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GEOLOGICAL SURVEY RESEARCH 1976

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1000

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 1000

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

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C.: 1976

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THOMAS S. KLEPPE, *Secretary*

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V. E. McKelvey, *Director*

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FOREWORD

Beginning with the publication of the first volume in 1960, the Geological Survey Research series has served to report the status and results of research underway in the Geologic Division of the USGS; the succeeding annual volumes have reported results of current research in other Divisions as well. The companion annual volumes of Short Papers, also begun in 1960, were discontinued in 1972 in favor of a subscription periodical issued six times a year—the Journal of Research of the U.S. Geological Survey—to further speed the release of research findings.

Research and factfinding are important components of the USGS's work, but other activities—such as lease management, Federal land classification and evaluation, the preparation of small-scale maps, and the archiving and distribution of Landsat imagery—are important also. Recognizing the need to report promptly on the progress of all our activities, we resumed the publication of the USGS Annual Report, beginning with the volume for fiscal year 1975, released in June 1976.

Some overlap may be found in these series, but, by and large, they serve the needs of different readerships. For the next few years, therefore, we plan to continue their publication as complementary means of reporting promptly on the progress and results of all our activities. We will not hesitate to further modify this format, however, if better means of reporting are found. Toward this end, suggestions will be welcome.

V. E. McKelvey,
Director.

CONTENTS

	Page
Foreword	III
Abbreviations	X
SI units and U.S. customary equivalents	XI
Mineral-resource and mineral-fuel investigations	1
Geology of metallic, nonmetallic, and industrial mineral commodities	1
Base metals	1
Rare metals	4
Precious metals	4
Ferrous metals	7
Light metals	8
Nonmetallic minerals	8
Mineral-resource assessments of areas	10
Alaskan Mineral Resource Assessment Program	10
Mineral-resource investigations related to the Wilderness Act	12
Mineral assessment program in the United States	14
Mineral assessment of Indian lands	17
Minerals Discovery Loan Program	17
Geochemical and geophysical resource technology	18
Areal geochemical studies	18
Instrumentation	19
Methodology	19
Topical geochemical studies	20
Useful tools in exploration	20
Useful sample media in geochemical exploration	21
Resource analysis	22
Resource data bases	22
Resource model studies	22
Energy-related mineral studies	23
Resource investigations	23
Coal resources	24
Computerization of the Nation's coal resources	24
Chemical data on coal	24
Laboratory investigations of coal geochemistry	25
Geophysical investigations of coal	25
Resource evaluation through the Energy Mineral Rehabilitation Inventory and Analysis Program	25
Montana	25
Wyoming	26
Utah	26
Coal exploration	26
Oil and gas resources	28
Oil-shale resources	34
Nuclear-fuel resources	35
Geothermal resources	39
U.S. geothermal resources assessed	39

	Page
Mineral-resource and mineral-fuel investigations—Continued	
Geothermal resources—Continued	
U.S. geothermal resources assessed—Continued	
Alaska	40
Arizona	41
California	41
Idaho	43
Montana	43
Nevada	44
New Mexico	44
Oregon	44
Utah	45
Eastern United States	45
Geothermal computer data file	46
Chemical resources	46
Lithium	46
Bentonite	47
Brines	48
Thallium	48
Fluorite	48
Regional geologic investigations	49
New England	49
Pleistocene	49
Urban area studies	51
Stratigraphy	51
Structure	54
Intrusive rocks	56
Metamorphism	57
Aeroradioactivity	58
Appalachian Highlands and the Coastal Plains	58
Central region and Great Plains	64
Kentucky	64
Michigan	65
Nebraska	67
Rocky Mountains	67
Mineral-resource studies	67
Igneous rocks	68
Geologic and stratigraphic studies	69
Structural studies	71
Environmental-geologic studies	72
Basin and Range region	72
Mineral-resource studies	72
Stratigraphic and structural studies	73
Igneous rocks	76
Geochronologic studies	77
Pacific coast region	77
California	77
Oregon	81
Washington	81
Alaska	82
General	82
Northern Alaska	82

	Page
Regional geologic investigations—Continued	
Alaska—Continued	
Central Alaska	84
Southern Alaska	86
Southeastern Alaska	87
Puerto Rico	89
Geologic maps	90
Large-scale geologic maps	91
Intermediate-scale geologic maps	91
Maps of large regions	95
Water-resource investigations	97
Northeastern region	99
Connecticut	100
Delaware	100
Indiana	101
Maryland	101
Massachusetts	101
Michigan	102
Minnesota	103
Minnesota, North Dakota, South Dakota, and Montana	104
New Jersey	105
New York	105
Pennsylvania	106
Rhode Island	107
West Virginia	107
Wisconsin	107
Wisconsin and Illinois	108
Southeastern region	108
Florida	109
Georgia	112
Kentucky	112
Mississippi	112
North Carolina	113
South Carolina	113
Tennessee	114
Central region	114
Multistate studies	115
Colorado	116
Kansas	120
Louisiana	120
Montana	121
Nebraska	122
New Mexico	123
North Dakota	123
South Dakota	124
Texas	125
Wyoming	126
Western region	126
Alaska	127
American Samoa	129
California	129
Idaho	130
Nevada	131
Oregon	131
Washington	132
Special water-resource programs	132
Data coordination, acquisition, and storage	132
Office of Water-Data Coordination	132
National Stream Quality Accounting Network	133
National Water Data Exchange	133
Water-data storage system	134

	Page
Water-resource investigations—Continued	
Special water-resource programs—Continued	
Urban water program	134
Quantity and quality of storm runoff in urban areas	134
Hydrologic effects of waste disposal in urban areas	135
Erosion and sediment	135
Water use	135
Coordinated water-quality programs	137
International Hydrological Program and related activities	138
Marine geology and coastal hydrology	141
Marine and coastal geology	141
Atlantic coast	141
Gulf coast and Caribbean Sea	144
Pacific coast	146
Alaskan-Arctic investigations	148
Gulf of Alaska	148
Bering Sea	149
Chukchi and Beaufort Seas	150
Oceanic studies	151
Estuarine and coastal hydrology	152
Atlantic coast	152
Pacific coast	153
Management of natural resources on Federal and Indian lands	154
Classification and evaluation of mineral lands	154
Classified land	154
Known Geologic Structures of producing oil and gas fields	154
Known Geothermal Resources Areas	154
Known leasing areas for coal and potassium	155
Waterpower classification—preservation of reservoir sites	155
Supervision of mineral leasing	155
Outer Continental Shelf lease sales for oil and gas	155
Cooperation with other Federal agencies	155
Geologic and hydrologic principles, processes, and techniques	157
Experimental geophysics	157
Rock magnetism	157
Geomagnetism	159
Petrophysics	160
Applied geophysical techniques	161
Geochemistry, mineralogy, and petrology	165
Experimental and theoretical geochemistry	165
Mineralogic studies in crystal chemistry	166
Crystal structure analysis	166
Pyroxene studies	167
Mineral studies	168
Volcanic rocks and processes	168
Hawaiian volcanoes	168
Alaskan volcanoes	170
Cascade volcanoes	170
Volcanic rocks in the Western United States	171
Volcanic rocks in the Eastern United States	174
Chemistry and mineralogy of volcanic rocks	175
Dating of volcanic rocks	176

	Page
Geologic and hydrologic principles, processes, and techniques—Continued	
Geochemistry, minerology, and petrology—Continued	
Plutonic rocks and magmatic processes	176
Metamorphic rocks and processes	176
Geochemistry of water and sediments	177
Diagenetic studies	177
Mineral alteration	178
Geologic controls on water chemistry	179
Mineral-equilibrium studies	180
Trace elements	180
Experimental kinetics	180
Statistical geochemistry and petrology	181
Isotope and nuclear geochemistry	182
Isotope tracer studies	182
Stable isotopes	183
Advances in geochronometry	184
Geothermal systems	185
Sedimentology	189
Variability of sediment yields	189
Sediment transport and deposition	190
Sedimentary structures	191
Channel scour	191
Glaciology	192
Paleontology	193
Mesozoic and Cenozoic studies	193
Paleozoic studies	195
Ground-water hydrology	197
Aquifer-model studies	198
Artificial recharge	199
Alaska	199
Florida	199
New York	200
Texas	200
Miscellaneous studies	201
Surface-water hydrology	203
Chemical, physical, and biological characteristics of water	206
Relation between surface water and ground water	209
Evaporation and transpiration	210
Limnology and potamology	211
Plant ecology	215
New hydrologic instruments and techniques	217
Sea-ice studies	218
Analytical methods	219
Analytical chemistry	219
X-ray fluorescence	219
Emission spectroscopy	219
Analysis of water	220
Geology and hydrology applied to hazard assessment and environment	222
Earthquake studies	222
Seismicity and Earth structure	222
Earthquake mechanics and prediction studies	222
Seismicity	222
Theoretical and laboratory studies of earthquake mechanics	225
Crustal strain studies	226
Earthquake prediction studies	228
Geologic studies	228
Earthquake hazard studies	229
Engineering geology	234
Geology and hydrology applied to hazard assessment and environment—Continued	
Engineering geology—Continued	
Slope stability	234
Geologic hazards in urban areas	237
Soil engineering	237
Rock mechanics	237
Subsidence-associated ground fractures	238
Environmental geology	239
Relation of radioactive waste to the hydrologic environment	242
Floods	245
Outstanding floods	245
Flood-frequency studies	246
Flood mapping	247
Water quality and contamination	249
Environmental geochemistry	252
Land subsidence	254
Astrogeology	257
Planetary studies	257
Comparative planetary geology	257
Topographic mapping of Mars and Mercury	258
Lunar investigations	258
Basins and craters	258
Volcanic units	259
Structure	260
Technical results	261
Terrestrial analog and experimental studies	261
Terrestrial impact craters	261
Volcanic features	262
Photogrammetric techniques	262
Lunar sample investigations	262
Petrology of lunar breccias	262
Petrology and mineralogy of lunar metamorphic rocks	263
Other mineralogical-chemical studies	264
Chemistry of lunar samples	265
Isotopic systematics	265
Remote sensing and advanced techniques	267
Earth Resources Observation Systems program	267
Lineament map of the United States	267
Western region	267
Central region	268
Eastern region	269
Foreign areas	269
Remote-sensing applications demonstrations by other Bureaus	271
Applications to geologic studies	272
Applications to hydrologic studies	276
Applications to cartographic studies	278
Satellite image maps	278
Investigations	279
User services	281
Follow-on Landsats	282
Applications to geographic studies	282
Land use and environmental impact	284
Multidisciplinary studies in support of land-use planning and decisionmaking	284
Greater Pittsburgh region studies	284
San Francisco Bay regional studies	284
Geotechnical and geohydrological studies in Fairfax County, Virginia	286
Connecticut Valley Urban Area Project	286
Urban studies in other areas	287

	Page
Land use and environmental impact—Continued	
Multidisciplinary studies in support of land-use planning and decisionmaking—Continued	
Snake River Canyon study	287
Land-Use Data and Analysis Program and other geographic studies	287
Land-use and land-cover mapping	287
Cooperative land-use mapping and data projects	288
Central Atlantic Regional Ecological Test Site Project	288
Geographic information systems software development	289
Economic impact on coastal areas	290
Environmental impact studies	290
International cooperation in the Earth sciences	292
Disaster response	292
Technical assistance and participant training	293
Scientific and technical cooperation	297
International commissions and representations	298
Summary by countries	299
Bolivia	299
Brazil	300
Colombia	300
Indonesia	300
Kenya	301
Mexico	301
Palau Islands (Trust Territories)	301
Nepal	301
Niger	301
Pakistan	302
Peru	302
Qatar	302
Saudi Arabia	302
Thailand and Laos	305
Yemen Arab Republic	306
Antarctic programs	306
Topographic surveys and mapping	308
Field surveying	308
Automated surveying systems	308
Geodetic data	308
Mapping standards	309
Equipment	309
Photogrammetric techniques	310
Aerotriangulation	310
Image correlation	310
Camera calibration	310
Equipment and materials	311
Photoimage mapping	311
Image quality	311
Image processing	311
Equipment and techniques	312
Orthophoto products	312
Map design	313
Intermediate-scale mapping	313
Coastal and wetland mapping	314
Special mapping projects	314
Equipment	314
Automated cartography	314
Hardware	314
Software	315
Experiments	316
Topographic surveys and mapping—Continued	
International activities	317
Antarctica	317
Algeria	318
Mexico	318
Saudi Arabia	318
United Nations Cartographic Conference	318
Canada/Mexico/United States Technical Exchange Meeting	320
Pan American Institute of Geography and History	320
Training and tours	320
Computer technology	321
Computer facilities	321
Reston batch processing	321
Reston disk storage	321
Time-sharing systems	321
EROS Data Center	321
Flagstaff image-processing facility	322
COM microfiche facility	322
U.S. Geological Survey publications	323
Publications program	323
Publications issued	324
How to obtain publications	325
Over the counter	325
By mail	325
References cited	327
Cooperators and other financial contributors during fiscal year 1976	345
Federal cooperators	345
State, county, and local cooperators	346
Other cooperators and contributors	352
U.S. Geological Survey offices	353
Headquarters offices	353
Principal field offices	353
Selected field offices in the United States and Puerto Rico	354
Computer Center Division	354
Conservation Division	354
Regional offices	354
Area and district offices	354
Earth Resources Observation Systems program	356
Geologic Division	356
Regional offices	356
Offices	356
Publications Division	357
Public Inquiries Offices	357
Distribution Centers	357
Topographic Division	357
Water Resources Division	358
Regional offices	358
District offices	358
Offices in other countries	359
Geologic Division	359
Water Resources Division	360
Investigations in progress in the U.S. Geological Survey	361
Indexes	398
Subject index	398
Author index	406

ILLUSTRATIONS

		Page
FIGURE 1.	Alaska Mineral Resource Assessment Program project locations	11
2.	Wilderness study locations in the Western United States and Alaska	13
3.	Mineral Assessment Program project locations	15
4.	Published geologic quadrangle maps of Kentucky as of April 1, 1976	64
5.	Curve depicting the rate of buildup of the intertidal sediment surface at Portage, Alaska	87
6.	Status of geologic mapping in the United States, 1976, by scales	91
7.	Index map of the conterminous United States showing 1:250,000-scale geologic maps published as of December 31, 1975	93
8.	Index map of Alaska, Hawaii, and Puerto Rico showing geologic maps published or on open file as of December 31, 1975	94
9.	Index map of the conterminous United States showing areal subdivisions used in the discussion of water resources	99
10.	Index map of Antarctica showing status of topographic mapping	319

TABLES

		Page
TABLE 1.	Status of geologic mapping by State	92
2.	Mineral production, value, and royalty for FY 1976	156
3.	Technical assistance to other countries provided by the USGS during FY 1976	295
4.	Technical and administrative documents issued in calendar year 1975 as a result of USGS technical and scientific cooperative programs	298

ABBREVIATIONS

A	angstrom
ABAG	Association of Bay Area Governments
a.c	alternating current
A.D	anno Domini
AIDJEX	Arctic Ice Dynamics Joint Experiment
AMRAP	Alaskan Mineral Resource Assessment Program
APD	antiphase domain
atm	atmosphere
bbl	barrel
BLM	Bureau of Land Management
BOD	biochemical oxygen demand
B.P	before present
Btu	British thermal unit
°C	degrees Celsius
cal	calorie
CARETS	Central Atlantic Regional Ecological Test Site project
CCD	Computer Center Division
CCOP	U.N. Committee for Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas
CCT	computer-compatible tape
CDP	common depth point
CENTO	Central Treaty Organization
CEQ	Council on Environmental Quality
Ci	curie
cm	centimeter
COD	chemical oxygen demand
COM	computer-oriented microform
CPU	central processing unit
CRIB	Computerized Resource Information Bank
d	day
d.c	direct current
DO	dissolved oxygen
DSDP	Deep Sea Drilling Project
EIA	Environmental Impact Analysis
EIS	environmental impact statement
EMRIA	Energy Mineral Rehabilitation Inventory and Analysis
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
EROS	Earth Resources Observation Systems
ERTS	Earth Resources Technology Satellite
eV	electronvolt
FAO	Food and Agriculture Organization
FIPS	Federal Information Processing Standards
f.l	focal length
FLD	Fraunhofer line discriminator
FY	fiscal year
g	gram
GIPSY	General Information Processing System
GIRAS	Geographic Information Research and Analysis System
GOES	Geostationary Operational Environmental Satellite
GRASP	Geologic Retrieval and Synopsis Program
h	hour
ha	hectare
HFU	heat-flow unit
hm	hectometer
HUD	Department of Housing and Urban Development
Hz	hertz
IDOE	International Decade of Ocean Exploration
IHD	International Hydrological Decade
IHP	International Hydrological Program
IMW	International Map of the World
in	inch
IR	infrared
ISO	International Standardization Organization
J	joule
JTU	Jackson turbidity unit
K	kelvin
kbar	kilobar
KCLA	Known Coal Leasing Area
KeV	kiloelectronvolt
kg	kilogram
KGRA	Known Geothermal Resources Area
KGS	Known Geologic Structure
kHz	kilohertz
kJ	kilojoule
km	kilometer
KREEP	potassium-rare-earth element-phosphorus
kWh	kilowatt-hour
l	liter
lat	latitude
loc	location
long	longitude
m	meter
M	magnitude (earthquake)
mcal	millicalorie
MEF	maximum evident flood
mGal	milligal
mi	mile
min	minute
mg	milligram
ml	milliliter
mm	millimeter
mo	month
MPa	megapascal
MSS	multispectral scanner
MW	megawatt
MWe	megawatts electrical
μcal	microcalorie
μg	microgram
μGal	microgal
μm	micrometer
μmho	micromho
μstrain/yr	engineering shear
NASA	National Aeronautics and Space Administration
NASQAN	National Stream Quality Accounting Network
NAWDEX	National Water Data Exchange
NCRDS	National Coal Resources Data System
NEIS	National Earthquake Information Service
ng	nanogram
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Survey
NRA	Nuclear Regulatory Agency
nT	nanotesla
NTIS	National Technical Information Service
OAS	Organization of American States
OCS	Outer Continental Shelf
ohm-m	ohm-meter
OME	Office of Minerals Exploration
OWDC	Office of Water-Data Coordination
Ω	ohm
PAIGH	Pan American Institute of Geography and History
PCB	polychlorinated biphenyls
pCi	picocurie
ppb	part per billion
ppm	part per million
PSRV	pseudo-relative velocity
R	range
RASS	Rock Analysis Storage System
REE	rare-earth element
RF	radio frequency
RMSE	root mean square error
R/V	research vessel
s	second
SFBRS	San Francisco Bay Region Environment and Resources Planning Study
SIP	strongly implicit procedure
SLAR	side-looking airborne radar
SMS	Synchronous Meteorological Satellite
SP	self potential
SRO	Seismic Research Observatory
t	tonne
T	township
TEM	transmission electron microscopy
UNDP	U.N. Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USPHS	U.S. Public Health Service
U.S.S.R	Union of Soviet Socialist Republics
UTM	Universal Transverse Mercator
V	volt
VHRR	very high resolution radiometer
VLF	very low frequency
W	watt
WMO	World Meteorological Organization
WRC	Water Resources Council
yr	year

SI UNITS AND U.S. CUSTOMARY EQUIVALENTS

[SI, International System of Units, a modernized metric system of measurement. All values have been rounded to four significant digits except 0.01 bar, which is the exact equivalent of 1 kPa. Use of hectare (ha) as an alternative name for square hectometer (hm^2) is restricted to measurement of land or water areas. Use of liter as a special name for cubic decimeter (dm^3) is restricted to the measurement of liquids and gases; no prefix other than milli should be used with liter. Metric ton (t) as a name for megagram (Mg) should be restricted to commercial usage, and no prefixes should be used with it. Note that the style of meter² rather than square meter has been used for convenience in finding units in this table. Where the units are spelled out in text, Survey style is to use square meter]

SI unit		U.S. customary equivalent	
Length			
millimeter (mm)	=	0.039 37	inch (in)
meter (m)	=	3.281	feet (ft)
	=	1.094	yards (yd)
kilometer (km)	=	0.621 4	mile (mi)
	=	0.540 0	mile, nautical (nmi)
Area			
centimeter² (cm^2)	=	0.155 0	inch² (in^2)
meter² (m^2)	=	10.76	feet² (ft^2)
	=	1.196	yards² (yd^2)
	=	0.000 247 1	acre
hectometer² (hm^2)	=	2.471	acres
	=	0.003 861	section (640 acres or 1 mi^2)
kilometer² (km^2)	=	0.386 1	mile² (mi^2)
Volume			
centimeter³ (cm^3)	=	0.061 02	inch³ (in^3)
decimeter³ (dm^3)	=	61.02	inches³ (in^3)
	=	2.113	pints (pt)
	=	1.057	quarts (qt)
	=	0.264 2	gallon (gal)
	=	0.035 31	foot³ (ft^3)
meter³ (m^3)	=	35.31	feet³ (ft^3)
	=	1.308	yards³ (yd^3)
	=	264.2	gallons (gal)
	=	6.290	barrels (bbl) (petroleum, 1 bbl = 42 gal)
	=	0.000 810 7	acre-foot (acre-ft)
hectometer³ (hm^3)	=	810.7	acre-feet (acre-ft)
kilometer³ (km^3)	=	0.239 9	mile³ (mi^3)
Volume per unit time (includes flow)			
decimeter³ per second (dm^3/s)	=	0.035 31	foot³ per second (ft^3/s)
	=	2.119	feet³ per minute (ft^3/min)

SI unit		U.S. customary equivalent	
Volume per unit time (includes flow)—Continued			
	=	15.85	gallons per minute (gal/min)
	=	543.4	barrels per day (bbl/d) (petroleum, 1 bbl = 42 gal)
meter³ per second (m^3/s)	=	35.31	feet³ per second (ft^3/s)
	=	15 850	gallons per minute (gal/min)
Mass			
gram (g)	=	0.035 27	ounce avoirdupois (oz avdp)
kilogram (kg)	=	2.205	pounds avoirdupois (lb avdp)
megagram (Mg)	=	1.102	tons, short (2 000 lb)
	=	0.984 2	ton, long (2 240 lb)
Mass per unit volume (includes density)			
kilogram per meter³ (kg/m^3)	=	0.062 43	pound per foot³ (lb/ft^3)
Pressure			
kilopascal (kPa)	=	0.145 0	pound-force per inch² (lbf/in^2)
	=	0.009 869	atmosphere, standard (atm)
	=	0.01	bar
	=	0.296 1	inch of mercury at 60°F (in Hg)
Temperature			
temp kelvin (K)	=	[temp deg Fahrenheit (°F) + 459.67]/1.8	
temp deg Celsius (°C)	=	[temp deg Fahrenheit (°F) − 32]/1.8	

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GEOLOGICAL SURVEY RESEARCH 1976

MINERAL-RESOURCE AND MINERAL-FUEL INVESTIGATIONS

GEOLOGY OF METALLIC, NONMETALLIC, AND INDUSTRIAL MINERAL COMMODITIES

The study of mineral deposits has been one of the USGS's major efforts for nearly 100 years. It has contributed greatly to the ability to find new deposits and to estimate the mineral-resource potential of the Nation. Studies conducted in 1975 ranged from formulating theories on ore genesis to analyzing resource potential and included descriptions of mineral deposits in 15 States. The results of these studies are described below, arranged by mineral commodities, beginning with the base metals (copper, lead, and zinc) and followed by the rare metals (tungsten, mercury, and tin), the precious metals (silver, gold, and platinum), the ferrous metals (chromium and iron), and the light metas (aluminum). The results of the nonmetallic mineral-resource studies (fluorspar, phosphate, potash, limestone, lightweight aggregate, and diamond) also are included.

BASE METALS

Age of mineralization in the Creede mining district of Colorado

M. A. Lanphere, P. M. Bethke, P. B. Barton, Jr., and T. A. Steven completed a study of the age of mineralization in the Creede mining district of Colorado. Potassium-argon measurements on vein adularia and on sericite from altered wall rocks yield a weighted mean age of 24.6±0.29 million years. The age of the Fisher Quartz Latite, the youngest volcanic unit exposed in the district, was previously determined by Steven, H. H. Mehnert, and J. D. Obradovich as 26.4±0.6 million years. The Fisher lavas were erupted through the ring fracture zone of the Creede caldera after the caldera had been resurgently domed. The data permit interpretation of the mineralization as being related to either a late intrusion of the Fisher period of activity or an early intrusion during emplacement of the volcanic rocks of the Hinsdale Formation.

Model for mineralization, Creede, Colorado

P. B. Barton, Jr., P. M. Bethke, Edwin Roedder, and R. O. Rye completed an initial evaluation of the physical and chemical environment of ore deposition for the OH vein at Creede, Colo. For those mineral assemblages composed of pyrite, hematite, chlorite, quartz, K-feldspar, sericite, sphalerite, galena, and chalcopyrite, they concluded, with the aid of fluid-inclusion data, that the typical environment was as follows: temperature, 250°C; pressure, about 50 bars (the fluids were boiling near the top of the ore zone); pH, 5.4; $(Na_{0.9}K_{0.1})Cl$ salinity, about 1 molal; and total concentration of sulfur in solution, $10^{-1.7}$ molal. The iron content in sphalerite indicated that the activity of oxygen and sulfur varied considerably during ore deposition. Reactions between hematite, iron-rich chlorite, pyrite, quartz, and water controlled reduction-oxidation reactions and prevented the chemical environment from varying enough to form bornite, anglesite, or magnetite. The bulk of the ore was deposited from solutions that were clearly rich in sulfate rather than sulfide. At times, the chemical conditions became so reducing that H_2S would have been the dominant sulfur species in aqueous solution if equilibrium had prevailed. A chlorite-bearing buffer is incompatible in an environment in which equilibrium is maintained between oxidized and reduced sulfur species, unless large changes in the amount of total sulfur in solution are permitted. Since the mineralogical evidence does not support large changes in sulfur concentration, it was concluded that there were recurrent departures from reduction-oxidation equilibrium, which suggested a lack of reduction-oxidation equilibrium between aqueous sulfur species.

The ores were deposited from a freely convecting hydrothermal system and were probably initially charged with meteoric solutions, as indicated by the ^{18}O and D isotopic compositions of the ore fluid. The salts, metals, and sulfur, however, may have been derived from deeper sources. The circulating solutions extracted metals and sulfur from whatever sources were available at depth and deposited gangue and ore minerals near the top of the convecting cell in a hypogene enrichment process. Boiling caused the acid components (H_2S and CO_2) to vaporize and recondense in the cooler overlying rocks, this process leading to the formation of an intensely altered, sericitic capping above the ore. Precipitation of ore was attributed to cooling and perhaps to a slight rise in pH in conjunction with a loss of acid constituents.

Clusters of finely banded, iron-rich zones in otherwise iron-poor sphalerite resulted from the introduction of small quantities of more reduced (magmatic?) fluid that imposed a local, temporary, low reduction-oxidation chemical signature upon the circulating system. Each successive pass of the same low reduction-oxidation pulse produced an iron-rich band in the sphalerite. The mass ratio of fluid to sphalerite deposited requires that only a few parts per million of zinc be deposited in each cycle. Combined with a previous estimate of flow rate, this ratio gives a geologically uncomfortable, but quantitatively tenable, estimate of length of time required for mineralization of from a few hundred to a few thousand years.

A circulating-fluid model for ore deposition has important implications for mineral exploration. Minerals having retrograde solubilities, such as molybdenite, anhydrite, and, under some circumstances, possibly chalcopyrite, are precipitated in the hottest part of the system. Those minerals with prograde solubilities (most ore minerals whose solubilities are known), however, are precipitated in the coolest portion of the system. In contrast to the conventional model, the circulating-system model predicts a wide, barren gap between the cool, shallow, and hot, deep facies of mineralization.

Source and structural control of ore deposits near Ray, Arizona

Copper mineralization with associated lead, zinc, silver, and gold in the El Capitan Mountain quadrangle of Arizona occurs in areas of moderate to intense deformation along or near major north- to northeast-trending, steeply dipping faults, according to H. R. Cornwall. This relationship is similar to that of the major copper deposit at Ray, 16 km to the west, which occurs along a major north- to northwest-trending shear zone, and suggests that the metal-bearing solutions that formed the deposits ascended from considerable depths along throughgoing ruptures in the Earth's crust.

Ore deposits and ring fractures, Thunder Mountain Caldera

All productive Au, Ag, Hg, Sb, and W lode-type deposits in the Big Creek-Yellow Pine area of central Idaho are on or within 1 km of discontinuous ring-fracture sets related to the Thunder Mountain caldera, according to B. F. Leonard. The low-grade strata-related silver-gold deposits of the nearby Thunder Mountain district are in the Challis Volcanics in the former sump of the caldera. The ring-fracture-related metal-bearing quartz lodes and disseminated deposits are in the Idaho batholith and its host rocks, the Challis Volcanics. The principal lodes and disseminated deposits are confined to a centrally truncated sector of the cauldron between 8:00 and 12:30 (12 is due north). The discontinuous ring fractures within this sector have radii that are 1/3, 1/2, 2/3, 5/6, and 6/6 of the cauldron radius r, which is equal to about 32 km. The largest ore deposits, Yellow Pine and Meadow Creek, were formed where major radial fractures intersected ring fractures of radius $1/2r$. The ring and radial fractures—the fundamental structural controls of ore deposition outside the caldera sump—can be sorted out from the complex of associated faults only when an area of some hundreds of square kilometers has been mapped geologically at an intermediate scale, generally smaller than 1:24,000 and larger than 1:250,000.

Radiometric age of Boyle Mountain stock and related mineral deposits

The small Boyle Mountain granite stock in the Warm Springs mining district of Blaine County, Idaho, appears to be the source of lead-silver and zinc deposits that produced about $1 million worth of ore before 1912. It was recently dated at 90 ± 2.2 million years by R. F. Marvin, who used K-Ar analyses of biotite concentrates from a sample collected by C. M. Tschanz. Analyses of selected samples collected by Tschanz from three places adjacent to the stock and from an area about 3.7 km from it show that the mineralization within the stock has similar geochemical characteristics, which suggest a common origin and a favorable potential for discovery of additional orebodies, especially zinc. In the stock, zinc veins containing relatively low lead and silver values grade upward to veins containing much more Pb, Ag (700–2,000 ppm), Au, As, and Sb near the upper contact, which is 152 to 184 m higher. Although it has not been previously reported, gold increases to as much as 7 to 18 ppm in rocks containing 1 to 4 percent As from the highest prospects. Tin locally reaches 1,500 to 3,000 ppm in deposits surrounding the stock and thus extends a north-trending belt of tin-bearing silver-lead-zinc deposits in central Idaho another 21 km south, the total known length thus increasing to about 83 km. Between 300 to 700 ppm W are present in the contact zone above Warfield Hot Springs, the highest amount being in massive sphalerite-galena ore. As much as 300 ppm Bi and 200 ppm In are also commonly present. Although as much as 3,000 ppm Cd are present in the contact zone, the Cd/Zn ratio varies from 200 to 380 in samples containing 32 to 50 percent Zn, in comparison with a worldwide average ratio of about 225 ppm for zinc concentrates. Except for quantitative arsenic, gold, and copper analyses, standard semiquantitative spectrographic analyses were used to determine the metal contents.

Middle Precambrian age of massive sulfide deposits in northern Wisconsin

The recently discovered volcanogenic massive sulfide deposits at Ladysmith, Wis., and at the Pelican River southeast of Rhinelander, Wis., have model lead ages of about 1,830 million years (B. R. Doe, written commun., 1976). Inasmuch as the deposits are considered to be submarine volcanogenic exhalative in origin, the associated volcanic rocks also are interpreted as being Precambrian X in age. The model lead ages are consistent with zircon U-Pb ages (1800–1900 million years) on volcanic and granitic rocks (Van Schmus and others, 1975) in nearby northeastern Wisconsin and northern Michigan. These data establish the existence of widespread volcanic rocks of Precambrian X age in this part of the Lake Superior region. These rocks are favorable for the occurrence of massive sulfide deposits.

P. K. Sims interpreted the volcanic rocks as having formed in a eugeosynclinal environment in the southern part of the Precambrian X basin of the Lake Superior region, which contains the great iron-formations for which the region is famed. The volcanic rocks in northern Wisconsin probably are grossly equivalent in age to the Badwater Greenstone and the Hemlock Formation of the Baraga Group of the Marquette Range Supergroup in northern Michigan.

Volcanogenic sulfide deposit at Sedalia Mine, Colorado

Field investigations by D. M. Sheridan and W. H. Raymond at the Sedalia Mine northwest of Salida, Colo., disclosed evidence suggesting that this Precambrian copper-zinc orebody may be a volcanogenic sulfide deposit. The orebody is alined essentially parallel to the layering of the host rocks and appears to be localized within and adajcent to a layer of cordierite-garnet-amphibole gneiss. Primary sulfide minerals occur both as disseminated grains and in crude laminations parallel to the layering and foliation. Although the host rocks of the mine area have been regionally metamorphosed to the upper amphibolite facies, they contain textural and lithologic features indicating that an important part of the stratigraphic section was orginally volcanic and volcaniclastic in origin. The stratiform character of the deposit, the preponderance of textural parallelism over discordance in the relations of sulfide minerals to minerals of the host rocks, and the association with metavolcanic rocks are believed to be significantly similar to features displayed by volcanogenic sulfide deposits in Canada and other parts of the world.

Fluid inclusions in New Lead belt ores from Missouri

Edwin Roedder studied fluid inclusions in a suite of ore samples from the New Lead belt in Missouri ("the Viburnum trend"), supplied in part by the St. Joseph Lead Company, St. Joseph, Mo. This material contained few fluid inclusions suitable for study, but over 100 small inclusions were located in sphalerite from several mines. Much metastability was encountered in freezing studies. With few exceptions, all inclusions had freezing temperatures in the range $-20°$ to $-28°C$, which correspond to those of very saline brines. Homogenization temperature ranged from 82° to 145°C. These results are very similar to those obtained on inclusions from many other Mississippi Valley-type deposits and indicate that the New Lead belt, although different from other Mississippi Valley-type deposits in several important features, was deposited by the same type of hot saline brines.

Do lead-zinc deposits exist in the Pickens-Gilbertown fault system?

Carpenter and others (1974) published data on oilfield brines in Cretaceous rocks of central Mississippi that are exceptionally high in lead and zinc. The average lead content is near 40 mg/l, and the average zinc content near 180 mg/l. The metal-bearing brines occur in an area of at least 5,000 km^2 at depths of 2.5 to 4 km. The underlying rocks are Jurassic and consist of thick evaporites overlain by sandstones and shales; their pore waters are high in salinity and H_2S but are very low in lead and zinc. Carpenter and others (1974) proposed that interstitial brines of the evaporites were expelled upward by compaction, leaching lead and zinc from the Upper Jurassic shales enroute to the overlying Cretaceous rocks.

D. E. White, in a review of present-day brine systems as indicators of the origin of hydrothermal ore deposits, suggested an alternative possibility: During compaction, H_2S-rich brines from the Jurassic rocks and metal-rich, H_2S-poor brines from the Cretaceous rocks migrated independently, parallel to bedding, to the Pickens-Gilbertown fault system, where the two kinds of brine mixed and precipitated metal sulfides. This model avoids several of the problems inherent in the Carpenter model (vertical flow through shales and solution of metals from shale by low-temperature high-H_2S brines) and is consistent with suggestions made by White (1968) and others to account for Mississippi Valley-type ore deposits by mixing of solutions.

RARE METALS

Metalliferous Mississippian siltstone in Utah and Nevada

According to F. G. Poole, spectrographic analyses showed that shaly carbonaceous phosphatic siltstone beds near the base of the marine Needle Siltstone Member of Sadlick (1966) of the Chainman Formation in the Confusion Range of western Utah contain relatively high concentrations of V, Cr, Ni, Zn, Y, La, and other elements. Stratigraphic evidence indicates that the siltstone was deposited slowly in a starved-basin setting between the outer edge of the shallow-water limestone shelf on the east and the deepwater flysch trough on the west. Slow deposition of the silt layers allowed concentrations of certain metal ions to build up in the organic-rich sediments. Similar high concentrations of these metals occur to the east in the basal phosphatic shale member of the Deseret Limestone, which correlates with the Needle Siltstone Member of the Chainman of western Utah and eastern Nevada.

Distribution of tungsten, central Sierra Nevada batholith

Tungsten contents of granitic rocks collected by F. C. W. Dodge and P. C. Bateman from 84 localities in the central Sierra Nevada were determined by F. O. Simon by neutron activation techniques. The values of the element range from 0.065 to 11.3 ppm, the average being 0.74 ppm. This value is approximately half that reported as average for granitic rocks of the world.

Tungsten deposits of the Sierra Nevada occur in skarn adjacent to granitic rocks of specific intrusive sequences. Other sequences are essentially barren of contiguous tungsten mineralization. The trace amounts of tungsten in the granitic rocks cannot be related to the presence or absence of tungsten deposits. Although the deposits are commonly associated with highly differentiated members of intrusive sequences, there is no direct correlation between tungsten content and the contents of other elements. There is great variation, however, in the abundance of tungsten in the more siliceous granitic rocks.

Mercury and uranuim mineralization within the McDermott caldera

The McDermott caldera, located north of Winnemucca, Nev., is a Miocene collapse structure 45 km in diameter, according to J. J. Rytuba. The caldera is a semicircular structure having a western boundary defined by a north-northwest-striking fault. Within the caldera are major mercury mines and uranium occurrences. The mercury deposits of the Cordero, McDermitt, Bretz, Ruja, and Opalite mines occur along ring-fracture faults and in adjacent silicified lake beds and flows; the uranium occurrences are restricted to rhyolite domes within the caldera. The temperatures of deposition, determined from fluid inclusions in quartz, are 340°C in the uranium occurrences and 200°C in the mercury occurrences. The mercury deposits formed in a shallow epithermal environment.

PRECIOUS METALS

Uranium, selenium, and tin in silver-lead-gold veins, Boulder Basin, Idaho

The unsuspected presence of 500 ppm U in the Golden Glow vein and remarkably high gold (1,000 ppm) and selenium (1,090 ppm) contents in the Champion vein was revealed by new analyses of ore samples collected by C. M. Tschanz. The samples were from dumps of inaccessible workings in the Boulder Basin in Blaine County, Idaho, which produced $1.3 million worth of ore, mostly from the Golden Glow vein before 1912. The sample containing uranium was from the middle adit and also contained more than 10 percent Pb and Zn and 15,000 ppm Cu, 7,000 ppm Sb, 2,000 ppm Ag, 1,500 ppm Cd, 1,000 ppm As, and 20 ppm Au, according to semiquantitative spectrographic analyses by H. G. Neiman. Uranium was not detected in three ore samples from the same vein or in three samples from other veins that were previously analyzed by a less sensitive field spectrographic method.

The sample from the highest shaft on the Champion vein contains over 10 percent Pb, but no detectable zinc, and 2,000 ppm Ag, 1,500 ppm Cu, 1,050 ppm Se, 1,000 ppm Au, and 1,000 ppm Sb. The gold content of this sample is 33 times higher than that of the richest of seven other samples from the vein, but three of the samples contain 2 to 3.5 times as much silver and one contains 3,000 ppm Sn, in comparison with the usual values of 100 to 700 ppm. Boulder Basin lies within a 53-km north-trending belt of tin-bearing silver-lead-zinc deposits in central Idaho that in two areas farther north locally contains 1 to 6 percent Sn. Selenium and gold are 2 and 9 times more abundant, respectively, in the Champion vein sample than they are in the next richest sample from the Sawtooth National Recreation Area.

Silver in ore deposits in the Appalachian structural belt

A. V. Heyl reported that byproduct silver is present in more than 50 percent of all the known base-metal deposits in the structural belt from Maine to Alabama. It is present in recoverable amounts in most massive sulfide deposits; in nearly all gold lodes; in nearly all base-metal veins in the metamorphic belt and some in the folded belt; in Appalachian Valley zinc-lead deposits in New York, Pennsylvania, Virginia, and eastern Tennessee near the Blue Ridge-Smoky Mountains; in magnetite deposits of the Cornwall type; and in porphyry copper deposits. Deposits in which silver is the main product are rare but are known in coastal Maine. Because of the prevalence of silver in these ores, the metal should not be overlooked in evaluating Appalachian deposits.

Lopoliths from natural nuclear explosions?

