (W. C. Prinz, NC)
Montana:
Bearpaw Mountains, petrology (B. C. Hearn, Jr., NC)
Boulder Batholith region (H. W. Smedes, D)
Butte North quadrangle (H. W. Smedes, D)
Cooke City quadrangle (J. E. Elliott, D)
Craig quadrangle (R. G. Schmidt, NC)
Crazy Mountains Basin (B. A. Skipp, D)
Decker quadrangle (B. E. Law, c, Casper, Wyo.)
Diatremes, Missouri River Breaks (B. C. Hearn, Jr., NC)
Elk Park quadrangle (H. W. Smedes, D)
Hardy quadrangle (K. S. Soward, c, Casper, Wyo.)
Jordan quadrangle (G. D. Mowat, c, Billings)
Lemhi Pass quadrangle (M. H. Staatz, D)
Melrose phosphate field (G. D. Fraser, c, D)
Monarch quadrangle (B. E. Barnum, c, D)
Northern Pioneer Range, geologic environment (E-an Zen, NC)
Pearl School quadrangle (G. L. Galyardt, c, Casper, Wyo.)
Rocky Reef quadrangle (K. S. Soward, c, Casper, Wyo.)
Wickiup Creek quadrangle (H. W. Smedes, D)
Wolf Creek area, petrology (R. G. Schmidt, NC)
Nevada:
Austin quadrangle (E. H. McKee, M)
Bellevue Peak quadrangle (T. B. Nolan, NC)
Carlin region (J. F. Smith, Jr., D)
Jordan Meadow and Disaster Peak quadrangles (R. C. Greene M)
Kobeh Valley (T. B. Nolan, NC; C. W. Merriam, M)
Lida Wash quadrangle (K. B. Krauskopf, M)
Midas-Jarbidge area (R. R. Coats, M)
Pinto Summit quadrangle (T. B. Nolan, NC)
Spruce Mountain 4 quadrangle (G. D. Fraser, c, D)
New Hampshire, cooperative mapping program, surficial (C. Koteff, Boston, Mass.)
New Mexico:
Acoma area (C. H. Maxwell, D)
Apache Springs and Galisteo quadrangles (R. B. Johnson, D)
Church Rock-Smith Lake (C. T. Pierson, D)

Geologic mapping—Continued
Map scale 1:62,500, and larger—Continued
States and territories—Continued
New Mexico—Continued
Cretaceous stratigraphy, San Juan basin (E. R. Landis, D)
Gallup East quadrangle (E. D. Patterson, c, Roswell)
Gallup West quadrangle (J. E. Fassett, c, Farmington)
Hillsboro quadrangle (D. C. Hedlund, D)
Iron Mountain (A. V. Heyl, Jr., D)
Manuelito quadrangle (J. E. Fassett, c, Farmington)
Manzano Mountains (D. A. Myers, D)
Pinos Altos Range (T. L. Finnell, D)
Raton coal basin, western part (C. L. Pillmore, D)
Samson Lake quadrangle (J. E. Fassett, c, Farmington)
Twin Butte quadrangle (J. E. Fassett, c, Farmington)
Valles Mountains, petrology (R. L. Smith, NC)
New York:
Pope Mills and Richville quadrangles (C. E. Brown, NC)
Taconic sequence (E-an Zen, NC)
North Carolina:
Central Piedmont (A. A. Stromquist, D)
Northern slate belt, North Carolina-Virginia (V. M. Seiders, NC)
North Dakota:
Clark Butte 15-minute quadrangle (G. D. Mowat, c, Billings, Mont.)