A study by W. B. Myers suggested that the Precambrian uranium deposits of Elliott Lake, Canada; Witwatersrand, South Africa; and other locations may have supported ancient nuclear explosions. The Sudbury and Bushveld lopoliths (1.95×10^9 years) are located in the depositional basins of, or are adjacent to, the Elliot Lake and Witwatersrand ore conglomerates, respectively. The recently advanced hypothesis—that lopoliths were generated by giant meteorite impacts—may be readily modified to include the possibility that smaller, and statistically more probable, meteorites served as the ballistic impulses to trigger natural nuclear explosions in the enriched uranium (3.5 percent ^{235}U) of 2 billion years ago. The extreme pressures of impact would have significantly reduced, by compression, the critical mass of uranium. The Vredefort dome, in the middle of the Witwatersrand basin, stands at one postulated point of impact and represents the slow diapiric upwelling of subsolidus shock-heated light basement underlying the thick sedimentary blanket. The central portion of the Bushveld roof rocks, which consist of fallback breccia, related granophyre, and red granite, covers a second postulated impact point. In the northern part of Canada's Saskatchewan Province, the Carswell Dome ($\sim 1.1 \times 10^9$ years) may be an analog of the Vredefort structure. An ancient gneissic core bearing the partially remobilized Cluff Lake pitchblende deposits is surrounded by a faulted collar of upturned younger Precambrian sedimentary rocks. Perhaps other uranium deposits of Beaverlodge (Eldorado) type in the core area were fissioned by meteorite impact to form the structure.

Gold potential, Ruby quadrangle, Alaska

Three previously unmapped granitic rock bodies in the Ruby quadrangle of Alaska were found by R. M. Chapman and W. W. Patton, Jr. The largest pluton, which is between the Telsitna and Sethkokna Rivers, has an area of about 250 km^2 and includes rocks ranging from granite to diorite. A dioritic stock about 0.8 km in diameter is exposed on the ridge between the Nowitna River and California Creek and about 4.8 km south of the Titna River. A small body of granite or quartz monzonite, possibly 5 km^2 in area, crops out near the southern bank of the Yukon River 13 km northeast of Ruby.

A few placer gold prospects and (or) small placer mines are known in the areas adjacent to these granitic bodies: a prospect prior to 1915 on Baker Creek, a tributary of the Sethkokna River; a recent placer mine on California Creek; and several old placer mines and many prospects in the vicinity of Ruby, Alaska. Apparently, most of these placer deposits are relatively small and not high grade, but little specific information is available on the extent and grade of the deposits or on the amount of exploration done in these areas. The geologic setting of these areas is similar to that of the Long area and other Alaskan placer gold districts, where placer gold and gold-cassiterite deposits occur adjacent to granitic bodies. Thus, more geologic work and sampling are warranted to adequately assess the mineral potential of the areas mentioned.

Geologic controls of gold mineralization in Alaska, a revised interpretation

According to C. L. Hummel (1975), the southwestern part of Alaska's Seward Peninsula has yielded three-fourths of the placer gold produced from the peninsula and contains most of the known lodes from which the placers were derived. The distribution of nearly all primary and secondary mineral deposits in the region can now be correlated with major structures. This correlation provides the basis for reinterpreting regional geological controls and the potential for new deposits.

Nearly all the bedrock is composed of regionally metamorphosed rocks of low and high grade. The low-grade rocks contain both old and young structures, whereas the high-grade rocks contain only young structures. The high-grade metamorphic rocks include orthogneiss from which whole-rock Rb-Sr ages of 750 million years have been obtained (Sainsbury, 1975, p. 16–17) and are probably the oldest rocks on the Seward Peninsula. They can be correlated with a thick suite of metasedimentary schist that constitutes the basal portion of the low-grade metamorphic sequence. These basal metasedimentary rocks are also inferred to be among the oldest on the peninsula. They are overlain by thick sections of schist and marble containing abundant metamafic bodies. The ages of the schist and marble have not been determined; some of the metacarbonate rocks, however, may be of Paleozoic age (Sainsbury, 1975, p. 20).

The contact between the basal low-grade metamorphic rocks and the overlying metamorphic rocks is a zone of movement, probably the principal and most widespread of numerous thrust faults in the low-grade terrane. This thrust fault and other faults in the rocks above and below have been folded to the same degree as the low-grade rocks in which they lie. These structures were subsequently strongly deformed and, in part, destroyed by later tectonic activity, which produced some of the youngest structural features in the region. The most predominant young structure is the eastward-trending welt marked by the Kigluaik and Bendeleben mountain ranges, which includes the Kigluaik uplift bounded by normal faults. The duration of the deformation that produced the structures is not known. Pleistocene glacial deposits, however, have been cut by the northern boundary fault of the Kigluaik uplift, which is still active.

The older folds and thrust sheets are cut and deformed by a second system of young structures—major northeast-striking and subordinate northwest-striking transcurrent faults and fractures. The Anvil-Hunker fault and the California Creek en-echelon faults comprise the principal features of this system. The system is thought to be related to the Kaltag fault, which has an age of deformation of Late Cretaceous to Tertiary (Patton and Hoare, 1968, p. D152–D153).

The sporadic occurrence of gold-bearing placers in the southwestern Seward Peninsula and their areal association with certain types of rocks have been established by Collier and others (1908, p. 113) and confirmed by Sainbury (1975, p. 68). These workers inferred possible syngenetic and epigenetic origins for the deposits from which the gold was derived. The same general relationships were reconfirmed during the current investigations. Several additional factors are now known, however. The lodes and the altered rocks have two different ages, the gold placers are associated with the basal portion of the low-grade metamorphic rocks, and the distribution of most primary and secondary mineral deposits and of the basal rocks is along the axes of major north-trending antiforms.

Many of the known lodes occur along the principal folded thrust zone between the basal and overlying low-grade metamorphic rocks. Nearly all the remaining lodes occur in and along the northeast-striking transcurrent faults or the subordinate northwest-striking faults and fractures. Later tectonic activity destroyed portions of the older folds, thrusts, and mineral deposits over the Kigluaik uplift. Older lodes were first exposed along antiforms, and gold from them was reworked in the drainage systems. Most of the gold placers that first formed in these drainages were destroyed by glaciation, and those that have formed since are the result of glacial, alluvial, and marine processes. The richest placers are at Nome, where gold derived from bedrock sources has been reworked from glacial and alluvial deposits into beach placers.

Platinum-group metals in mafic rocks of Glacier Bay, Alaska

G. K. Czamanske and Joseph Haffty carried out analyses for platinum-group metals on 17 samples from the Brady Glacier copper-nickel deposit associated with the LaPerouse-Mount Crillon layered gabbro complex in southeastern Alaska. Average, combined platinum-group metal values and their ranges for three sample types are as follows: massive sulfide, 1.29 ppm (0.19–2.98); gabbroic rocks with disseminated sulfide, 0.18 ppm (0.06–0.41); and ultramafic rocks with disseminated sulfide, 0.23 ppm (0.13–0.33).

Although concentrations of a few tenths of a part per million may appear trivial, these levels are of considerable economic interest if the platinum-group metal values are recoverable during typical standard beneficiation procedures. Any feasible mining venture in this area would require reserves of several hundred million tonnes of ore and hence would potentially recover hundreds of thousands of grams of platinum-group metals.

Platinum confirmed in ultramafic rock of the Eagle C-3 quadrangle, Alaska

A small ultramafic body in the Eagle C–3 quadrangle of Alaska yielded a significant value for platinum-group metals in two samples (Keith and Foster, 1973). Rocks from 32 different bodies in the Eagle quadrangle were analyzed for platinum-group metals, but this ultramafic body was the only one that yielded values above 0.03 ppm Pt. Later, more material was collected from this body by H. L. Foster, and 12 additional analyses were made. One specimen yielded 3 ppm Pt, 1.5 ppm Pd, and 0.030 ppm Rh. Other specimens in the group gave values ranging from not detected to 0.200 ppm Pt and not detected to 0.015 ppm Pd.

Platinum associated with hydrothermal copper ores of the Medicine Bow Mountains, Wyoming

Fieldwork and analytical work by M. E. McCallum, R. R. Carlson, E. F. Cooley, and T. A. Doerge (USGS) and R. R. Loucks (Colorado State University) in the Medicine Bow Mountains of southern Wyoming confirmed the presence of significant concentrations of palladium (average, 71 ppm) and platinum (average, 3 ppm) in copper ores at the New Rambler mine. Four principal mineral assemblages were defined in the hypogene ore paragenesis: An early assemblage of magnetite, pyrite, cubanite solid solution, and nickeliferous pyrrhotite, deposited at temperatures in the 325° to 350°C range; two copper-rich main-stage assemblages consisting principally of chalcopyrite and pyrrhotite but differing in accessory platinoid and base-metal minerals, formed below about 325°C; and a late minor assemblage of pyrrhotite, chalcopyrite, and pentlandite. At least eight platinum and palladium minerals are present, but only sperrylite has been identified.

Geochemical studies of the precious metals Pt, Pd, Rh, Au, and Ag indicate that, in the weathering cycle, Pt, Rh, and Au exhibit moderate solubilities and have undergone secondary enrichment in the strongly oxidized ore horizon. Palladium and silver have been extensively mobilized by weathering processes.

Ore textures, hydrolitic alteration of the host rock, form and structural control of orebodies, and ratios of platinoid elements in the deposit support the interpretation that the metal content of the ores was derived by hydrothermal leaching of a large volume of cataclastic mafic rocks within shear zones. Ore fluids apparently favored dilatant zones in the shear system as loci for ore deposition. The high content of platinoids in the New Rambler deposit demonstrates that hydrothermal fluids may be exceptionally effective in concentrating these metals at submagmatic temperatures.

FERROUS METALS

Ore deposits as indicators of different parentages in rocks of the ophiolite assemblage

According to T. P. Thayer, two petrologically distinct groups of rocks, the alpine peridotite-gabbro group and the tholeiitic volcanics-stratiform complex group, are distinct with regard to their related ore deposits. The alpine group contains podiform chromite (in peridotite) that has low iron (less than 15 percent) and an inverse aluminum and chromium relationship. Significant copper-iron sulfide deposits are lacking. The tholeiitic group commonly contains copper-iron sulfide deposits in pillow lavas and copper-iron-nickel-platinum deposits at the base of stratiform complexes. Layered chromite in the stratiform complexes contains iron in excess of 20 percent and has an inverse iron and chromium relationship. Platinum is associated with peridotite in both groups. The metallogenic differences between the peridotites and gabbroic rocks in the alpine (ophiolitic) complexes and those in the stratiform complexes are believed to have resulted from different magmatic lineages, and most evidence points to tholeiitic basalt as the parent magma of stratiform complexes. Gabbroic partial melts rich in magnesium and calcium and very low in iron and titanium were described in alpine lherzolite by Dicky (1970) at Serrania de la Ronda, Spain, and by Boudier and Nicolas (1972) at Lanzo, Italy. These rocks are believed to represent possible parent magma for alpine peridotite and gabbro rather than for the pillow basalts with which they are commonly associated.

Bimodality of alpine chromite deposits

Microprobe analyses of 120 chromite samples in alpine ultramafic complexes throughout the world indicated that the chromite is bimodal with respect to its content of chromic oxide. According to M. L. Bird, one mode occurs near 54 percent Cr_2O_3 and corresponds to metallurgical-grade chromite. The other mode is near 37 percent Cr_2O_3 and corresponds to refractory-grade chromite. The chromic oxide varies reciprocally with alumina, but ferric oxide is low and nearly constant.

Iron resources of the Marquette district of Michigan

A computer-aided analysis of concentrating-grade iron resources in the Negaunee Iron-formation of the Marquette district of Michigan by W. F. Cannon indicated that there are about 181 billion tonnes of iron-formation in the district. The average iron content is about 32 percent, and 95 percent of the material contains at least 28 percent Fe. In spite of this immense tonnage, a maximum of only about 10 billion tonnes Fe is recoverable from the district under current technologic and economic conditions, if the most favorable circumstances possible for development are assumed. A more realistic assessment—one that takes into account additional economic, legal, and environmental restraints not considered in the resource estimate—would be perhaps 5 billion tonnes. The resource base of the district could be expanded greatly (at least doubled) by developing the ability to mine from deeper open pits or to extract concentrating-grade ore from underground mines.

Distribution of minor metals in magnetite and ilmenite

Microprobe analyses by M. L. Bird of titaniferous magnetite "ores" from Essex County, New York, collected by Harry Klemic indicated that granular magnetite and ilmenite contain minor amounts of magnesium, manganese, and vanadium. Magnetite also contains aluminum and minor amounts of chromium. Ilmenite has a higher content of manganese and a lower content of vanadium than magnetite and contains no aluminum and only trace amounts of or no chromium. Interference caused by titanium makes the quantitative determination of vanadium difficult. Late-stage veinlets of magnetite are low in minor metal content.

LIGHT METALS

Land-use demands cause reduction in bauxite resource estimates

S. H. Patterson concluded that resource estimates of the ferruginous bauxite deposits of Hawaii should be reduced because of increased demands for other uses of the land in bauxite-rich areas. The low-grade bauxite deposits were estimated (Patterson, 1962, p. 2; 1971, table 12, p. 65, 66) as follows: Kauai, 100 million tonnes; west Maui, 8 million tonnes; and east Maui, 20 million tonnes. Since 1961, considerable bauxite acreage on Kauai has been used for real estate development rather than mining. In the Princeville Ranch area of northern Kauai (Patterson, 1971, pl. 1), hotels, condominiums, and recreational facilities now in existence, under construction, or planned have taken up so much land seaward from Hawaii Highway 56 that virtually none of the bauxite in this area is accessible. Considering the withdrawal of these resources and the likelihood that bauxite lands will continue to be put to other, more valuable uses, the total subeconomic bauxite resources in Hawaii have been effectively reduced by at least one-fourth.

NONMETALLIC MINERALS

Fluorspar deposits along late Tertiary fault zones in the Poncha Springs district of Colorado

Geologic investigations in the Bonanza NE quadrangle of Colorado by R. E. Van Alstine showed that the Poncha Springs fluorspar district, about 5 km west of Salida, is localized along the northward extension of the Rio Grande rift (Van Alstine, 1968) and at the intersection of north-trending and east-trending late Tertiary fault zones. These normal fault zones are major regional structures that bound the Sangre de Cristo Range on the western side and northern end and were previously unmapped in this area.

The fluorspar occurs as epithermal veins and stockworks of fluorite, quartz, and calcite in brecciated Precambrian metasedimentary and metaigneous gneisses and amphibolite. Although the mines are now inactive, the deposits have been worked underground and from several open pits. The past production and the more than one million tons of fluorspar resources that remain in this district show that it is one of the largest concentrations of fluorspar in the United States.

California phosphorite

A reconnaissance geologic survey by A. E. Roberts of the western part of the Diablo Range of California located five additional occurrences of phosphorite. Exposures of marine Miocene rocks were measured, described, and sampled in detail for phosphate analyses and micropaleontological studies. The rocks are assigned to the Monterey Group that includes the following formations in ascending order: Sobrante Sandstone (0.60 m), Claremont Shale (40–240 m), Oursan Sandstone (45–230 m), Tice Shale (45–165 m), Hambre Sandstone (95–840 m), and Rodeo Shale (0–105 m). Each formation represents a different marine depositional environment. The typical sequence of rocks in the mapped area is characteristic of the Monterey Group in other parts of the Coast Ranges of California. Siliceous organic shale, chert, fine-grained arkosic sandstone, clayey mudstone, and impure limestone lenses comprise the bulk of the formation, the phosphorite zones being closely associated with the siliceous shale in the Claremont and Tice and the fine-grained sandstone in the Oursan and Hambre.

Uranium in phosphate rock

According to J. B. Cathcart, uranium is a trace constituent of all apatites in amounts that typically range from <0.001 to 0.003 percent for guano and guano-derived deposits, from 0.001 to 0.010 percent for igneous apatites, and from 0.005 to 0.030 percent for marine phosphorites. Uranium may be enriched to as much as 0.05 percent in phosphorites reworked in a marine environment, and isolated bones and concretions may contain as much as 0.8 percent U as a result of enrichment by ground water.

Uranium as U(IV) replaces calcium in the apatite structure. Possibly some U(IV) occurs as UO_4^{-2} groups. Uranium is readily removed from apatite by weathering, and enrichment of phosphate after deposition is accompanied by the addition of this released uranium, as in the case of the lateritic weathering of deposits in Florida. In the case of the brown rock deposits of Tennessee, however, enrichment of uranium is residual, caused by the removal of more soluble constituents, principally calcite.

Uranium has been recovered as a byproduct of the manufacture of phosphoric acid by the wet process. In 1972, about 14 million tonnes of phosphate rock was used to make phosphoric acid in the United States. This phosphoric acid probably contained about 1,400 t U. Increased demand for phosphatic fertilizers and increases in the amount of phosphate rock used to make phosphoric acid make it likely that tonnages of uranium in phosphoric acid will reach about 4,500 t/yr within the next 25 years. Thus, marine phosphates are a significant source of uranium for the future.

Potash isopleth map, Paradox basin

According to R. J. Hite, the construction of an isopleth map based on the percentage of potash (>15 percent K_2O) in the evaporites of the Paradox Formation showed that the distribution of potash in the Paradox basin of Colorado corresponds closely to the paleoslope of the basin. The map, showing the percentage of potash in the evaporite column, was prepared by estimating the K_2O content and the deposit thickness from gamma-ray logs of petroleum test holes. Potash in the evaporite column ranges from 1.24 percent on the southwestern limits of the potash area to 9.45 percent along the Uncompahgre front, the northeastern limit of the potash area. The distribution of potash maintains a uniform regional pattern, even in diapiric salt anticlines where the evaporite sequence is complexly deformed. In these anticlines, the potash deposits intersected by drill holes are frequently steeply dipping or repeated by faulting and folding, so that their true original thicknesses are unknown. The other associated evaporite layers are also affected to a similar degree by the same structure, however, so that the relative percentage of each evaporite component remains the same as it was in the original undeformed deposit.

The isopleth map is a valuable tool for evaluating potash resources within the Paradox basin. It can be used to make fairly accurate appraisals of potash resources in any of the salt anticlines, even when there is little or no drill-hole data. For example, the Fisher Valley anticline, which is undrilled, is located between the 9- and 10-percent isopleths. On the basis of geophysical data, the thickness of the evaporite column in Fisher Valley is estimated to exceed 3,000 m. Therefore, the vertical sequence of evaporites in this structure should contain 275 to 300 m of potash (>15 percent K_2O) or about 600 million t/km^2.

Depositional environment of high-calcium limestone in western Virginia

The New Market Limestone in western Virginia is a high-calcium limestone in many places. According to H. A. Hubbard, the New Market is a lithified carbonate mud that accumulated in shallow marine water on submarine banks or on emergent tidal flats. Land-derived detritus settled to the bottom in deeper water nearer land or bypassed the banks and flats through tidal channels and left extensive areas of uncontaminated carbonate mud. High-calcium limestone occurs in other Middle Ordovician formations and consists of grainstones or packstones formed in agitated bottom waters that winnowed out fine-grained land-derived impurities. High-calcium limestone is an important industrial raw material; more limestone is used annually than any other nonfuel-mineral raw material except sand and gravel. Depositional models can help geologists define favorable places in which to look for new economic deposits of high-calcium limestone, which comprises less than 2 percent of all limestones.

Peat resources in Coastal Plain settings

Peat studies by C. C. Cameron, covering four 7½-minute quadrangles in eastern Carteret County, North Carolina, between the Neuse River and Core Sound, revealed that an estimated 7 million tonnes of air-dried humus-type peat occur in freshwater swamps on drainage divides. This peat lies above sea level and over sandy and silty peat and organic clay, silt, and sand filling estuaries and lagoons behind barrier bars of Pleistocene age oriented roughly at right angles to the modern Core barrier bar. Unlike the Core barrier, which is migrating landward as the sea transgresses, the Pleistocene barriers are believed to have been formed during the retreat of the sea.

The freshwater swamps are fringed with tidal marshes into which the sea is advancing. Here, sandy and silty peat lies at depth of 1.8 m below the organic silts, sands, and clays of the marsh, where appreciable accumulation of peat has not yet occurred. Analyses show that, in the humus-type peat of the freshwater swamps, total carbon averages 53 percent and total sulfur averages 0.18 percent. In contrast, the sandy and silty peats buried under the tidal marshes average 16 percent total C and 2.1 percent total S.

Plants extracted Cu, Ni, Zn, Ag, B, and Mg from water flowing through the thick, unconsolidated sediments of the Coastal Plain and deposited them in the plant tissues from which the humus peat formed. This process also occurred during the development of peat in bedrock areas of coastal Maine. However, the amounts of these elements that accumulated in the peat deposits of eastern Carteret County are less than those that accumulated in Maine peat deposits. Apparently, the trace-element content of peat is largely determined by the trace-element content of the water available through the roots of plants and, ultimately, by the trace-element content of the rocks through which the water flows.

Diamonds in Colorado and Wyoming kimberlite diatremes

Work done by M. E. McCallum (USGS), D. H. Eggler (Geophysical Laboratory, Carnegie Institute of Washington), and C. D. Mabarak (Colorado State University) on kimberlite diatremes near the Colorado-Wyoming State line led to the discovery of diamonds in both States. The initial discovery was made when a small (~1 mm) diamond was encountered during the preparation of a thin section of a serpentinized garnet peridotite nodule from one of the Wyoming pipes. This diamond and several others subsequently recognized in the nodule represent the first authenticated occurrence of diamonds in Wyoming and the second known occurrence of diamonds from a kimberlite pipe in North America (the first being at Murfreesboro in Pike County, Arkansas). Furthermore, the nodule is only the second reported diamond-bearing xenolith of its type in the world.

Following the recognition of diamonds in the Wyoming nodule, a program was initiated to evaluate weathered kimberlite in the State line district for diamonds. Several diamonds were recovered from weathered kimberlite at the Sloan diatremes in northern Colorado, and a few were recovered from weathered kimberlite in Wyoming. More than two dozen crystals ranging from approximately 0.1 to 1.85 mm have now been recovered, and most of the State line pipes are currently being evaluated. A stream-sediment exploration program for the location of additional pipes is also being conducted.

MINERAL-RESOURCE ASSESSMENTS OF AREAS

ALASKAN MINERAL RESOURCE ASSESSMENT PROGRAM

The Alaskan Mineral Resource Assessment Program (AMRAP) is designed to provide a careful, systematic evaluation of Alaska's mineral endowment (fig. 1). A rapid assessment of this vast and potentially mineral-rich region is required both to plan a viable, long-range national minerals policy and to assist in making forthcoming decisions on Alaskan land use and development. One immediate objective of AMRAP is to provide substantive resource information about lands specified under Section d–2 of the Alaskan Native Claims Settlement Act.

AMRAP assessment of mineral-resource potential systematically integrates existing knowledge with new geologic, geochemical, geophysical, and telegeologic information that is analyzed by computerized statistical methods. Results are published as 1:250,000 map folios that include a text and geologic, geochemical, geophysical, and interpretive mineral-resource maps.

The first mineral assessment to be completed under AMRAP was of the 1°×3° Nabesna quadrangle (loc. 1, fig. 1), for which a folio of 12 miscellaneous field studies maps and an accompanying circular (Richter and others, 1975) have been published. Fieldwork in three more quadrangles—Tanacross, McCarthy, and Chandalar (locs. 2, 3, and 4, respec-

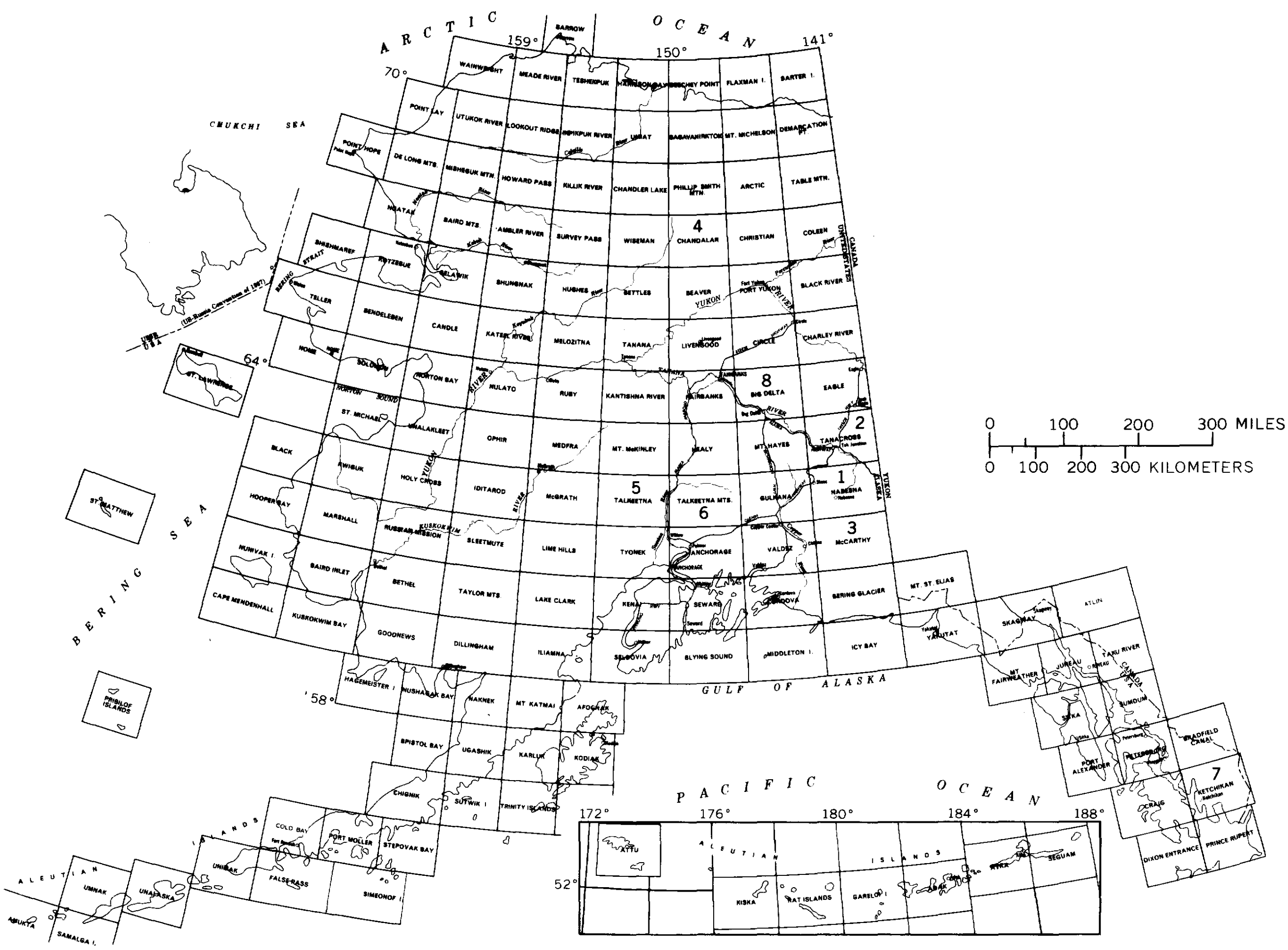


FIGURE 1.—Alaska Mineral Resource Assessment Program (AMRAP) project locations.

tively)—is completed, and studies are in progress in 11 other quadrangles.

Each quadrangle is studied by an interdisciplinary team of geochemists, geophysicists, telegeologists, and regional mappers, under the management of a team leader. The AMRAP projects are examining significant known mineralized areas and identifying new areas of mineral potential in Alaska. Results are reported here for mineralized areas in the Talkeetna, Talkeetna Mountains, Ketchikan, and Big Delta quadrangles.

Chromite-bearing ultramafic rocks in the Alaska Range, Talkeetna quadrangle

B. L. Reed, S. W. Nelson, and R. L. Detterman discovered a northeast-trending belt of chromite-bearing ultramafic rocks during reconnaissance mapping in the Talkeetna quadrangle of Alaska (loc. 5). The belt is discontinuously exposed for at least 20 km north of the Yentna and Lacuna Glaciers. It lies immediately north of and parallel to a northeast-trending suture that is the boundary between upper Paleozoic flysch on the north and an extensive Cretaceous greywacke-argillite sequence on the south. The ultramafic rocks were examined briefly at only a few places and were found to consist of chromite-bearing dunite in typical podiform-alpine-type ultramafic bodies. Chromite occurs as disseminations, streaks, and lenses and as massive chromite pods, lenses, and blocks of various shapes up to 3 m thick and about 20 m long. Larger chromite bodies may exist within this large unexplored belt of ultramafic rocks.

Geochemical anomalies in the Willow Creek mining district, Talkeetna Mountains quadrangle

Geochemical reconnaissance studies were carried out by M. L. Silberman and R. M. O'Leary in the now largely abandoned Willow Creek mining district in the southwestern Talkeetna Mountains of Alaska (loc. 6). Between 1908 and 1952, the district produced nearly $18 million worth of gold and silver from quartz veins and Mesozoic diorite (Ray, 1954). The veins contain gold, copper, lead, and zinc sulfides. Northeast of the Talkeetna Mountains, in the eastern Alaska Range, porphyry copper deposits occur in batholithic granitic rocks similar to those in the Talkeetna Mountains, but the level of erosion in the eastern Alaska Range is deeper. Results of a preliminary geochemical survey suggest that the gold deposits and base-metal vein deposits in the Willow Creek district may overlie undiscovered porphyry copper deposits at depth.

Geochemical survey reveals new mineral belt, Ketchikan quadrangle

According to H. C. Berg and E. H. Cobb (1967), mineral deposits on the Cleveland Peninsula of southwestern Revillagigedo Island, Alaska (loc. 7), include small inactive lode mines that have produced ore containing Au, Z, Cu, Pb, and Ag. Numerous other occurrences of these commodities and one of antimony have been prospected but not mined. Reconnaissance geochemical investigations suggest that these lodes are part of a northwest-trending belt, several kilometers wide, of sulfide-bearing metamorphosed sedimentary and igneous rocks that contain quantities of these metals ranging from traces to possibly significant amounts. Some of the most conspicuous sulfide deposits are associated with iron-stained pyrite-quartz-muscovite-carbonate schist that may be recrystallized sills or flows. The possibility that the mineral deposits are locally remobilized stratabound volcanogenic sulfide deposits is being investigated.

Discovery of new mineralized zones, Big Delta quadrangle

Reconnaissance mapping by H. C. Foster, F. R. Weber, and T. E. C. Keith in the eastern part of the Big Delta quadrangle (loc. 8) in east-central Alaska indicated several areas of mineralization. Not enough data are yet available, however, to determine whether these areas are promising exploration targets. An extensive altered zone was mapped around a biotitic quartz monzonite intrusion in the C–2 quadrangle. Locally, anomalous values in Cu, Pb, Sn, An, Ag, and Zn were found in the altered rocks. The second zone of alteration occurs around another small pluton in the D–2 quadrangle. Some of these rocks contain anomalous amounts of Au, Ag, Sn, Pb, Zn, Cu, and An.

MINERAL-RESOURCE INVESTIGATIONS RELATED TO THE WILDERNESS ACT

The Wilderness Act of 1964 directs the Secretary of Agriculture and the Secretary of the Interior to review the suitability of lands being considered for inclusion in the National Wilderness Preservation System. To aid in evaluating suitability for wilderness inclusion, the USGS and the U.S. Bureau of Mines make mineral-resource assessments of candidate wilderness areas in the national forests as well as of wilderness areas established by the act (fig. 2).

Mineral surveys have been completed on all 35 primitive areas designated by the Wilderness Act. Results have been published as USGS bulletins. Mineral surveys also have been completed on 19 of the 54 wilderness areas established by the Wilderness Act of 1964. Fieldwork is underway in four wilderness areas—the John Muir in California (loc. 1, fig. 2), the Superstition in Arizona (loc. 2), the Rawah and additions in Colorado (loc. 3), and the Washakie in Wyoming (loc. 4). Mineral-resource surveys are also underway in study areas proposed for inclusion in the Wilderness System by the U.S. Forest Service. To date, fieldwork has been completed in 92 study areas and is underway in 15 additional study areas. The Secretary of the Interior has directed that mineral surveys of six Interior lands amounting to 7.8 million acres be made by 1980. Fieldwork has been completed on two of these areas, the Charles Sheldon (loc. 5) and the Charles Russell (loc. 6) Game Ranges in Nevada and Montana, respectively, and is underway on two other game ranges and the Glacier Bay National Monument (loc. 7) in Alaska. Specific scientific and economic findings of wilderness investigations are detailed below.

Uranium and thorium anomalies, Beartooth-Absaroka study area, Montana

Uranium and thorium anomalies, principally in stream-sediment samples, were recently discovered by J. E. Elliot in the North Absaroka study area in the Beartooth and Absaroka Ranges of Montana (loc. 8). Uranium and thorium anomalies discovered by the Johns Manville Corporation were confirmed and further extended by present USGS investigations. Analyses by neutron activation techniques indicate up to 430 ppm U and 115 ppm Th in stream sediments and 100 ppm U and 750 ppm Th in rocks. The source of the uranium and thorium may be biotite-rich zones of granitic gneiss and felsic pegmatites of a metamorphosed older Precambrian pluton. The uranium and thorium anomalies, which correlate with a weak molybdenum anomaly, occur along

FIGURE 2.—Wilderness study locations in the Western United States and Alaska.

a northwest-trending zone more than 16 km long on the flank of a magnetic high.

Phosphate, Gros Ventre study area, Wyoming

The Gros Ventre study area (loc. 9) contains an extensive occurrence of the Permian Phosphoria Formation, according to F. S. Simons. Near the northeastern edge of the area, the formation is exposed intermittently from lower Crystal Creek southeastward to the headwaters of Tosi Creek, an airline distance of about 32 km. The formation dips gently northeastward and ranges in thickness from 45 to 60 m. It is exposed over, or is presumed to underlie, an estimated area of about 80 km^2 within the study area. Phosphorite beds in the Phosphoria Formation range from a few centimeters to 3 m in thickness, but most are 5 to 15 cm thick, and only five of the beds are as much as 30 cm thick. Phosphorus content ranges from 3 to 12 percent (7 to 28 percent P_2O_5) and averages about 9 percent P (21 percent P_2O_5).

Porphyry-molybdenum and chimney-copper deposits, South San Juan-Chama study area, Colorado

G. J. Neuerburg, Theodore Botinelly, M. R. Brock, and D. L. Gaskill mapped and compared geochemical patterns and mineral zonation in areas of altered rock in the Crater Creek area of the Chama-South San Juan study area of Colorado (loc. 10) with mineralization at Summitville and other mining districts in the San Juan volcanic field. Their studies indicate a barely exposed chimney pipe containing copper, an exposed top of a porphyry-molybdenum deposit, and probably a deeply buried porphyry-metal deposit.

Geologic and geochemical studies indicate leakage of metals, Sheldon Antelope Range and Refuge

Geologic studies of the Sheldon Antelope Range and Refuge in northwestern Nevada (loc. 5) undertaken by R. C. Greene and J. B. Cathrall (USGS) and C. T. Tuchek (U.S. Bureau of Mines) revealed that much of the area is underlain by a sequence of rhyolitic welded tuffs and flows, all of late Miocene age (14–15 million years old). These rocks are capped by tuffaceous sediments and by basalt of probable Pleistocene age.

Geochemical surveys done by Cathrall, D. F. Siems, G. L. Crenshaw, and E. F. Cooley indicated that elements such as As, Hg, Sb, W, Au, and Mo may have leaked through the volcanic rocks of Miocene age and younger along suspected faults and areas of geothermal activity.

High background lead in Little Cottonwood stock, Lone Peak study area, Utah

In the Lone Peak study area of Utah (loc. 11), C. S. Bromfield reported that background lead from stream sediments crossing the Little Cottonwood stock is about 100 to 150 ppm; background lead from the area underlain by sedimentary rocks, primarily Paleozoic carbonate rocks, is less than 50 ppm. High lead in the former area is believed to reflect a high average lead content in the quartz monzonite, the K-feldspar phenocrysts, and the fillings in the joints that cut the stock. The average lead content of 16 samples of the stock is 50 ppm (ranging from 20 to 100 ppm), more than twice the value reported in the literature for intermediate igneous rocks. Five samples of K-feldspar range from 70 to 300 ppm Pb, and Slawson and Nackowski (1959) reported a mean content of 55($\pm$8) ppm for eight samples of K-feldspar from the Little Cottonwood stock. Nine samples from weathered iron-oxide-stained joint surfaces had lead contents ranging from 10 to 1,000 ppm (averaging about 200 to 300 ppm). Although the high background lead in the stock is widely dispersed and not thought to imply any local resource potential, it is interesting to recall that the stock is in the Park City-Bingham mineral belt, from which 98 percent of Utah's lead production has come (chiefly Park City and Bingham).

MINERAL ASSESSMENT PROGRAM IN THE UNITED STATES

The objective of this program of mineral assessment studies is to provide geologic, geochemical, and geophysical data for resource evaluations of regions in the lower 48 States (excluding wilderness areas) that are believed to have mineral potential. These surveys provide information to be used by Congress and governmental agencies as well as by industry for making policy decisions on management, land-use planning, environmental impact, and resource availability. Some of these projects are conducted in cooperation with State and Federal agencies. Increasing program emphasis is being placed on the evaluation of resources on Federal lands managed by the Department of the Interior (Bureau of Land Management, National Park Service, and Fish and Wildlife Service) and on public lands where urbanization is encroaching on areas of potential mineral resources (fig. 3).

Geochemical survey, Hartford 2° quadrangle, Connecticut

Geochemical data maps were prepared by J. P. D'Agostino for the Hartford 2° quadrangle of Connecticut (loc. 1, fig. 3) at a scale of 1:250,000. Past production of metals indicates the presence of distinct mineral districts having mines for barite and copper located in bedrock of Triassic age or younger in the central part of the Hartford quadrangle, for arsenopyrite and other sulfides in Precambrian and lower Paleozoic bedrock of the central and west-central part, and for limonite in Precambrian bedrock of the southwestern part. No significant mineralization is present in the eastern part of the quadrangle.

Geology and mineral resources, Tucson 2° quadrangle, Arizona

Geologic surveys conducted by T. G. Theodore, P. M. Blacet, H. R. Cornwall, and S. C. Creasey in the Tucson 2° quadrangle of Arizona (loc. 2) as part of the Phoenix-Tucson urban study led to compilation of a generalized geologic map showing the potential for the occurrence of copper deposits. The map will be used by local government agencies in establishing the best use for lands in the region.

Mapping in the region west of Tucson led to the recognition of a broad northwest-trending zone of relatively high mineral potential that parallels a similar zone previously recognized in the east-central part of the Tucson 2° quadrangle. These zones seem to intersect two east-northeast-trending belts of high copper in the northern part of the quadrangle. The trends of all these zones of Laramide mineralization are strongly controlled by regional structural elements that commonly produce similar orientations in associated elongate plutons and crosscutting east-northeast dike swarms.

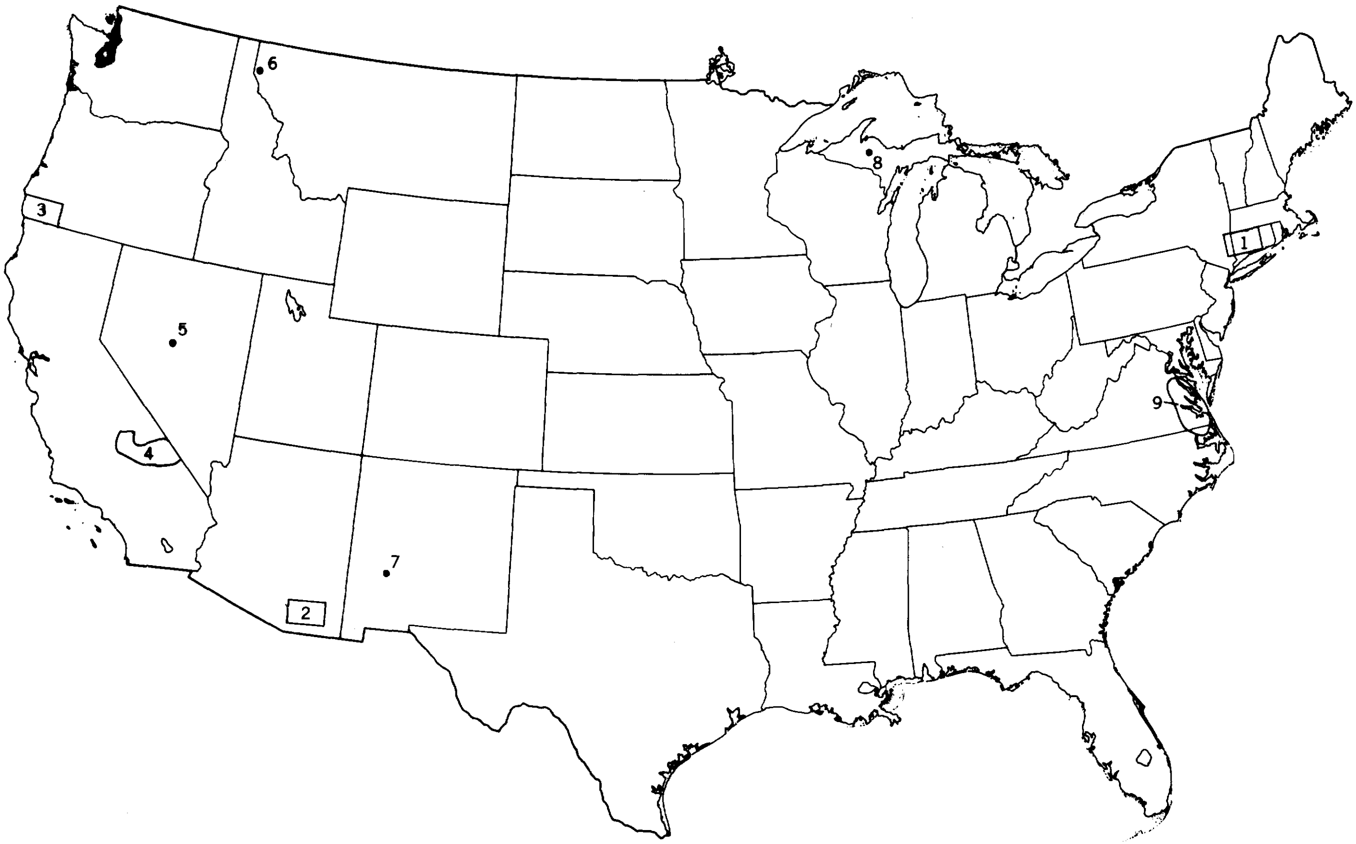


FIGURE 3.—Mineral Assessment Program project locations.

Occurrence of platinum-group metals, Medford and Coos Bay 2° quadrangles, Oregon

As part of a program to evaluate the mineral resources of the Medford and Coos Bay 2° quadrangles in Oregon (loc. 3), the occurrence of platinum-group metals was documented by N. J Page, M. G. Johnson, Joseph Haffty, and Len Ramp (1975). Platinum-group metals have been known to occur in beach sands and stream gravels in Oregon since the 1850's; 62,767 g of unrefined platinum concentrates were produced during the period 1903–45 (Ramp and Brooks, 1969). Most platinum production was a byproduct of gold placer mining in the Medford and Coos Bay 2° quadrangles.

Modern analytical techniques demonstrate that platinum-group elements are present in the ultramafic rocks in the area and that they are particularly concentrated in the chromites. Platinum-group metals have been verified in deposits from streams draining areas that contain ultramafic rocks and also in one unique copper-nickel lode deposit in norite. Electron microprobe analyses of grains from beach sands and stream gravels showed the presence of platinum-iron alloys, platinum-gold alloys, and osmiridium alloys. In view of the presence of osmiridium alloys in the placers, it may be important to examine the concentration of osmium and iridium in the ultramafic rocks. Although the concentrations of platinum, palladium, and rhodium found in the Medford and Coos Bay quadrangles have no economic potential at this time, the data are still limited in amount and areal distribution. In the future, the possibility of obtaining byproduct platinum-group metals from chrome mining operations should not be overlooked.

Mineral-resource information for Bureau of Land Management, California desert lands

Studies of the mineral-resource potential of California desert lands (loc. 4) were conducted by R. M. Smith and H. K. Stager in cooperation with the U.S. Bureau of Land Management (BLM). Administrative reports were prepared summarizing the mineral resources and mining activities of study areas within the California desert lands so that the BLM could classify these lands for the protection of mining and the environment. Reports were completed on the mineral resources of the Yuha Desert, the Soline Valley, the west Mojave area, the east Mojave area, and the east Mojave-Mojave Basin area.

Potential for resources of gold, porphyry copper, and molybdenum, Round Mountain, Nevada

A resource assessment by D. R. Shawe of the Round Mountain quadrangle of Nevada (loc. 5) indicated that, in addition to a large low-grade gold deposit in Tertiary rhyolite at Round Mountain now being developed by the Copper Range Exploration Company, there may also be a significant potential for gold deposits of the Carlin type and for porphyry copper-molybdenum deposits. A small Carlin-type deposit in thrust-faulted carbonaceous silty carbonate rock of Ordovician age and near Oligocene rhyolite intrusive rocks may be more extensive than previously realized, and similar undiscovered deposits may occur nearby. Extensive mineralization that is in many ways similar to that bordering some known porphyry copper-molybdenum deposits is present around the edges of a small Tertiary diorite stock 3 km east of Round Mountain and in the vicinity of a postulated buried intrusive centered at an aeromagnetic anomaly 3.5 km south of Round Mountain.

Criteria for assessing potential for stratabound copper, northwestern Montana

The Revett Formation of Precambrian Y age is the most important host for stratabound copper and silver deposits in northwestern Montana (loc. 6). Geological and geochemical comparisons made by R. L. Earhart and T. D. Bowden of a stratabound copper-silver orebody in the Revett Formation near Spar Lake with other copper-silver occurrences in the Revett are useful in delineating and evaluating target areas that may contain buried stratabound deposits of possible economic importance.

The Revett has been divided into eight correlatable lithostratigraphic units based on distinctive differences in the relative amounts of quartzite, siltite, and argillite that occur in stratigraphic intervals of significant thickness. The metalliferous stratabound deposits are in these units where quartzite is dominant.

Rhyolite containing perlite in the Big Burro Mountains, New Mexico

Preliminary geologic mapping by D. C. Hedlund indicated that the intersection of smaller faults with major northwest-striking faults or rifts may have an important bearing on the loci of early Tertiary magmatic intrusion in the Big Burro Mountains in the Hillsboro and San Lorenzo quadrangles of New Mexico (loc. 7).

A series of large northwest-striking faults extends through the southern part of the Big Burro Mountains in the southwestern part of the State. These faults, of probable Laramide or early Tertiary age, include the Mangas Valley fault, the Walnut Creek-Uncle Sam faults, the Malone fault, and a range-front fault that is concealed by colluvium about 1 to 2 km southwest of the Langford Mountains along the northern edge of Lordsburg Valley.

The Malone fault has dropped and tilted Tertiary volcanic rocks to the northeast. Along its inferred projection to the southeast through the Werney Hill quadrangle, the faulting of Tertiary volcanic rocks against Precambrian gneiss is less apparent, and there is evidence for postfaulting extrusion and volcanic eruption along the fault. Detailed mapping of the volcanic rocks along C Bar Canyon and Burro Cienega Creek has indicated the presence of a rhyolitic volcanic cone or extrusive dome along the projected strike of the Malone fault near its intersection with the Silver City Draw fault. Within the dissected rhyolite extrusion, an older white to light greenish-gray altered rhyolite is overlain by fresh pinkish-gray rhyolite that has an extensive vitrophyric base, which is locally perlitic. Large tonnages of perlite suitable for lightweight aggregate probably exist in the area.

Geology and metal potential, Gogebic County, Michigan

W. C. Prinz compiled a geologic map of the Precambrian W and X rocks of Gogebic County, Michigan (loc. 8), at 1:125,000 scale that provides a basis for a preliminary evaluation of the resource potential of the county. Gogebic County has produced large amounts of high-grade iron ore, and the host iron-formations have been extensively explored for iron deposits. Unmined high-grade iron deposits are known in the county, but the economics for their exploitation is currently unfavorable, and no iron mines are now operating there. The potential for low-grade concentrating ores of iron is less well known but is not as great as it is in the Marquette district of Michigan or the Mesabi range of Minnesota, the two largest sources of iron in the country.

Although very little work has been done on deposits of other metals in Gogebic County, there are indications that areas favorable for the occurrence of base and precious metals exist. Three volcanic units warrant investigation as potential hosts for volcanic rocks of Archean (Precambrian W) age that crop out south of the Gogebic iron range from Bessemer eastward to within a few kilometers of Lake Gogebic. This unit is composed of mafic to intermediate flows and intermediate to felsic pyroclastic and volcaniclastic rocks. Rocks at the eastern end of this belt are highly metamorphosed gneisses and schists that had been considered by several previous workers to be altered Palms Formation of Precambrian X age. They are now known to be metamorphosed Archean volcanic and associated clastic rocks. A second unit of rocks that should be investigated for sulfide deposits includes the Blair Lake strata of Precambrian X age that crop out in a belt 24 km long between Marenisco and Watersmeet. They are composed of metamorphosed mafic pyroclastic and volcaniclastic rocks, pillowed lava flows, and some iron-formation. Little is known, however, of their petrology or of the distribution of various rock types within the unit. The third unit is the Emperor Volcanic Complex of Precambrian X age that is interbedded with and overlies the Ironwood Iron-formation between Wakefield and Lake Gogebic. This unit is composed of coarse volcanic conglomerate or breccia and pillowed lava flows. Most rocks in the formation are andesitic to dacitic in composition.

The basal beds of the Copps Formation and correlative beds in the Tyler Slate also warrant investigation as hosts for metal deposits. These beds are fine- to medium-grained clastics, arkosic in places, cemented by and interbedded with metachert and iron-rich carbonate or iron oxide (hematite or magnetite). Basal Copps beds are conformable, locally, with the underlying Emperor Formation and were apparently deposited during the waning stages of the volcanic period that produced the Emperor. Volcanic fluids may have been the source of silica (metachert) and iron in the basal beds. The basal Copps beds are host for one lead sulfide prospect, the Copps "mine" north of Marenisco, and massive pyrite beds occur locally in the basal Tyler.

Heavy minerals in Pleistocene(?) shoreline sands, eastern Coastal Plain

E. R. Force, P. J. Geraci, and J. W. Whitlow completed a study of Appalachian sediments in the Coastal Plain of Virginia (loc. 9). Results show approximate distribution of Pleistocene(?) shoreline sand bodies and heavy-mineral content of the sands. The tenor of the heavy minerals is too low for ores of any element or combination of elements present. A heavy-mineral content of 1.55 percent by weight is the highest found, and 0.59 percent by weight titanium dioxide or 5.9 kg/t of sand is the highest reported.

MINERAL ASSESSMENT OF INDIAN LANDS

The USGS and the U.S. Bureau of Mines, under an agreement with the Bureau of Indian Affairs, are assessing the mineral resources of Indian lands. The program is proceeding in three phases:

- Summary and analysis of the status of mineral-resource information on all Indian lands.
- Field studies to provide regional mineral-resource information on Indian lands where such information is lacking or deficient.
- Special studies aimed at evaluating resources at specific sites and their potential for economic development.

Phase I of the program resulted in 10 reports on 9.7 million acres of Indian lands in 1975 and 14 reports on 7.9 million acres in 1976. A review of available information indicates that the Papago Reservation in Arizona has a high potential for undiscovered porphyry copper deposits, but extensive new geologic, geophysical, and geochemical data must be gathered before resources can be located and assessed. The Wind River Reservation in Wyoming and the Spokane Reservation in Washington both have a potential for undiscovered uranium deposits. The Colville Indian Reservation in Washington has been studied little, but many small known ore deposits suggest a potential for more and perhaps for porphyry copper deposits as well. The Crow and Northern Cheyenne lands in Montana contain vast coal deposits now being explored by industry. Indian lands in parts of northern Minnesota that are underlain by rocks similar to some in Canada that are hosts to important ore deposits may contain massive sulfide deposits.

On the basis of recommendations resulting from Phase I, Phase II studies were begun on three Indian reservations—the Papago (USGS and Bureau of Mines), Wind River (USGS), and Spokane (Bureau of Mines). A program of geologic mapping and geophysical surveys is underway on the Papago Reservation, the ultimate objective being a modern assessment of mineral potential. Studies to locate areas favorable for uranium resources are in progress on the Wind River Reservation.

MINERALS DISCOVERY LOAN PROGRAM

The Office of Minerals Exploration (OME), under Public Law 85–701, approved August 21, 1958, is authorized to offer financial assistance to private industry on a participating basis to explore deposits of certain minerals or mineral products. Of the 210 contracts executed in the 17 years of OME's operation, 54 have been certified as successes, having discovered ore reserve valued at about $170 million. Government expenditures for contract support and administrative and technical services have totaled about $9 million.

The OME program has had limited success to date in making significant discoveries of mineral reserves, and various proposals are being considered to improve its effectiveness. Whether an OME-type program is the most effective means of assisting industry in minerals exploration, whether an alternative program should be undertaken, and what the level of government participation should be are under consideration. Pending a decision on the future of the program, funds for new exploration contracts have not been requested since FY 1974.

Funds have been requested and received to continue the technical and administrative services required to manage active contracts and to administer completed and certified contracts having continuing obligations for royalty payments on production. Unused funds released from completed prior-year contracts have been used to support contracts awarded since FY 1974.

GEOCHEMICAL AND GEOPHYSICAL RESOURCE TECHNOLOGY

AREAL GEOCHEMICAL STUDIES

Coeur d'Alene district, Montana and Idaho

In the Coeur d'Alene district of Montana and Idaho, J. B. Cathrall and G. B. Gott used vegetation as a sample medium to test the ability of various conifer species to delineate areas of known and suspected mineral belts revealed by rock and soil samples. Regardless of the species sampled, early evaluation of the data indicated a clear delineation of known mineral belts and possible extensions of these belts.

In the same area, Cathrall and Gott used geochemical data to establish a model explaining the origin and history of the ore deposits. The mineral deposits, which were emplaced in well-defined belts, were intruded by Cretaceous monzonite; this intrusion destroyed some mineral deposits in the vicinity of the monzonite. The ore-forming metals were then remobilized, redistributed, and reprecipitated in a halo surrounding the monzonite stocks. Where the remobilized and redistributed metals overlapped the belts, the mineral deposits were enriched for a second time. Later, post-ore deposition movement along some major faults within the district displaced several fault blocks. Restoring these fault blocks to their original position reveals that geochemical halos of An, Pb, As, S, and Cd surround the monzonite stocks.

Caridad porphyry copper deposit, Sonora, Mexico

M. A. Chaffee (USGS) and J. L. Lee-Moreno and L. F. Caire (Consejo de Recursos Naturales no Renovables of Mexico) (Lee-Moreno and others, 1975) conducted a geochemical survey in the vicinity of the Caridad porphyry copper deposit in northern Sonora, Mexico. Samples of Mexico's ¼-mm stream sediments, panned concentrates, and trees common to the area were collected from the arroyos near and downstream from the Caridad deposit and later analyzed for up to 32 elements. Although surveys using any one of the three sample media would have pinpointed the deposit, copper, molybdenum, and tungsten in stream-sediment samples showed the most extensive and effective anomalies.

Kalamazoo porphyry copper deposit, Arizona

M. A. Chaffee (1975) plotted concentration versus depth for trace elements in samples of drill cores and cuttings from the Kalamazoo porphyry copper deposit of Pinal County, Arizona, and found distinct high- or low-concentration zones for at least 17 elements. These zones are naturally related to the ore zone (70.5 percent Cu) and extend as much as 300 m above the top of the ore zone for elements such as Fe, Cu, Mo, Au, Co, and Rb and extend at least 900 m for elements like S and Se. Elemental zoning is more quantitative than gross mineralogical zoning and should be at least as effective for evaluating rock bodies thought to contain blind ore deposits similar to the Kalamazoo deposit.

Hillsboro and San Lorenzo quadrangles, New Mexico

K. C. Watts and J. R. Hassemer reported that heavy-mineral sampling in the Hillsboro and San Lorenzo 15-minute quadrangles delineated several geochemically anomalous target areas. An intricate framework of linear geochemical anomalies in the limonite-rich concentrate connects areas of known mineral deposits with areas containing intense geochemical anomalies. These linear trends are oriented north-northwest, corresponding to the direction of the geologic structures in the area and east-west-cutting known geologic boundaries having no apparent relationship to surface geologic features. The intersections of these trends are sites of strong geochemical anomalies and known mineral deposits.

Sheeprock Range, Utah

In the Sheeprock Range in Tooele County, Utah, W. R. Griffitts reported that geologic mapping showed that the red- and white-weathering granite facies represented alteration by late magmatic or postmagmatic fluids. Deposition of beryl in the white-weathering granite and monazite in the red-weathering granite was related to this alteration.

Hidden copper anomalies revealed by partial extraction

In Lewis and Clark County in western Montana, D. J. Grimes and R. W. Leinz found that the ratio of partially extractable copper to the total copper in stream-sediment samples revealed copper anomalies not seen in bulk sediment analysis. The sorbed copper associated with hypogene mineralization is soluble in dilute nitric acid, and the found copper is left behind. The ratio of total copper to extractable copper may be used to distinguish between ore-related and nonore-related anomalies.

Anomaly enhancement in geochemical exploration

In southwestern New Mexico, H. V. Alminas reported that stream-sediment studies revealed geochemical patterns and trends that may reflect buried porphyry-type mineralization. Initially, he separated the stream-sediment samples into sulfide and oxide fractions before trace-element analysis. Higher trace-element anomalies were found in the oxide fraction in volcanic cover and in the sulfide fraction in sedimentary cover. East-west-trending geochemical patterns crossing the local north-south fabric were revealed by this technique and may indicate older mineralized structures.

INSTRUMENTATION

Helium detection

R. C. Bigelow designed and developed an analyzer for helium in soil gas that ratios the helium content of 20- to 40-ml samples of soil gas against the helium content of ambient air by using the "leak rate" indicator of a Varian leak detector. The instrument operates without cold traps and appears to be insensitive to either carbon dioxide or hydrocarbons in the air sample. Sensitivity is approximately 1 percent or 50 ppb for helium in air.

Using a modified helium-leak-detector mass spectrometer installed in a four-wheel-drive vehicle, G. M. Reimer evaluated helium in soil gas as an exploration tool for uranium. At the Schwartzwalder uranium mine in Jefferson County, Colorado, detectable helium anomalies are found to be associated with the mineralization.

Irving Friedman reported that the on-site measurement of the helium content of soil gas with a portable mass spectrometer has a definite value as a prospecting and resource evaluation tool in geothermal areas and in gas and oil prospecting. The helium content of soil (~0.6 m deep) over Harley dome in Utah, a natural gas reservoir with a high (~7 percent) helium content, is double the helium content in the atmosphere. The truck-mounted spectrometer can detect helium concentration changes of about 20 ppb in 1 to 2 minutes.

Tree luminescence

R. D. Watson, R. C. Bigelow, and W. R. Hemphill reported that a redesigned Fraunhofer line discriminator is capable of measuring differences between the luminescence of trees growing in soils containing anomalous concentrations of copper and molybdenum and the luminescence of trees growing in background soils nearby. In general, the differences were more pronounced when the cloud cover was less than 10 percent.

METHODOLOGY

Determination of trace elements in water

After more than a year of testing, W. H. Ficklin established that flameless atomic absorption methods using a graphite furnace are suitable for the chemical analysis of very low levels of many elements in water. Methods for Cu, Pb, Zn, and Mo are rapid, precise, and sensitive to concentrations in the part-per-billion range. The methods provide a means of obtaining detectable values for small concentrations that are of interest in geochemical prospecting and in studies of the geochemistry of trace elements in waters.

Tin determination for geochemical exploration

E. P. Welsch and T. T. Chao developed an atomic absorption method for determining traces of tin in rocks, soils, and stream sediments. The method is rapid and free from common interferences and is capable of measuring as little as 2 ppm with relative standard deviations of from 2 to 14 percent. Amounts up to 20 percent Fe and 1,000 ppm Cu, Pb, Zn, Mn, Hg, Mo, V, or W in the sample do not interfere.

Determination of soil gases

M. E. Hinkle and R. L. Turner used molecular sieves to collect soil gases prior to analysis by gas chromatography. Concentrations of carbon oxysulfide, hydrogen sulfide, and carbon dioxide were detected above background level over a gravel-covered copper deposit in southern Arizona. High helium concentrations were found over the San Andreas fault in the Imperial Valley of southern California.

Luminescence remote sensing in resource technology

According to R. D. Watson, a redesigned Fraunhofer line discriminator (FLD) demonstrated the capability of measuring differences in the luminescence of trees growing in soils containing anomalous concentrations of copper and molybdenum. The FLD was tested in both ground-based and airborne experiments to determine its ability to detect geochemically stressed trees and other resource materials. In tests conducted near Denver, Colo., the luminescence contrast between stressed and nonstressed trees tended to be higher during periods when the cloud cover was less than 10 percent; in most cases, contrast was insignificant when the cloud cover exceeded 10 percent. In other airborne tests, the FLD distinguished luminescing phosphate rock and gypsum from sandstone and siltstone near Pine Mountain, Calif.; at the Cement, Okla., oilfield, a correlation coefficient of 0.62 at the 99-percent confidence level was established between luminescence and manganese content in carbonate-cemented rocks.

Helium sniffer used for detecting natural gas

A. A. Roberts, Irving Friedman, and E. H. Denton completed work on the concentration of helium in the soil gas overlying a natural gas field at Harley dome in Utah. The structure of the Harley dome field is a northwest-trending anticline on the edge of the Uinta Basin. Gas is produced from the Entrada Sandstone at an average depth of 260 m and contains about 7 percent He. This shallow production zone and the high helium content should greatly enhance the chances of detecting seepage at the surface. The good correlation observed between the area of anomalously high helium concentration (up to three times greater than background concentration) and the known producing area suggests that helium sniffing may be useful as a direct detection device in prospecting for natural gas fields containing helium.

Precision of the six-step semiquantitative spectrographic method

An analytical precision study of the six-step semiquantitative spectrographic method was completed by J. G. Viets. Over 2,700 separate analyses were made on 22 different geologic samples selected to cover wide concentration ranges for 30 elements. Results were obtained from mixed analytical conditions with few laboratory controls enforced. In general, the method is shown to be within one adjoining reporting interval on each side of the mean 83 percent of the time and within two adjoining intervals on each side of the mean 96 percent of the time.

TOPICAL GEOCHEMICAL STUDIES

T. T. Chao and R. F. Sanzolone developed a sequential fractionation scheme whereby a metal or metals in stream sediments or soils can be separated by using various selective chemical extractants related to manganese oxides, amorphous iron oxides, crystalline iron oxides, sulfide minerals, and silicate matrices. The distribution of a given metal obtained from this fractionation provides information useful during the orientation phase of a geochemical exploration program. The proper selection of sample media and chemical treatment is also useful during the followup phase to evaluate the significance of geochemical anomalies.

USEFUL TOOLS IN EXPLORATION

Europium-rich monazite as a guide to ore deposits

W. C. Overstreet and Sam Rosenblum reported that europium-rich oolitic dark monazite, probably formed by contact metamorphism, was found in four panned concentrates from 25 sites in Montana where streams drained the Phosphoria Formation-granitic rock contact areas. In addition to being an ore of the rare-earth elements, the mineral may provide a guide to phosphate layers and granitic contact zones with metalliferous deposits

Gravity mapping as an aid to mineral exploration

G. P. Eaton prepared complete Bouguer gravity maps using data obtained at 1,030 gravity stations in southwestern New Mexico. The broad region covered by the maps includes many major mining districts, small mines, prospects, and thermal springs. Because the distribution of known ore deposits and thermal springs displays some general relationships to the gravity field, the gravity field could possibly be used to aid further exploration.

Although the region straddles the boundary between the Basin and Range province on the south and a high Tertiary volcanic plateau on the north, the residual gravity map suggests a continuation of uplifted structural blocks of pre-Cenozoic rocks northwestward and northward beneath the Tertiary volcanic cover. For example, a single, continuous, structurally high block is seen to trend from the Cooke Range to Glenwood, some 150 km. An area of intense hydrothermal alteration at Alum Mountain and the mining districts of Santa Rita, Hanover, Pinos Altos, Silver City and Gila are all within this block. Cenozoic volcanic rocks and sediments obscure the actual continuity of this block, and Laramide plutons show up as gravity lows. Within the Basin and Range province, the gravity maps show that the structural edges of uplifted blocks in place lie many kilometers basinward from exposures of the older rocks, suggesting the possibility that there may be hidden exploration targets beneath pediment surfaces or volcanic flows.

Moderate to steep gravity gradient zones indicative of faults display three directions of trend: northwest, northeast, and east-west. Thermal springs are alined along the northwest-trending gradients, and fluorite deposits are alined along the crests of highs bounded by these gradients.

USEFUL SAMPLE MEDIA IN GEOCHEMICAL EXPLORATION

Muck

In northeastern Minnesota, much of which is covered by swamps, H. V. Alminas reported anomalous concentrations of copper and nickel in stagnant swamp water over muck (organic-rich swamp-sediment material). The muck tends to concentrate the metals and is therefore a useful sample medium for geochemical exploration.

Secondary iron oxides

In a study of residual soils over two porphyry copper deposits in Puerto Rico, T. T. Chao, R. E. Learned, and R. F. Sanzolone showed that a substantial fraction (averaging about one-third) of the total copper content is related to secondary iron oxides. A selective extraction method developed by Chao was used to differentiate copper related to secondary manganese oxides, amorphous iron oxides, and crystalline iron oxides. In soils over deeply weathered and strongly leached areas of the deposits, most of the oxide-related copper occurs in crystalline iron oxide; in soils over weakly leached areas of the deposits, most of the oxide-related copper occurs in amorphous iron oxides. Copper-iron ratios of both amorphous and crystalline secondary oxides are much higher in soils over weakly leached areas than they are in soils over intensely leached areas, and it appears that the ratios are high enough even in the soils over intensely leached deposits to distinguish them from soils over barren rocks.

Manganese-iron concretions

G. A. Nowlan found that the geochemical anomalies of some elements are enhanced when manganese-iron concretions are used for the sample medium rather than the routine minus-80-mesh stream-sediment sample. A model for the formation of concretionary hydrous manganese-iron oxides in streams has been developed to aid in the recognition of conditions under which the potential for the formation of oxides exists; the model permits optimum efficiency in sample collection.

Water

Water as a sampling medium in prospecting has been neglected, owing in part to the success achieved with other sample media and also to the lack of sensitive analytical techniques suitable for routine analysis of large numbers of water samples. Flameless atomic absorption spectrophotometry using a graphite furnace allows rapid, precise, and sensitive analysis of minute amount of trace elements in water. W. R. Miller and W. H. Ficklin sampled waters from the Absaroka Mountains of Wyoming and found that the contrast between background values and anomalous values tended to be low, but subsequent analysis of stream sediments in an area judged to be anomalous on the basis of water analysis confirmed the presence of an anomaly. In a similar study in the White River National Forest in Colorado, the contrast between the trace-element contents of stream waters was found to be as much as several orders of magnitude. In both Colorado and Wyoming, molybdenum gave a greater contrast than either copper or zinc.

Water was also used by K. J. Wenrich-Verbeek as a sample medium in uranium exploration. Sample sites were chosen that drained a broad variety of geologic terranes and represented major drainage basins in Colorado, New Mexico, and Arizona. To obtain optimum consistency in the results, samples were filtered and acidified at the collection site. Both dissolved and suspended fractions of the sample were analyzed because of the lack of correlation between uranium concentrations in the two fractions. The elements As, Ca, Al, B, Mg, K, and Na correlated positively with uranium in the surface waters sampled. Maximum uranium concentration in water correlated either positively or negatively with discharge, depending on the type of uranium source within the drainage basin; this relationship between the uranium concentration and the discharge is helpful in determining optimum sampling dates.

Wenrich-Verbeek also demonstrated that grain sizes less than 90 μm are optimum for minimizing the dilution effect and enhancing the chances of detecting a uranium anomaly. The uranium content of stream sediments correlated positively with K, Mn, Mg, Ti, Ca, Fe, Al, Pb, Cr, Y, Zr, Li, Zn, and As. Uranium anomalies observed in stream sediments were not necessarily reflected in coexisting waters, and vice versa.

RESOURCE ANALYSIS

RESOURCE DATA BASES

Computerized Resource Information Bank

The Computerized Resource Information Bank (CRIB) continued to grow in size and use under the direction of J. A. Calkins. The CRIB mineral-resource data file program widened its data acquisition sources and its user community under a cooperative agreement with the U.S. Forest Service and an arrangement for data exchange with the U.S. Bureau of Mines and with the beginnings of data acquisition from South Africa under the Minerals Attaché program. During 1975, the CRIB data base increased to 49,453 records, of varying completeness, on mineral deposits and occurrences throughout the world—an increase of about 14,000 records since 1974. A recent contract providing public access to the CRIB file through the University of Oklahoma's computer facilities is a major advance toward the development of a broad user community.

Oil and Gas Data Bank

The outlines of oil and gas fields have been digitized for Alabama, North Dakota, and the northern half of Michigan; oil and gas fields are being digitized for Indiana, Wyoming, Utah, and the western half of Montana. These data sets are added continually to the Oil and Gas Data Bank at the University of Oklahoma.

Release of the Oil and Gas Data Bank to the public, through the University of Oklahoma's computer facilities, resulted in such a large user demand that the data base has been placed on a commercial time-share network to better serve its users.

Geologic Retrieval and Synopsis Program

The Geologic Retrieval and Synopsis Program (GRASP) was completely documented (R. W. Bowen and J. M. Botbol, 1975) and modified to accommodate data from the Rock Analysis Storage System (RASS) and to output data sets for the USGS Statistical Package (STATPAC) system. GRASP has been expanded to include the ability to compute additional variables for output or further use in an interactive session.

RESOURCE MODEL STUDIES

Mineral-resource development model

A preliminary analysis of grades and tonnages of nickel deposits by D. A. Singer and others suggested that both variables are approximately log-normally distributed. Average grade is independent of total tonnage for sulfide and laterite deposit types; thus, very large tonnage, low-grade deposits are just as rare as very large tonnage, high-grade deposits.

Singer and L. J. Drew also developed a theory and a working computer program that can be used to calculate the area of influence of drill holes or samples with respect to elliptical or circular resource targets. The procedure can be used to determine the degree to which areas within a region have been explored and to estimate the probability that points are centers of undiscovered deposits. Deposit errors of recognition can be used with the method.

Coal-resource development models

Two models were built by M. S. Hamilton for studying the development of coal resources. The first model assesses the effects of changes in economic and political conditions on annual production and recovery rates of existing coal mines. The second model evaluates the regional impact of strip mining in the Yellowstone River drainage basin. Both models can be used to assess regional constraints on national coal development objectives due to local conditions (geologic, economic, or political). The models can also be used to assess the regional impact (on land, water quality and quantity, and so on) of developing public and private coal lands.

Petroleum-resource appraisal method

L. J. Drew developed a technique that can be used to construct a new resource appraisal method based on an explicit measure of the volume of petroleum discovered per unit of rock explored by drilling. This technique uses the concept that every exploratory and development drill hole has a definable area of influence. At each point within the domain of this area of influence, an explicit probabilistic statement can be made about the completeness of exploration for deposits of various sizes. From these spatial probabilities, the degree to which a search area has been evaluated by each exploratory and development hole can be computed. A large-scale pilot study to test the method is currently underway in the 104,000-km^2 Denver-Julesburg Basin in Colorado, where more than 23,000 holes were drilled between 1949 and 1975.

Mineral exploration modeling study

An interactive modeling technique developed by J. M. Botbol allows an investigator to compare a region of high mineralization potential with a known mining area within the region. This technique provides vast improvements in the quality and timeliness of exploration modeling studies and, ultimately, may improve the probability estimates involved in exploration planning. An analysis of computer-generated maps using this technique revealed the degree of association of cells in the Coeur d'Alene region of Idaho with each of five major mining areas in the region. Two large areas (10 km^2) showed consistent high soil geochemical association with the major mining areas. These areas have not yet been thoroughly explored but appear to have high resource potential.

ENERGY-RELATED MINERAL STUDIES

L. F. Rooney completed a study of the energy-related minerals that will be needed if the United States is to achieve energy independence during the period 1975–90. Investigations of the demand for energy-related minerals needed by the energy industries—fossil fuel and geothermal, hydroelectric, nuclear, and solar energy and their subtypes—indicate that large amounts of concrete and steel and substantial amounts of other materials such as aluminum, barite, bentonite, manganese, and nickel will be needed (Albers and Bawiec, 1976). Supplying the needed commodities poses a number of problems. Imports satisfy a significant portion of the demand for such energy-related commodities as aluminum (bauxite), fluorite, nickel, and tungsten. Reserves of only a few commodities—barite, bentonite, copper, iron ore, lead, molybdenum, and zinc—needed by U.S. energy industries are adequate to meet the national demand for 1975–90. Significant increases in production above 1975 levels for aluminum, barite, bentonite, iron ore, and tungsten, however, will be needed to satisfy the demand of the energy industries for 1975–90.

In a separate three-part study, J. H. DeYoung, Jr., compared and contrasted resource programs in terms of public policies affecting energy-related mineral industries in Canada and the United States. The first part compared four factors considered to have the greatest impact on the present mineral-resource development of Canada: resource endowment, infrastructure development, tax incentives, and government and private involvement in exploration and development financing. Certain provisions of Canadian tax laws applicable to resource industries were found to provide great stimulus for mineral development. Sweeping tax reforms instituted by Federal and Provincial legislators since 1972 removed many of these incentives. The second part of the study reviewed these changes and the unpredicted effects that they had owing to lack of coordination between different levels of government. The final section of the study assessed the economic impact that continuing tax reforms are having on Canada's mineral industries. These impacts were examined by reviewing predictions of the effects that law changes would have and by analyzing indicators of industrial activity prior to and after tax reforms were enacted. The post-1972 reforms of the Canadian tax system removed many of the financial advantages that had previously existed for mining operations in Canada. The added uncertainty created by these changes is significant for future mineral development but is difficult, if not impossible, to quantify.

RESOURCE INVESTIGATIONS

Alaska

Mineral resources are known in all the major geographic subdivisions of Alaska and have been described in reports issued during the last 75 years. E. H. Cobb (1974a–e, 1975a–e) prepared 10 mineral-resource maps, based on these reports, that show the locations of occurrences of 10 metallic commodities. Cobb also summarized all references to mineral occurrences in 18 1:250,000-scale quadrangles in west-central and northern Alaska (Cobb, 1975f–i) and thereby made data from old, out-of-print reports as well as results of current investigations readily available.

Wyoming

A study of the Lance Formation in central Niobrara County, Wyoming, by H. W. Dodge, Jr., revealed an ancient coastal plain composed of stacked sandstone stream-channel deposits surrounded by organic-rich mudstone flood-plain deposits. Measurements of the trough axes of crossbedding in the channel deposits indicated a general southeastern paleoflow direction. No uranium mineralization was reported from the area studied. Some 80 km north, however, uranium mineralization was related to sediments deposited in a rapidly prograding Lance deltaic paleoenvironment. Paleoenvironments may have played a major role in the presence or absence of uranium mineralization.

COAL RESOURCES

COMPUTERIZATION OF THE NATION'S COAL RESOURCES

The National Coal Resources Data System (NCRDS), designed and coordinated by M. D. Carter, S. M. Cargill, A. C. Olson, and A. L. Medlin, was established by the USGS to meet increasing demands for rapid retrieval of information on coal location, quantity, quality, and accessibility. An interactive conversational query system devised by the USGS retrieves information from the data bank through a standard computer terminal. The system is being developed in two phases to accommodate the availability and complexity of the data.

Phase I, which is currently available, contains published areal resource and analytical data. The primary objective of this phase is to retrieve and calculate resource data by area on a local, regional, or national scale. Factors available for retrieval are: State, county, quadrangle, township, range, section, American Association of Petroleum Geologists province code, coal province, region, district, field, coal bed, formation, geologic age, source and reliability of data, and coal-bed rank, thickness, overburden, and tonnage, or any combination of these variables. Analytical items include individual values for proximate and ultimate analyses, sample type, analysis type, Btu value, and other physical and chemical tests. Information will be validated and deleted or updated as needed.

Phase II of the NCRDS is being developed to store, retrieve, and manipulate observation-point data. Lithologic, geochemical, and petrographic values for any area will be aggregated to produce isoline maps, calculate resources and overburden, and combine factors as desired. The goal of Phase II is to update Phase I data and to produce end-use maps for individual coal beds or for entire coal basins to facilitate optimum end use according to the characteristics of individual beds.

CHEMICAL DATA ON COAL

During the last 5 years, as a part of the USGS program on coal geochemistry, approximately 2,500 coal samples from operating mines and drill cores in 30 States were analyzed by modern methods and the data entered into the USGS Rock Analysis Storage System (RASS) and the National Coal Resources Data System (NCRDS). About 30 percent of these samples were collected and submitted by State Geological Surveys under cooperative agreements, about 60 percent by USGS personnel, and about 10 percent by coal companies and other groups. The chemical analyses were completed in the Denver, Colo., and Reston, Va., branches of the USGS Analytical Laboratories and in the U.S. Bureau of Mines' laboratories in Pittsburgh, Pa. The data include proximate, ultimate, Btu, and forms of sulfur analyses; major-element composition of coal ash; quantitative determinations of 11 trace elements; semiquantitative determinations of an additional 20 to 30 trace elements; and relevant locality and geologic data. The resulting information is used in the preparation of environmental impact statements, published in numerous USGS and Bureau of Land Management reports on field areas, and sent out in reply to requests by more than 200 Federal, State, university, environmental, and industrial groups. The program is coordinated by V. E. Swanson and J. R. Hatch in Denver and J. H. Medlin and S. L. Coleman in Reston. The following are some of the program's more notable discoveries:

- Anomalous Mo, Ni, Cd, U, and Th values have been recorded in Indiana coal samples.
- High germanium values are evident in several Michigan samples.
- Lignite samples from Mississippi contain more than the normal amounts of uranium and thorium.
- Samples from Iowa and Missouri have some of the highest lead, zinc, and cadmium values ever reported in coal.
- The concentrations of major, minor, and trace elements in low-sulfur Western coals are similar to those previously reported in the existing geological literature.

Freshwater peats, Florida Everglades

Through a program of probing and coring in the freshwater peats and limestones of the southern Everglades of Florida, Z. S. Altschuler, J. H. Medlin, and C. S. Zen demonstrated that Holocene peats are deposited in a very broad and shallow depression on underlying Pleistocene limestones. The major part of the peat deposit is approximately 1 m thick. Correlating and tracing thin zones within the deposit for 15 to 30 km establish the synchroneity of deposition. The base of the peat deposit was dated by Meyer Rubin at approximately 4,300 years. Peat in the freshwater Everglades in Dade, Broward, and Collier Counties thus accumulates at a rate of approximately 2.5 cm per 100 years.

After comparing normative data for plants with the "coal" analyses performed on closely spaced peat cores across the southern Everglades. Altschuler and Zen reported that the major chemical character of peat is acquired very early in its formation. The greatest changes in the concentration of C, N, H, and O occur in the uppermost few centimeters of the 1-m-thick freshwater peats. Further change in major constitutents to a depth of 1 m is relatively slight, oxygen being the one exception. Thus freshwater peat is similar to lignite in composition and in heat value, even at the slight depth of 15 cm, or at a time equivalent of about 500 to 600 years. The sulfur content generally declines from the top to the bottom of each core, but the relative proportion of sulfide sulfur always exhibits a pronounced increase. An increase in the pyrite content at the base of coal beds is typical of many coal basins. The peat cores clearly indicate that this pattern develops very early in the coal-forming process rather than as a late addition or remobilization of sulfur to coal beds.

LABORATORY INVESTIGATIONS OF COAL GEOCHEMISTRY

Summaries of experiments with peat and coal conducted by I. A. Breger, J. C. Chandler, M. R. Krasnow, and D. T. Ligon, Jr., revealed:

- Degradation of plant debris is accompanied by a rapid loss of cellulose near the top of a peat accumulation. The buildup of humic acid a short distance below the surface is thought to inhibit further extensive microbial degradation, and the loss of cellulose farther down in the peat column proceeds very slowly, probably by chemical hydrolysis.
- Organic sulfur in coal appears to be about equally divided between that present in thiol groups and that present in heterocyclic structures. An attempt is being made to devise a procedure for the elimination of heterocyclic sulfur by the simple processing of coal.
- Lignite can be hydrogenated at room temperature by hydrogen atoms and actuated hydrogen gas without the use of catalysts. These studies suggest a new method for the hydrogenation of coal to produce liquid fuel.
- Some iron in coal is not associated with sulfur as pyrite but rather is organically bound or present as iron oxide.

GEOPHYSICAL INVESTIGATIONS OF COAL

A nuclear borehole sonde using californium-252 as a neutron source was tested down a borehole through a coal bed in Belmont County, Ohio, by F. E. Senftle, A. B. Tanner, P. W. Philbin, and G. R. Boynton (USGS). Continuous hydrogen and aluminum logs were used to determine the depth of the bed. Gamma spectra were made in the hole above, in, and below the bed. Interpretation of the spectra will be made when chemical analyses are completed. A mobile analytical system for analyzing coal specimens brought up by the core drill is also being tested to obtain in-place analyses.