Dengate quadrangle (C. S. V. Barclay, c, D)
Heart Butte and Heart Butte NW quadrangles (E. V. Stephens, c, M)
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., NC)
Claysville-Avella area (S. P. Schweinfurth, NC)
Northern anthracite field (M. J. Bergin, NC)
Southern anthracite field (G. H. Wood, Jr., NC)
Western Middle anthracite field (H. Arndt, NC)
Wind Gap and adjacent quadrangles (J. B. Epstein, NC)
Puerto Rico (J. M. Aaron, San Juan)
South Dakota:
Black Hills Precambrian (J. A. Redden, Hill City)
Keystone Pegmatite area (J. J. Norton, NC)
Rapid City area (J. M. Cattermole, D)
Texas, Tilden-Loma Alta area (K. A. Dickinson, D)
Utah:
Basin Canyon quadrangle (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 Peak quadrangle (W. E. Bowers, c, D)
Coal-mine bumps, Sunnyside mining district (F. W. Osterwald, D)
Collet Top quadrangle (H. D. Zeller, c, D)
Confusion Range (R. K. Hose, M)
Crawford Mountains (W. C. Gere, c, M)
East-of-the-Navajo quadrangle (F. Peterson, c, D)
Fourmile Bench quadrangle (W. E. Bowers, c, D)
Horse Mountain quadrangle (W. E. Bowers, c, D)

Geologic mapping—Continued
Map scale 1:62,500, and larger—Continued
States and territories—Continued
Utah—Continued
Jessen Butte quadrangle (E. M. Schell, c, Casper, Wyo.)
Matlin Mountains (V. R. Todd, M)
Needle Eye Point quadrangle (H. D. Zeller, c, D)
Oak City area (D. J. Varnes, D)
Ogden 4 NW quadrangle (R. J. Hite, c, D)
Pete's Cove quadrangle (H. D. Zeller, c, D)
Salt Lake City and vicinity (R. Van Horn, D)
Seep Flat quadrangle (E. V. Stephens, c, M)
Sheeprock Mountains, West Tintic district (H. T. Morris, M)
Ship Mountain Point quadrangle (H. D. Zeller, c, D)
Sooner Bench quadrangle (F. Peterson, c, D)
Sunset Flat quadrangle (F. Peterson, c, D)
Wah Wah Summit quadrangle (L. F. Hintze, Salt Lake City)
Wide Hollow Reservoir (E. V. Stephens, c, M)
Willard Peak area (M. D. Crittenden, Jr., M)
Virginia:
Culpeper Basin (K. Y. Lee, NC)
Delmarva Peninsula (J. P. Owens, NC)
Northern Blue Ridge (G. H. Espenshade, NC)
Northern slate belt, North Carolina-Virginia (V. M. Seiders, NC)
Rapidan-Rappahannock (L. Pavlides, NC)
Washington:
Chewelah No. 4 quadrangle (F. K. Miller, M)
Glacier Park area (F. W. Cater, D)
Loomis quadrangle (C. D. Rinehart, M)
Olympic Peninsula, eastern part (W. M. Cady, D)
Olympic Peninsula, northwestern part (P. D. Snavely, Jr., M)
Stevens County (R. G. Yates, M)
Twin Lakes quadrangle (G. E. Becraft, NC)
Wisconsin:
Black River Falls and Hatfield quadrangles (H. Klemic, NC)
Lead-zinc district (W. S. West, Platteville)
Wyoming:
Acme quadrangle (B. E. Law, c, Casper)
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)
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)
Gas Hills uranium district (F. C. Armstrong, Spokane, Wash.)
Gillette Coal Field (W. L. Rohrer, c, Casper)

Geologic mapping—Continued
  Map scale 1:62,500, and larger—Continued
    States and territories—Continued
    Wyoming—Continued
      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)
      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)
      Reid Canyon quadrangle (W. H. Laraway, c, Casper)
      Riner quadrangle (R. B. Sanders, c, D)
      Savery quadrangle (C. S. V. Barclay, 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)
      Wapiti quadrangle (W. G. Pierce, M)
Geomagnetism (Boulder, Colo):
  External geomagnetic-field variations (W. H. Campbell)
  Geomagnetic-data analysis (C. O. Stearns)
  Geomagnetic observatories (J. D. Wood)
  Geomagnetic secular variation (L. R. Alldredge)
  Magnetic-field analysis and U.S. charts (E. B. Fabiano)
  World magnetic charts and analysis (E. B. Fabiano)
Geomorphology:
  Channel adjustment, Cochiti Dam (J. D. Dewey, w, Albuquerque, N. Mex.)
  Forest geomorphology, Pacific coast (R. J. Janda, w, M)
  Morphology, provenance, and movement of desert sand (E. D. McKee, D)
  Ohio River Quaternary (M. P. Weiss, DeKalb, Ill.)
  Ohio River Valley, geologic development (L. L. Ray, NC)
  Studies of erosion control (N. J. King, w, D)
  Quaternary landforms and deposits interpreted from ERTS-1 imagery, midwest and Great Plains (R. B. Morrison, D)
  States:
  Arizona, post-1890 A.D. erosion features interpreted from ERTS-1 imagery (R. B. Morrison, D)
  Colorado, mountain soils, regolith (K. L. Pierce, D)
  Idaho, eastern Snake River plain, Quaternary geology (E. T. Ruppel, D)
  Indiana, Ohio River Quaternary (M. P. Weiss, Dekalb, Ill.)
  Massachusetts, sea-cliff erosion studies (C. A. Kaye, Boston)
  New Mexico, Chaco Canyon National Monument (H. E. Malde, D)
  Oregon, coastal sedimentation (R. J. Janda, w, M)
  Wyoming:
    Wind River Mountains, Quaternary geology (G. M. Richmond, D)
    Yellowstone National Park, glacial and postglacial geology (G. M. Richmond, D)
  See also Sedimentation; Geochronological investigations.
Geophysics, regional:
  Airborne and satellite research:
    Aeromagnetic studies (M. F. Kane, D)
    Electromagnetic research (F. C. Frischknecht, D)
    Gamma radioactivity studies (J. A. Pitkin, D)

Geophysics, regional—Continued
  Airborne and satellite research—Continued
    Regional studies (I. Zietz, NC)
    Satellite magnetometry (R. D. Regan, NC)
  Antarctica, Pensacola Mountains, geophysical studies (J. C. Behrendt, Woods Hole, Mass.)
  Basin and Range, geophysical studies (W. E. Davis, M)
  Crust and upper mantle:
    Aeromagnetic interpretation of metamorphic rocks (I. Zietz, NC)
    Aeromagnetic studies of the United States (I. Zietz, NC)
    Analysis of traveltime data (J. C. Roller, M)
    Fault-zone geophysical studies (W. H. Jackson, M)
    Seismicity and Earth structure (J. N. Taggart, Boulder, Colo.)
    Seismologic studies (J. P. Eaton, M)
  Engineering geophysics (H. D. Ackermann, D)
  Florida Continental Shelf, gravity studies (H. Kriboy, Corpus Christi, Tex.)
  Ground-water geophysics (W. D. Stanley, D)
  Magnetic chronology, Colorado Plateau and environs (D. P. Elston, E. M. Shoemaker, Flagstaff, Ariz.)
  Mobile magnetometer profiles, eastern United States (M. F. Kane, D)
  National aeromagnetic survey (J. R. Henderson, D)
  New England, magnetic properties of rocks (A. Griscom, M)
  Program and systems development (G. I. Evenden, W. L. Anderson, D)
  Rock magnetics, northern Rocky Mountains (W. F. Hanna, M)
  Rocky Mountains, northern (D. L. Peterson, M. D. Kleinkopf, D)
  Southeastern States geophysical studies (P. Popenoe, NC)
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  Ultramafic rocks, geophysical studies, intrusions (G. A. Thompson, M)
  United States, aeromagnetic surveys (E. R. King, NC)
  Yellowstone National Park, geophysical study (H. R. Blank, Eugene, Oreg.)