A recent study by A. H. Balch (USGS), Frank Rusky and C. M. Lepper (U.S. Bureau of Mines), and Steven Peterson (Colorado School of Mines) indicated that coal beds can be identified on reflection seismic records at the Lincoln Mine in Greeley County, Colorado, and at a Southern Ohio Coal Company mine in Meigs County, Ohio. Coherent coal-bed reflections were recorded in both areas. The records clearly indicated those localities where the coal beds are interrupted by normal faults and channel-form sandstone units; these findings can guide the planning and execution of mining operations.

RESOURCE EVALUATION THROUGH THE ENERGY MINERAL REHABILITATION INVENTORY AND ANALYSIS PROGRAM

MONTANA

The area around and including the Otter Creek, Mont., Energy Mineral Rehabilitation Inventory and Analysis (EMRIA) program study site (an area of about 1,204 ha) contains demonstrated coal resources estimated at 289 million tonnes. Approximately 232 million tonnes are overlain by 61 m or less of overburden. All the estimated resources are in the Knoblock coal bed, which is about 18 m thick in that area. A report on the study site in Powder River County, Montana, prepared by E. J. McKay, J. R. Hatch, and E. R. Landis (U.S. Geological Survey, 1975a) for incorporation into a series of reports on reclamation study sites, presented analytical information showing that the Knoblock bed is subbituminous C in rank and has an average heat value of 19 million J/kg. The average ash content of the Knoblock is 5.5 percent, and the average sulfur content is 0.15 percent. Analyses of coal, coal ash, and rock samples indicate that the concentration of trace elements is generally below the average for these elements in the continental crust. Only selenium (0.4 ppm for the Knoblock coal as compared with 0.05 ppm for the crustal average) is higher.

WYOMING

Hanna Basin study site

Estimated identified original coal resources having 61 m or less of overburden in Wyoming's Hanna Basin EMRIA reclamation study site and the adjoining area total 37 million tonnes; 26 million tonnes are classed as measured resources, 10 million tonnes as indicated resources, and 1 million tonnes as inferred resources. Coal beds ranging from 0.75 to 1.5 m in thickness make up 9 million tonnes of the estimated resources, beds 1.5 to 3 m thick make up 17 million tonnes, and beds more than 3 m thick make up 11 million tonnes. Measured resources in beds more than 1.5 m thick and having 30 m or less of overburden total 11 million tonnes. A report prepared by G. D. Stricker, P. T. Hayes, and E. R. Landis (U.S. Geological Survey, 1975b) showed that the coal at the Hanna Basin study site in Carbon County, Wyoming, is high volatile C bituminous in rank. In five samples, the average heat value as received was 24 million J/kg, the average ash content was 8.6 percent, and the average sulfur content was 0.6 percent. The concentrations of most trace elements in the coal are of the same order of magnitude as their abundances in the continental crust. Only selenium has been enriched or depleted by more than an order of magnitude (0.9 ppm as compared with an average crustal abundance of 0.05 ppm).

Recluse model area

A seven-hole drill program was conducted in the Recluse model area of Campbell County, Wyoming, under the supervision and guidance of E. R. Landis and R. G. Hobbs. A total of about 945 m of drilling resulted in the selection of about 500 coal, rock, and gas samples that will be analyzed by USGS and U.S. Bureau of Mines laboratories. The Recluse program involves cooperation and coordination of activities with other projects in the Branch of Coal Resources, four other branches of the Geologic Division, three sections of the U.S. Bureau of Mines, three sections of the U.S. Bureau of Land Management, and agencies of the States of Wyoming and Montana. An unanticipated feature of this program, as well as other EMRIA programs, was the high degree of cooperation and coordination possible among groups having such divergent responsibilities in coal-related activities.

UTAH

Estimated identified original coal resources of the Alton, Utah, EMRIA reclamation study site, an area of about 932 ha in Kane County, total almost 44 million tonnes. Of these estimated resources, approximately 25 million tonnes are in beds more than 3 m thick and are overlain by less than 61 m of overburden in the study site itself. A larger area surrounding and including this study site contains estimated original identified coal resources of almost 280 million tonnes. In the larger area, about 80 million tonnes are in beds more than 3 m thick and having less than 61 m of overburden. All the estimated resources are in the Smirl Zone in the upper part of the Dakota Formation of Cretaceous age. A report prepared by W. E. Bowers, A. A. Aigen, and E. R. Landis (U.S. Geological Survey, 1975c) showed that the coal is subbituminous B in rank and has an average heating value of about 22 million J/kg, a sulfur content of about 1.0 percent, and an ash content of 7.2 percent. When the elements in the Alton area coal samples are compared with the elements in the crust of the Earth as a whole, only selenium and boron are found to be present in amounts greater than the average crustal abundance; Be, F, Ni, Zn, and Zr are present in amounts less than the average crustal abundance.

COAL EXPLORATION

Exploratory coal drilling finds coal bed in West Virginia

A drilling program was designed primarily to obtain stratigraphic data for the Pennsylvanian System Stratotype Study in West Virginia. One hole penetrated an economically important coal bed in the New River Formation in Fayette County, where the strata at depth were previously considered to be barren of coal resources. According to S. P. Schweinfurth, H. H. Arndt, and K. J. Englund, the coal bed is at a depth of 304 m, is 94 cm thick, and is correlative with the Fire Creek coal bed that crops out about 32 km to the east and south. In Wyoming County in the southeastern part of West Virginia, lithologic data from a core hole confirmed the intertonguing relation between the basal Pennsylvanian Pocahontas Formation and the underlying Bluestone Formation. Drilling in Jackson County in the east-central part of the State failed to show any significant lithic difference between beds of Late Pennsylvanian age and the overlying Dunkard Group of Pennsylvanian and Permian age.

Reassessment of coal resources in part of the Appalachian coal field, southeastern Virginia

C. R. Meissner, Jr., calculated that original coal resources in beds more than 36 cm thick in the Duty 7½-minute quadrangle of Virginia totaled 619 million tonnes. Eleven coal beds were mapped and assessed, but more than half of the resources occurred in the Tiller coal bed alone. Coal mined and lost during mining to date totals 194 million tonnes; thus, 425 million tonnes of coal remain in the ground.

Coal in the Powder River Basin of Wyoming and Montana

W. C. Culbertson reported that, in an area of 842 km^2 in east-central Sheridan County, Wyoming (western Powder River Basin), the Eocene Wasatch Formation is as much as 520 m thick and contains as many as 18 beds of subbituminous coal, each more than 60 cm thick. The resources of coal in beds more than 3 m thick are estimated to be 2.1 billion tonnes, 1.9 billion tonnes of which are contained in two beds, the Ulm 1 and the Ulm 2, whose maximum thicknesses are 13 and 9 m, respectively. Most beds are not suitable for recovery by strip mining because of high local relief, but the Ulm 1 and Ulm 2 locally underlie flat upland areas at shallow depths, principally in the Verona and Ulm 7½-minute quadrangles, in the vicinity of T. 54 and 55 N., R. 81 W. Analyses of coal samples from the outcrop indicate that the Ulm beds contain 0.4 to 1.9 percent S.

On the basis of an analysis of the total thickness of coal and the relative physical position of coal beds beneath the surface on logs from more than 2,500 wells, R. W. Jones, G. C. Martin, S. P. Buck, and T. F. Tyler inferred that coal resources are approximately 1,085 billion tonnes at depths of less than 914 m within the boundaries of the Known Coal Leasing Areas in the Powder River Basin of Wyoming and Montana. Of this total, 200 billion tonnes occur in Montana and 885 billion tonnes in Wyoming. Approximately 74 percent of the resource is at depths of 457 m or less, and almost 50 percent is at depths of 305 m or less.

Early Tertiary deformation appears to have influenced the deposition and subsequent erosion of coal beds in the upper part of the Fort Union and lower part of the Wasatch Formations of the eastern Powder River Basin in Wyoming. In the Reno Junction-Antelope Creek area, at least two important faults coincide with zones where the Wyodak coal bed (Fort Union) splits into the Anderson and Canyon coal beds, separated by as much as 90 m of intercoal sediments. A comparison of structure contour and coal thickness maps prepared by N. M. Denson, J. H. Dover, and L. M. Osmonson shows the Wyodak and Anderson coal beds to be relatively thick in synclines and anomalously thin or absent over anticlines. Some structures in the Fort Union Formation do not penetrate the Wasatch, and those that do are more subdued than those in the Fort Union, the indication being that deformation culminated prior to the time of Wasatch deposition. Fieldwork by Denson, combined with cross sections constructed from oil- and gas-well data, indicates that the Fort Union-Wasatch contact in this part of the basin is an unconformity with several hundred meters of relief. Thickness variations of the Wyodak and Anderson coal beds are a result of structure-controlled depositional patterns and (or) accelerated pre-Wasatch erosion related to this unconformity. Recognizing and delineating thickness variations in these coal beds are critical to their commercial development and reclamation throughout the eastern Powder River Basin.

Exploration for coal in Carbon County, Wyoming

A total of 21 holes was drilled in the Fort Union Formation of Paleocene age and the Almond Formation of Late Cretaceous age west of the Sierra Madre in Carbon County, Wyoming. C. S. V. Barclay, G. M. Edson, and R. D. Hettinger, Jr., reported that, of the 13 holes drilled in the Fort Union Formation, 11 penetrated several coal beds at depths of 160 m or less. Preliminary analysis of the drilling indicates that the lower part of the Fort Union in the Fillmore Ranch 7½-minute quadrangle contains four to six coal beds 1.2 to 6.4 m thick and that the upper part of the Fort Union in the Seaverson Reservoir 7½-minute quadrangle contains two to three coal beds 1.2 to 3.4 m thick. Preliminary results of geologic mapping and an analysis of data from the other eight drill holes indicate that, in the eastern part of the Doty Mountain 15-minute quadrangle, the Almond Formation may contain as many as six coal beds ranging from 1.2 to 4.9 m in thickness at depths of 188 m or less.

L. F. Blanchard mapped a series of clinkered beds in the Hanna Basin of Wyoming; these previously unrecognized coal beds indicate that the structure of the coal deposits is more complex and the extent greater than previous work in the area (Dobbin, Bowen, and Hoots, 1929) has shown. One clinkered zone may represent a coal bed as much as 15 m thick, almost twice as thick as any previously known in the Hanna Basin; however, the bed thins to less than a meter within a distance of several meters, the resulting distribution being very lenticular. At one locality a 1-m-thick baked carbonaceous mudstone whose polygonal jointing is very similar to columnar jointing in basalt underlies approximately 1.5 m of slag. The columnar jointing is parallel to bedding and perpendicular to a major set of joints within the baked mudstone. The vertical set of joints probably acted as a cooling surface.

Coal in the Mesaverde Group, Rangely, Colorado

Geologic mapping and stratigraphic measurements by B. E. Barnum and R. S. Garrigues of the Mesaverde Group (Upper Cretaceous) between Blue Mountain and Massadona, Colo., resulted in two tentative conclusions:

- Economic coal within the Mesaverde is restricted to a zone approximately 100 m thick. Locally, this zone contains as much as 6 m of coal in beds more than 1.2 m thick. The base of this zone is approximately 300 m above the top of Buck Tongue of the Mancos Shale.
- The Trout Creek Sandstone Member of the Iles Formation of the Mesaverde is not present as a mappable unit in this study area.

Additional coal resources in the Kaiparowits field, Utah

Additional coal resources have been found in the Kaiparowits coalfield in Garfield and Kane Counties, Utah. The coal occurs in a 36-km^2 area in the upper part of North Creek, 19 km west of Escalante. By projecting coal depositional trends, geologic structure, and coal thicknesses from the south, H. D. Zeller estimated that the area is underlain by at least 700 million tonnes of coal in beds more than 1.5 m thick at depths of less than 914 m. Half of the resources are less than 610 m below the surface, and 150 million tonnes are inferred to be less than 305 m below the surface.

OIL AND GAS RESOURCES

Eolian reservoirs

T. S. Ahlbrandt and S. G. Fryberger found diagnostic criteria that identify three eolian dune types on the basis of work done in the Sand Hills of northern Nebraska, the largest dune field in North America. In general, sedimentary structures can be used to define dune types. For example, convex upward crossbed sets lacking avalanche deposits suggest a blowout or parabolic dune. Dune type can be determined by using both the mean dip angle of laminae and the mean angular deviation of the dip direction, which are diagnostic for barchan, transverse ridge, and blowout dunes. The dune types recognized in the Nebraska Sand Hills include barchan, barchanoid ridge, transverse ridge, blowout, parabolic, dome (the small variety), and a few reversing(?) dunes. Some elongate dunes in the Sand Hills seem to be linear (seif) on the basis of their morphology; however, their internal structures indicate that they may be transverse ridge types. Interdune deposits that separate dune sands may form permeability barriers. Organic-rich interdune deposits may also be indigenous hydrocarbon sources, as analyses of organic material from interdunes in the Nebraska Sand Hills suggest.

The eolian sand trap, a device designed to simultaneously measure sand-flow rates, wind direction, and wind speed in the field, is nearing completion. The eolian sand trap represents a significant contribution to eolian sedimentology because detailed field studies of sand-transport rates and the resultant textures and structures can now be analyzed quantitatively.

Measured sections of Beluga and Sterling Formations

Tertiary nonmarine rocks of Miocene and Pliocene age, exposed on the southeastern flank of the Cook Inlet basin near Homer, Alaska, were measured, described, and sampled for heavy-mineral and palynological studies by W. L. Adkison and J. S. Kelley (USGS) and K. R. Newman (Colorado School of Mines). These rocks are assigned to the Beluga and overlying Sterling Formations in the upper part of the Kenai Group on the Kenai Peninsula of Alaska. The Beluga is about 940 m thick and consists of sandstone interbedded with siltstone, shale, and coal. The Sterling Formation, about 915 m thick, is lithologically similar to the Beluga, except that the upper 175 m of the Sterling includes only a few thin, very impure coal beds. In the seacliff exposures northeast of Homer, the contact between the formations is broadly determined by a change in the heavy-mineral suites generally outlined by Kirschner and Lyon (1973, p. 404). According to K. T. Biddle (written commun., 1974), heavy minerals in the upper part of the Beluga consist mainly of epidote and small amounts of zircon, garnet, and sphene, whereas the heavy minerals in the Sterling are dominantly hornblende and hypersthene. A major concealed fault probably separates the seacliff exposures mentioned above from exposures of the Beluga and Sterling Formations in the Homer escarpment to the west (Beikman, 1974a). Tentative correlation of the formations across the fault is based primarily on rough similarities in the sequence of pollen taxa. In the Homer escarpment area, the change in heavy-mineral suites occurs stratigraphically lower than it does in the seacliff exposures northeast of Homer. These measured sections provide surface control for subsurface stratigraphic units that produce gas in the upper Cook Inlet basin.

Petroleum potential of the Lisburne Group

The Lisburne Group is a thick sequence of Mississippian and Pennsylvanian carbonate rocks underlying most of the eastern Arctic Slope of northern Alaska. These carbonates have good petroleum potential. Studies by K. J. Bird (USGS) and C. F. Jordan (American Stratigraphic Company) indicated the presence of porous reservoir rocks adjacent to hydrocarbon source beds in an area having the potential for numerous structural and stratigraphic traps. Dolomite and sandstone are the best reservoir rocks. The dolomite, which was deposited in an intertidal to supratidal environment, is present throughout the area but thins northward. This dolomite has yielded many oil shows and contains oil and gas in the Prudhoe Bay field. The sandstone is a relatively thin, nearshore marine sand. It is present in only two wells near the northern coast of Alaska but may be more widespread in the subsurface offshore. Source rocks include an oil source (Lower Cretaceous shale) in contact with the Lisburne east of Prudhoe Bay and a gas source (Mississippian coal beds) beneath the Lisburne. Stratigraphic traps may be formed by unconformities at the top and possibly within the Lisburne over a wide area. Structural traps related to normal faulting may occur along the trend of the Barrow arch, and faulted anticlines are numerous in the foothills of the Brooks Range.

Organic geochemistry and thermal maturation of Permian Phosphoria black shales

A regional organic geochemical study made on the black shale beds of the Permian Phosphoria Formation by G. E. Claypool and E. K. Maughan showed high concentrations of organic carbon in the Meade Peak Phosphatic Shale Member along the Idaho-Wyoming border and in the Retort Phosphatic Shale Member of southwestern Montana. The average organic carbon content at these two localities is about 9 to 10 percent. Organic carbon content decreases regularly with distance away from these localities. The distribution of phosphorite and trace elements (especially Ag, Ba, Cr, Cu, La, Mo, Sr, V, Y, and Zn) in these black shale beds is similar to that of organic carbon. This concentration of elements is believed by Maughan to be due to localized upwelling marine currents and high organic productivity during the times when the black shale beds were deposited.

Within the black shale members of the Phosphoria Formation, the degree of conversion of organic matter to petroleum hydrocarbons varies widely, apparently owing to regional differences in maximum paleotemperature or depth of burial. Concentrations of extractable heavy hydrocarbons relative to organic carbon, alteration color and the atomic hydrogen-to-carbon ratio of the insoluble organic matter (kerogen), and the detailed distribution of heavy saturated hydrocarbons as determined by gas chromatography show regular and consistent variation with inferred maximum depth of burial. These changes in the chemical nature of the organic matter observed by Claypool and his associates reflect increasing degrees of organic metamorphism. The black shale beds of the Phosphoria Formation are thermally immature in southwestern Montana, except in areas where igneous heat sources apparently caused the same chemical changes as heating caused by deep burial. In west-central Wyoming, the equivalent rocks still retain the chemical imprint of burial to optimum depths and temperatures for petroleum hydrocarbon generation, whereas Phosphoria black shales in the foredeep of the Cordilleran geosyncline have been incipiently metamorphosed by burial under as much as 10 km of sediment and consequent thermal destruction of disseminated heavy hydrocarbons.

Studies in ancient and modern Continental Shelf

The search for energy resources needs to be expanded into the deeper marine environments of the Outer Continental Margin. Understanding the nature of these marine environments, the processes operating in these environments, and the effect of these processes on the geometry and textural character of the sediments is of increasing importance.

Results of H. E. Cook's comparative study of ancient and modern deeper water settings (Cook and Taylor, 1975) indicated that a 700-m-thick lower Paleozoic section of eastern Nevada contains algal stromatolites, flat-pebble breccias, fenestral fabrics, and other features inferred to represent deposition under shoal-water conditions. Detailed trilobite biostratigraphy showed that correlative rocks 170 km to the west are only 100 m thick. The western strata comprise dark-colored lime mudstones and wackestones interbedded with abundant coarse-grained allochthonous gravity flow and slump deposits interpreted to have formed in a slope environment.

Factors influencing slope sedimentation involved an interplay of depositional and erosional processes. The carbonate mudstones and wackestones of early Paleozoic age represent hemipelagic sedimentation. Although individual submarine gravity movements were small-scale events (a few centimeters to 10 m thick), they were a dominant process in this environment. Almost half of the section is composed of allochthonous sediments, including: slumps and slides that originated in a slope setting, some of which were transformed into debris and turbidity flows; and debris and turbidity-flow limestone conglomerates and calcarenites that originated in shoal-water settings to the east and that incorporated a variety of constituents during their transport basinward.

On the basis of abundant small-scale slump and flow deposits in this ancient deeper water setting and others similar to it, it is reasonable to speculate that resedimentation processes may dominate on modern continental slopes. The smooth undisturbed nature of modern slopes as seen on continuous seismic profiles may be in part a function of the limited resolving power of much surface seismic equipment.

Vertebrate fossil indicates Eocene lacustrine sedimentation near Ely, Nevada

The maxillary portion of a skull and three molar teeth were identified by C. L. Gazin (National Museum of Natural History) as being from the Eocene perissodactyl *Hyrachus*. The fossil was recovered by T. D. Fouch, F. G. Poole, and G. E. Claypool (USGS) from units assigned to the Sheep Pass Formation at Elderberry Canyon near Ely, Nev. The host rocks are interpreted as being of lacustrine origin, but the age of the units has been in doubt. Similar Eocene lacustrine rocks are dated only at Sheep Pass Canyon (52 km south of Ely), although lacustrine rocks in a large area of central Nevada have been assigned to or compared with the Eocene units in Sheep Pass Canyon. The Sheep Pass Formation is a reservoir for oil in the Eagle Springs field approximately 96 km southwest of Ely. In addition, similar lacustrine rocks near Elko, Nev., and in the central Rocky Mountains (Green River Formation) contain petroleum source rocks. The age of the lacustrine sequence in Elderberry Canyon may indicate that Eocene lacustrine sedimentation was present on a more regional scale than has previously been recognized.

Porosity variation in the Tensleep Sandstone, western Wyomfng

J. E. Fox, P. W. Lambert, R. F. Mast, N. W. Nuss, and R. D. Rein completed a study of porosity in the productive upper zone of the Pennsylvanian Tensleep Sandstone, which is one of the major oil- and gas-producing formations in Wyoming. Trend and residual contour maps of average porosity indicate areas of anomalously high and low porosity in the Bighorn, Wind River, and greater Green River Basins of Wyoming. Areas of high porosity (15 percent or greater) occur around the flanks of the Bighorn and Wind River Basins; in these areas, the Tensleep is considered to have superior reservoir properties. Although it is less porous in the greater Green River Basin, the Tensleep can be considered a good hydrocarbon reservoir. In all three basins, there is a general trend of decreasing porosity with increasing depth of burial and decreasing permeability with decreasing porosity.

Petrographically, the Tensleep is remarkably homogeneous, as is evidenced by cores from nine widely separated wells in the Wind River and greater Green River Basins. The major detrital minerals (quartz and feldspar) and the kind and order of precipitation of the major cements (quartz, dolomite, and calcite) are the same in all nine wells. However, the abundance of the cements seems to be influenced by the present depth of burial. Quartz cement, in the form of quartz overgrowths around detrital quartz grains, is more abundant in deeper wells and is responsible for the generally low porosity of deeply buried Tensleep rocks. Most of western Wyoming was a broad shelf until the present basins formed in Laramide time. The fact that the amount of quartz cement increases as the present depth of burial increases suggests that the quartz, the earliest of the present reservoir cements, was precipitated during or shortly after the Laramide orogeny. Petrographic evidence also suggests that much of the quartz cement was precipitated by migrating solutions and was not a result of local pressure solution and precipitation.

Possible subsurface fracture-porosity traps

Analysis by L. D. Harris (1976) of limited seismic data located in the western part of the Valley and Ridge province in the Kingston area of Tennessee indicated a fundamental change in the subsurface from west to east in both the total section preserved and the structural complexity. Cambrian and Middle Ordovician rocks in the Valley and Ridge have been thrust westward over a subsurface projection of Cambrian through Mississippian rocks of the Appalachian Plateau. Structure within the plateau projection is characterized by splay anticlines, whereas structure in the Valley and Ridge is dominated by a series of imbricate thrust sheets containing isolated fault-bound masses of Cambrian sandstone and shale. Both splay anticlines and large fault-bound masses of rock preserved in the subsurface in eastern Tennessee may contain favorable fracture-porosity hydrocarbon traps.

Faulting related to oil and gas evaluation, Gros Ventre Mountains, Wyoming

It has long been thought that the Cache Creek thrust fault of western Wyoming extended under the steep southwestern flank of the Gros Ventre Mountains throughout the entire length of the mountains and thereby made the northern, overridden part of the Green River Basin very deep. Studies by J. D. Love and W. R. Keefer showed that, about halfway along the southwestern flank of the mountains, the thrust veers abruptly to the south, steepens, and then dies out in the northern Green River Basin. Nevertheless, the precipitous southwestern flank of the mountains continues southeastward with no topographic break but is marked by normal faults down on the south rather than by the thrust. The significance is that the northeastern margin of the Green River Basin is several thousand meters shallower than had previously been postulated, and the stratigraphic sequence within economic depths needs to be reevaluated for its oil and gas potential.

Oil from fracture shale

Oil and gas are produced from fractures in Cretaceous shale in Colorado and New Mexico. According to W. W. Mallory, existing producing fields lie in three belts: the western part of the Denver basin on the eastern flank of the Front, Rampart, and Wet Mountain ranges of central Colorado; an east-northeast-trending belt that crosses structural trends in northwestern Colorado; and a belt of steep dip on the western, northern, and eastern margins of the San Juan basin in southwestern Colorado and northwestern New Mexico. Much of the area included in these belts is undrilled, and the prospects of finding oil and gas in Cretaceous shale at shallow depth seem to be high in several areas.

New engineering practices for drilling into fractured shale, for detecting the presence of oil-filled voids, and for completing wells without sealing off the fractures have been developing during the last 20 years.

Present cumulative production of oil from shale is not large, but systematic exploration, new engineering techniques, and higher prices make the future for this excellent grade of crude much brighter.

Potential petroleum stratigraphic traps, Bighorn Basin, Wyoming

The Frontier Formation of early Late Cretaceous age is a major source of petroleum at anticlinal traps in the Bighorn Basin of northwestern Wyoming. Recent investigations of the formation by E. A. Merewether, W. A. Cobban, and R. T. Ryder (1975) located potential stratigraphic traps that are sparsely explored and may contain oil and gas. The investigations consisted of correlating and interpreting about 210 well logs, 13 detailed outcrop descriptions, and about 50 fossil collections.

The Frontier Formation is composed of intertonguing shale, siltstone, and sandstone units of Cenomanian, Turonian, and Coniacian Age that were deposited in marine, marginal marine, and continental environments. Sandstone units of marginal marine origin at the top of the Frontier intertongue with marine siltstone and shale petroleum source beds in the lower part of the Cody Shale. The Frontier and the lower part of the Cody contain one and, locally, two unconformities. Near Cody, Wyo., on the northwestern flank of the Bighorn Basin, strata of late Cenomanian Age are unconformably overlain by beds of middle Turonian Age, which are, in turn, unconformably overlain by strata of early Coniacian Age. In most of the region, these two unconformities apparently overlap and are represented by a single erosion surface that separates Cenomanian beds from overlying uppermost Turonian and lower Coniacian rocks. The area of greatest truncation trends north-northwest along the western flank of the Bighorn Basin, from Hamilton dome to Ralston, Wyo. The hiatuses in the sequence probably resulted from uplift and erosion during the early Turonian and arching and subsequent erosion during the late Turonian.

Oil and gas resources of the United States

A comprehensive assessment of the oil and gas resources of the United States and its continental shelves was completed and reported in USGS Circular 725, "Geologic estimates of undiscovered recoverable oil and gas resources of the United States," authored by B. M. Miller, H. L. Thomsen, G. L. Dolton, A. B. Coury, T. A. Hendricks, F. E. Lennartz, R. B. Powers, E. G. Sable, and K. L. Varnes.

The assessment indicated that the Nation's undiscovered recoverable resources were 50 to 127 billion barrels of oil and 9 to 18 trillion m^3 of gas at the 95- and 5-percent probability levels, respectively. The findings suggest that nearly one-half of the undiscovered recoverable oil resources and more than one-quarter of the undiscovered recoverable gas resources may occur in offshore regions of the United States and in the onshore frontier provinces of Alaska.

Appalachian structural traps

Petroleum industry drilling to date has discovered structurally trapped natural gas in fractured Lower Devonian sandstone in the Valley and Ridge foldbelt of eastern West Virginia. Other potential reservoir rocks in the area include Silurian sandstones and Cambrian and Ordovician carbonate rocks. W. J. Perry, Jr., tentatively concluded that the abundance of calcite and quartz-filled fractures (veins) in brittle rocks exposed below the thick Middle to Upper Devonian shale sequence indicates that abnormally high fluid pressures, sufficient to hydraulically fracture rocks of Early Devonian age and older or to open preexisting fractures, may have existed during late Paleozoic folding and faulting in this area. The geometry and orientation of the fractures indicate that they were formed by tectonic stresses. The eastern margin of the foldbelt, overridden by the tectonically thickened North Mountain thrust sheet, provided a source of tectonically induced geopressures by excess loading. Additional resources of natural gas are anticipated along the eastern and western margins of the foldbelt.

Oil in Chainman Shale, Nevada

Liquid oil of varying viscosities was found in cavities within limestone nodules and thin limestone beds in outcrops of the upper part of the Chainman Shale of Late Mississippian (late Chesterian) age by F. G. Poole and T. D. Fouch. The age of the oil-bearing interval was established by cephalopod faunas of the *Cravenoceras hesperium* and *C. merriami* Zones of Gordon (1970). The Chainman, in east-central Nevada, represents Mississippian flysch deposited in the eastern part of the Antler foreland basin (Poole, 1974). The presence of oil and pale alteration colors of palynomorphs and conodonts indicates that the rocks at these localities were subjected to moderate paleotemperatures of probably less than 100°C. Thus, the depth of burial has been relatively shallow, and the heat-flow regime has been relatively moderate since Mississippian time in several parts of the Great Basin. Occurrences of liquid oil in the rocks and the inferred moderate temperatures of less than 100°C for the flysch units suggest that many organic-rich beds in the Chainman are at optimum maturity.

Origin of shallow accumulations of natural gas

Large resources of natural gas occur at shallow depths in the northern Rocky Mountain region and elsewhere, according to D. D. Rice. This gas, chiefly methane, is the principal product of the immature stage of organic diagenesis (Rice, 1975). Methane originates from the breakdown of organic matter by anaerobic bacteria and is generally called biogenic gas. In both marine and nonmarine environments, reduction of CO_2 is the principal mechanism of methane generation during anaerobic diagenesis; in marine environments, however, methane generation is preceded by the biochemically analogous process of sulfate reduction. After sediment burial, the major limiting factors of methane generation are temperature (0°–66°C) and the amount of organic matter and oxygen in the sediments. The accumulation of biogenic gas is dependent on the rapid deposition of organic-rich sediments, the presence of a reservoir and seal during peak generation or later during exsolution, and, in deep marine or permafrost environments, the stabilization of the solid methane hydrate. Accumulations of ancient biogenic gas are associated with both marine and nonmarine sequences and have been reported in Cretaceous and Cenozoic rocks at depths from near surface to more than 1,800 m. Ancient biogenic gas is characterized by enrichment in the light isotope C^{12} ($\delta C^{13} < -0.58$) and large amounts of methane ($C_1/C_{1-n} > 0.98$). With increasing age and temperature, biogenic gas is progressively diluted by higher hydrocarbon gases and isotopically heavier methane, which result from thermocatalytic reactions.

Remote sensing of petroleum accumulations

A survey of the concentration of helium in soil gas over a portion of the Denver basin in Boulder and Weld Counties in Colorado was completed by A. A. Roberts, Mary Dalziel, and L. A. Pogorski (USGS) and S. G. Quirt (Chemical Projects, Ltd., Toronto, Canada). The average helium concentration above background around producing wells in this area (1.5 ± 0.4 ppm) was significantly higher than that around dry wells (0.8 ± 0.6 ppm), the suggestion being that higher helium concentrations are associated with these petroleum deposits.

A possible petroleum-related geochemical anomaly was reported previously by Donovan and others (1975) within the 250-km^2 area surveyed. They observed patterns of low iron concentrations, high manganese concentrations, and anomalous carbon and oxygen isotope ratios, each in the form of a halo around a potential petroleum prospect. These halos may represent hydrocarbon leakage around the reservoir seal and subsequent diffusion to the surface. The helium concentration data outline these halos and lend further support to the existence of an undrilled petroleum prospect centered near Panama Reservoir No. 1, between Boulder and Longmont, Colo.

Preliminary field and laboratory studies by R. D. Watson, T. J. Donovan, and R. L. Noble suggested that variable concentrations of manganese in carbonate lattices of cemented rocks overlying petroleum deposits may be mappable remotely by means of a Fraunhofer line-depth method. The variable manganese concentrations, which have been shown to vary systematically over oilfields, cause variations in the luminescence of carbonate cements; the preliminary data suggest that a helicopter-borne Fraunhofer line discriminator can suitably map the luminescence variations if manganese concentrations exceed baseline values of about 1,500 ppm.

Seismic detection of stratigraphic traps, Powder River Basin, Wyoming

A recent study by R. T. Ryder, R. C. Anderson, A. H. Balch, and W. S. Head (USGS) and M. W. Lee (Colorado School of Mines) suggested that sandstone units in the Minnelusa Formation (Pennsylvanian and Permian) and the Canyon Springs Sandstone Member of the Sundance Formation (Jurassic) are potential exploration targets for stratigraphically trapped oil in the southeastern Powder River Basin of Wyoming. In the Red Bird field on the northern plunge of the Old Woman anticline, oil is trapped in the 24-m-thick Canyon Springs Sandstone Member, where it wedges out updip against an erosional outlier of red siltstone and claystone units of the Spearfish Formation (Triassic). Oil is also trapped in the porous 15-m-thick first "Leo Sandstone," an economic unit in the Minnelusa Formation, where it grades laterally into anhydrite, anhydrite-cemented sandstone, and dolomite. Synthetic seismic sections based on numerous sonic and density logs from this area suggest that the porous sandstone units of the Minnelusa have a density ρ of 2.6 g/cm^3 and velocity V of 3.3 km/s. These sandstones can be differentiated on seismic records from equivalent nonporous anhydrite-cemented sandstone units ($\rho=2.75$ g/cm^3, $V=5.4$ km/s). Likewise, the Canyon Springs Sandstone Member ($\rho=2.25$ g/cm^3, $V=2.8$ km/s) should be detectable on seismic records where it pinches out against the nonporous Spearfish Formation ($\rho=2.25$ g/cm^3, $V=3.8$ km/s).

Petroleum potential of basal Deseret phosphatic unit, Utah

Field reconnaissance and preliminary conodont studies by C. A. Sandberg (USGS) and R. C. Gutschick (University of Notre Dame) revealed some important biostratigraphic, paleotectonic, and economic facts regarding the thin basal phosphatic unit of the Mississippian Deseret Limestone. This unit occupies a much larger area of Utah and adjacent southeastern Idaho than had been suspected previously and extends beyond the limits of the Deseret into time-equivalent strata. Its base, which everywhere overlies lower Osagean carbonate rocks, is a virtual depositional time plane. The unit, which comprises mainly phosphatic shales interbedded with thin phosphorites and deep-water limestones, is interpreted to have been deposited in a starved basin east of the Mississippian carbonate shelf. Conodont faunas from the base, middle, and top of the thin phosphatic unit demonstrate that its deposition spanned early, middle, and late Osagean (late Early Mississippian) time. The high organic content of samples from the phosphatic unit suggests that these rocks could have been a major source of petroleum that may have migrated into overlying Mississippian carbonate reservoir rocks in Utah. Thus, its economic significance is analogous to that of the phosphatic shales in the Permian Phosphoria Formation just to the north in Idaho and Wyoming.

Application of chalk diagenesis to petroleum exploration problems

An examination of the diagenesis of chalks on a worldwide basis by P. A. Scholle revealed that most porosity loss is a result of pressure solution during burial. Pore-water chemistry plays a large role in controlling the rate of solution and reprecipitation. (Freshwater is associated with higher rates than marine water.) In situations where marine pore fluids are retained during burial, relatively early overpressuring or oil entry into chalks can lead to the retention of good reservoir characteristics to great burial depths. The excellent North Sea oil production from chalks comes from this type of reservoir. The much poorer gulf coast oil and gas production comes from the freshwater-flushed, burial-cemented, and later fractured Cretaceous Austin Chalk.

Porosity preservation in reefs, Belize, Central America

The USGS diver-operated underwater drilling device was used to drill a series of shallow core holes across the Belize barrier reef of Central America and on lagoonal patch reefs behind the barrier, according to E. A. Shinn, R. B. Halley, J. H. Hudson, B. H. Lidz, and W. B. Charm.

Core holes drilled as deep as 12 m in sediments at a water depth of 8 m seaward of the reef flat revealed porosity reduction due to marine sedimentation. Cores recovered from holes drilled on and immediately behind the reef flat showed little, if any, porosity reduction. A carbonate sand and rubble island situated on the reef flat also showed little, if any, cementation, except for a 15-cm-thick belt of surficial beach rock.

A patch reef as much as 15 m thick and surrounded by lagoonal carbonates and clays, one of hundreds of similar patches, was cored. Four holes were drilled in the lagoonal sediments surrounding the patch reef. Cementation was totally lacking in the porous and permeable reef sediments and also in the porous but impermeable muds surrounding it. This small reef, which is thought to be similar to hundreds of even larger patches in the area, could serve as a model for exploration and exploitation of patch reefs in the geologic column. Porosity appears to be preserved because agitation and significant tidal action are absent.

OIL-SHALE RESOURCES

Geology of some lower Tertiary rocks in northwestern Colorado

Geologic mapping of the Indian Valley and White Rock quadrangles of Rio Blanco and Moffat Counties in Colorado was completed by G. N. Pipiringos and G. C. Rosenlund. Compilation of the results obtained thusfar indicated that Colorow Mountain, trending northeastward in the Indian Valley quadrangle, and Grey Hills, trending northwestward in the White Rock quadrangle, occupy synclines. These synclines joined to form a T-shaped structure. The leg of the T separates the Midland anticline on the north from the White River Dome on the south, and the head of the T separates both of them from the Wilson Creek-Price Creek anticlinal axis.

A study was made of drill cuttings and geophysical logs from six wells drilled for gas in or near the area. This study suggests that the stratigraphic and structural relations of subsurface rocks of Paleocene and Eocene age differ significantly from those of Paleocene and Eocene rocks exposed at the surface.

Unnamed tongue of the Green River Formation revealed

Mapping by R. C. Johnson revealed an apparent intertonguing of the Wasatch and Green River Formations along lower Roan Creek in the southwestern Piceance Creek basin of Colorado. The lower, unnamed tongue of Green River consisted of siltstone, sandstone, calcareous gray clay-shales, carbonaceous shales, and thin coal beds; it resembled the Douglas Creek Member of the Green River Formation. To the southeast and southwest, the unit graded into variegated sandstones and mudstones of the Wasatch Formation, but, to the north, it persisted toward the center of the basin. The interval between the top of the unnamed tongue and the base of the main body of the Green River Formation varied from 86 to 18 m and decreased rapidly to the west toward the Douglas Creek arch This rapid thinning suggests that the intervening Wasatch Formation may be locally truncated by the main body of the Green River Formation.

Preliminary investigation of clinker zones in oil shale

Mapping by R. C. Johnson of the Green River Formation in the southern portion of the Piceance Creek basin of Colorado revealed several areas of naturally burned oil shale that contained clinkerlike material. Some of this material appeared to have formed in place, and some appeared to have formed in rubble accumulated in talus cones. A glassy, lava-like material with a ropy texture was produced. This material was repeatedly injected into surrounding, relatively less burned rock. A ground magnetometer survey revealed very localized anomalies of up to 4,000 gammas associated with the areas of burned oil shale. These anomalies were probably caused by a highly magnetic mineral such as magnetite, which formed during burning. An electron microprobe analysis performed on a sample of ropy glass by G. A. Desborough indicated a highly siliceous composition similar to that of rhyolite.

Fracture zone in south-central Piceance Creek basin

Investigations by W. J. Hail and R. C. Johnson in the Cutoff Gulch, Bull Fork, and Figure Four Spring quadrangles in the Piceance Creek basin of Colorado showed the presence of a zone of structural weakness marked by discontinuous mineralized fractures, including local graben-type faults. The fracture zone extends through exposed rocks of the Uinta and Green River Formations and trends about N. 70°–80° W. In the Cutoff Gulch and Bull Fork quadrangles, the fracture zone roughly coincided with a monoclinal or anticlinal flexure expressed in exposed rocks of the Uinta Formation. The zone is in alinement with a similar fracture zone in the northwestern part of the Figure Four Spring quadrangle, where it coincides with a monoclinal flexure expressed in rocks of the Parachute Creek Member of the Green River Formation. Mineralization in the Cutoff Gulch and Bull Fork quadrangles appears to be largely calcitic. Barite is present in the zone in the Figure Four Spring quadrangle.

Mercury content of Green River oil shale

An investigation by J. R. Donnell and V. E. Shaw demonstrated that concentrations of mercury in oil shales from eastern Utah, previously reported to be as high as 4 ppm, upon reanalysis averaged 0.35 ppm. Core samples from the rich Mahogany Zone oil shale in a core hole adjacent to tract C-b contained an average of 0.37 ppm Hg. In one oil-shale sample from the Green River Formation, 58 percent of the mercury in the Fischer assay products was in the gas plus loss fraction, and only 2 percent was in the spent shale.