  States and territories:
  California:
    San Andreas fault, ground studies (W. F. Hanna, M)
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  Idaho, Snake River Plain (D. L. Peterson, D)
  Maryland, Cooperative Survey (J. L. Meuschke, D)
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    Geophysical studies (M. F. Kane, NC)
  Minnesota:
    Keweenawan rocks, magnetic studies (K. G. Books, NC)
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  Nevada:
    Applied geophysics, Nevada Test Site (G. D. Bath, D)
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  New Mexico, Rio Grande graben (L. E. Cordell, D)
  Pennsylvania, magnetic properties of rocks (A. Griscom, M)
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Florida:
Biscayne aquifer analog model (E. H. Cordes, w, Miami)
Hydrologic base, Dade County (F. W. Meyer, w, Miami)
Miami Canal infiltration (F. W. Meyer, w, Miami)
Well fields, west-central Florida (L. H. Motz, w, Tampa)
Kansas, quality of water, Cedar Bluff (R. B. Leonard, w, Lawrence)
Minnesota:
Sewage treatment and lake quality (R. J. Wolf, w, St. Paul)
Water table in Highway 100 area (M. S. McBride, w, St. Paul)
Nebraska, Platte Basin water resources (P. A. Emery, w, Lincoln)
New Mexico, Pecos River-miscellaneous (G. E. Welder, w, Roswell)
North Carolina, effect of channel improvement on hydrologic conditions in Creeping Swamp (M. D. Winner, w, Raleigh)
North Dakota, Kindred Reservoir (J. S. Downey, w, Bismarck)
Pennsylvania, level monitoring, Matamoras (W. C. Roth, w, Harrisburg)
Rhode Island, hydrology, Branch Blackstone (H. E. Johnston, w, Providence)
Washington, Water Yakima Reservation (D. O. Gregg, w, Tacoma)
Wisconsin (w, Madison):
Hydrologic effects of dredging small spring ponds (W. J. Rose)
Hydrologic system of the Lake Wingra basin and the effects of urban development on the system (J. H. Green)
Hydrology of Cedar Lake (R. S. McLeod)
Madison digital model (R. S. McLeod)
Nederlo Creek hydrology (P. A. Kammerer, Jr.)
Wetland hydrology (E. A. Bell)
Wyoming, alluvial aquifer, North Platte (M. A. Crist, w, Cheyenne)

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Appalachian region:
Mineral resources, Connecticut-Massachusetts (J. P. D'Agostino, NC)
South-central (A. A. Stromquist, D)
Hydro- and bio-geochemistry (T. T. Chao, D)
Mineral paragenesis (J. T. Nash, M)
Regional variation in heavy-metals content of Colorado Plateau stratified rocks (R. A. Cadigan, D)
Rocky Mountain region, fossil beach placers (R. S. Houston, Laramie, Wyo.)
Solution transport (G. K. Czamanske, M)
Southeastern states, geochemical studies (H. Bell III, NC)
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Alaska:
Gulf of Alaska, nearshore placers (Erk Reimnitz, M)
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Southeastern part (D. A. Brew, M)
Southern Alaska Range (B. L. Reed, M)
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Hydraulics, ground water:
Applicability of the unsaturated flow theory to the phenomena of infiltration and drainage (J. Rubin, w, M)
Computer analysis—ground-water problems (S. S. Papadopulos, w, NC)
Mechanics of ground-water flow (G. F. Pinder w, NC)
Regional hydrologic system analysis—hydrodynamics (P. C. Trescott, w, NC)
Regional hydrologic system analysis—permeability distribution (J. D. Bredehoeft, w, D)
Theory of multiphase flow—applications (A. F. Moench, w, D)
Transient phenomena in ground-water flow (C. E. Mongan, w, Boston, Mass.)
Transport processes in fluid flows (A. Ogata, w, Honolulu, Hawaii)

Hydraulics, surface flow:
Flow characteristics:
Dispersion by turbulent flow in open channels (N. Yotsukura, w, NC)
Effect of temperature on winter runoff (W. D. Simons, w, M)
Mechanics of flow structure and fluid resistance—movable boundary (R. S. McQuivey, w, Bay St. Louis, Miss.)