Oil-shale resources in the Piceance Creek basin

C. W. Keighin calculated that certain rich oil shales of the Parachute Creek Member of the Green River Formation in the Piceance Creek basin of Colorado contain at least 68 billion tonnes of oil. Only those beds thicker than 3.05 m and yielding 7.25 kg of oil per tonne or more were included in the calculations. The richest oil-shale zone is the Mahogany Zone, which contains more than 20 billion tonnes of oil in shale yielding 7.25 kg/t and at least 14 billion tonnes in shale yielding 8.7 kg/t or more.

Assay data for oil shale containing analcime, dawsonite, or nahcolite

G. A. Desborough and J. K. Pitman (1975) found, during Fischer assaying of oil shale from the Green River Formation, that analcime, dawsonite, and nahcolite did not react as predicted from experimental thermal treatment of the individual minerals. Heating the individual minerals to 500°C causes analcime to lose all water and dawsonite and nahcolite to lose all CO_2 and water. However, when these minerals are subjected to the same thermal treatment in the presence of kerogen, all minerals retain some water. It was thought that this retention of water was due to the high partial pressure of H_2O vapor generated by kerogen during pyrolysis.

NUCLEAR-FUEL RESOURCES

Uranium and thorium in the Zane Hills pluton, Alaska

Preliminary studies were conducted on two radioactive zones of monzonite and syenite in the Zane Hills pluton in west-central Alaska by T. P. Miller and M. H. Staatz. One zone covers an area of 13 km^2 in the southeastern part of the pluton; the other covers an area of 25 km^2 in the southern part of the pluton. Grab samples collected from the southeastern zone contained from 11 to 130 ppm U and 46 to 269 ppm Th. Allanite is the most abundant uranium and thorium mineral in the southeastern zone, but uranothorianite, thorite, betafite, sphene, and zircon are also found. Grab samples from the southern zone contained 15 to 33 ppm U and 75 to 135 ppm Th. Allanite is also the most common uranium and thorium mineral in the southern zone, where it is found with minor amounts of sphene and zircon.

Uranium occurrence in Dakota Sandstone, Gallup area of New Mexico

M. W. Green and C. T. Pierson reported that the deposition of uranium in parts of the Cretaceous Dakota Sandstone near Gallup in McKinley County, New Mexico, is related to the presence of carbonaceous laminae or pockets in the host rock and to the presence of an overlying impervious caprock. The host rock consists of fine- to medium-grained sandstone deposited in distributary channels that crossed a swampy flood plain. The favorability of the host rocks is related to depositional energy levels within the swamp distributary system. The carbonaceous laminae and pockets were deposited in low- to medium-energy areas near the banks of the channels. The winnowing out of the carbonaceous material in the deeper, high-energy parts of the channels created a central channel facies of very highly permeable sandstone. These central channel rocks may have served as conduits for the entrance of uranium-bearing water. The impervious caprock, present at all known uranium deposits in the Gallup area, was deposited in the very low energy swampy areas between distributary channels.

Uranium in sedimentary rocks, Appalachian Basin

Reconnaissance of Paleozoic rocks in the Appalachian Basin by A. F. Jacob (1975) showed that some Cambrian sandstone beds, which show maximum radioactivity 20 times background, probably are fossil placers. Some local postdepositional mobilization and concentration of uranium or thorium from the placers have occurred. Uranium deposits (maximum 0.3 percent U) near Jim Thorpe, Pa., in the Catskill Formation (Devonian) are in fluvial sandstone deposited on the landward part of a deltaic plain. Small low-grade deposits further west are in fluvial sandstone deposited on the seaward part of a deltaic plain. Small high-grade deposits (maximum 1.8 percent U) are in fluvial conglomerate in the upper part of the Mauch Chunk Formation (Mississippian and Pennsylvanian), also near Jim Thorpe. Radioactive anomalies (maximum 45 times background) in the Pocono Formation (Mississippian) near Marlinton, W. Va., are in fluvial sandstone deposited on the seaward part of a deltaic plain. Chemical and petrologic data show that these deposits are fossil placers. Sandstone beds in the Permian Dunkard Group in the Dunkard Basin of southwestern Pennsylvania and West Virginia, which were deposited in channels on a shallow-water delta, show radioactivity about 2 times background. One sandstone sample from the Dunkard contained 0.009 percent U.

Uranium occurrences, Newark-Gettysburg Triassic basin

Reconnaissance with a scintillometer in the Newark-Gettysburg basin of Pennsylvania and New Jersey by C. E. Turner-Peterson resulted in the location of several new gamma-ray anomalies in the Lockatong Formation, which overlies the Stockton Formation and underlies the Brunswick Formation. The new anomalies, together with known occurrences in other parts of the basin, suggest that the channel sandstones of the Stockton Formation and the lacustrine black mudstones and calcareous units within the Lockatong Formation have the greatest potential for uranium. The uranium in the Stockton is in laterally discontinuous mineralized zones, and the uranium in the Lockatong is in laterally continuous zones that conform to the bedding. Only one small anomaly was found in the red shales and siltstones of the Brunswick Formation.

Pinch-out of Burro Canyon Formation, Piceance Creek basin, Colorado

The Burro Canyon Formation (Lower Cretaceous) is a potential uranium-bearing host rock in western Colorado and southeastern Utah. It projects beneath the southwestern margin of the Piceance Creek basin of western Colorado but is absent at the outcrop along much of the northeastern margin of the basin. Field studies by L. C. Craig (1975) suggested that the pinch-out edge of the formation extends in a southerly direction beneath the basin from a point a short distance south of Meeker on the northeastern margin of the basin to a point near Crawford south of the basin. The position of this pinch-out in the basin fixes an eastern limit for the occurrence of potential uranium host rocks in the Burro Canyon Formation. The pinch-out probably results from depositional thinning owing to slight structural movements and postdepositional erosion before the deposition of the overlying Dakota Sandstone (Lower and Upper Cretaceous).

Uranium, Marshall Pass district, Colorado

In the Marshall Pass district of Saguache and Gunnison Counties in Colorado, J. C. Olson found uranium deposits in the Belden Formation of Pennsylvanian age, the Leadville Limestone of Mississippian age, the Harding Quartzite of Ordovician age, and Precambrian granite and schist. The principal deposits are in several of these rock units in and near the Pitch mine and are localized along a complex fracture zone associated with the Chester reverse fault. The upper part of the 10- to 13-m-thick Harding Quartzite contains low-grade uranium deposits in a limonitic zone 1 to 2 m thick that also contains organic material, including carbonized vegetal material, fish scales, and asphaltic pellets. These low-grade uranium deposits are widely distributed in the district.

Uranium-bearing Triassic rocks, San Rafael Swell, Utah

Uranium deposits in the Triassic Chinle Formation in the San Rafael Swell of Emery County, Utah, are related to sedimentary depositional environments. R. D. Lupe (1975) found that depositional sedimentary textures that developed in low-energy environments appear to have influenced uranium mineralization. The Chinle consists of three fining-upward sequences that were deposited in braided stream and lake environments. Uranium is concentrated in the lower part of the lowest sequence in localities where sediments deposited in low-energy environments are complexly interbedded with sediments deposited in high-energy environments. Areas favorable for uranium exploration exist in the subsurface to the north, west, and south of the Chinle outcrop in the San Rafael Swell. This determination is based on the distribution and temporal patterns of the depositional environments.

Uranium deposits, Powder River Basin, Wyoming

Paleocurrent maps by D. A. Seeland showed transport directions in the Eocene fluvial sandstones of the Powder River basin in Converse, Campbell, and Johnson Counties, Wyoming. The maps also defined sedimentation patterns and sediment source areas that appear related to the uranium deposits of the basin. The southern part of the basin includes the Pumpkin Buttes and southern Powder River basin uranium districts. Three-fourths of the two districts and all of the high-grade, large deposits in these districts occur where the Eocene Wasatch Formation is derived primarily from the Precambrian core of the Laramie Range. The Hartville uplift provided a small part of the sediment in the southern Powder River basin, but, more importantly, it prevented the streams of the northwestern flank of the Laramie Range from flowing eastward onto the Great Plains, as they do today.

The ancestral Eocene Wind River left the Wind River basin near Waltman, Wyo., crossed the Casper arch, and entered the Powder River basin about 25 km northeast of Midwest, Wyo. It flowed almost due north through the Powder River basin, passing about 15 km east of Buffalo, Wyo., and entered Montana about 25 km northeast of Sheridan, Wyo. The eastern two-thirds of the basin is dominated by sediments deposited by streams flowing westward from the Black Hills. In contrast, the streams flowing eastward off the Bighorns had a relatively minor effect on the sedimentation patterns of the basin and contributed relatively little to the sediment now preserved in the basin.

Crooks Gap uranium district, Wyoming

Geologic mapping near the Crooks Gap uranium district in Fremont and Sweetwater Counties, Wyoming, by L. J. Schmitt, Jr., indicated that uranium deposits are closely related to supergene alteration of the Battle Spring Formation of early and middle Eocene age. Uranium is found close to the lowermost stratigraphic occurrence of red hematitic alteration of conglomeratic arkose. In places, the base of the alteration coincides with the base of conglomerate beds overlying an angular unconformity. The alteration commonly extends downward from the boulder beds an indeterminate distance, in excess of 100 m in places.

The hematitic alteration was primarily supergene. The downward-directed nature of the process is indicated by the geometry of hematite distribution and locally by hematite concentrations capping cobbles and small boulders. The downward passage of the altering fluids was apparently inhibited by carbonaceous material and perhaps by pyrite in the sediments. Hematitic alteration and uranium mineralization were confined to the uppermost parts of the sedimentary section where there was much carbonaceous material. Where there was little carbonaceous material, the altering and mineralizing fluids passed through the sediments without depositing uranium.

Uranium in the Eastern United States

Analysis by R. I. Grauch and Katrin Zarinski of the spatial, geological, and age variations of the uranium content of exposed rocks in the Eastern United States suggested that there have been at least two major periods of uranium enrichment. In the Precambrian, there were apparently four major loci for the introduction and dispersion of uranium: northwestern North Carolina; a belt extending from eastern Pennsylvania across northern New Jersey to southeastern New York; the northwestern Adirondack Mountains of New York; and the southern Green Mountains of Vermont. The White Mountain igneous intrusion of Jurassic age in New England apparently was the mechanism for enrichment and provided several loci for the accumulation of uranium.

Uranium in Permian rocks in the Southwestern United States

Literature review and field reconnaissance of Permian sedimentary basins of the Southwestern United States by J. A. Campbell (1975) indicated that there are numerous suitable host rocks and geologic settings for the occurrence of uranium. The basins with the highest potential in the midcontinent area are the Hollis basin, which is south of the Wichita and Arbuckle Mountains in southern Oklahoma and northern Texas, and that portion of the Midland basin that extends into western Oklahoma. The Wichita Group contains the potential host rocks in the Hollis basin, and the Quartermaster Formation is the potential host in the Midland basin.

The basins with the highest potential in the southern Rocky Mountain area are the Central Colorado basin, extending from north-central New Mexico to northern Colorado, and the Uncompahgre basin, extending from Durango, Colo., to Moab, Utah. The Maroon and Sangre de Cristo Formations are the potential host rocks in the Central Colorado basin, and the potential host rocks in the Uncompahgre basin are in the Cutler Formation.

Alteration of iron-titanium oxide minerals in uranium-bearing sandstone

R. L. Reynolds (1975) reported that titanomagnetite and ilmenite are abundant detrital minerals in the uranium-bearing sandstone of the Texas Gulf Coastal Plain and are easily distinguished by their different magnetic and optical properties. Alteration of these iron-titanium oxide minerals in oxidizing environments created secondary products (hematite) different than those produced under reducing conditions (sulfides). Pyrite replaces marcasite, and both are found together replacing Fe-Ti oxides. Oxidation of previously sulfidized Fe-Ti oxides produced ferric oxyhydroxides and hematite with textures that mimic those of the sulfides. Relict sulfide within Fe-Ti oxides is commonly preserved in these zones. Similar alterations are present in uranium-bearing sandstones in New Mexico (Morrison Formation) and northeastern Colorado (Laramie Formation), in spite of a different source terrane and the longer diagenetic history of these rocks. The alteration of Fe-Ti oxides explains the paleomagnetic and geochemical history of these uranium deposits and also provides an exploration guide.

Mobility of uranium in granitic rocks

Studies of uranium, thorium, and lead isotopes by J. S. Stuckless, C. M. Bunker, and I. T. Nkomo (1975) in drill-core samples were used to demonstrate uranium mobility to depths in excess of 400 m in granitic rocks from the Granite Mountains of Wyoming. Analyses of these and other alkali granites suggest that published worldwide thorium and uranium averages and thorium-uranium ratios for granite may not be representative of alkali biotite granites. Although only a few alkali granites have been analyzed, thorium contents may be 3 to 4 times higher than those reported for average granites, and present-day thorium-uranium ratios may be higher in alkali granites by a factor of 2. If the results from the Granite Mountains are generally applicable, then other alkali biotite granites may have lost large amounts of uranium (10–20 $\mu g/g$) as a result of exposure to near-surface conditions.

Comparisons of uranium content determined chemically (U) with uranium content obtained by gamma-ray spectrometry (Raeg U) may provide a test for uranium mobility. Disequilibrium between uranium-238 and radium-226 has been demonstrated in 32 of 41 samples from the Granite Mountains. Thus, comparison of chemical U and Raeg U may provide a simple guide to favorable uranium source rocks.

Secondary enrichment of uranium, Midnite Mine

Uranium ore averaging 0.23 percent U_3O_8 at the Midnite mine in Stevens County, Washington, is believed to result from redeposition and concentration during multiple stages. The geometry of ore bodies and structural and geochemical features outlined by J. T. Nash and N. J. Lehrman (1975) suggested that uranium minerals were deposited over a span of time from Late Cretaceous to late Tertiary. Initial emplacement of uranium, probably from the nearby porphyritic quartz monzonite, could have been by hydrothermal or supergene solutions. Subsequently, ore resulted from downward or lateral migration of uranium into permeable zones, where deposition was caused by reactions in acid sulfur-rich solutions near a fluctuating water table. Oxidation of pyrite in fine-grained metamorphic rocks acidified the descending solutions that carried uranium in a complex form, possibly as $UO_2(SO_3)_2^{-2}$. The breakdown of unstable sulfur species, such as thiosulfate, to sulfide ion could have been the chief chemical reductant that caused deposition of pitchblende and iron sulfide.

Thorium, Wet Mountains, Colorado

Preliminary mineralogical and geochemical studies in the Wet Mountains area of Colorado by T. J. Armbrustmacher (1975) showed that the thorium-rich carbonatites, "red rock" syenites, quartz-barite veins, and shear zones are characterized by extremely variable mineral and element contents. Carbonatites contain abundant calcite and dolomite and variable amounts of magnesite, quartz, alkali feldspar, aegirine, crocidolite, siderite, rhodochrosite, goethite, magnetite, and hematite. The accessory minerals in the carbonatites include phlogopite, chlorite, rutile, epidote, fluorapatite, barite, spinel, pyrite, bastnaesite, synchisite, monazite, xenotime, and pyrochlore. These carbonatites contain relatively large concentrations of rare-earth elements, niobium, and thorium, the ratios of rare earth to thorium generally being greater than one. Thorium averages about 220 ppm and uranium about 20 ppm in the carbonatites. "Red rock" syenites contain abundant alkali feldspar and variable but usually trace amounts of iron oxides, thorite, barite, rutile, xenotime, bastnaesite, and brockite. The syenites contain smaller amounts of cerium-group rare earths than the carbonatites but larger amounts of yttrium-group rare earths and thorium. Quartz-barite veins contain large amounts of quartz, alkali feldspar, barite, and carbonates, as well as many of the previously mentioned accessory minerals, including rutile and sulfide minerals. These veins contain larger average amounts of base metals and thorium than carbonatites and "red rock" syenites, and the average rare-earth content of the veins is intermediate between the two. Mineral assemblages similar to these are not unique in shear zones. Iron oxides are especially abundant along fractures, and thorite is the primary source of thorium. The highest average concentrations of yttrium and thorium occur in shear zones, where the thorium averages 3,000 ppm.

Thorium resources, Lemhi Pass district

Thorium resources of the Lemhi Pass district in Lemhi County, Idaho, and Beaverhead County, Montana, were calculated by M. H. Staatz for all veins at least 6 cm thick. Indicated reserves are 160,000 t ThO_2, and inferred reserves are 117,000 t ThO_2. Ninety-six percent of the total reserves are in the 10 largest veins, which are: (1) Last Chance, (2) Shear zone, (3) Contact, (4) Cago No. 12, (5) Thorium Oxide, (6) Black Rock (Montana), (7) G and G Nos. 6 and 8, (8) G and G Nos. 1, 2, and 5, (9) Lucky Horseshoe, and (10) Beaverhead. The ore from these 10 veins averages 0.43 percent ThO_2.

Paleochannels, conduits for uranium-bearing water in the formation of southern Texas deposits

Several uranium deposits in Karnes County in southern Texas were apparently formed by uranium-bearing ground water reaching the depositional sites through paleochannels in porous sandstone in the Whitsett Formation of the Jackson Group (upper Eocene) and in the Catahoula Tuff (Miocene). K. A. Dickinson reported that two channels within the Whitsett Formation have been mapped in the subsurface by drilling, and two channels at the base of the Catahoula were noted in mines. One channel, the Kellner (Dickinson, 1976), has been traced from the outcrop through the Kellner, Weddington, and Rosenbrock uranium deposits. This channel cuts into a beach sandstone, the main host rock for the unoxidized uranium deposits in the Karnes County area. Another channel, the Lauw, extends through the Lauw and Beiker deposits and apparently transects an underlying beach sandstone, the main host rock for the oxidized uranium deposits. Channels at the base of the Catahoula Tuff were probably important ground-water conduits that carried uranium into the Brown and Mocszygemba deposits. In these deposits, the porous channel sandstone bodies extend within a meter or two of the beds in the Whitsett Formation that form the uranium host rock.

Borehole geophysics as an aid to uranium exploration

Borehole geophysical measurements of electrical resistivity, induced polarization, and magnetic susceptibility were made by J. H. Scott and J. J. Daniels in the vicinity of roll-type uranium deposits in Live Oak County, Texas. Variation in the clay sulfide and magnetic mineral contents across the geochemical interface associated with some uranium deposits can be detected by these methods. Clay content, an indication of porosity, can be estimated from borehole resistivity measurements. Differences in sulfide and clay concentrations near a roll-front deposit can be detected by using induced polarization. Changes from magnetic to nonmagnetic iron minerals can be detected by magnetic susceptibility measurements. Since these mineral changes can be several hundred meters broader than the uranium orebodies, roll-type deposits can perhaps be found with fewer exploration drill holes than traditional approaches require.

Landsat and thermal data used as aids in uranium search

Landsat data from the Crooks Gap uranium district in Fremont County, Wyoming, and from the Box Creek uranium district in Converse County, Wyoming, were used by T. W. Offield (1975) and T. E. Townsend to test the usefulness of remote sensing in the search for uranium. Computer enhancement, which includes increasing the contrast and eliminating shadows to bring out subtle differences in the data, can detect the reddish altered ground that has served as an exploration guide in these districts. Statistical analysis suggests that altered areas can be distinguished and mapped according to the intensity of discoloration.

Thermal-infrared images made just before dawn of the Freer area of Duval County in southern Texas and interpreted by T. W. Offield may be used in the search for uranium. Conglomerate channel fill in the generally clayey Catahoula Tuff shows as distinctly warmer areas. Thermal data may help significantly in mapping these channels, which are potential loci of uranium deposition and commonly are difficult to map by regular geologic methods.

GEOTHERMAL RESOURCES

U.S. GEOTHERMAL RESOURCES ASSESSED

The first comprehensive assessment of the geothermal resources of the United States (White and Williams, 1975) was prepared in cooperation with the U.S. Energy Research and Development Administration. The assessment was divided into two parts:

- Estimates of the total heat in the ground above 15°C to a depth of 10 km under all 50 States without regard to its recoverability (geothermal resource base).

- Estimates of the part of this total heat that is recoverable with present technology, regardless of price (geothermal resources).

The geothermal resource base was divided into three categories according to the dominant mode of heat transport: hydrothermal convection systems, hot igneous systems, and regional conductive environments.

Hydrothermal convection systems are characterized by relatively high temperatures at shallow depths and include the most attractive targets for development at present prices. J. L. Renner, D. E. White, and D. L. Williams (1975) estimated that the heat stored in identified high-temperature (>150°C) hydrothermal convection systems is 396×10^{18} cal. For intermediate-temperature systems (90°–150°C), the stored heat is an estimated 345×10^{18} cal. An additional $2{,}309 \times 10^{18}$ cal are probably present in undiscovered hydrothermal convection systems.

R. L. Smith and H. R. Shaw (1975) estimated that at least $25{,}000 \times 10^{18}$ cal of heat are contained in hot igneous geothermal systems in the upper 10 km of the crust of the United States. Of these, about $13{,}000 \times 10^{18}$ cal are in molten magma bodies at temperatures between 650° and 1,200°C, and the remainder are in partially crystallized and crystallized magma and adjacent country rocks. D. L. Peck (1975) discussed the feasibility of using the energy contained in the molten portion of hot igenous systems and concluded that, before this resource can be tapped, a number of formidable technological problems must be solved. These problems include: developing drilling tools capable of operating at the high temperatures and pressures involved, developing equipment for in-hole monitoring and sampling, finding a means for keeping the hole open and stable during drilling and heat extraction, and developing methods for inducing magmatic convection if natural convection rates are low.

W. H. Diment, T. C. Urban, J. H. Sass, B. V. Marshall, R. J. Munroe, and A. H. Lachenbruch (1975) estimated that the heat contained in the crust in regions of conductive heat flow is in excess of 8×10^{24} cal, equivalent to the heat of combustion of approximately 5,520 trillion barrels of oil or 1,118 trillion tonnes of coal. Most of this heat is not recoverable by present technological means; however, the geopressured areas of the northern Gulf of Mexico basin are among the more attractive sites available for improving present technology.

Resource estimates were made for three types of geothermal systems: high-temperature (>150°C) hydrothermal convection systems, which might be used for the generation of electricity by using fluids extracted from depths of less than 3 km; intermediate-temperature (90°–150°C) hydrothermal convection systems, which are attractive for nonelectrical applications such as space and process heating; and geopressured sedimentary fluids present in onshore gulf coast sediments of Tertiary age to depths up to 7 km, which might be used for the generation of electricity.

Manuel Nathenson and L. J. P. Muffler (1975) estimated that the stored heat in identified high-temperature hydrothermal convection systems could produce 8,000 MW-centuries of electricity and that an additional 38,000 MW-centuries may be present in undiscovered high-temperature systems. Recoverable heat in identified and undiscovered intermediate-temperature hydrothermal systems was estimated at 83×10^{18} cal, equivalent to the heat of combustion of 57 billion barrels of oil.

S. S. Papadopulos, R. H. Wallace, Jr., J. B. Wesselman, and R. E. Taylor (1975) estimated that the energy recoverable from geopressured geothermal reservoirs within onshore Tertiary sediments along the Texas and Louisiana gulf coast is equivalent to between 9,000 and 35,000 MW-centuries of electricity, depending upon the production plan. This range excludes the energy value of recoverable methane entrained in the fluids, which is probably equal in value to the thermal energy.

Geothermal systems not assessed include: hydrothermal convection systems with maximum temperatures below 90°C (inadequate data), hot igneous systems (technological problems involved in using this heat), and geopressured sedimentary environments other than the onshore Tertiary sediments of the gulf coast (inadequate data).

National parks were given a special status in the assessment. They were included in estimates of the total resource base, but, because they are considered to be permanently withdrawn from resource exploitation, they were not included in the geothermal resource estimates.

ALASKA

Two previously unreported volcanoes in the Aleutian volcanic arc were found during geothermal reconnaissance investigations conducted by T. P. Miller and R. L. Smith. The first volcano, Mount Kialagvik, is located on the Alaska Peninsula about 130 km east-northeast of Port Heiden. The volcano appears to be a dacitic dome with associated dacitic ash flows. The relative lack of erosion of the unconsolidated ash flows suggests a very young age, perhaps a few thousand to a few tens of thousands years.

The other volcano, Hayes Volcano, is at the foot of Mount Gerdine 150 km west of Anchorage in the Tordrillo Mountains. It is about 90 km north of Mount Spurr, which had been considered the easternmost volcano in the 2,600-km-long Aleutian volcanic arc. The original vent appears to be mostly covered by the Hayes Glacier. Only a remnant of unconsolidated ash fall and avalanche deposits can still be found along the margin of the glacier. This volcano is the probable source of the air-fall ash that immediately underlies surface vegetation in the upper Susitna River drainage and may be the source of some of the air-fall ash found in the general area of Anchorage.

The existence of two ash-flow sheets surrounding Okmok caldera on Umnak Island in the eastern Aleutians was also documented by Miller and Smith. The relationship between the ash-flow sheets can best be seen on the northwestern side of the island, where the sheets are locally separated by a basalt flow 6 to 9 m thick. The occurrence of two ash-flow units indicates at least two major caldera-forming eruptions of Okmok caldera, a possibility first raised by F. M. Byers, Jr., who suggested that Okmok might be a double caldera.

ARIZONA

Intrusion of basaltic and silicic lavas has been broadly contemporaneous in the upper Cenozoic San Francisco volcanic field, located on the southern Colorado Plateau in northern Arizona. Mafic rocks include alkali-olivine basalt, alkali-rich high-alumina basalt, and basaltic andesite. More silicic rocks include a compositional spectrum from andesite through dacite and rhyolite, which, together with the basalts, comprise an apparently consanguineous assemblage transitional between alkalic and calc-alkalic suites. Geologic mapping by R. F. Holm, R. B. Moore, G. E. Ulrich, and E. W. Wolfe (USGS); published K-Ar dates (Damon and others, 1974; McKee and Anderson, 1971); new K-Ar dates by E. H. McKee (USGS) and P. E. Damon and Muhammed Shafiqullah (University of Arizona); and paleomagnetic measurements by T. C. Onstott (USGS) of the rocks on San Francisco Mountain permitted reconstruction of the following sequence of events:

- About 15 million years ago, volcanism began in the region south of the Mogollon rim.
- Four to six million years ago, basaltic volcanism was extensive in the central and southern parts of the San Francisco field, and silicic eruptions occurred in the southwestern part.
- Within the past 3 million years, compositionally bimodal volcanism produced tens of silicic domes and hundreds of basaltic cones and flows in the interior of the field.
- Over the interval from 0.7 to 0.4 million years ago, a composite cone, San Francisco Mountain, was constructed, composed of interlayered lava flows and pyroclastic deposits of basaltic andesite, andesite, dacite, and minor basalt overlying a complex of older silicic domes.
- The youngest known rocks, including basalt as young as 910 years and rhyolitic domes and plugs ranging in age from about 230,000 to 50,000 years, occur in the same general region in the eastern part of the San Francisco field. All but one of these younger rhyolitic vents are alined and on strike with the east-northeast-trending grabenlike interior valley of San Francisco Mountain formed approximately 200,000 to 400,000 years ago. This alinement coincides with a distinct, narrow magnetic low (Sauck and Sumner, 1970); the zone thus defined may be a particularly promising target for additional geophysical exploration to identify hot or molten rock within the crust.

CALIFORNIA

Regional structures related to geothermal resources in The Geysers-Clear Lake area

Geologic mapping in The Geysers-Clear Lake area of California by R. J. McLaughlin, B. C. Hearn, Jr., J. M. Donnelly, and F. E. Goff delineated regional structures that correspond to features noted in recent geophysical investigations and that may be of considerable significance in terms of geothermal resources. The prominent northwest-trending Collayomi fault zone of late Quaternary age transects a regional 30-mGal negative residual gravity anomaly centered over the Clear Lake Volcanics (upper Pliocene? to Holocene) and interpreted by Isherwood (1975) to be due to the presence of hot magma at depth. A study of the fault zone by Donnelly and others (1976) revealed multiple faults having both vertical and probable right-lateral displacements. The zone, which is parallel to the San Andreas fault system, is a partial control of the southwestern boundary of the Clear Lake Volcanics and is in part the boundary between the Franciscan assemblage and the Great Valley sequence. Indications that the zone is active include offset of young deposits, apparent right-lateral offset of streams, and local earthquakes. An average rate of movement of 1 mm/yr is suggested by a 0.4-km offset of 0.4-million-year-old volcanic rocks. The Collayomi fault zone also corresponds to a prominent constriction in the gravity contours, separating the negative circular anomaly into northeastern and southwestern lobes. In addition, the zone roughly bounds the southwestern side of a major resistivity low (Stanley and others, 1973) centered over the Clear Lake Volcanics.

The Collayomi fault zone may control the undetermined northeastern extent of The Geysers steam field. Studies of spring geochemistry done by J. M. Thompson, P. C. Russell, and R. H. Mariner suggested that geothermal resources in the area northeast of the Collayomi fault zone are largely dominated by hot water, whereas the geochemistry of hot springs southwest of the Collayomi fault zone in The Geysers steam field is consistent with the presence of a vapor-dominated system.

South of The Geysers steam field, the southwestern side of the gravity low roughly coincides with the 60° north-dipping Mercuryville fault zone. The absence of hydrothermal alteration and other surface thermal phenomena south of the Mercuryville fault zone suggests that the heat source, presumably expressed by the gravity low, does not extend south of the fault zone.

Of further significance to steam distribution in The Geysers steam field are northeast-southeast-dipping imbricate thrust faults that separate slabs of fractured graywacke from less fractured and more highly sheared slabs of greenstone, melange, and serpentinite. Steam zones are largely related to open fractures and faults in the graywackes, whereas the less fractured, more highly sheared rocks tend to cap and seal off the reservoir rocks. The imbricate structure of the basement rocks probably acts in part to direct steam and heat southwestward and updip from the Clear Lake region to The Geysers steam field.

Konocti Bay fault zone shows geothermal potential

Geologic mapping in the Clear Lake volcanic field by F. E. Goff, J. M. Donnelly, and B. C. Hearn, Jr. (Goff and others, 1976), delineated the Konocti Bay fault zone. The zone strikes N. 25°–30° W., bisects the central portion of the Clear Lake volcanic field, and displays evidence of geothermal potential. The zone can be traced for at least 18 km, from the Seigler Springs area to the eastern flank of Mount Konocti. Microearthquakes indicate that the zone is active. Analyses by J. M. Thompson of water from warm springs and wells (25°–52°C) associated with the zone show a high magnesium content (up to 320 mg/l), which suggests that shallow serpentinite occurs beneath the volcanic rocks along the fault zone. Reservoir temperatures are estimated to be 195° to 210°C on the basis of mixing model geothermometry. The relatively chloride-rich waters and the absence of acid-sulfate springs suggest a hot-water system rather than a vapor-dominated system.

Geothermal significance of boron in spring waters in The Geysers-Clear Lake area

The boron content of water from springs sampled by P. C. Russell and R. H. Mariner in The Geysers-Clear Lake area indicated that the distribution of boron may be significant in geothermal resource studies. Boron values from springs in Franciscan terrane of The Geysers steam field southwest of the Collayomi fault zone range from <0.02 to 0.4 ppm. Water from springs northeast of the Collayomi fault zone, in Clear Lake Volcanics terrane underlain by marine strata of the Great Valley sequence, show boron values ranging up to several hundred parts per million.

The significance of these different boron contents is presently under study. At least two interpretations seem possible from present data:

- The high boron content of water northeast of the Collayomi fault zone may indicate the presence of hot water, which permits more complete rock-water reaction and aqueous transport of boron than the steam-rock reactions of the vapor-dominated Geysers field southwest of the Collayomi fault zone.
- The boron increase may simply reflect the high permeability of Great Valley sequence strata, which permit more complete rock-water reaction than the relatively impermeable Franciscan rocks of The Geysers steam field.

Heat flow at The Geysers

Temperatures were measured by T. C. Urban, W. H. Diment, and J. H. Sass (USGS) and I. M. Jamieson (Pacific Energy Corporation) in two deep holes over a producing part of The Geysers steam field (Urban and others, 1975). They found that temperature over the steam reservoir exhibits a linear increase with depth to the maximum depth logged (~1 km). Extrapolation of depth to the steam zone

(1.5 km) yields the temperature of the steam zone (~240°C). This suggests that the transfer of heat in the cap is largely conductive and that this condition has persisted for several thousands of years or more. Although conductive heat flow is high ($\sim 10^{-6}$ cal/cm^2/s), it is small in comparison with the heat extracted from the steam wells, which, in turn, is small in comparison with the heat stored in the ground.

These measurements suggest that, at least in some localities at The Geysers, temperature measurements in shallow holes (~100 m) are a useful exploration technique and perhaps a reliable indicator of the depth to steam.

Geoelectric investigations at Coso Hot Springs

D. B. Jackson and J. E. O'Donnell reported that preliminary analysis of a telluric current survey covering most of the Coso ring structure (Duffield, 1975a) defines an area of moderately high conductances related to high-temperature water and alteration of the fractured granitic bedrock in the vicinity of Coso Hot Springs and the Devils Kitchen thermal area. Rose Valley and Indian Wells Valley, both partially within the ring structure, have even larger conductances than the Coso Hot Springs-Devils Kitchen anomaly; these large conductances, however, are probably related to thick sections of conductive valley fill. Preliminary interpretation of a magnetotelluric sounding 1.5 km north of Devils Kitchen shows a conductive horizon (<10 ohm-m) at a depth of about 3 to 5 km that may be the source of the heat driving the Coso Hot Springs-Devils Kitchen geothermal system. Preliminary interpretation of a second magnetotelluric sounding about 16 km north of the ring structure in the Talc Hills also defines a conductive horizon of less than 10 ohm-m, but at a depth of approximately 11 km. The relationship, if any, between the conductive horizon north of Devils Kitchen and the conductive horizon beneath the Talc Hills is not yet understood.

IDAHO

Flow tests of RRGE No. 1 and RRGE No. 2, the first two deep (1,526 and 1,840 m, respectively) geothermal wells drilled by the Energy Research and Development Administration (ERDA) in the Raft River basin of Cassia County, Idaho, confirmed that sufficient volumes of hot water (147°C) are present in the geothermal system to supply a pilot or demonstration powerplant to test the economic feasibility of producing electricity from a hot-water hydrothermal system. Selection of the well sites was based on information supplied by USGS geologists and geophysicists in cooperation with personnel from ERDA and other organizations (Williams and others, 1975).

Geophysical logs of RRGE No. 1, RRGE No. 2, and the Malta deep well were made by J. K. Sullivan, Joe Sena, and R. E. Hodges. The logs of RRGE No. 2 indicated an inflow of hot water at the bottom of the hole that had gone undetected by all other logs and surface tests. The discovery of the hot-water zone was a primary factor in the decision to deepen the hole.

Preliminary results of heat-flow measurements made in the Raft River Valley and adjacent areas by T. C. Urban and W. H. Diment (1975) indicated that: (1) conductive heat flow is as high (2.2–3.0 μcal/cm^2/s) as it is in the higher parts of the Basin and Range province; (2) anomalously high heat flows (~8 μcal/cm^2/s) in parts of the valley are associated with hydrothermal convection in the subsurface; and (3) the hottest waters observed (~150°C) in the deepest hole (~2 km) could result from circulation of meteoric water to a depth of about 3 km.

E. G. Crosthwaite supervised the drilling of a fifth intermediate-depth core hole 220 m deep in the Raft River Valley. The hole penetrated 9 m of weathered granitic rock from 210 to 220 m. An offset hole drilled within 30 m of the core hole penetrated the same section but passed from granitic rock to fine-grained sedimentary rock at approximately 236 m.

Two exploratory wells approximately 365 m deep were drilled in the upper Raft River basin to provide geologic and hydrologic information for a mathematical model of the upper basin. One well encountered warm water at a depth of less than 46 m, the temperatures exceeding 75°C. Temperatures in the other well were about 25°C, normal for the area. More accurate temperature data will be collected later.

MONTANA

R. B. Leonard visited about 30 hot springs in southwestern Montana to establish precise locations, ease of access, temperatures, and geologic settings for a more detailed geothermal reconnaissance of the region. The springs are located in stream valleys adjacent to extensive uplands underlain by fractured granitic intrusive rocks of Late Cretaceous to early Tertiary age or by Precambrian rocks.

About two-thirds of the springs are within the Boulder and Idaho batholiths and associated intrusions or near their boundaries with Precambrian country rock. Extensive fracturing and faulting characterized outcrops of those rocks near the springs. Detailed surface geologic studies at some of the sites show that the fractures are conduits for water, whereas the associated faults can constitute either conduits for or barriers to flow. Circulation of thermal waters and low thermal gradients in fractured crystalline rock were observed at depths greater than 1,000 m in the deep mines at Butte and greater than 2,000 m in a test hole at Marysville. Structural relations near most of the remaining springs and the chemical composition of the discharge suggest migration of thermal water into younger sediments from adjacent or underlying fractured Precambrian rocks.

Temperatures of the springs ranged up to about 80°C. Where it was known, the chemical composition of the waters implied a predominantly meteoric origin and maximum subsurface temperatures of 150°C or less in hot-water convective systems of low salinity. The batholithic intrusions probably are too old to be considered as shallow sources of residual heat of emplacement, and younger volcanic sources are suspected at only three of the springs. The combined evidence suggests that most of the springs studied, as well as some anomalously high geothermal gradients measured in shallow test holes, result mainly from deep convective circulation of meteoric water through fractured crystalline rock.

NEVADA

J. H. Sass, F. H. Olmsted, and M. L. Sorey (USGS), H. A. Wollenberg (Lawrence Berkeley Laboratory, University of California), and A. H. Lachenbruch, R. J. Munroe, and S. P. Galanis, Jr. (USGS) (1976), completed a hydrologic study of heat flow involving the drilling of 10 test wells near two spring systems in Neveda. The thermal observations indicate that Leach Hot Springs in Grass Valley and Buffalo Hot Springs in Buffalo Valley overlie localized upflows of hot water enclosed by relatively impermeable sediments. Upward and downward water flows occurring at points a few kilometers from the spring system at Grass Valley indicate a complex system of hydrothermal circulation. High heat flows measured near Panther Canyon in the Sonoma Range were confirmed by a determination of about 5 HFU near the eastern margin of Grass Valley, about 2.5 km west-southwest of the previous determination by Sass and others (1971).

NEW MEXICO

F. W. Trainer (1975) reported that ground-water data from the southwestern part of the Jemez Mountains volcanic mass in north-central New Mexico suggest that much of the subsurface drainage from Valles caldera follows marginal faults at the western side of the Rio Grande rift zone. (The mountain mass stands astride the marginal fault zone.) Thermal springs and several cold springs and wells in San Diego Canyon, some of them near or associated with the faults, yield waters believed to be mixtures of thermal and shallow nonthermal ground water. The thermal springs, temperature observations in a well, and the presence of a small fumarolic area, all outside of the caldera rim, indicate active subsurface drainage of thermal water. This drainage contributes substantially to the chemical load of water in the Jemez River and in its alluvium, adding constituents such as As, B, Cl, F, and Li that are considered characteristic of volcanic water. In a few places, concentrations of the minor constituents have been found to exceed U.S. Public Heath Service standards for potable water.

OREGON

Heat-flow reconnaissance in southeastern Oregon

J. H. Sass, S. P. Galanis, Jr., R. J. Munroe, and T. C. Urban (1976) drilled 11 heat-flow holes (~100 m deep) and made heat-flow measurements in 5 additional existing holes (107–565 m deep) as part of a geothermal reconnaissance of the southeastern half of the Brothers fault zone in southeastern Oregon (MacLeod and others, 1975). With the exception of values obtained from two holes drilled within 2 km of Mickey Hot Springs, all values to date are within or somewhat below the range normally expected in the North American Cordillera. This result is not surprising for a region in which the preponderance of igneous rocks on the surface are 5 million years old or more. There is a suggestion of a thermal anomaly associated with the very young (~5,000 years) Diamond Craters lava field, and the thermal regime on both sides of Steens Mountain appears to be controlled to some degree by lateral and vertical movement of water.

Heat-flow data from Klamath Falls

Two holes were drilled by J. H. Sass and E. A. Sammel to depths of about 180 m in the Lower Klamath Lake Basin south of Klamath Falls, Oreg., to obtain heat-flow data and to provide estimates of the thermal conductivity of the valley fill. Twentynine thermal conductivity determinations on eight cores give a mean conductivity of 1.82 mcal/cm s °C (0.75 W/m K). Curvature in the upper 50 m of both temperature profiles indicates a decrease in surface temperature of about 1.8°C, presumably resulting from reclamation of what was previously marshland in the early part of this century. A surprisingly low heat flow of 0.3 HFU was measured at a site near the center of the basin. Seven kilometers to the east and 2 km from the Klamath Hills geothermal zone, the heat flow was 1.44 HFU, also a low value in this setting. Temperature profiles in 15 unused water wells in the area had uniform gradients ranging from 47° to 170°C/km. The corresponding lower limits of heat flow (using conductivities measured at the two heat-flow sites) range from 0.8 to 3.1 HFU. These variations in heat flow evidently are caused by temperature variations in a convecting system within the near-surface volcanic rocks and do not provide firm constraints on the nature of heat sources at depth.