Mechanics of fluid resistance (H. J. Tracy, w, Atlanta, Ga.)
Numerical simulation of hydrodynamic phenomena by digital computer (Chintu Lai, w, NC)
Unsteady flow and saline intrusions in rivers and estuaries (R. A. Baltzer, w, NC)
Laboratory studies:
Time-of-travel studies:
Indiana (P. B. Rohne, Jr., w, Indianapolis)
Maryland (K. R. Taylor, w, Parkville)
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Hydrologic-data collection and processing:
Drainage-area determinations, Indiana (R. E. Hoggatt, w, Indianapolis)
Hydrologic probability models (W. H. Kirby, w, NC)
Statistical inferences (E. J. Gilroy, w, NC)
State:
New York, Long Island, computer applications (D. E. Vaupel, w, Mineola)
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Hydrologic instrumentation:
Analog model unit (E. P. Patten, Jr., w, NC)
Electronic-equipment development—water (J. E. Eddy, w, NC)
Ground-water network (L. C. Dutcher, w, M)
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Relation to slope stability (S. Subitzky, w, Carnegie)
Well data from driller cards (D. W. Speight, w, Philadelphia)
South Carolina (w, Columbia):
Capacity use study (A. L. Zack)
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South Dakota, basic hydrologic research (E. F. LeRoux, w, Huron)
Utah (w, Salt Lake City):
Hydrology, Beaver Valley (R. W. Mower)
Navajo Sandstone ground water (R. M. Cordova)
Virginia, Norfolk injection study (D. L. Brown, w, Norfolk)
Washington (w, Takoma):
Ground-water hydrology, east-central Washington (A. J. Hanson, Jr.)
Pullman (H. H. Tanaka)
Wisconsin (w, Madison):
A study of ground-water pollution in the Niagara dolomite of Door County, Wis. (M. G. Sherrill)
Fish-hatchery water management (R. P. Novitzki)

Hydrology, surface-water:
Evaluation of low-flow runoff (W. D. Simons, w, M)
Hydrology defined by rainfall simulation (G. C. Lusby, w, D)
Hydrology of estuaries (D. W. Hubbell, w, Bay St. Louis, Miss.)
Improvement in flood-frequency analysis (C. H. Hardison, w, NC)
Modeling principles (J. P. Bennett, w, Bay St. Louis, Miss.)
Open channel experiments (F. A. Kilpatrick, w, Bay St. Louis, Miss.)
Operation models (M. E. Jennings, w, Bay St. Louis, Miss.)
Physical modeling (V. R. Schneider, w, Bay St. Louis, Miss.)
Runoff simulation (P. H. Carrigan, Jr., w, NC)
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Alabama, hydraulics of bridge design (K. W. Causseaux, w, Montgomery)
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Effects of vegetation changes (H. W. Hjalmarson, w, Phoenix)
Flood hydrology of Arizona (B. N. Aldridge, w, Tucson)
California:
Flood hydrology, Butte Basin (R. G. Simpson, w, Sacramento)
Special studies (L. R. Peterson, w, M)
Delaware River Master activity (J. V. B. Wells, w, Milford, Pa.)
Florida, hydrograph simulation studies (J. F. Turner, Jr., w, Tampa)
Georgia, small area flood hydrology (H. G. Golden, w, Atlanta)
Idaho, special studies (C. A. Thomas, w, Boise)
Kansas (w, Lawrence):
Channel geometry (E. R. Hedman)

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Kentucky, low-flow investigation (R. V. Swisshelm, Jr., w, Louisville)
Louisiana (w, Baton Rouge):
Bridge-site computations (B. L. Neely, Jr.)