Geothermal potential of Newberry Volcano

Reconnaissance geologic and geophysical studies by N. S. MacLeod and Andrew Griscom of the area around Newberry Volcano southeast of Bend, Oreg., suggested that two areas outside the caldera at the volcano's summit may be underlain by young silicic igneous bodies. About 200 basaltic cinder cones are spread over the flanks of the volcano's western side. Several basaltic cinder cones adjacent to this area have inclusions of rhyolite, and the rhyolite domes at McKay Butte in the center of the area are about 0.6 million years old. If a silicic magma body underlies this area and is responsible for the absence of basaltic vents because of a shadow effect, this part of the volcano may have a high geothermal potential. A gravity low on the northeastern flank of the volcano may also be due to a shallow mass of rhyolite. The gravity low trends northwestward from the 0.7-million-year-old rhyolite dome at China Hat, which was dated by E. H. McKee. China Hat is the westernmost of a northwest-trending group of domes that become progressively younger as they approach China Hat. Thus, if the gravity low is the result of a rhyolitic body at depth, it may be even younger than China Hat and thus of interest to geothermal exploration. Alternatively, the gravity low may be a subsurface extension of the rhyolitic vent complex that forms Pine Mountain about 10 km northeast of the low. Potassium-argon dating by McKee indicated that the Pine Mountain rhyolites are 21 million years old and of no geothermal interest.

UTAH

As part of a regional reconnaissance of young volcanism around the margins of the Colorado Plateau, P. W. Lipman and P. D. Rowley mapped little-eroded rhyolitic tuffs, domes, and flows that cover an area of about 25 km^2 in the Mineral Range of southwestern Utah within 5 km of the Roosevelt Known Geothermal Resource Area (KGRA). Most rhyolite vented near the crest of the Mineral Range and was deposited in west-draining valleys, burying essentially modern topography. Initial eruptions produced two low-vicosity flows of nonporphyritic rhyolite characterized by much high-quality obsidian of probable archeological significance. These were followed by pyroclastic eruptions of bedded air-fall pumice and nonwelded ash-flow tuff. The youngest activity produced as many as 10 viscous domes and small flows of sparsely porphyritic rhyolite.

Potassium-argon dates by H. H. Mehnert indicated that the rhyolite volcanism occurred between 0.7 and 0.5 million years ago. The rhyolite rests on dissected granite of the Mineral Range batholith, the largest intrusion in Utah, which has yielded published K-Ar ages of 10 to 15 million years. This apparent young age of the granite, in conjunction with the Pleistocene age of the rhyolite in the Mineral Range, indicates a major late Cenozoic thermal anomaly, the size and age of which are significant to the evaluation of the Roosevelt KGRA.

EASTERN UNITED STATES

W. A. Hobba, Jr., reported that many of the thermal springs in the Appalachian Mountains discharge along faults or at the intersections of two or more faults. Many of the faults are readily apparent on Landsat imagery or on side-looking radar. Some of the faults visibly extend for 113 km and give rise to both warm and cold springs. One northwest-southeast-trending fault gives rise to several warm springs in the Valley and Ridge province and to at least one large salty (4,000 mg of chloride per liter) cold spring where the fault cuts the Appalachian Plateaus province. The locations of some of these faults have been field checked and verified. Chemical analyses of 35 water samples collected from the warm springs, nearby wells, and cold springs may provide additional clues as to the source of heat and the depth of circulation of the water.

GEOTHERMAL COMPUTER DATA FILE

A computer data file (GEOTHERM) was created to permit the storage and retrieval of information relating to the location, exploration, and evaluation of geothermal resources. The computer file will allow more rapid and universal access to the growing quantity of geothermal data, both national and international.

The General Information Processing System (GIPSY), a storage and retrieval computer program developed at the University of Oklahoma, was selected to handle the geothermal data file. In order to accommodate and provide both general and specific data, the file was constructed in sections of logically related information. Initially, the file had eight sections: (1) Geothermal Field/Area; (2) Surface Sample Data; (3) Well Sample Data; (4) Gas Analysis from Wells; (5) Water Analysis from Wells; (6) Isotopic Data; (7) Space and Process Heating; and (8) Binary Systems. The file went through several revisions, and 150 records were entered to test and demonstrate the system.

Revision 8, done by J. R. Swanson, combined sections 2, 4, 5, and 6 into one section called "Chemical Analysis." Since the file was initially planned to stress the geologic and chemical aspects of geothermal fields, sections 7 and 8 were set aside for future considerations. The three subtopics of GEOTHERM Revision 8 are: (1) Geothermal Field or Area; (2) Chemical Analysis; and (3) Geothermal Well/Drillhole.

Section 1 is specifically designed to give locality, description, developments, and performance of a geothermal field or area. Its coverage is very broad and is subject to change with time. Records of this sort will be updated periodically to include recent information.

Section 2 contains information on surface or well samples of a geothermal field. Space is provided for three possible types of analyses, including water, condensate, and residual gas. One section is provided for cases in which gas and water are sampled in one collection event.

Section 3 is designed to give the locality and performance of geothermal wells or drillholes.

In most cases, the information in all these sections relates to a specific geothermal field. Additional sections can be added when they are needed.

Each section is considered one record for the file. Thus, for each field (section 1) there may be many wells (section 3), and from each well there may be many samples (section 2). The information ranges from a broad description in section 1 to specific data in section 2.

CHEMICAL RESOURCES

LITHIUM

Lithium occurrences and tectonics, Clark County, Nevada

R. G. Bohannon completed geologic mapping of the Valley of Fire region in the North Muddy Mountains of Clark County, Nevada. The mapped area includes a deposit of lithium-rich magnesite identified as a lithium resource. Much of the deformation in the North Muddy Mountains is late Tertiary in age. High-angle west-dipping normal faults apparently caused much of the tilting of strata. A low-angle fault, thought to be a gravity slide, occurs between some of the normal faults. This fault was previously thought to be part of the Cretaceous Sevier orogenic belt, but its probable Tertiary age precludes this interpretation.

Migration and accumulation of lithium in the near-surface environment

C. L. Smith studied the migration and accumulation of lithium in waters of the Western United States. Studies of Nevada hot springs (Mariner and others, 1974) indicate that lithium is removed from solution as ground water becomes more concentrated. The removal of lithium is indicated by a characteristic negative slope on a plot of the logarithm of the lithium-chloride concentration versus the logarithm of the chloride concentration. The data indicate that lithium-rich brines will not form by simple evaporative concentration of normal ground water. Hot springs geographically associated with lithium-rich brines can be identified by this method of graphical display. There are lateral variations in the lithium concentration of some playa interstitial brines that cannot be related to evaporative concentration. Analyses of both interstitial brines and enclosing sediments by A. L. Meier indicated that there may be little correlation between the lithium concentration of the interstitial brines and that of the associated sediments.

Relationship of lithium distribution to Cenozoic geology

Reconnaissance fieldwork and geochemical sampling done by J. R. Davis in selected areas of Arizona, Nevada, and California indicated that the distribution of lithium in playa sediments shows no stratigraphic correlation with present-day drainage basin area. Modification of the basin area to simulate the overflow of pluvial lakes during the Pleistocene or to simulate hydrologic underflow produced significant correlation.

Anomalous lithium concentrations in western Utah

R. K. Glanzman and A. L. Meier reported on probable areas of lithium-rich brine and clay in western Utah. Pilot Valley, near Wendover, contains near-surface brine similar in concentration and chemistry to brine from which potassium salts are presently produced at Wendover. Brine and clay in the Sevier and Black Rock desert area of west-central Utah probably contain high concentrations of lithium derived from the Upper Sevier River Valley, the Roosevelt, Thermo, Meodow, and Hatton thermal springs, and the Nevada-Utah beryllium belt (Shawe, 1966). Water samples plotted on a diagram showing potassium concentration versus lithium concentration result in three distinct environmentally segregated distributions.

Flint clay rich in lithium

H. A. Tourtelot found that shale, black shale, kaolinite-rich underclay, and flint clay in coal-bearing strata of Pennsylvanian age in western Pennsylvania commonly contain more than 100 ppm Li. The largest values, found in flint clay from Clearfield County, range from 300 to 1,400 ppm Li. The mode of occurrence of the lithium in the flint clay has not been determined. A sample containing 1,400 ppm Li contains only 22 ppm exchangeable Li. Structural substitution seems an unlikely mode of occurrence because of the generally invariant composition reported for kaolinite. Lithium may be present in flint clay in a lithium mineral formed during or after the leaching of alkali and alkaline-earth elements.

Potential new uses for lithium could create a demand crisis

According to J. D. Vine (1975a), nearly one-third of our 800,000 t of identified recoverable resources of lithium will be required for ceramics, greases, aluminum reduction, and other established uses by the year 2000. The remainder may be required for lithium batteries to power electric vehicles before that time. Additional lithium may be needed for batteries to store off-peak power, for absorption refrigeration equipment, and for primary batteries. A serious shortage of lithium could limit the development of thermonuclear power.

Potential resources of lithium may be found in brines and sedimentary rocks associated with nonmarine evaporites, geothermal brines, oilfield formation waters, and hydrothermal deposits and in volcanic ash deposits associated with lithium-rich brines (Vine, 1975b; Vine and others, 1975). Areas of anomalous lithium are widespread in the Great Basin and occur locally in other parts of the country.

Areas and environments of anomalous lithium concentrations

E. B. Tourtelot identified areas of anomalous lithium concentrations in southwestern New Mexico, Creede, Colo., and southern Nevada. Some samples from alkaline lake beds in the Gila Conglomerate (Pliocene and Pleistocene) near Buckhorn, N. Mex., contain more than 200 ppm Li. Data from other areas of southwestern New Mexico suggest that lithium was leached from country rocks by hot-spring systems and was deposited when the spring water reached the alkali lake environment. Alkaline lake waters in Nebraska and Wyoming show anomalously low lithium contents relative to total conductivity.

BENTONITE

Identification of the Clay Spur Bentonite

C. A. Wolfbauer found a lamina of quartz, feldspar, and biotite grains capping indurated organic-rich sandstone or burrowed silty shale underlying the Clay Spur Bentonite Bed in the Mowry Shale throughout eastern and central Wyoming and western South Dakota. The presence of this lamina is the only conclusive means of identifying the Clay Spur Bentonite Bed in areas outside the Black Hills and is exceptionally valuable for obtaining precise stratigraphic correlation in drill cores.

Relationship of bentonite to volcanic sources

C. A. Wolfbauer reported that Upper Cretaceous bentonites from the Hell Creek Formation in northeastern Montana have a range of green compressive strength values similar to that of Lower Cretaceous bentonites from the Mowry and Thermopolis Shales in Wyoming. Values for the Bearpaw Shale (Upper Cretaceous) are markedly higher. Because all four formations have similar ages and weathering regimes and because the Mowry, Thermopolis, and Bearpaw Shales have similar compositions and depositional environments, different source areas for the volcanic ash may be indicated—possibly the Idaho batholith for the Mowry, Thermopolis, and Hell Creek Formations and the Boulder batholith or Elkhorn volcanic area for the Bearpaw Shale.

BRINES

Chemical and isotopic data from the commercially exploited upper Quaternary continental evaporites in Searles Lake, Calif., show that both the brines and the salts have changed in composition since they were initially deposited. Phase data compiled by G. I. Smith allowed reconstruction of the crystallization path of the original desiccating lake brines. The present interstitial brines in the saline layers have compositions that differ from those that could have produced the present mineral assemblages. Downward migration of meteoric waters has apparently resulted in dilution of the original brines. This downward migration from the dry lake surface was made possible by the higher equivalent hydraulic head of the interstitial fluids in the lake relative to that of the ground water in the surrounding basin. Resulting changes in the brine compositions were in the direction required to maintain equilibrium with the existing saline minerals, and most of the change apparently occurred long before any commercial extraction of chemicals from the deposit. Within a few hundred or a few thousand years after initial deposition, significant quantities of brine also began to migrate through the seemingly impermeable muds. This process resulted in the crystallization of secondary gaylussite and pirssonite when primary calcite and aragonite crystals reacted with the migrating sodium-bearing brines. Radiocarbon ages show that many of these crystals contain "younger" (but probably not modern) carbon; textural evidence, however, shows that compaction of the muds was nearly complete before the growth of the crystals. The present deuterium content of the interstitial brines in both the muds and the salts, determined by Smith in collaboration with Irving Friedman, suggests that approximately half of the water in the original interstitial brines has been replaced by meteoric water. The concentration of valuable elements found only in the brines is thus probably about half the concentration in the orginal brine. The concentrations of elements present in both brine and minerals are nearly the same, however, because the lost components were replaced by partial solution of the crystal body.

THALLIUM

The first quantitative thallium analyses of the Phosphoria Formation in southeastern Idaho were obtained by R. A. Gulbrandsen. Values range from less than 1 to 130 ppm. Rocks in the vanadiferous zone (3.4 m thick) in Bloomington Canyon southwest of Montpelier average 40 ppm Tl, much higher than most known thallium occurrences. If thallium can be recovered during the mining and processing of vanadium and phosphate ores, reported thallium reserves (Robinson, 1973, p. 631) will be greatly increased.

FLUORITE

Fluorite of diagenetic origin was identified in zeolitic tuffs in a lacustrine deposit several kilometers west of Eastgate in Churchill County, Nevada. Studies by R. A. Sheppard and A. J. Gude III indicated that the fluorite occurs in a 10-m-thick unit of tuff and tuffaceous mudstone in the Monarch Mill Formation (Pliocene) of Axelrod (1956). The fluorite-bearing strata crop out for about 3.5 km along the strike of the beds. Although the fluorite content ranges from less than 1 percent to about 13 percent, a 4-m-thick mordenite-rich tuff in the upper part of the sampled section has an average fluorite content of about 8 percent. The fluorite in the zeolitic tuff occurs as disseminated grains less than 1 μm in size. This low-grade deposit of fluorite is sizable, but subsurface data are needed to determine the extent and grade of the deposit. The Eastgate deposit is similar in grade, occurrence, and origin to one described by Sheppard and Gude (1969) in lacustrine rocks near Rome, Oreg.

REGIONAL GEOLOGIC INVESTIGATIONS

NEW ENGLAND

PLEISTOCENE

Surficial geology synthesis, Quinebaug River basin, Connecticut

Compilation and regional synthesis of the surficial geology of the Quinebaug River basin of eastern Connecticut (index map, loc. 1) were begun by B. D. Stone. The detailed Quaternary geology of seven photoreduced 1:24,000-scale maps in the Geologic Quadrangle and open-file series was transferred to the new State 1:125,000 topographic base. Glacial melt-water deposits were grouped into deposits of four large glacial lakes that occupied major lowlands during deglaciation as well as upland fluvial and small ice-marginal lakes. At the intermediate scale (1:125,000), individual ice-front positions, inferred from ice-contact heads of outwash sequences (Jahns, 1941; Koteff, 1974), are shown within the major lake basins and marginal to upland deposits. A derivative textural map, shown by overprint symbols, distinguishes gravel and sand, sand, and fine and superposed gravel-over-sand deltaic deposits. The detailed intermediate-scale surficial geologic map clearly illustrates ice-retreat patterns and chronology within major depositional basins and implies local and regional correlations across drainage divides.

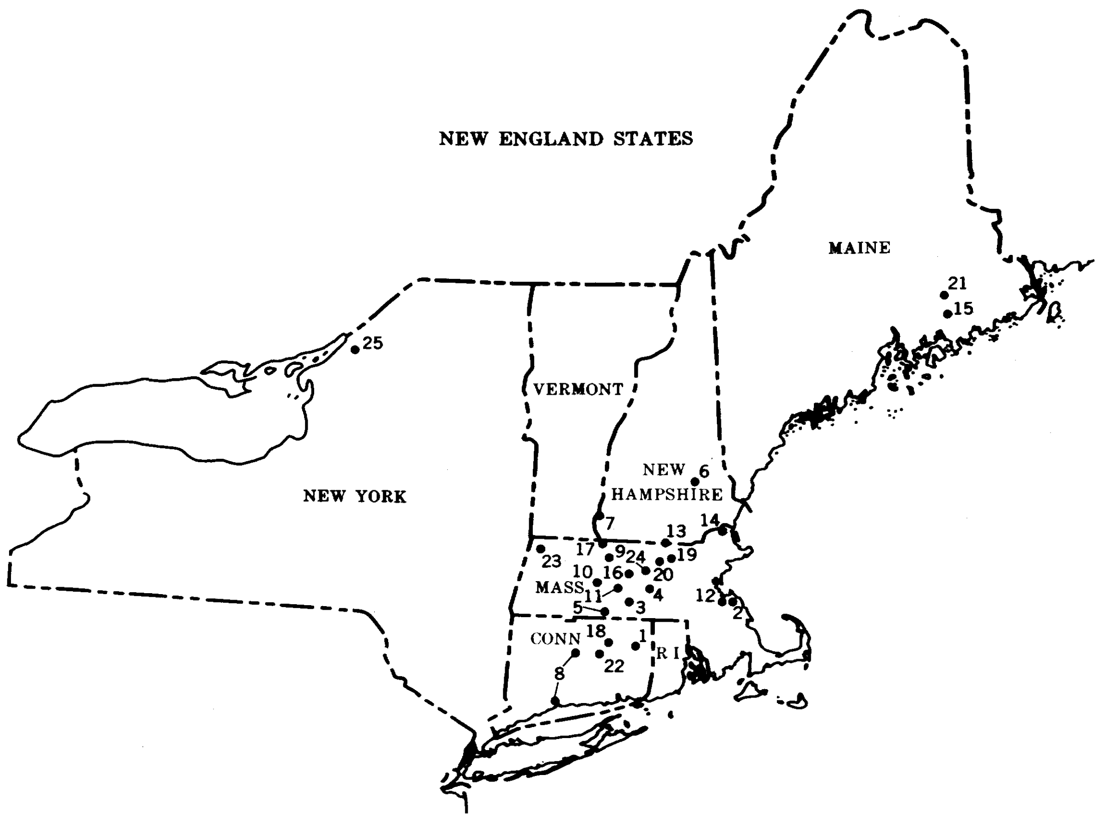
Two tills in the Cohasset quadrangle, Massachusetts

A field conference, led by A. V. deForest and including Carl Koteff, M. H. Pease, Jr., B. D. Stone, J. R. Stone, and D. A. Nellis (USGS), F. G. Adinolfi (University of Massachusetts), and D. F. Vlash (Tufts University), examined a pit exposing two tills on the eastern flank of Prospect Hill in Wampatuck State Park, located in the Cohasset quadrangle of Massachusetts (loc. 2). The upper (upper Wisconsinan) sandy gray till, which contains angular cobbles and boulders, overlies, in a complex relationship, a compact olive brown lower till. The lower part of the upper till contains grayer and less oxidized lower till material, which appears to have been sheared up into the upper till.

The upper till also overlies a very compact sand and gravel unit, which itself appears to lie against and stratigraphically over the lower till. Elsewhere in the same exposure, the lower till exhibits a normal oxidation profile of about 6 m of brown till grading downward into gray till. The two tills and similar stratigraphic and structural relationships have been seen elsewhere in New England (Schafer and Hartshorn, 1965; Pessl and Schafer, 1968; Koteff, 1970). However, the presence of a sand and gravel unit stratigraphically between the two tills is very rare. It is possible that this water-laid unit may be a meltwater deposit laid down during the retreat of the ice sheet that produced the lower till.

Two tills in the East Brookfield quadrangle, Massachusetts

J. S. Pomeroy found two tills—a lower and an upper—that can be distinguished stratigraphically (Pessl, 1971) and that possibly have different ages in the East Brookfield quadrangle of Massachusetts (loc. 3). With one possible exception, however, the tills were never observed in contact with each other. The lower till is a predominantly olive brown to dark grayish brown to olive gray, silty to clayey, dense, hard, compact lodgement till containing variable amounts of cobbles and boulders. Most material, locally called hardpan, exhibits low permeability and is inferred to make up drumlin cores. The upper till is represented by two phases—a fairly compact lodgement facies locally overlain by loose ablation facies. The upper till is a poorly sorted, nonoxidized, gray to tan mixture of sand, silt, pebbles, cobbles, boulders, and clay. The more compact phase can be shoveled with some difficulty but breaks down readily in the hand, and its matrix is predominantly silty rather than sandy. The loose phase is easily shoveled and frequently mistaken for poorly sorted stratified drift. This type of till contains more sand than silt and is very stony, having clasts of all sizes. In the East Brookfield quadrangle, the lower till and the compact phase of the upper till appear to have been deposited by separate ice sheets that flowed south-southeast.



Regional outwash correlations, Worcester area of Massachusetts

Detailed mapping in the Worcester North quadrangle of Massachusetts (loc. 4) by B. D. Stone revealed that major upland glaciofluvial valley trains in the Tatnuck and Beaver Brook Valleys are graded to glaciofluvial terraces along the Blackstone River valley in the Worcester South quadrangle. In the northern half of the Worcester North quadrangle, the locations of local ice-contact deltaic deposits near Unionville and West Boylston and major ice-marginal deltaic deposits of glacial Lake Nashua in West Boylston indicate a local northwest orientation of the ice front during retreat. Lobation of the ice front in the Nashua River lowland is inferred.

Ice-retreat history of the Monson and Palmer quadrangles, Massachusetts and Connecticut

According to J. D. Peper, the retreat of the late Wisconsinan ice front was generally from southeast to northwest in the Monson and Palmer quadrangles of Massachusetts and Connecticut (loc. 5), as indicated by patterns of outwash deposition. Ice-marginal glacial Lake Quaboag initially drained southward to a spillway at 187 m near South Monson, Mass. With northward ice retreat, the lake expanded and drained to the west at elevations of 184 m and then 169 m. Coarse gravel was trapped in kame deltas and fluvial ice-contact deposits at elevations of 204, 186, and 174 m north of Palmer, Mass. The Quaboag valley and its north-flowing tributaries southwest of Palmer were partially filled with lacustrine sand. When the ice front had retreated northwest of Mount Dumplin and Kings Mountain in the Palmer quadrangle, Lake Quaboag became segmented, and small low-level ponds drained over different local spillways in the Palmer quadrangle. Further ice-front retreat northwest of Baptist Hill opened melt-water drainage to spillways west of the quadrangle.

Topographic control of retreatal positions

Surficial mapping by Carl Koteff (USGS) and Thomas Pike (Queens College, New York) in the Suncook River valley of central New Hampshire (loc. 6) indicated at least four major retreatal positions for the last ice sheet that overran New England. The Suncook valley trends northeast from the south-trending Merrimack River valley, and this northeast trend strongly influenced the local pattern of ice retreat. The regional ice trend during advance and retreat here was south-southeast. In the Suncook valley, however, ice appears to have retreated more in a northerly to slightly northeast direction. Strong local topographic features have been known to affect ice directions elsewhere, but here the process has been defined extremely well by the chronologic positions of at least four morphologic sequences.

Pleistocene deposits, Keene quadrangle, New Hampshire and Vermont

Stratified drift deposits in the Martin Brook-South Branch valley and the Partridge Brook valley in the Keene quadrangle of New Hampshire and Vermont (loc. 7) were mapped by W. H. Langer. The distribution of these deposits indicates that the Wisconsinan ice sheet retreated from these drainages in a systematic manner characterized by stagnation-zone retreat. Both valleys drain north, and, as the ice melted from each valley head, ice-marginal lakes formed in the southern area of each valley. Melt water drained southward through the lowest available outlet, and deltaic sediments were deposited into the lake basins. As the ice continued its northward retreat, new lower level spillways opened, the lake level lowered, and sediment was deposited into lakes of successively lower levels. Internal structures, altitudes of the deposits (decreasing from south to north), and local topography have been used to determine the chronologic ice-retreatal history of the area.

URBAN AREA STUDIES

Members of the Connecticut Valley Urban Area Program, directed by Fred Pessl, Jr., prepared a new type of unconsolidated-materials map for the Windsor Locks, Avon, Glastonbury, Manchester, Hartford South, and New Haven-Woodmont quadrangles of Connecticut (loc. 8). Previous maps showed only those materials that occur in the upper 1 to 2 m below the soil layer. The new maps present additional information on the nature and distribution of materials that occur at depth beneath the surface map unit. This information is provided in the form of subsurface areal map units and by logs of selected water wells. With these maps, information on unconsolidated materials can be applied to problems of environmental concern and resource management more accurately and in more detail.

STRATIGRAPHY

Similarity of Ammonoosuc Volcanics to Keene dome rocks

Exploration of the detailed stratigraphy within the Ammonoosuc Volcanics on the western flank of the Monson Gneiss of Massachusetts (loc. 9) by Peter Robinson (University of Massachusetts) and students showed it to have a sequence of lithic types similar to the sequence known on the Keene dome of Vermont, including a basal unit of mafic volcanic rocks with pillow lavas, a discontinuous middle unit of quartz-garnet-grunerite granulite, and an upper unit of predominantly felsic volcanic rocks. The grunerite-bearing granulite is interpreted as metamorphosed ferruginous chert. Its widespread occurrence precisely at the contact between two contrasting volcanic sequences must have geochemical and paleogeographic significance. In the basal unit, in addition to characteristic anthophyllite- and cummingtonite-bearing amphibolites and gneisses, previously overlooked lenses of deeply weathered hornblende-diopside marble have been located.

Stratigraphy of the Pelham dome, Shutesbury and Belchertown quadrangles, Massachusetts

Peter Robinson (University of Massachusetts) and his students, mapping in the southern part of the Pelham dome in Massachusetts (loc. 10), found the general stratigraphy of probable upper Precambrian rocks from oldest to youngest to be as follows:

- Dry Hill Granite Gneiss (Ashenden, 1973) with related Pelham Granite and other gneisses. Zircon from the Dry Hill hornblende member gave an age of 575 million years (Naylor and others, 1973).
- So-called "Mount Mineral Formation," kyanite-garnet-mica schist, amphibolite, and muscovite quartzite. Some specimens of mica schist contain relict sillimanite, orthoclase, and pyrope-rich garnet (Robinson, Tracy, and Ashwal, 1975), indicative of a high-grade pre-Acadian metamorphism. The base of this unit includes four lenses of altered harzburgite, consisting of relict olivine, serpentine, talc, and chlorite, cut by veins of asbestiform anthophyllite. The historic Pelham asbestos mine is located in two of these lenses.
- So-called "Four Mile Gneiss," consisting of a variety of quartz-plagioclase gneisses—some with hornblende, others with muscovite—that overlie the "Mount Mineral Formation" and underlie the Middle Ordovician cover. For the most part, these are believed to be metamorphosed volcanic rocks, but, according to Robinson, particularly coarse, massive rocks in the extreme southwestern part of the dome resemble the coarse plutonic rocks known in the nearby Glastonbury dome of Connecticut and Massachusetts.

Stratigraphy, east-central Massachusetts

According to M. T. Field (University of Massachusetts), the stratigraphy of most of the Ware area of Massachusetts (loc. 11) consists largely of mica schist of the Partridge Formation (Middle Ordovician) and the Littleton Formation (Lower Devonian), locally separated by calc-silicate rocks assigned to the Fitch Formation (Middle Silurian). At the western edge of the Ware area, this sequence has a basal contact directly on the Monson Gneiss (Lower and Middle Ordovician) of the Bronson Hill anticlinorium. In the eastern part of the Ware area and in the North Brookfield area, the Partridge is overlain by the Paxton Quartz Schist (Emerson, 1917). Field found that these rocks are predominantly gray biotite granulite with calc-silicate, and he believed that they are lithically similar to the rocks of the Oakdale Quartzite of east-central Massachusetts, the Hebron Formation of eastern Connecticut, and the Madrid and Vassalboro Formations (Silurian and (or) Devonian) of Maine. A basal member consisting of pyrite-sillimanite-orthoclase schist with colorless magnesian biotite-cordierite and rutile appeared to him to be lithically similar to the Small Falls Formation (Silurian?) of Maine.

According to Field, the contact between the sequence in the Ware area and the Monson Gneiss is an unconformity that has been traced continuously into the Orange area of Massachusetts. Peter Robinson (University of Massachusetts) found evidence to support the proposed unconformity in the Orange area, where a thin lens of quartz-pebble conglomerate having a calcareous matrix has been located at the contact between the Monson Gneiss and the Ammonoosuc Volcanics.

Field's interpretation of the stratigraphy in east-central Massachusetts conflicts sharply with the interpretation of investigators working in the Brimfield area along strike to the south into Connecticut, who considered these rocks to be a northwest-dipping, largely homoclinal sequence. Peper, Pease, and Seiders (1975) divided this thick geosynclinal sequence into four formations from oldest to youngest (Southbridge, Bigelow Brook, Hamilton Reservoir, and Mount Pisgah); they did not concur with Field's correlation that these rocks are equivalent to the Bronson Hill anticlinorium sequence repeated by folding, but they did agree that the age may range from Ordovician to Devonian.

The Paxton Quartz Schist in this area, moreover, is on strike with metavolcaniclastic rocks in Connecticut that have been mapped as the upper gneiss member of the Hamilton Reservoir Formation, stratigraphically well above the type Paxton that was renamed the Southbridge Formation by M. H. Pease, Jr. (1972). The schist that lies below the "Paxton" of Field is on strike with the middle schist member of the Hamilton Reservoir Formation, according to Peper, Pease, and Seiders (1975).

Description of Precambrian-Carboniferous(?) unconformable relationship in the Weymouth quadrangle, Massachusetts

D. A. Nellis observed the contact between the Dedham Granodiorite and stratified clastic and volcaniclastic rocks at two different sites in the Weymouth quadrangle of Massachusetts (loc. 12). According to Nellis, the contact is clearly unconformable; it is not an intrusive contact. Clasts of granodiorite (Dedham) are found in conglomerate resting on the Dedham, and stratification in the overlying rocks is parallel to the contact. At the western side of the two exposures, the overlying strata have been assigned to the Weymouth Formation (Lower Cambrian) (Emerson, 1917). Thus, the unconformable relationship supports the Precambrian radiometric age assigned to the Dedham by Zartman and Naylor (1972).

Refinements of stratigraphy, Nashua River area

The Nashua River Basin area of Massachusetts and New Hampshire (loc. 13) is underlain by metamorphic rocks that, according to E. L. Boudette, range in age from Precambrian(?) to Silurian and Devonian. The younger rocks are intruded by at least three plutonic series of probable Early to Middle Devonian age. It is probable that the Precambrian(?) is intruded by plutonic rocks as well. Regional faults cut the rocks into segments (I–IV, southeast to northwest) maintaining the northeast-trending tectonic grain. Precambrian(?) flysch, the Tadmuck Brook Schist of Bell and Alvord (1976), comprises the northwestern edge of segment I. Segment I is succeeded to the northwest by segment II, comprised of rocks of the Ayer crystalline complex of Gore (1976) and biotite schist. Segment II is succeeded to the northwest by orthoquartzite, flysch, and cyclic turbidites of the Merrimack Group (Emerson, 1917) continuous with units 1–4 of Peck (1975, 1976) in the adjacent Clinton quadrangle of Massachusetts, which extend northeasterly through the Naribex region. Segment IV on the northwest is comprised of flysch and aquagene volcanic rocks of the Merrimack Group continuous with unit 5 of Peck. The rocks of segment IV rise in metamorphic grade to the west and gradually pass into injection gneiss and migmatite, which bound the northwesternmost strike belt of Devonian plutonic rocks on the southeast.

Hebron Formation, Worcester North quadrangle, Massachusetts

J. C. Hepburn indicated that the western and southwestern portions of the Worcester North quadrangle of Massachusetts (loc. 4) are underlain by a unit lithologically similar to and likely continuous with the Hebron Formation in the Eastford quadrangle of Connecticut and the Webster quadrangle of Connecticut and Massachusetts, as mapped by Pease (1972) and P. J. Barosh (personal commun., 1975), respectively. This unit consists of thinly interbedded quartz-feldspar-biotite and biotite-quartz-feldspar metasiltstone and calc-silicate-bearing calcareous metasiltstone. Discontinuous lenses of rusty-weathering dark-gray garnetiferous phyllite or mica schist are present within the unit and have a maximum thickness of 75 m. The Hebron grades westward into a gray muscovite-quartz-sillimanite-almandine schist having abundant pegmatite north and east of Holden Reservoir in the west-central portion of the quadrangle. According to M. H. Pease, Jr., this unit is probably correlative with the Bigelow Brook Formation of Peper, Pease, and Seiders (1975).

Lithologic comparison of metamorphic rocks, northeastern Massachusetts

A. F. Shride reported that feldspathic gneisses, coarse- to fine-grained amphibolites, and fine-grained metasedimentary rocks occur immediately south of the Clinton-Newbury fault in the Newburyport West quadrangle of Massachusetts (loc. 14). These rocks are similar in metamorphic grade and occurrence to the Boxford Formation (new Member of the Nashoba Formation) and the Fish Brook Gneiss, which occur in the Georgetown and South Groveland quadrangles immediately to the south and southwest, and to parts of the Nashoba Formation, which occurs more widely still farther to the southwest. To date, however, there is little detailed petrography or sequence to hint that metamorphic rocks of the Newburyport West quadrangle can be specifically correlated with the metamorphic terranes of contiguous areas.

Stratigraphic correlation between Massachusetts and Maine

Field conferences held in southeastern Maine and northeastern Massachusetts by E. L. Boudette, P. J. Barosh, and M. H. Pease, Jr. (USGS), and A. M. Hussey II (Bowdoin College) confirmed an earlier tentative correlation made by J. H. Peck (USGS) of the Eliot Formation in Maine with units 3 and 4 in the Clinton quadrangle of Massachusetts. The Berwick Formation above and to the west correlates with the Oakdale Quartzite and the basal Paxton Quartz Schist (Emerson, 1917), which lie to the west of units 3 and 4. Hussey considered unit 2, which underlies unit 3, as equivalent to the basal Eliot Formation. The quartzite of unit 1 in the Clinton quadrangle apparently correlates with part of the Kittery Quartzite, which lies east of the Eliot. The correlation is thus based on a sequence of five stratigraphic units in the same order in both areas. According to Barosh, both sequences top to the west, and repetition is probably caused by either a large fault dropping the eastern side down or a tight syncline and anticline passing through the eastern part of the Pepperell quadrangle of Massachusetts and New Hampshire. The Rye Formation forms the base of Hussey's sequence in Maine. It consists of an upper metavolcaniclastic rock member and a lower metasedimentary rock member, but neither top nor bottom has been observed where it is exposed in coastal Maine. The Reubens Hill metavolcanic rocks structurally underlie unit 1 in the Clinton quadrangle, and roof pendants in plutonic rocks that underlie the Reubens Hill are metasedimentary. Barosh speculated that these two rock types might be equivalent to the Rye Formation. Boudette would tentatively correlate the Rye Formation with the Nashoba Formation on the basis of lithologic similarities between exposures of the Rye on the Maine coast and exposures of the Nashoba in Massachusetts. Possibly the three units represent in part the same stratigraphic position, but correlation of the Rye with the Nashoba crosses a major structural discontinuity, the Clinton-Newbury fault zone.

Stratigraphy of the Ellsworth structural block, eastern coastal Maine

A large (350×60 km) structural block (loc. 15) having a distinctive geologic history dating back to the early Paleozoic was recognized by D. B. Stewart (USGS) and D. G. Brookins (University of New Mexico). The block, which makes up eastern coastal Maine, extends northeasterly from the western Penobscot Bay to the U.S.-Canadian boundary between Calais and Eastport and continues into southern New Brunswick. The oldest exposed rock within the U.S. portion of the block is a small horst of Precambrian metamorphic rocks exposed in the town of Islesboro, near the western edge of the block. Over most of the block the Ellsworth Schist is the oldest exposed bedrock. The Ellsworth Schist and its equivalents consist of feldspathic sediments, mafic and silicic flows, fragmental volcanic rocks, minor impure quartzite and carbonate beds, and very rare hypabyssal intrusive rocks. Ellsworth Schist from the vicinity of Ellsworth and Blue Hill, Maine, was found by Rb-Sr whole-rock geochronology to be 510 ± 10 million years old and hence Late Cambrian or Ordovician(?) in age. The Ellsworth Schist was metamorphosed mostly to chlorite grade and became highly foliated, but it was only locally tightly folded prior to Early Silurian (C_3) time. Pebbles and cobbles of metamorphosed Ellsworth Schist are found in the fossiliferous basal conglomerates that overlie the schist at several localities in Maine. The Ellsworth Schist is basement for the Silurian and Devonian volcanic rocks of the Maine coastal volcanic belt and comprises a structural block that differs in lithology, structure, and geologic history from the structural blocks contiguous on the west that are separated from it by large regional faults with right-lateral strike-slip components.

Another block with similar lithology, structure, and geologic history is exposed north of the Chedabucto fault in the Antigonish Mountains of central Nova Scotia. Rocks of the Browns Mountain Group are here correlated with the Ellsworth Schist on the basis of comparable lithology and stratigraphy, described by Benson (1974) and dated isotopically by Cormier (1974). These rocks are also overlain by Silurian and Devonian volcanic rocks comparable to those on the Ellsworth structural block. It is postulated that this particular Nova Scotian terrane is a structural block equivalent to the Ellsworth structural block. These blocks could have originated close to each other and subsequently been widely separated by major faults, or they could represent segments of a much more extensive linear geologic province that is now disrupted.

STRUCTURE

Crest of central Massachusetts foliation arch located

The crest of the central Massachusetts arch, described in a report on the Quabbin Aqueduct Tunnel by Fahlquist (1935) and in an earlier report by Emerson (1917), was identified by Robert Tucker (University of Massachusetts) in the southern part of the Barre quadrangle of Massachusetts (loc. 16). Preliminary studies of the foliation arch suggest that it trends N. 20° E., plunges about 1° NNE, and deforms mineral lineation believed to have formed in the third of three phases of folding synchronous with the growth of the Bronson Hill anticlinorium. East of this arch, according to Tucker, east dips predominate all the way to the vicinity of Worcester.

Structural geology of Ware, Massachusetts

The Ware area of Massachusetts (loc. 11), mapped by M. T. Field (University of Massachusetts), is dominated by a series of highly attenuated anticlines and synclines believed to have formed in the first of three deformations synchronous with development of major west-directed nappes in the adjacent Bronson Hill anticlinorium. One major fold hinge has been located to date. The present gentle to steep westward dip of the bedding in the entire area and of the axial surfaces of the attenuated folds is believed to be due to later eastward overturning of the eastern limb of the Bronson Hill anticlinorium.

This interpretation is in direct conflict with a structurally simpler, stratigraphically more complex interpretation proposed by Peper, Pease, and Seiders (1975) for the area along strike to the south. These investigators mapped a largely homoclinal sequence isolated in a fault-bounded, fault-imbricated wedge in Connecticut and southern Massachusetts that extends northward to include the Ware area. The boundary of this wedge with the Monson Gneiss of the Bronson Hill anticlinorium sequence is the Bonemill Brook fault in Connecticut. Further north, the boundary is more complex, formed by several splays from the Bonemill Brook fault.

Deep-seated Acadian faulting

J. D. Peper reported that four isoclinal folds, overturned to the southeast, extend northeastward from the Monson quadrangle of Massachusetts into the eastern third of the Palmer quadrangle of Massachusetts (loc. 5). Rocks of the Mount Pisgah Formation form the cores of synclines, and rocks of the Hamilton Reservoir Formation form the cores of anticlines. The folds plunge generally northward and are truncated southward by a fault system along the eastern edge of the Monson Gneiss. The three easternmost folds are breached successively northward by semiconcordant bodies of foliated diorite, porphyritic quartz monzonite, and granite. The fault system, which is characterized by zones of cataclastic rock, appears to extend northward and is believed to separate the Bronson Hill anticlinorium sequence on the west that was undergoing erosion during the Taconic orogeny from the Merrimack synclinorium sequence on the east that was receiving sedimentation during the Taconic. The system was probably active throughout the Acadian orogeny. Zones of closely spaced fractures, associated with deep-seated faulting of Acadian age and younger, are most abundant east of the Monson Gneiss in the Monson and Palmer quadrangles.

Postmetamorphic faults in proposed Northfield-Quabbin tunnel area

A series of north- to northeast-trending postmetamorphic faults (loc. 17) related to the Bear's Den fault was discovered in part by D. D. Ashenden (University of Massachusetts) during mapping for the proposed Northfield-Quabbin tunnel in Massachusetts and is being investigated. It is not clear whether these faults are related to late Paleozoic retrograde metamorphism or to the Mesozoic of the Connecticut valley.

Imbricate thrusting between two major thrusts, South Coventry quadrangle, Connecticut

A west-trending belt of imbricate thrust sheets broken by high-angle tear faults that lies above the Bigelow Pond fault and south of the trace of the Kinney Pond fault (Peper, Pease, and Seiders, 1975) was mapped by R. J. Fahey and M. H. Pease, Jr., across the center of the South Coventry quadrangle of Connecticut (loc. 18). The Bigelow Pond fault and the Kinney Pond fault both dip gently northward and trend westward in the western part of the South Coventry quadrangle to abut against the north-trending Bonemill Brook fault, a major fault that separates rocks of the Merrimack synclinorium from rocks correlated with the Bronson Hill anticlinorium (Billings, 1956).

Strata in this belt, which have been broken into numerous disoriented structural blocks, are mostly assigned to the Bigelow Brook Formation. West of the Willimantic River, however, rocks of the younger Hamilton Reservoir Formation are juxtaposed with blocks of the Bigelow Brook.

Harvard Conglomerate Lentil of Worcester Formation, Pin Hill, Massachusetts—a fault sliver

The contacts of the Harvard Conglomerate Lentil of the Worcester Formation with the surrounding plutonic rocks at the type locality of Pin Hill, Massachusetts (loc. 19), were interpreted as intrusive by Emerson (1917), Jahns (1952), and Hansen (1956) and as an unconformity by Grew (1973). Recent mapping by R. Z. Gore revealed that a narrow zone of cataclastic rocks and extensive silicification separates the Harvard from the plutonic rocks on the eastern side of Pin Hill. The conglomerate is also separated from the adjoining plutonic rocks on the western side of Pin Hill by a fault (Gore, 1976). These faults are splays of the major Clinton-Newbury fault zone.

The Harvard therefore cannot be shown to be unconformable upon the older rock units. In addition, it cannot be shown that the Harvard is intruded by rocks of the Ayer Granite. Thus, the clastic rocks at Pin Hill cannot be used to support any hypothesis for regional correlation. Their age remains to be established, although E. L. Boudette contends that they are Silurian.

Clinton-Newbury fault zone in Harvard and Littleton, Massachusetts

R. Z. Gore reported that the Clinton-Newbury fault zone of Massachusetts (loc. 19) shows considerable variation in width and character. In the vicinity of Harvard Center, the zone is between 3,000 and 5,000 m wide and is characterized by mylonite gneiss and narrow zones of mylonite.

About 3 km northeast of Harvard Center, the fault zone narrows to less than 250 m. Almost continuous exposures across this narrow part of the fault zone show a complete gradation from massive granite to strongly laminated mylonite. The zone widens again, so that in Littleton, 3.8 km further northeast, it is over 650 m wide and is dominated by mylonite gneiss, blastomylonite, and mylonite. According to E. L. Boudette, compound dislocations of the fault involve (at least) initial southeast-over-northwest thrust transport (present geometric context) and then clockwise rotation (viewed northeast in section), followed by right-lateral strike-slip movement.

Northward extension of the Wekepeke fault system

The Wekepeke fault and unnamed faults mapped by J. H. Peck (USGS) in the Clinton quadrangle of Massachusetts (loc. 20) were traced northeastward by S. L. Russell (USGS) and R. W. Allmendinger (Stanford University) in the Shirley quadrangle of Massachusetts, R. Z. Gore (USGS) in the Ayer quadrangle of Massachusetts, and G. R. Robinson, Jr. (Harvard University), in the Pepperell quadrangle of Massachusetts and New Hampshire. According to E. L. Boudette's regional interpretation, the Wekepeke fault splays into major strands, the Catacoonamug and Beaver Brook faults, which bound minor parallel imbricate reverse faults dipping northwesterly; the unnamed faults mapped by Peck to the east of the Wekepeke apparently coalesce into a single presently unnamed fault, which separates rocks of the Merrimack Group from those of the Ayer Granite. Little is presently known about the geometry and history of the unnamed fault, but the Catacoonamug and Beaver Brook are interpreted to be characterized by compound dislocations on the basis of observations of minor deformational structures and the juxtaposition of contrasting metamorphic zones. These faults were apparently initiated by northwest-over-southeast thrust transport with concomitant, eastward-stepping, right-lateral en echelon imbrication, followed by counterclockwise rotation (viewed northeast in section).

Right-lateral Paleozoic faults

Maine's Norumbega fault (Stewart and Wones, 1974) (loc. 21) was determined by D. R. Wones to have right-lateral strike-slip motion of at least 25 km. Pre-Ordovician gneisses and schists lie on the southeastern side of the fault in the Bucksport quadrangle, and the same units are found on the northwestern side of the fault 25 km to the northeast in the Great Pond quadrangle. Similar displacements have been recognized for the granite of Lead Mountain and may also be present in the Carboniferous rocks of New Brunswick. The fault zone is marked by well-developed mylonite in the gneisses and pervasive cleavage developed in the metsedimentary rocks of Paleozoic age.

INTRUSIVE ROCKS

Intrusive rocks of the Ware and North Brookfield area

According to M. T. Field (University of Massachusetts), plutonic rocks of the Ware area of Massachusetts (loc. 11), all of which are more or less affected by regional metamorphism, include the concordant biotite-hornblende-bearing Hardwick Granite, the semiconcordant to discordant biotite-garnet gneiss of Ragged Hill, and minor bodies of pyroxene diorite, olivine gabbro, and olivine phlogopite hornblendite. The Coys Hill Granite sheets appear to be confined to the Littleton Formation and have the same lithic character and tectonic significance as the Kinsman Quartz Monzonite of New Hampshire.

Intrusive rocks in the Nashua River Basin

In the Nashua River Basin of Massachusetts and New Hampshire (loc. 13), R. Z. Gore recognized three major facies in the Ayer Granite crystalline complex: The so-called "Devens Gneiss," the "Chelmsford Granite," and the "Clinton Quartz Monzonite." All three facies are intruded by late pegmatite bodies and lamprophyre dikes. G. R. Robinson, Jr. (Harvard University), defined a major diorite-granite complex in the Pepperell quadrangle of Massachusetts and New Hampshire that continues on regional strike an unknown distance to the northeast. Four facies are mapped in this unnamed complex: amphibole diorite, biotite diorite, biotite granodiorite, and leucogranite. Plutonic rocks equivalent to the Milford Granite of New Hampshire (Fitchburg plutonics of Emerson (1917)) are found in a third strike belt northwest of the other plutonic units. The migmatite and injection gneiss in the zone gradational between rocks of the Berwick Formation and the Milford Granite are apparently equivalent to the "Massabesic units" of New Hampshire. The Milford-type granite is thought by Gore to result from anatexis of the country rock.

Glastonbury Gneiss body, Massachusetts and Connecticut

G. W. Leo (USGS) made field and petrologic studies of the Glastonbury Gneiss body (Leo, 1974; Leo and others, 1976), an elongate Oliverian-type dome trending along the axis of the Bronson Hill anticlinorium from southern Massachusetts to central Connecticut (loc. 22). He suggested that the northern silica-rich and potash-poor part of the gneiss was very likely derived by partial melting and crystal-mush emplacement of the underlying Monson Gneiss and older volcaniclastic units. Gneiss in the southern part of the body, by contrast, has a more normal calc-alkaline composition and exhibits progressive differentiation, all of which suggests a separate intrusion. The complex textures, variable composition, and definitely intrusive contacts of the northern gneiss and the heterogeneous nature of the southern gneiss distinguish the Glastonbury from more typical Oliverian domes (Naylor, 1969), in which potash-poor, layered, and unmobilized gneisses of volcaniclastic origin are intruded by more normal homogeneous calc-alkaline plutons.

Instrumental neutron-activation analyses done by L. J. Schwarz and J. J. Rowe (USGS) of trace elements in the Glastonbury rocks showed progressive increases in Rb, Ba, Cs, and Th from the Monson Gneiss to the northern Glastonbury to the southern Glastonbury. Rare-earth patterns for all the rocks showed relative enrichment in light rare-earth elements and depletion in heavy rare-earth elements; the Glastonbury Gneiss showed negative europium anomalies, whereas the Monson Gneiss showed no anomaly. These data are compatible with, though not uniquely diagnostic for, an anatectic origin of the northern gneiss.

Results of whole-rock Rb-Sr dating of the Glastonbury done by D. G. Brookins (University of New Mexico) were somewhat ambiguous but did suggest that the northern gneiss may be older than the southern. A preliminary composite whole-rock isochron for both northern and southern gneisses yielded an apparent age of 440±20 million years. Additional age determinations are underway. The $^{87}Sr/^{86}Sr$ value was 0.707, the same as that for the Monson Gneiss, and indicated a crustal origin for the Glastonbury.

METAMORPHISM

Implication of kyanite-bearing schists, northwestern Connecticut

Kyanite-bearing assemblages were found by E-an Zen along the Housatonic River in Connecticut in the Walloomsac Formation (Ordovician), metamorphosed during the Acadian event. The rock now contains the assemblage kyanite-staurolite-garnet-biotite-muscovite-plagioclase-ilmenite-quartz (plus accessories). The reaction leading to the assemblage appears to be:

staurolite + chlorite + muscovite
= biotite + kyanite + quartz + H_2O.

The outcrop is about 2 km northwest of Canaan Mountain (loc. 23) across the wide flood plain of the Housatonic River; at Canaan Mountain, the garnet-sillimanite-muscovite-assemblage is long known. Thus, the trace of the sillimanite-kyanite univariant boundary projects to the flood plain. The pressure of metamorphism here must have been at least that of the triple point of the aluminum silicates. This pressure is 5.5 kbar, according to Richardson, Gilbert, and Bell (1969), which corresponds to about 18 km of rock of density 3 (more if the rock was less dense), or 3.8 kbar, according to Holdaway (1971), which corresponds to about 14 km of rock of density 3. Yet about 40 km to the west-northwest, on the Hudson River, is Becraft Mountain, where the overburden during Acadian metamorphism could not have exceeded about 1 km. Thus, a load gradient of about 1 in 3 exists in a reconstruction of the metamorphic terrane; the actual gradient may have been much steeper because the 1-km isopach could have been considerably farther southeast. Was this tilting regional, or was it, as seems more probable, due to differential uplift of limited blocks, possibly during the Triassic block-faulting episode?

Progressive metamorphism of slightly calcic schists

E-an Zen made a systematic study of the pelitic and psammitic schists of southwestern Massachusetts and adjacent Connecticut and New York that span the metamorphic grades from below the chloritoid zone to the kyanite-staurolite zone. This effort has been greatly aided by the conceptual framework of an eight-phase multisystem consisting of the pseudoinvariant points staurolite, grossularitic almandine-rich garnet, chloritoid, chlorite, biotite, muscovite, epidote, and plagioclase. Quartz is in excess. Rocks having unusual compositions, such as the highly calcareous hornblendic rocks, cummingtonite-bearing rocks, or paragonite-bearing rocks, cannot be handled in this framework but can be included by extending it. Balanced reactions using the chemical compositions determined by wet analyses and microprobe data can be written and a unique multisystem net constructed. Comparisons of predicted assemblages and observed assemblages allow the conclusion that the pseudoinvariants chloritoid, epidote, and biotite are realized. The observed assemblages can then be explained as a result of progressive metamorphism through this petrogenetic grid. True isograds, for which specific reactions can be written, can be identified and differentiated from the "zone markers," which are strictly petrographic observations of the appearance-disappearance of given minerals, but cannot be attributed to specific reactions. The controversial "alternative" assemblages of biotite + chloritoid versus garnet + chlorite + muscovite are shown to be parts of the same assemblage because garnet is not calcium free and so the system is not in the AFM projection; this conclusion fits the observation that these two "assemblages" are, in fact, a single assemblage. Epidote is important from the subchloritoid zone into staurolite-bearing rocks. Chloritoid and staurolite coexist over a wide range of conditions. The siderophilites (ferrocities) of the minerals (from iron rich to iron poor) are: garnet, staurolite, chloritoid, hornblende, biotite, and chlorite. Typical $Fe_T/(Mg+Fe_T)$ values are, respectively, 195, 0.93, 0.86, 0.75, 0.60, and 0.56. Chloritoid finally disappears from the area by reacting with plagioclase to form garnet + staurolite + chlorite.

Retrograde metamorphism in the Quabbin Aqueduct Tunnel, central Massachusetts

A suite of thin sections of specimens from the Quabbin Aqueduct Tunnel of Massachusetts (loc. 24) was obtained through the cooperation of the Metropolitan District Commission of Boston. According to Robert Tucker (University of Massachusetts), these specimens show that the reappearance of muscovite, beginning about 1 km east of the Coys Hill Granite, is probably a product of retrograde metamorphism associated with low-dipping cataclastic zones rather than of reduction of the regional metamorphic grade.

AERORADIOACTIVITY

Aeroradioactivity and geology, southeastern Connecticut

Comparisons of patterns of aeroradioactivity with the geology of southeastern Connecticut and adjacent Rhode Island and New York made by Richard Goldsmith, Isidore Zietz, and H. R. Dixon showed that the patterns clearly reflect bedrock geology. This relationship is not greatly affected by surficial deposits of Pleistocene age because most deposits are locally derived and bedrock outcrops are relatively abundant.

Four fields denoting different levels and patterns of radioactivity coincide with major geologic provinces. A granite-gneiss terrane that contains abundant potassic ledge-forming granitic rocks, the Sterling Plutonic Group, coincides with a field of relatively high radioactivity in which subordinate lows reflect outcrop areas of quartzitic rocks of the Plainfield Formation. This terrane is flanked to the west and north by layered metavolcanic rocks of mafic to intermediate composition belonging mostly to the Quinebaug Formation. These rocks coincide with a field of relatively low to moderate levels of radioactivity. The lowest level within this field is produced by the Preston Gabbro, which is at the right-angled bend in the structure.

A sequence of metasedimentary schist and gneiss of the Tatnic Hill Formation, the Hebron Formation, the Scotland Schist, and the sill-like Canterbury Gneiss overlies the Quinebaug Formation. These rocks produce a field of moderate levels of radioactivity but have nodes of high radioactivity where pegmatite is abundant. A field of moderate intensity south of the east-trending anticlinorium of granitic gneiss coincides with layered and massive granodioritic and quartz-dioritic gneiss and subordinate amphibolite equivalent stratigraphically to the layered metavolcanic rocks to the north of the anticlinorium. The late-metamorphic to postmetamorphic, low-angled Honey Hill and Lake Char faults, which follow the bend in the structure at the base of and within the metavolcanic rocks on the northern and western sides of the anticlinorium, respectively, can be recognized only by the radiometric pattern, which reflects the tectonic pinch-out of the Quinebaug Formation westward along the Honey Hill fault.

A pluton of Narragansett Pier Granite of Late or post-Pennsylvanian age, which has associated dikes of Westerly Granite, is reflected in a subfield of high radioactivity in southern Rhode Island. Material derived from these rocks is apparently responsible for a relatively high level of radioactivity in the Charlestown moraine immediately south of the outcrop area.

Aeromagnetic survey in St. Lawrence County, New York

An aeromagnetic survey was completed (Brown, 1975) of an area that includes most of 15 1:62,500 quadrangles bounded on the west by the St. Lawrence River and on the east by the Adirondack Highlands and extending from lat 44° N. near Watertown, N.Y., to lat 44°45′ N. near Ogdensburg, N.Y. (loc. 25).

M. P. Foose and C. E. Brown (1976) reported that a comparison of geologic and magnetic maps of St. Lawrence County, New York, reveals a close correlation between certain rock types and magnetic patterns. The most obvious association is between bodies of leucocratic granitic gneiss ("phacoliths" of Buddington (1929)) and strong positive anomalies that mimic the outcrop outline of the gneiss. Granitic gneiss bodies mapped by Brown (1969) east of Beaver Creek and large areas of granitic gneiss near Alexandria Bay, in contrast, do not have associated positive anomalies. This result is important because the granite gneiss at Alexandria Bay was described as typical of the gneiss in the "phacoliths" (Buddington, 1939, p. 147). Thus, magnetic data verify the presence of at least two distinct granitic gneisses. A correlation of amphibolitic rocks and positive anomalies is less distinct, and a correlation of negative anomalies and large areas of marbles is quite apparent.

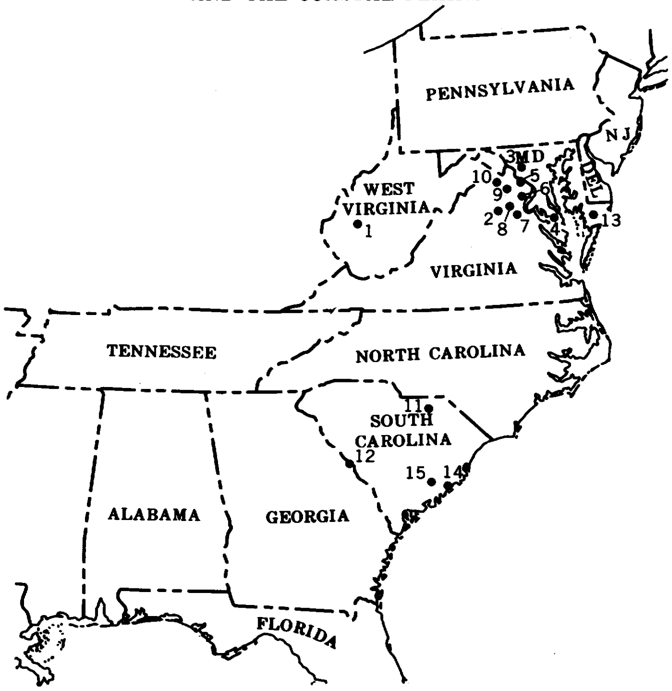
The magnetic pattern of exposed rocks of Precambrian age can be used in a general way to predict the distribution of rocks in areas of poorly exposed or concealed crystalline rocks. Rocks of Paleozoic age fringe the area of magnetic study, but the strong pattern of magnetic anomalies continues in these areas. The geology of the basement rocks here can be predicted from the magnetic map.

APPALACHIAN HIGHLANDS AND THE COASTAL PLAINS

Transport direction of Pennsylvanian sandstone, central West Virginia

Geological investigations in eastern Kanawha County, West Virginia (index map, loc. 1), by T. W. Henry indicated that a widespread sandstone bed in the upper part of the Allegheny Formation is

STATES IN APPALACHIAN HIGHLANDS
AND THE COASTAL PLAINS



a distinct and readily mappable unit. The sandstone is fine to medium grained, contains 45 to 65 percent quartz, and commonly includes a quartz-pebble conglomerate or conglomeratic sandstone with transported *Cordites* logs at its base. The sandstone bed is about 10 to 45 m thick, and a preliminary isopach map suggests a lobate, bifurcating pattern analogous to that of a distributary system of a modern delta. Preliminary analysis of crossbedding suggests a source from the southeast.

The top of the sandstone is gradational into red and (or) green shales and siltstones referred to the Conemaugh Formation (Upper Pennsylvanian) by previous investigators. Krebs (1914) referred to this unit (at least in part) as the Mahoning Sandstone Member and assigned it to the base of the Conemaugh Formation.

Triassic stratigraphy, northern Culpeper basin

The Newark Group (Triassic and Jurassic) in the northern Culpeper basin of Virginia (loc. 2) was redefined by K. Y. Lee into (ascending): the Manassas Sandstone (400 m thick), the Balls Bluff Siltstone (187.5 m thick), and the Bull Run Formation (906 m thick). The Manassas Sandstone is subdivided into the Reston Member and the overlying unnamed sandstone member. The Bull Run is divided into the Leesburg Limestone Conglomerate Member and the overlying unnamed basaltic flow-bearing clastics member. The fluvial coalescence fan-shaped deposits of the Manassas Sandstone and the Bull Run Formation are conglomerate, sandstone, siltstone, and shale, associated with fan-front sequences of fine sandstone, siltstone, and shale, and locally a fan-lateral swamp sequence of carbonaceous shale, coal, and impure limestone. The Balls Bluff siltstone, which is chiefly calcisiltite, grades into and intertongues with the Manassas Sandstone below and the Bull Run Formation above.

Occurrence and geochemistry of basaltic flows

Three principal events of tholeiitic fissure-flow emanation in the Bull Run Formation of the Newark Group in the Culpeper basin of Virginia (loc. 2) probably occurred during the late stage of Bull Run sedimentation, according to field investigations conducted by K. Y. Lee. Each event consists of a group of individual flows, characterized by zeolite-filled vesicles and heterogeneous textures. The flows are separated by thick sequences of red beds and locally intruded by diabase. The individual flows expanded and branched as fresh lava fed into old flows (Moore, 1975, p. 269–277). Chemical analyses of two lower flow samples and four upper flow samples indicate a SiO_2 content of 47.5 to 51.8 percent and a $Na_2O + K_2O$ content of 2.20 to 4.82 percent. The lower flows have higher contents of SiO_2, MgO, TiO_2, B, Co, Cu, Cr, Nb, Ni, Sr, V, Zn, Zr, Gd, Lu, and Y than the upper flows but lower values of Na_2O, K_2O, Ba, Mn, Mo, Sc, Pr, and Yb. The middle flows are generally the least intensely hydrothermally altered and mineralized.

Late Precambrian triple junctions in the Appalachians

As the result of a regional synthesis, D. W. Rankin (1975) suggested that Appalachian salients (convex toward the craton) and recesses (concave toward the craton) are inherited from the initial breakup of the continental mass by the intersection of rift valleys radiating from triple junctions beginning about 820 million years ago. The trace of axes of anticlinoria exposing crystalline rocks older than 1 billion years, named the Blue-Green-Long axis after major Precambrian massifs, roughly coincides with the western margin of a series of late Precambrian water-filled grabens. The rift system east of the axis probably did not open far enough to produce significant oceanic crust but, like the Triassic basins of a later opening cycle, was an initial stage in the opening of an ocean basin ultimately located still farther east. Although metamorphosed basalt is widely distributed along the Blue-Green-Long axis, known upper Precambrian or Eocambrian metamorphosed rhyolite is restricted to three salients: Mount Rogers in Virginia, South Mountain in Pennsylvania, and the Sutton Mountains in Quebec, Canada. These rhyolites are peralkaline in affinity, are constituents of basalt-rhyolite suites, and, near Mount Rogers and South Mountain, are associated with consanguineous aegirine granites.

Suggestions of failed-arm troughs or aulacogens are found at all three salients. The basal Cambrian clastic sequence is thickest near the Mount Rogers and South Mountain salients. Basal conglomerates are coarsest near Mount Rogers. Geophysical anomalies (Fleming and Sumner, 1975) suggest an area of buried mafic igneous rocks projecting northwest from the South Mountain salient. The Ottawa-Bonnechère graben, the most convincing of the failed-arm troughs, strikes into the Sutton Mountains salient. The Cambrian carbonate bank of Rodgers (1968) in northwestern Vermont faces north into this graben, which also contains alkaline ring complexes of probable Cambrian age (Lowdon and others, 1963; Doig, 1970) at its western end at Lake Nipissing in Ontario.

Recesses near Roanoke, Va., and New York, N.Y., are triple junctions whose failed arms have been carried away. An anomalously thin basal Cambrian clastic sequence between western Massachusetts and eastern Pennsylvania may reflect a structurally high area (Palmer, 1971) that coincides with the concave side of the New York recess.

The Wilson cycle implies that fracture zones may be reactivated as zones of weakness in subsequent events. The incipient opening of the present Atlantic (as evidenced by the trends of the Triassic basins between North Carolina and Massachusetts) was essentially parallel to and nearly coincident with the incipient opening of the Iapetus along the Blue-Green-Long axis. The trend of the Monteregian intrusion, which extends from the Ottawa-Bonnechère graben to the Sutton Mountains salient, suggests reactivation of another zone of weakness.

Western Maryland Piedmont

Geologic mapping by M. W. Higgins showed that the Sugarloaf Mountain range of Maryland (loc. 3) is a major refolded fold composed of the same rock units that crop out east and southeast of the mountain.

Basement rocks, Maryland Coastal Plain

Very little is known about the geology of the basement rocks beneath the Maryland Coastal Plain (loc. 4). Since very few wells penetrate the basement, geophysical data are the principal source of information. D. L. Daniels found that the gravity data of southern Maryland are dominated by several large-scale (15×30–60 km), linear, positive gravity anomalies with northeasterly trends. For each of these gravity highs, presumably caused by mafic masses in the basement, the gradient is steepest on the southeastern or eastern side, suggesting that each is a westward-dipping body. Comparisons with aeromagnetic data for the same area show a close correspondence with similar magnetic anomalies. The geophysical signature of one of these anomalies at Leonardtown, Md., is very similar to that of the "Baltimore Gabbro Complex" as used by Hopson, (1964), which is a smooth, large-amplitude gravity high and a mixture of magnetic highs and lows.

Wissahickon Formation of Potomac River gorge may be allochthonous

Metasedimentary rocks of staurolite to sillimanite grade and migmatites in the Wissahickon Formation along the Potomac River between Sherwin Island and Glen Echo, Md., are cataclastically deformed and retrogressively metamorphosed to chlorite-muscovite schist and phyllonites (Reed and Jolly, 1963; Fisher, 1970). Continuing field study of the crystalline rocks in Fairfax County, Virginia (loc. 5), by A. A. Drake, Jr., showed that this zone of sheared and retrograded rocks extends in a sinuous arcuate belt across the county to near Manassas, Va., where it is covered by Triassic rocks. The sheared Wissahickon rocks, which appear to have been deformed five times, structurally overlie a sequence of micaceous metasiltstone and phyllite with prograde biotite (Clifton Phyllite of Bennison and Milton (1954)) that has only a weak second fabric. It seems likely that the contact between the metasedimentary units is a major tectonic break, although the possibility of an overturned unconformity cannot yet be ruled out completely.

The metamorphosed mafic complex previously reported is an intimate mixture of severely metamorphosed mafic and ultramafic rocks (possibly gabbro sheets and dikes in peridotite) intruded by plagiogranite. This mafic-ultramafic complex lies entirely within the Wissahickon terrane rather than between the two different metasedimentary units, as was previously reported.

It seems likely that the previously postulated continental suture lies along the contact between the Wissahickon and Clifton terranes and that the Wissahickon Formation of the Potomac River gorge may well be part of a large allochthon.

Refolded folds, Virginia Piedmont

Near Occoquan, Va. (loc. 6), several auger holes drilled through the thin edge of Atlantic Coastal Plain deposits by V. M. Seiders and R. B. Mixon added new data on the structure of the underlying metamorphic rocks. Surface exposures along the Occoquan River show that the Quantico Slate is folded into an inverted syncline plunging northeast. The underlying Chopawamsic Formation is exposed on the northwestern limb of the fold, and the southeastern limb is partly covered by the Coastal Plain deposits. Previous work (Seiders and others, 1975) had suggested that the inverted fold might die out to the northeast and pass into a steeply dipping homocline. The drilling showed, however, that the Chopawamsic reappears on the southeastern side of the Quantico. Thus, the map pattern is very similar to the type 2 interference pattern of Ramsay (1967, p. 527) and probably developed when an early northwest-trending recumbent anticline, overturned to the southwest, was refolded by upright northeast-trending folds. The orientation of the early recumbent fold at a high angle to the contact of the Occoquan batholith just to the northwest supports the previous suggestion (Seiders and others, 1975) that some of the folding predated emplacement of the pluton about 560 million years ago.

Structure and stratigraphy in the Piedmont of northeastern Virginia

Mapping in the Salem Church 7½-min quadrangle of Virginia (loc. 7) by Louis Pavlides delineated a large refolded fold that gives an outcrop pattern similar to the type 2 of Ramsay. This fold pattern is defined, in large part, by the outcrop pattern of a hornblende-biotite gneiss that structurally overlies staurolite and sillimanite schist of the Quantico Slate. The hornblende-biotite gneiss occurs in a lunate synform (plan view) within the Quantico that is convex to the northeast as a result of being refolded around the axis of a northeast-trending and plunging antiform. In and close to the region of the antiformal axis, the axial surface of the refolded synform is overturned towards the south, whereas, along its northwestern and southeastern segments, the synformal axial surface is generally upright.

The Berea pluton, which has given a concordant zircon age at one place of about 350 million years, was apparently intruded as an irregular sill-like mass within the synformal hornblende-biotite gneiss. Consequently, this Devonian pluton also has been folded by the younger antiform and has a lunate map pattern conformable with that of the enclosing hornblende-biotite gneiss. This relationship dates the latest folding in the region as Devonian or younger, namely, post-Berea. The syncline having an inverted northeastward plunge that has been mapped in the Occoquan quadrangle farther to the northeast in contiguous terrane of Virginia Piedmont (Seiders and others, 1975, fig. 2) may also be a refolded fold of Devonian age or younger rather than an Early Cambrian or older fold, as is suggested by the discordant zircon ages of the Dale City Quartz Monzonite (about 560 million years old) that intrudes this fold. If this correlation of folding patterns and this age of folding are meaningful, then the pre-560-million-year age (Seiders and others, 1975, p. 509) of the Quantico Slate may not necessarily be valid, and the Quantico should be regarded as being of uncertain Paleozoic age.

A northeast-trending linear belt of metavolcanic rocks was mapped west of the Cambrian metavolcanic Chopawamsic Formation of northeastern Virginia and separated from the Chopawamsic by a terrane of metasedimentary rocks and felsic plutons. This belt may be Chopawamsic Formation repeated by folding and faulting or both or a separate volcanic formation at a different stratigraphic level than the Chopawamsic. K. E. Wier mapped this metavolcanic belt northeastward through the Richardsville and Midland quadrangles of Virginia (loc. 8) to where it is covered by the southeastern margin of the Triassic and Jurassic Culpeper basin. Although its southwestern extent has not been traced by geologic mapping, its magnetic signature suggests that it may be coextensive with the metavolcanic rocks that underlie the Arvonia Slate along the northwestern limb of the Arvonia syncline.

Basement involvement in deformation of Blue Ridge tectonic province

Work in the Orlean quadrangle of Virginia (loc. 9) by J. W. Clarke provided some new insights into how the basement was involved in the processes that deformed the Blue Ridge tectonic province. Basement rocks and the lower part of the lower Precambrian-Paleozoic sedimentary section are exposed in the Orlean quadrangle. A concordant zircon age of 1,081 million years has been determined for the

Flint Hill Gneiss, one of the principal units within the basement. The uranium and thorium clocks for this zircon were completely reset at this time and were not subsequently disturbed by the Avalonian, Taconic, Acadian, or Alleghenian orogenies, which affected other terranes in Virginia. This lack of post-Grenville lead loss suggests that temperatures within the basement were never high enough for plastic deformation after the Grenville event. Also indicative of the absence of plastic deformation of the basement is the presence immediately above the top of the basement of Precambrian pelitic rocks that have been metamorphosed only to the greenschist facies. With such low maximum temperatures, the underlying basement could not have deformed plastically.

Deformation of the basement must have been confined to shearing. Two types of shearing are observed here. The first consists of large fractures that are kilometers in length and kilometers apart; they cut the rocks into large fault blocks. These faults affect both basement and sedimentary cover. The second type of shearing consists of faults a few meters apart; displacement on these is only a few centimeters. Such faults are confined to the basement. If the basement were involved in plicative folding of the cover, the accommodation of the basement to the folding could have been accomplished by slippage along these closely spaced faults, the rocks in between remaining rigid.

Although the evidence against plastic deformation is persuasive for the rocks in the Orlean quadrangle, boulders about 40 km to the northeast in the Lincoln quadrangle lying directly on the basement surface have been deformed plastically. Consequently, the role of plastic deformation of the basement in the post-1-billion-year development of the Blue Ridge tectonic province is not entirely clear.

Varied lithology of "Fauquier Formation" suggests late Precambrian continental deposition

The lithology of the "Fauquier Formation" (upper Precambrian) on the eastern limb of the Blue Ridge anticlinorium in northern Virginia (loc. 10) is highly variable and represents fluvial and possibly lacustrine deposition, according to G. H. Espenshade. Medium- to coarse-grained meta-arkose composed of detritus from the underlying granitic terrane is the dominant rock; crossbedding is common. Metasiltstone and rhythmite in the basal beds of the "Fauquier" near Marshall, Va., may be of lacustrine deposition. The basal beds became conglomeratic about 9.5 km northeast of Marshall; pebble to boulder conglomerate continues more than 16 km farther northeast into the Lincoln quadrangle (Parker, 1968). Marble occurs at the top of the "Fauquier" and just beneath the metabasalts of the Catoctin Formation near Marshall and also in the Lincoln quadrangle (Parker, 1968).

The "Fauquier Formation" is essentially equivalent to the Lynchburg and Swift Run Formations. The term "Fauquier" is a modification by Espenshade and Clarke (1976) of the original usage of Furcron (1939).

Paleomagnetic poles of Triassic diabase

Paleomagnetic poles of compass-oriented samples of Triassic diabase collected by Henry Bell III from a large diabase dike in Chesterfield County, South Carolina (loc. 11), were found by K. G. Books to have remnant magnetic poles tightly clustered near the commonly accepted position for paleomagnetic Triassic poles. This normally polarized dike and others being studied are part of a dike swarm that cuts rocks of the Carolina slate belt in the vicinity of the Haile and Brewer gold mines.

Cartersville fault found to be two intersecting thrusts

The Cartersville fault is generally believed to be a single thrust that extends across northwestern Georgia from Tennessee to Alabama. Results of an investigation by C. W. Cressler (USGS) and T. J. Crawford (West Georgia College and the Georgia Department of Natural Resources) indicated that the Cartersville fault is actually two separate faults that intersect near Emerson in Bartow County, Georgia. The part of the Cartersville that trends nearly north from Emerson to the Tennessee line is a continuation of the Great Smoky fault. The other part of the fault, which trends diagonally from Emerson to the Alabama line, is a relatively low-angle thrust that overrides the Great Smoky southeast of Emerson and continues to the northeast across Lake Allatoona. East of the lake, isolated bodies of this thrust sheet remain as erosional remnants on a broad expanse of Corbin Granite.

Holocene fault movement in Eastern United States

Investigations by D. C. Prowell (USGS) and Bruce O'Connor (Georgia Geological Survey) showed that the Belair fault zone in Augusta, Ga. (loc. 12), was active in the Holocene. The fault zone is a series of en-echelon shears at least 21 km long and having up to 30 m of displacement. A trench exposed one of the faults cutting surficial deposits on Coastal Plain strata. Sheared organic material in the fault plane was dated by Meyer Rubin by means of carbon-14 methods as 2,450±1,000 years before present. This information indicates that the Belair fault zone is by far the youngest known fault in the Eastern United States.

Evidence for faulting along Coastal Plain-Piedmont interface, northeastern Virginia

Reconnaissance mapping by R. B. Mixon and W. L. Newell along the inner margin of the northeastern Virginia Coastal Plain (loc. 7) revealed a zone of en-echelon northeast-trending structures that deform Cretaceous and Tertiary lithostratigraphic units. Steep east-dipping structure contour gradients with maximum displacements ranging from 30 to 75 m define four linear structures. Outcrops at several localities along the structures show northwest-dipping high-angle reverse faults that juxtapose Piedmont crystalline rocks and Cretaceous sediments. Truncation of Eocene beds along the easternmost structure by middle Miocene strata indicates an important episode of deformation in late Eocene to early Miocene time. Whether Tertiary strata have been faulted or merely warped has not yet been determined.

The sense of movement on the major faults and flexures, herein called the Stafford fault zone, is up to the Piedmont. Hence, this structural zone is the mirror image of up-to-the-coast displacements along the Brandywine fault zone of southern Maryland. Deep wells, geophysical data, and known Triassic basin trends suggest that the Stafford and Brandywine fault zones may reflect late Mesozoic and Cenozoic compressional stresses and a resultant reversal of movement along preexisting Triassic normal faults.

The structures extend for at least 56 km parallel to the Fall Line and the northeast-trending reach of the Potomac estuary. This relationship supports the hypothesis that the Fall Line and major river deflections along it have been tectonically influenced.

Stratigraphic correlation in and between Coastal Plain depositional basins

J. P. Minard reported that detailed mapping continues to demonstrate the continuity of some stratigraphic units across individual basins or embayments in the northern Atlantic Coastal Plain (loc. 13). Some units also can be correlated between different basins. The stratigraphic section in the Raritan Embayment in the northern part of the New Jersey Coastal Plain and Long Island is more complete than the generally thicker section in the Salisbury Embayment to the southwest. As units are traced southwest from the Raritan Embayment, several progressively thin to extinction. Thin but persistent marine units having high glauconite contents throughout New Jersey gradually lose their distinctive characteristics and high glauconite contents toward the southwest. They are replaced and overlapped by coarser and less glauconitic units that were deposited in shallower waters. The section that thins the most is of Late Cretaceous age; the section thickening the most is of Early Cretaceous age. Downdip toward the coast and under the Continental Shelf, the section thickens rapidly, and units are present that represent geologic time not generally found in outcrop.

Lithologic changes within and between basins reflect the rapidity and extent of the shoalings and transgressions of marine waters during depositional cycles. During these pulses, strata that may be possible sources of hydrocarbons interfinger with potential stratigraphic trap reservoir beds. The changes and relations within or between basins give insight into the large-scale correlations needed to help determine whether economic accumulations of hydrocarbons exist beneath the shelf.

Texas Gulf Coastal Plain lineaments

Interpretation of Skylab and NASA 1:60,000-scale color infrared imagery by E. R. Verbeek added to knowledge of the lineament pattern of part of the Texas Gulf Coastal Plain. Two main trends dominate the pattern. Lineaments of northeast trend are thought to represent the surface expression of faults known at depth. Lineaments of northwest trend have a similar field and photogeologic expression and are nearly as well developed as those of the northeast-trending set. Field investigations correlate some lineaments with low scarps and vegetation breaks; at least one correlates with a currently active surface fault.

A prominent belt of northeast-trending lineaments west of Houston, Tex., may mark an area susceptible to fault activation by possible future fluid withdrawal.

Deep core hole in South Carolina Coastal Plain

A continuously cored test hole was drilled in the South Carolina Coastal Plain 41 km northwest of Charleston, S.C. (loc. 14). B. B. Higgins and G. S.

Gohn reported that the total depth of the hole was 792 m with 70 percent core recovery. The formations recognized in the core, their provincial stages, and their approximate thicknesses are:

- Quaternary: unconsolidated deposits, 7 m.
- Tertiary: Cooper Marl, Jacksonian, Vicksburgian, and Chickasawhayan, 61 m; Santee Limestone, Claibornian, 58 m; Black Mingo Formation, Midwayan and Sabinian, 66 m; Beaufort Formation, Midwayan, 52 m.
- Cretaceous: Peedee Formation, Tayloran and Navarroan, 114 m; Black Creek Formation, upper Austinian and Tayloran, 205 m; Middendorf Formation, lower Eaglefordian, 123 m; Cape Fear Formation, lower Eaglefordian and upper Woodbinian, 62 m; and amygdaloidal basalt, 42 m.

Potassium-argon age determinations of two samples of basalt by R. F. Marvin yielded ages of 94.8 ± 1 million years and 109 ± 1 million years. Because one of these samples is enriched in potassium, the ages must be considered minimum ages.

Seismic refraction in the Charleston, South Carolina, earthquake area

H. D. Ackermann recorded 13 seismic refraction spreads northwest of Charleston, S.C. (loc. 14). Results show three continuous marker horizons in the upper 2,500 m of section. The shallowest is a flat 2.7-km/s Eocene limestone (Santee Limestone) approximately 100 m deep. The next is a 4.5- to 5.2-km/s basalt layer 800 to 900 m deep at the base of the Upper Cretaceous. Correlations are based on drill-hole data at Clubhouse Crossroads, 45 km north-northwest of Charleston. The basalt layer is underlain by rocks of lower velocity, perhaps a Lower Cretaceous sedimentary section. The underlying basement complex horizon has a velocity of 6.4 km/s and dips southeastward at about 60 m/km.

The two shallower horizons were traced from the Clubhouse Crossroads well 20 km eastward to the location of recent low-magnitude earthquake activity and the maximum intensity isoseismal contour from the disasterous 1886 earthquake. Both of the shallower marker horizons appear slightly downwarped in the immediate area of the earthquake. Furthermore, the basalt layer undergoes a decided velocity change, from 5.2 km/s at Clubhouse Crossroads to 4.5 km/s in the earthquake area.