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Ohio (w, Columbus):
Flood hydrology, small areas (E. E. Webber)
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Low-flow of Ohio streams (R. I. Mayo)
Time-of-travel studies of Ohio streams (A. O. Westfall)
Oregon, Alsea River basin, effects of logging on streamflow, sedimentation, and temperature (D. D. Harris, w, Portland)
South Carolina (w, Columbia):
Data reports, flood forecasting (H. H. Jeffcoat)
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South Dakota, small streams flood frequency (L. D. Becker, w, Huron)
Tennessee, small streams modeling (H. C. Wibben, w, Nashville)
Texas (w, Austin):
Hydrology of small drainage areas (E. E. Schroeder)
Small watersheds (R. D. Hawkinson)
Virginia, urban hydrology, Fairfax County (P. L. Soule, w, Fairfax)
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Anadromous fish hydraulics (C. H. Swift III)
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Wisconsin (w, Madison):
Flood frequency study (D. H. Conger)
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Iron:
Resource studies, United States (H. Klemic, NC)
Michigan:
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Negaunee and Palmer quadrangles (J. E. Gair, NC)
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Isotope and nuclear studies:
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Molluscan faunas, Caribbean (N. F. Sohl, NC)
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Ordovician:
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Silurian-Devonian:
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North Dakota, White Butte 15-minute quadrangle (K. S. Soward, c, Great Falls, Mont.)
Pennsylvania, Greater Pittsburgh region oil and gas fields (W. S. Lytle, Carnegie)
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Phosphate:
Phosphoria Formation, stratigraphy and resources (R. A. Gulbrandsen, M)

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Cretaceous stratigraphy, western New Mexico and adjacent areas (E. R. Landis, D)
East-coast Continental Shelf and margin (R. H. Meade, Jr., Woods Hole, Mass.)
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Stratigraphy, Florida and Alabama (J. A. Miller, w, Raleigh, NC)
Williston basin, Wyoming, Montana, North Dakota, South Dakota (C. A. Sandberg, D)
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Magnetic chronology, Colorado Plateau and environs (D. P. Elston, E. M. Shoemaker, Flagstaff)
California, Southern San Joaquin Valley, subsurface geology (J. C. Maher, M)
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South-central part, Jurassic stratigraphy (G. N. Pipiringos, D)
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Structural geology and tectonics:
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Talc, New York, Pope Mills and Richville quadrangles (C. E. Brown, NC)

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- Cauldron and ash-flow studies (R. L. Smith, NC)
- Columbia River basalt (D. A. Swanson, M)
- Regional volcanology (R. L. Smith, NC)
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- Hawaii:
  - Hawaiian Volcano Observatory (D. W. Peterson, Hawaii National Park)
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- Montana, Wolf Creek area, petrology (R. G. Schmidt, NC)
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- Data coordination, acquisition and storage:
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  - Systems Analysis Laboratory (N. C. Matalas, w, NC)
  - Water Data Coordination (R. H. Langford, w, NC)
- East Triassic waste-disposal study (G. L. Bain, w, Raleigh, N.C.)
- Foreign countries:
  - Brazil, surface water, national program (W. W. Evett, w, Rio de Janeiro)
  - Ethiopia, ground water, national program (H. E. Gill, w, NC)
  - India, ground-water investigations in states of Madhya Pradesh, Gujarat, Maharashtra and Mysore (J. R. Jones, w, NC)
  - Kenya, hydrogeology of eastern Kenya (W. V. Swarzenski, w, Nairobi)
  - Nepal, hydrogeology off Terai region (G. C. Tibbitts, Jr., w, Katmandu)
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- Ground-water appraisal, Great Basin (T. E. Eakin, w, Carson City, Nev.)
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- Ground-water, Southeastern States (D. J. Cederstrom, w, NC)
- Hazardous wastes study (E. G. Otton, w, Parkville, Md.)
- Intensive river quality assessment (D. A. Rickert, w, Portland, Oreg.)
- Northeast drought (M. T. Thomson, w, NC)
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