Charleston core provides detailed zonation

The USGS Charleston Project Deep Core Hole No. 1 in Dorchester County, South Carolina (loc. 15), has provided a large number of samples from strata of Cenomanian to Oligocene age. Such a complete series of samples has not been available previously from the southern Atlantic Coastal Plain. N. O. Frederiksen, R. A. Christopher, and F. E. May studied the fossil spores, pollen grains, and dinoflagellates from these samples and divided the sequence into at least eight Cretaceous and five Paleogene zones. Cretaceous and Paleocene zones of the core hole can be readily correlated with biostratigraphic units of the New Jersey Coastal Plain, and the Paleogene zones may be correlated with those of the gulf coast.

CENTRAL REGION AND GREAT PLAINS

KENTUCKY

Geologic mapping of State

A cooperative project with the State of Kentucky, begun in 1960, was more than 90 percent completed by April 1, 1976, when 547 geologic maps had been printed (fig. 4), another 61 maps had been approved for publication, and an additional 29 maps were undergoing editorial review. Geologic mapping was in progress in 65 quadrangles. About 710 maps will be published to cover 763 $7\frac{1}{2}$-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 a 1:24,000 scale and published in the Geologic Quadrangle map series.

Regional tectonic implications of central Kentucky

Maps showing the geologic structure, aeromagnetics, and Bouguer gravity of an area covering 70 $7\frac{1}{2}$-min quadrangles in central Kentucky were compiled by D. F. B. Black (USGS), G. R. Keller (University of Kentucky), and R. W. Johnson, Jr.

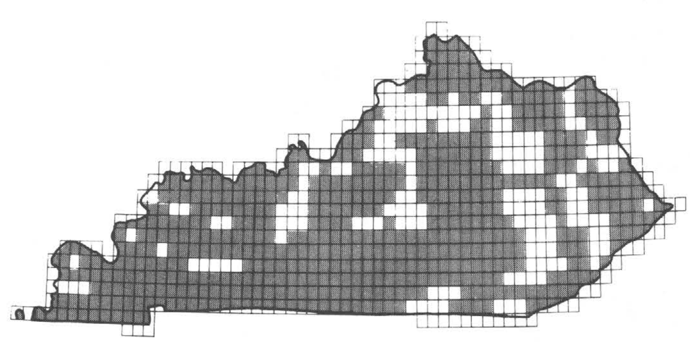


FIGURE 4.—Published geologic quadrangle maps (patterned areas) of Kentucky as of April 1, 1976. Small squares are $7\frac{1}{2}$-min quadrangles.

STATES IN CENTRAL REGION AND GREAT PLAINS

(Tennessee Valley Authority). The area (index map, loc. 1) includes the juncture of several major fault systems and is crossed by the north-trending axis of the Cincinnati arch and the east-trending 38th-parallel lineament.

The Lexington lineament is a newly recognized linear structure revealed by these maps. The northeasterly trending lineament is marked by a group of surface faults that coincides with a boundary between areas of different magnetic fabric and with the western border of a large positive gravity anomaly. Irregularities in these linear features show a close correspondence.

Numerous northwest- to west-northwest-trending elongate blocks bounded by lineaments marked by surface faults are conspicuous on the structure map, as are folds, but both are poorly reflected on the geophysical maps. Tectonic dolostone occurs locally along some lineaments.

The aeromagnetic map shows abrupt decreases in intensity coincident with and on downthrown (southern) sides of the east-northeast-trending part of the Kentucky River fault system and the east-northeast-trending Irvine-Paint Creek fault system. These decreases are caused by the steplike southward thickening of lower Paleozoic rocks shown in the few wells drilled near the fault systems along the northern border of the Rome trough.

Neither the large gravity anomaly nor the change in magnetic fabric along the north-northeast-trending Lexington lineament is offset laterally along the Kentucky River or the Irvine-Paint Creek fault systems. Thus, no major east-west strike-slip movement has occurred along these fault systems of the 38th-parallel lineament since emplacement of the billion-year-old igneous mass that caused the elongate positive gravity anomaly.

A prodelta turbidite-fan apron in the Borden Formation

Delta-front, base-of-slope, and basin environments were recognized by R. C. Kepferle in the terrigenous clastic rocks of the Borden Formation (Mississippian) near Louisville, Ky. (loc. 2). Geologic mapping and detailed petrologic and paleocurrent studies indicate that the Kenwood Siltstone Member of the Borden contains medium-grained arkosic siltstone that accumulated as turbidite beds on at least two coalescing submarine fans along the front of a westward-prograding delta platform in water depths postulated as circalittoral (16–180 m). This front marks an edge of the Catskill-Pocono-Price delta system, which began building westward in Late Devonian time. The end of the westward progradation is recorded by a widespread, burrowed, glauconite-strewn surface at the top of the terrigenous clastic sequence overlying the Kenwood. The glauconite probably formed during a hiatus in the deposition of terrigenous clastic rocks in Kentucky and southern Indiana at the end of the Acadian orogeny. This interpretation of the local paleogeography during Early Mississippian time should facilitate the location of economically important sedimentary facies.

MICHIGAN

Precambrian oxidized weathering zone in Marquette County

A zone of oxidative weathering was found by W. F. Cannon along an unconformity between black shale of the Michigamme Formation (about 2 billion years old) and gray granitic gneiss (about 2.6 billion years old). At two localities in the Dead River basin in the central upper peninsula of Michigan (loc. 3), gray granitic gneiss is altered to leucocratic pink granite in a thin zone 5 cm beneath an unconformable contact with unoxidized black pyritic shale. A few pebbles of the gray gneiss in basal beds of the shale have similar altered rinds. Pockets of fine-grained rocks rich in secondary limonite are also present along the unconformity and may represent iron-rich residual soil that would be expected to form during oxidative weathering. The oxidation took place before deposition of the shale and is therefore older than 2 billion years. As such, the zone is one of the world's oldest known oxidized weathered zones. The oxidation may have been synchronous with the period of oxidative weathering that formed an extensive oxidized zone on iron-formation in the Marquette trough about 16 km to the south.

Stratigraphy and structure of the western Amasa uplift

Mapping of the western Amasa uplift near Crystal Falls, Mich. (loc. 4), by M. P. Foose indicated that a basement complex of Precambrian W biotite and granite gneisses is separated by an unconformity from Precambrian X units. The Precambrian X units are the Randville Dolomite, the Hemlock Formation, the Amasa Formation, and the Michigamme Formation. The Hemlock Formation consists of a lower part composed dominantly of massive flows and an upper part composed mostly of angular, coarse-grained pyroclastic rocks with a few interbeds of slate. This formation has a maximum thickness of 9,000 m but thins abruptly to 1,400 m over a distance of 8 km. This abrupt change in thickness and the coarse clastic character of the upper part suggest that major volcanic centers were located near this area. A small gabbroic lens is intruded more or less conformably within the lower part of the Hemlock. The Amasa Formation, which apparently conformably overlies the volcanic rocks, is composed dominantly of ferruginous quartzites and chert. The Amasa is, in turn, overlain by the Michigamme Formation, a thick sequence of greywackes and slates. Large east-trending folds and faults affect the Precambrian X rocks but do not deform the gneisses of the Precambrian W basement complex.

Magnetic profile over Keweenawan volcanic rocks

A north-trending aeromagnetic profile over Keweenawan volcanic rocks near Ironwood, Mich. (loc. 5), was matched by a model consisting of a series of dipping layers calculated by E. R. King (1975). The dips were measured by H. A. Hubbard in the Black River Valley, and the remanent and induced magnetizations of 39 oriented cores from the same valley were determined by K. G. Books. Felsite from Chippewa Hill and basalt from Algonquin Falls of middle Keweenawan age have normal Keweenawan magnetization, and lower Keweenawan rocks of the Powder Mill Group have reverse magnetization. In the model, these magnetizations were assigned to 26 layers, which alternated with very weakly magnetized layers. The best match of the calculated composite anomalies of remanent and induced magnetizations and the aeromagnetic profile occurs if a deeper block of steeply dipping Powder Mill rocks is assumed to underlie the southern units of middle Keweenawan flows.

Age of Puritan Quartz Monzonite—Precambrian W

The Puritan Quartz Monzonite, named by R. G. Schmidt from exposures in the Ironwood area of Michigan (loc. 6), was shown by geologic mapping to compose a batholith at least 50 km long and as much as 20 km wide on the southern side of the Gogebic iron range. It is associated with subaqueous metavolcanic rocks assigned to the Ramsay Formation (Precambrian W) and with a complex gneissic unit of the same age. The granite and associated rocks underlie the Ironwood Iron-formation and accompanying strata of middle Precambrian age.

The quartz monzonite was determined by Z. E. Peterman to have a Rb-Sr isochron age of 2,710 ±40 million years and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7015±0.0017. The low initial ratio suggests that the rock was derived directly or indirectly from the mantle.

Basement rock studies in Lake Superior region

Regional reconnaissance and radiometric dating of lower Precambrian rocks in northern Michigan and northern Wisconsin by P. K. Sims and Z. E. Peterman showed that rocks comparable in age to the 3.5-billion-year-old migmatitic gneisses in southwestern Minnesota (Goldich and others, 1970) extend eastward, across the midcontinent rift system, into Wisconsin and Michigan, as Morey and Sims (1976) suggested. In the eastern part of the Lake Superior region, the gneisses underlie Precambrian X rocks assigned to the Marquette Range Supergroup, except where they have been relatively uplifted in the cores of gneiss domes and fault-bounded blocks.

Dating of the gneisses is difficult because the rock systems have been severely disturbed by complex tectonic and thermal events subsequent to primary crystallization. Disturbance of the rock system is indicated isotopically by a lowering of the whole-rock Rb-Sr ages of many samples from about 3.0 billion years to between 1.8 and 1.7 billion years and by a scattering of the data points, although some of the points can be fitted to secondary isochrons (Sims and Peterman, 1976). Another indication of the disturbance of the isotopic systems is the common Rb-Sr (Van Schmus and Woolsey, 1975) and K-Ar (Aldrich and others, 1965) mineral ages in the range 1.65 to 1.35 billion years in both lower and middle Precambrian rocks.

Petrographic and isotopic data on the gneisses are consistent with an interpretation that, at approximately 1.8 to 1.7 billion years ago, after deposition of the supracrustal middle Precambrian rocks, the gneisses were reactivated to form mantled gneiss domes and uplifted fault-bounded blocks. Reactivation was accompanied by strong internal dynamothermal metamorphism, which produced cataclasis and recrystallization, and also by minor partial melting, which yielded small bodies of anatectic granite. Lesser thermal tectonic events continued intermittently in the gneiss terrane until at least 1.5 billion years ago.

The thermal activity related to reactivation of the gneiss is a possible explanation for the pre-Keweenawan metamorphic zones delineated by James (1955) in northern Michigan and Wisconsin.

NEBRASKA

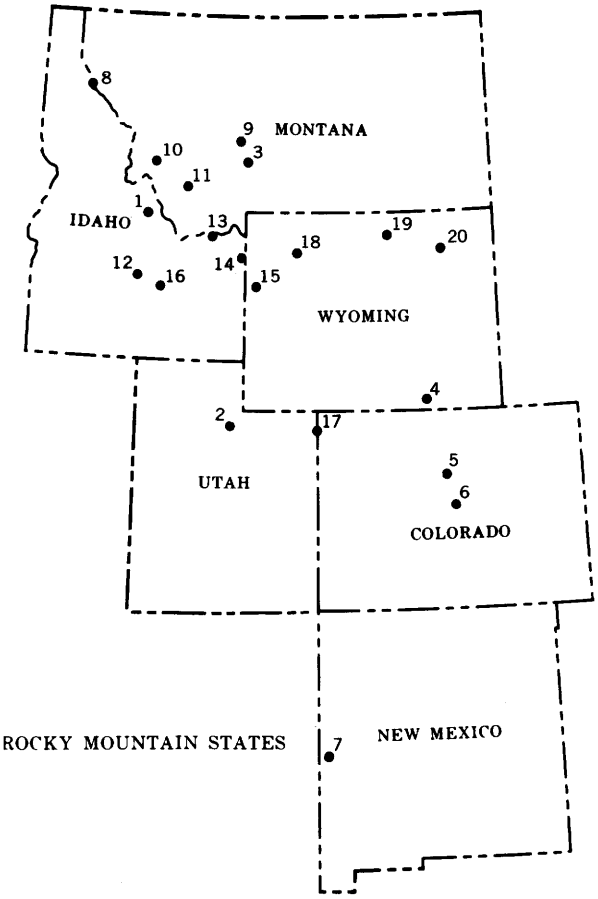
Data from test-hole logs, published and unpublished maps, and field notes from the files of the Nebraska Geological Survey were used by R. R. Burchett, E. C. Reed, and V. H. Dreeszen (Nebraska Geological Survey) and G. E. Prichard (USGS) (1975) in compiling a bedrock geologic map of part of eastern Nebraska. The map, which also shows the combined thickness of Quaternary surficial deposits of loess, till, dune sand, alluvium, and lake sediments, is at a scale of 1:250,000.

ROCKY MOUNTAINS

MINERAL-RESOURCE STUDIES

Mineral deposits and Idaho-Montana thrust faults

The geologic relations of intrusive igneous rocks produced deposits of metallic minerals in and near the central part of the Lemhi Range of Idaho, (index map, loc. 1). The emplacement of the igneous rocks was to a large extent controlled and limited by structural features associated with the Medicine Lodge thrust system. The relations observed in the Lemhi Range appear to be repeated on other major thrust faults in southwestern Montana, according to E. T. Ruppel. These occurrences of thrust-controlled intrusive bodies suggested to him the possible existence of more widespread mineral deposits and therefore enhanced exploration prospects in this region.



Age of igneous rocks and hydrothermal minerals, Park City, Utah

In the Park City mining district of Utah (loc. 2), C. S. Bromfield and H. H. Mehnert (USGS), in cooperation with A. J. Erickson, Jr. (The Anaconda Company), reported that the history of igneous events was varied and occupied a brief time period from earliest Oligocene to possibly very late Eocene. The intrusions and extrusions include two phaneritic plutons, six porphyry stocks, and a volcanic field consisting of volcaniclastic rocks, flows, and shallow volcanic stocks. Nineteen K-Ar determinations on igneous rocks differ by only a few million years; nevertheless, hornblende dates are somewhat older than biotite dates.

If the biotite dates are valid, they suggest that the igneous events spanned about 5 million years, between 31 and 36 million years. If the hornblende dates are in part valid, they suggest that the igneous events may have spanned a period of about 10 million years, between 31 and 41 million years.

Seven determinations on hydrothermal alteration minerals, represented by sericite, muscovite, phlogopite, and hydrothermal biotite closely associated with ore mineralization in the Mayflower and Ontario mines, show that mineralization most probably occurred during early Oligocene time (33–36 million years). The time of mineralization, as reflected in alteration minerals, is thus indistinguishable, within the limits of accuracy of the method, from the time of intrusion and extrusion.

IGNEOUS ROCKS

Cretaceous volcanism, Maudlow area, Montana

Rhyodacitic volcanism in the Maudlow area of Montana (loc. 3) at the eastern edge of the Elkhorn Mountains volcanic field is neatly bracketed by radiometric ages determined by J. D. Obradovich (written commun., 1974) on hornblendes from members B and F of the Maudlow Formation of the Livingston Group defined by B. A. Skipp and L. W. McGrew. The age of member F (74.9 ± 1 million years) is the same as the middle of the estimated cooling time of the Butte Quartz Monzonite (76–74 million years ago) (Tilling, 1974), the suggestion being that, at least along the eastern margin of the Elkhorn Mountains volcanic field, volcanism was contemporaneous with the emplacement of that volumetrically major part of the Boulder batholith. R. I. Tilling (1974, p. 1927) thought that major volcanism ceased before emplacement of the Butte mass and that radiometric ages obtained from adjacent volcanics could be affected by reheating. The volcanic rocks of the Maudlow Formation are too distant from the Boulder batholith to have been reheated by it.

Cyclic units in the Lake Owen mafic complex, Albany County, Wyoming

R. S. Houston and J. L. Ridgley identified cyclic units in the Lake Owen, Wyo. (loc. 4), gabbroic layered complex. These cyclic units strongly resemble those described by Jackson (1970) as occurring in the ultramafic parts of classic layered intrusions such as the Stillwater Complex and Muskox intrusions. The number of cycles detected in the Lake Owen mafic complex depends upon the number of samples per unit area. Major cycles, such as those reported by Houston and Ridgley (1976), can be detected in the field, but minor cycles (unit thickness of 100 m or less) require detailed sampling in the more felsic or gabbroic complexes. Preliminary results of petrographic and chemical studies suggest that variations in mineral composition within a cycle are more pronounced in the gabbroic complex than in the ultramafic parts of layered intrusions. The distribution of trace elements in the complex is related to mineralogy, as expected (for example, the typical sympathetic variations of nickel with olivine and of vanadium and titanium with magnetite). Variation in platinum content from less than 0.001 to 0.150 ppm, however, appears to be random.

"Rosalie Granite," a phase of the Mount Evans pluton

Small plutons of coarse-grained granite in gneissic granodiorite near Mount Evans in the Colorado Front Range (loc. 5), named the "Rosalie Granite" by Ball (1906) and correlated with the Pikes Peak Granite by Lovering (1929), differ in texture and structure from the Pikes Peak Granite, according to field and petrographic data gathered by B. H. Bryant. The rock resembles the coarser grained phases of the quartz monzonite of the 1,710-million-year-old Boulder Creek batholith. Rubidium and strontium contents of the "Rosalie Granite" determined by C. E. Hedge are distinctly similar to those of plutonic rocks of the 1,710-million-year age group. The Sr^{87}/Sr^{86} ratios indicate an age of $1{,}745 \pm 100$ million years for this more felsic phase of the Mount Evans pluton.

A sodic pluton in the Pikes Peak batholith, Lake George, Colorado

In a study of a 6×8-km intrusive center at the western edge of the Pikes Peak batholith near Lake George, Colo. (loc. 6), R. A. Wobus (Williams College) found that the rocks within the intrusive occur in a crudely concentric pattern. The ring complex is well expressed topographically and is centered on a 5-km^2 syenomonzonite stock. The rocks of the center are of two compositional varieties: (1) fine- to medium-grained granites thought to be late-stage textural variants of the Pikes Peak Granite and (2) ring dikes of fayalite-ferrohastingsite granite and quartz syenite and the central syenomonzonite stock. Both varieties are products of a more sodic differentiation trend ($Na > 5$ percent) and are younger than the other granitic rocks. Small bodies of alkali gabbro and porphyritic granodiorite are cut by rocks of the intrusive center and may be early differentiates of the magma that produced the Pikes Peak Granite.

Correlation of precaldera ash-flow tuffs, Bursum caldera, New Mexico

Geologic mapping by J. C. Ratté (USGS) and isotopic and fission-track dating by R. F. Marvin and

C. W. Naeser (USGS) of Tertiary volcanic rocks in the Kelley, Saliz, and San Francisco Mountains near Reserve, N. Mex. (loc. 7), north of the Bursum caldera, provided a basis for the correlation of three major ash-flow tuff sheets with part of the ash-flow tuff sequence beneath Shelley Peak in the southern wall of the Bursum caldera about 80 km away. The three sheets, which are mapped as a single unit on previously published reconnaissance maps and were combined as the extensively altered Pacific Quartz Latite in the Mogollon mining district (Ferguson, 1927), are the tuff of Davis Canyon, the tuff of Shelley Peak, and the 26.5-million-year-old Bloodgood Canyon Rhyolite of Elston (1968). The sequence rests unconformably on an older andesitic and latitic volcanic terrane of flows and extensive breccias. A thin discontinuous rhyolite tuff interlayered several hundred meters below the top of the andesitic rocks yielded a sanidine K-Ar age of 31.7±0.8 million years and a fission-track age (zircon) of 32.0±2.7 million years. These pre-ash-flow tuff volcanic rocks are part of an extensive andesitic terrane that can be traced at least 50 km southwestward, where hornblendic lavas have been dated at 35.6±2.7 and 37.4±3.9 million years (K-Ar hornblende) by P. E. Damon (University of Arizona) (Ratté and others, 1969). These andesitic rocks appear to be comparable in age to rocks of similar composition in the Rubio Peak Formation north and east of Silver City, N. Mex. Northward from the Kelley, Saliz, and San Francisco Mountains the ash-flow tuff sequence thins, and volcaniclastic and windblown sandstones thicken between the tuff sheets.

GEOLOGIC AND STRATIGRAPHIC STUDIES

New correlation of the Belt Supergroup, Idaho and Montana

Geologic mapping at a 1:250,000 scale in the Wallace 2° quadrangle of Idaho and Montana (loc. 8) has now carried knowledge of the stratigraphy of the Belt Supergroup from the low-grade part of the Belt basin into the high-grade metamorphic zone around the Idaho batholith. An improved understanding of systematic facies changes in particular generates a stratigraphic section somewhat different from that previously inferred by investigators who attempted to correlate a sequence of high-grade metamorphic rocks with a simpler and somewhat different Belt sequence several kilometers away. Cretaceous and Tertiary thrust faults north and northeast of the batholith complicate paleotectonic reconstruction of the old Belt basin; but, if the new stratigraphic sequence identified by J. E. Harrison is correct, then the edge of the Precambrian basin was probably only a few tens of kilometers to the south.

Belt Supergroup stratigraphy, Big Belt Mountains, Montana

Geologic mapping and stratigraphic studies by M. W. Reynolds in the Belt Supergroup of the Big Belt Mountains of Montana (loc. 9) extended the known distribution of the basal Neihart Quartzite and documented facies changes in the Newland Limestone. Large xenoliths of quartzite that have bedding and petrographic characteristics identical to those of the Neihart occur in the quartz monzonite pluton of Mount Edith, which is intruded into the lower part of the Newland Limestone. The occurrence is about 60 km southwest of previously mapped outcrops of the Neihart and extends the area of the pre-Belt platform known to be covered by the Neihart. South and southeast along the Big Belt Mountains, limestone units in the upper part of the Newland grade from offshore carbonate facies to nearshore intertidal facies. The carbonate content of argillite and siltite beds composing the lower part of the formation increases in the same directions. Both of these facies changes and the stratigraphy of adjacent units in the eastern (Helena) embayment of the Belt basin support the hypothesis (Harrison and others, 1974) that subsidence was gradual and sedimentation was not characteristic of an aulacogen.

Revision of Belt Supergroup stratigraphy, Sapphire Mountains, Montana

Precambrian sedimentary rocks formerly assigned to the Ravalli Group of the Belt Supergroup (Ross, 1963) are thermally metamorphosed rocks of the Missoula Group. Reconnaissance geologic mapping in the northern Sapphire and John Long Mountains of Montana (loc. 10) by C. A. Wallace and M. R. Klepper traced the Helena or Wallace, Snowslip, Shepard, and Mount Shields Formations southward from the Clark Fork River across a series of reverse and thrust faults into rocks previously considered to be Ravalli Group, which underlies the predominantly carbonate Helena Dolomite or Wallace Formation. Rocks of the Missoula Group show the increasing effects of thermal metamorphism as they are traced toward exposed adamellite and gabbro stocks. At the biotite grade of metamorphism, noncarbonate Missoula Group rocks are characterized by a succession of greenish siltstone and fine sandstone interbedded with blackish-gray silty argillite that superficially resembles the Burke Formation, the Revett Formation, and the lower part of the St. Regis Formation. The metamorphic aureoles in the Missoula Group provide an approximate indication of the great lateral extent of intrusive rocks that are buried at a shallow depth beneath the surface in the northern Sapphire Mountains.

Precambrian basement and Cambrian strata, Pioneer Mountains, Montana

Precambrian rocks in the Pioneer Mountains of southwestern Montana mapped by E-an Zen in the Vipond Park quadrangle and vicinity (loc. 11) consist of feldspathic gneiss and amphibolite containing at least two and locally three penetrative cleavages and entirely metamorphic microscopic textures. A tentative Rb-Sr isochron indicates an age in the range of 1.0 to 1.5 billion years. Discordant, and therefore minimal, Pb-U, Pb-Th, and Pb-Pb ages range from 1.3 to 1.8 billion years. Zen found a sample of what seem to be rather old, conceivably volcanic basement rocks. They were intruded by several generations of rocks that are now also gneissic. A complex history prior to the Paleozoic is indicated.

Zen also found Belt Supergroup rocks lithologically suggestive of the Missoula Group overlain directly by Middle Cambrian strata (Hasmark Formation). In other places, the Hasmark passes down conformably and gradationally into the Silver Hill Formation, which has produced Cambrian trace fossils and includes a basal crossbedded conglomerate as much as 500 m thick that abuts old basement rocks. Large-scale tectonic relief and possibly topographic relief at the inception of the Paleozoic are suggested.

The conglomerate is unlike Belt rocks and contains clasts of gneiss, schist, and jasper; the bulk of the clasts consists of clear, smokey, amethystine, and rose quartz and feldspar. Zen suggested that the Silver Hill Formation is correlative with the Cash Creek Quartzite mapped by S. W. Hobbs in Custer County, Idaho, perhaps deposited on the opposite side of a major paleotectonic positive element.

Upper part of the Wood River Formation may be Late Permian or Early Triassic in age

W. E. Hall and J. N. Batchelder (USGS) studied an overturned, folded section of the Wood River Formation, estimated to be about 1,500 m thick, that is younger than and in most places overlies in thrust contact units 1–7 of the Wood River Formation, which they previously described (Hall and others, 1974). This section, designated unit 8, was measured along the ridge between Wilson and Trail Creeks about 15.25 km northeast of Ketchum, Idaho (loc. 12). It consists of interbedded gray and brown siltstone, siltite, quartzite, dark-gray siliceous argillite that in many places contains abundant worm trails, and minor silty and sandy limestone beds that locally contain a poorly preserved microfauna. Thin sections of limestone from unit 8 were examined by G. P. Sossipatrova (Institute of Arctic Geology, Leningrad, U.S.S.R.) (oral commun., 1975), who identified lagenid forms, and by Bernard Mamet (University of Montreal), who identified nodosariids; Mamet (oral commun. to B. A. Skipp, 1975) said that the assemblage looks post-Carboniferous, possibly Late Permian or Early Triassic.

Beaverhead Formation correlatives, Centennial Range, Montana

Pollen and spores identified by R. H. Tschudy from a sample collected by D. L. Schleicher from folded sandstone beds assigned to the Aspen(?) Formation (Lower Cretaceous) by Witkind (1975) in the western Centennial Range of Montana (loc. 13) are of Late Cretaceous age. Tschudy (written commun., 1975) stated that the assemblage indicates an age no older than Coniacian. This find and mapping by Schleicher and B. A. Skipp extended sedimentary rocks correlative with the syntectonic sediments of the Beaverhead Formation (Upper Cretaceous to Eocene) eastward into the southwestern corner of the Lower Red Rock Lake quadrangle of Montana.

Pleistocene dunes southwest of Yellowstone Park

Geologic mapping of large piedmont lobes of glacial drift beneath a thick loess cover immediately southwest of Yellowstone National Park, (loc. 14) by G. M. Richmond revealed large numbers of longitudinal loess dunes superposed on the overall loess mantle. The dunes tend to occur in clusters, chiefly on the lee slopes of hills, although some ascend the windward slopes. Their principal orientation is northeast. Many are 5 to 15 m high and 0.3 to 0.5 km long. A few are 0.7 km long. The dunes appear to have formed chiefly during the latter part of the last glaciation, although deposition of the main body of the loess appears to have immediately preceded the last major glacial advance.

Pre-Wisconsinan glaciation, Jackson Hole and Gros Ventre Mountains, Wyoming

J. D. Love found a till below the Huckleberry Ridge Tuff (1.9 million years old) at Signal Mountain on the floor of Jackson Hole in Wyoming (loc. 15). Possibly correlative till, much older and topographically higher than Blackwelder's (1915) "Buffalo Till," is present in the Gros Ventre Mountains 45 km south-southeast of Signal Mountain. On several mountain passes above 3,050 m, the till contains erratics of Absaroka volcanic rocks that have come from the Absaroka Range 45 km to the northeast and quartizite boulders from the Mount Leidy Highlands 20 km north-northeast. From both sources, the ice had to cross major drainage systems 610 to 915 m deep. Thus, the ice must have been the most extensive and the thickest of the ice masses in the Jackson Hole region. What happened where the spillover ice flowed southward from the Gros Ventre Mountains is a matter of conjecture, but the ancestral Hoback River may possibly have begun its superposed course westward across the Hoback Range from the margin of this ice mass.

STRUCTURAL STUDIES

Anomalous eastern trend of the Centennial Mountains, Idaho and Montana

After completing detailed mapping of the Centennial Range of Idaho and Montana (loc. 13), I. J. Witkind entertained a new hypothesis to explain the eastward trend of this range in a region dominated by northwest-trending mountains. The eastern Centennials are an eastward-plunging anticline from which the northern limb and part of the core have been eroded away. The western Centennials are a dome from which most of the northern flank has been eroded away. A probable diatreme in the east and many small mafic dikes and plugs in the west may indicate that the two folds reflect underlying mafic intrusive masses. Intrusion may explain the orientation of the range but not the seismicity of the active Centennial fault (Witkind, 1975) along the northern flank.

Great Rift extended

LaPoint (1975) and H. J. Prostka (1975) contended that, in the region of the eastern Snake River Plain of Idaho, the alinement of basaltic rift zones reflects prevolcanic structural trends outside the plain, a spectacular illustration being the northwestern extension of the Great Rift zone (Craters-of-the Moon) into Dry Fork Valley (loc. 16), where young normal faults and Holocene volcanic vents trend parallel to and are located just west of the trace of the major thrust (of Sevier age) that brings Mississippian flysch (Copper Basin Formation) over Mississippian miogeoclinal rocks (Skipp, 1975).

New look at structures, eastern Uinta Mountains

After a close look at structures in the vicinity of Dinosaur National Monument in Colorado and Utah (loc. 17), W. R. Hansen concluded that monoclinal folding rather than faulting accounts for most of the near-surface displacement observed, although the folds clearly reflect subjacent faults.

The Mitten Park fault breaks rock at the surface in the immediate vicinity of Whirlpool Canyon; it dies out a kilometer or so back from the Green River and then reappears 2 km farther south. Elsewhere, its extension is a monocline. The Yampa fault is a monocline for more than half its length. The Red Rock "fault" is really a sharp asymmetrical fold—a monocline superimposed on a regional dip.

Fault movements in the eastern Uinta Mountains began in Precambrian time and continued intermittently and locally until, apparently, the Holocene. A northward extension of the Mitten Park trend, which might be continuous with the Mitten Park fault at depth, offsets the Uinta Mountain Group in Lodore Canyon but not the overlying Lodore Formation—clearly a Precambrian displacement. The Mitten Park fault to the south just as clearly has Laramide offset. On Diamond Mountain, several kilometers west, faults that break the Bishop Conglomerate (Oligocene) appear to be Holocene. Where they are adequately exposed, nearly all the larger fault segments—the Yampa, the Mitten Park, the Island Park, and others—have reverse habits.

South Fork detachment fault extended

Subsurface drilling information, which was used by W. G. Pierce in compiling a geologic map of the Cody 2° quadrangle of Wyoming (loc. 18), extended the area of the upper plate of the South Fork detachment fault southeastward beneath Carter Mountain and extended the area of the detachment by about 250 km^2.

Quaternary deleveling between Jackson Hole and Gros Ventre Mountains, Wyoming

An unnamed preglacial, partly lacustrine tuffaceous Quaternary sequence less than 60 m thick was found by J. D. Love to extend eastward from the floor of Jackson Hole in Wyoming (loc. 15) at an elevation of 1,830 m to the higher part of the Gros Ventre Mountains at 3,050 m. The lithology of this sequence is distinctive, and the age is based on mollusks and sparse vertebrate fossils. The geographic distribution of these rocks provides evidence of at least 1,220 m of differential movement between the Gros Ventre Mountains and Jackson Hole in Quaternary time.

ENVIRONMENTAL-GEOLOGIC STUDIES

Geomorphic zones, western Powder River basin, Wyoming

In the course of preparing a geologic map of the Buffalo-Sheridan corridor of Wyoming (loc. 19), S. P. Kanizay and F. W. Osterwald recognized geomorphic zones basic to land development of the northwestern part of the Powder River basin. A central zone, where urban development will have the greatest impact, consists chiefly of sediment-terrace surfaces lying on nearly horizontal strata of the Fort Union and Wasatch Formations. On the east, burned coal beds and associated baked rocks (clinker) are resistant to erosion but are intricately dissected. On the west, Paleozoic and Mesozoic strata are upturned against granitic rocks of the Bighorn Mountains.

Stable landscape, Gillette area, Wyoming

Mapping of surficial sediments and landforms and related studies of geomorphic processes in the Gillette area of Wyoming (loc. 20) by D. A. Coates, V. S. Williams, and D. S. Fullerton showed that large portions of the landscape overlying strippable coal deposits, through exposure to weathering and erosion and by cover of vegetation, have become stabilized to the point that little disturbance of bedrock and surficial materials is taking place at the present time. However, this natural balance is fragile, and, when it is disrupted by surface mining or other activity, centuries may be required for the disturbed semiarid lands to readjust fully to the new set of conditions. This relationship should be taken into account in the planning of all future mining and reclamation activities.

BASIN AND RANGE REGION

MINERAL-RESOURCE STUDIES

Cenozoic volcanism and mineralization, Great Basin

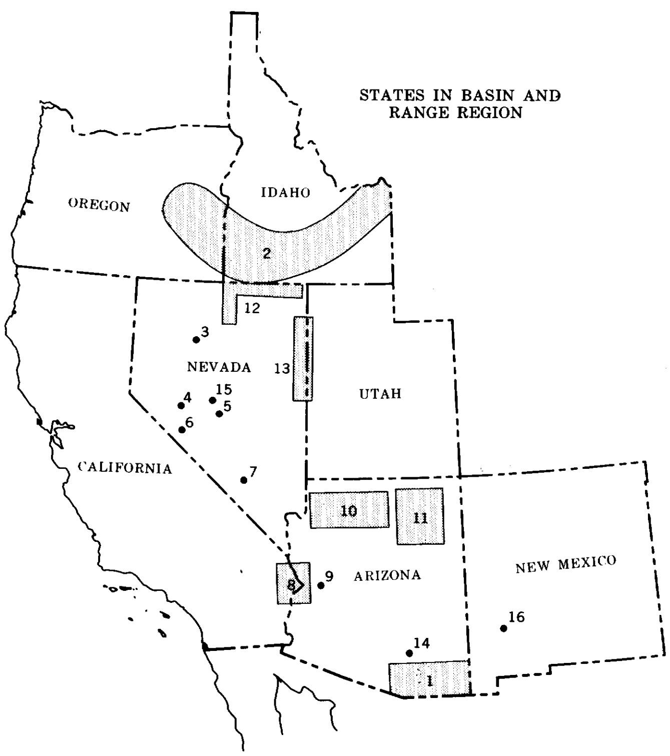
M. L. Silberman determined the isotopic ages of 40 hydrothermal precious-metal deposits of Cenozoic age in the Great Basin, and E. H. McKee and J. H. Stewart helped evaluate the time and space relations of these deposits to igneous processes and the tectonic framework. Three major suites of volcanic rocks were erupted in the Great Basin during middle and late Cenozoic time. The first suite probably reflects subduction of the Pacific plate (Farallon plate) beneath the North American plate. Subduction resulted in the generation and eruption of andesitic volcanic rocks between 42 and 34 million years ago in the northern Great Basin and in the generation and eruption of voluminous rhyolite and quartz latite ash-flow sheets between 34 and 17 million years ago farther southwestward. This phase ended with the onset of crustal extension and north-trending Basin and Range (rift) faulting. The second volcanic suite, which erupted between 17 and 8 million years ago in the northern Great Basin, was mostly basaltic, or bimodal basalt and rhyolite. The third volcanic suite consists of andesite and rhyolite lava flows and some basalt flows erupted between about 22 and 7 million years ago along the northwest-trending Walker Lane structural zone in the western Great Basin.

Hydrothermal ore deposits are associated with all suites of volcanic rocks, but the most productive deposits are associated with andesitic rocks of the third suite (22–7 million years) in the western Great Basin. The oldest (34–42 million years) andesitic rocks (first suite) of the northern Great Basin produced some large ore deposits, but slightly younger silicic rocks of this suite are mostly barren. Many small ore deposits are associated with the 17- to 8-million-year-old basaltic suite in northern Nevada.

Tectonic control of major ore deposits, Arizona

Although most of the major mineral deposits in southeastern Arizona (index map, loc. 1) are of Late Cretaceous or Paleocene age and are associated with features of the Laramide orogeny, an older set of faults appears to be the key control for mineralization, according to H. D. Drewes. These faults generally have a northwesterly trend, dip steeply, and were reactivated many times. The earliest movement on some faults was probably in Precambrian time; other segments of these faults were reactivated as recently as late Tertiary time. Total displacement on some faults may be many kilometers; movement was principally left slip but at times was normal.

Major ore deposits and many intrusive bodies are located close to the northwest-trending faults. Typically, the ore deposits occur in favorable lithologies along second- and third-order faults a few kilometers from the northwest-trending faults.



STRATIGRAPHIC AND STRUCTURAL STUDIES

Genesis of Snake River Plain

New surface data obtained by H. J. Prostka, S. S. Oriel, and their associates confirmed downwarping and faulting of the Snake River Plain in southern Idaho (loc. 2) during Cenozoic Basin and Range crustal extension but did not establish genesis.

The concept that the Snake River Plain represents the 17-million-year-old trace of the continental plate drifting westward over a mantle plume now under Yellowstone National Park accounts for a northeastward decrease in the age (4 cm/yr) of rhyolites along the eastern Snake River Plain but does not explain the contemporaneous west-northwest decrease in the age of rhyolites across Oregon or the continuing basaltic eruptions along the central and eastern plain. Attributing the origin of the eastern Snake River Plain to buried basement controls leaves unexplained the western Snake River Plain trend and the apparent absence of basement controls in the eastern part of the region in pre-Miocene time. Northwestward drift of the Idaho batholith structural block does not explain the simple graben (rather than strike-slip) structure and positive gravity anomalies of the western Snake River Plain.

The Snake River Plain may be part of an "aulacogen" complex. Four linear segments—the eastern and western arms of the Snake River Plain, the Oregon rhyolite belts, and the central axis of the Basin and Range province—radiating from near Twin Falls, Idaho, are confined to the >1,000-km-wide region of crustal extension that includes the Basin and Range south and north of the Snake River Plain and the Oregon plateaus southeast of the Blue Mountain front. The segments may reflect the spread of a broad rising diapir (Scholz and others, 1971) centered near Twin Falls that produced crustal extension, high heat flow, depletion of sialic crust as evidenced by outwardly migrating rhyolitic volcanism, and underplating at the downgoing flow limbs accompanied by isostatic adjustments, as indicated by greater elevations and seismicity along the periphery of the extended region.

Age of Inskip Formation, Nevada

Poorly preserved conodonts collected by D. H. Whitebread from several limestone beds in the lower half of the Inskip Formation in the East Range of Pershing County, Nevada (loc. 3), were identified by A. G. Epstein as Early Devonian to Mississippian in age. Previously, the Inskip was tentatively assigned to the Mississippian on the basis of corals collected from a limestone unit at the base of the formation (Silberling and Roberts, 1962). The Inskip Formation has no known lithostratigraphic equivalents in adjacent ranges.

Fault patterns in Walker Lane, Nevada

Geologic mapping of the Walker Lane east of Walker Lake, Nev. (loc. 4), by E. B. Ekren, F. M. Byers, Jr., and R. F. Hardyman delineated five northwest-trending right-lateral en-echelon strike-slip faults. These faults lie within a zone 30 km wide between long 118°00′ W. and 118°45′ W. and have a combined displacement of about 48 km. The faults show maximum displacements between lat 38°35′ N. and 38°50′ N. and cannot be traced north of about 39°00′ N. and south of about 38°25′ N., a distance of about 70 km.

The faults have localized intrusive masses ranging in composition from basaltic andesite to rhyolite, and they have served as conduits for sulfide-bearing hydrothermal solutions. They are inferred to be deep-seated structures that penetrate deeply into or through the thin crust of the Basin and Range province.

Fault movement began at least 19 million years ago and has continued to within at least a few thousand years of the present. An isotopic date of 5.8±0.2 million years (R. F. Marvin, written commun., 1975) was obtained from basaltic andesite intruded along one of the fault zones, and, although most of the right-lateral displacement occurred prior to this intrusion, postemplacement strike-slip movement brecciated and displaced the andesite. Rhyolite was intruded along another fault zone and is megascopically very similar to a nearby plug of rhyolite that has been dated as 19.2±0.7 million years (R. F. Marvin, written commun., 1974). Ekren, Byers, and Hardyman inferred that the rhyolite in the fault zone is about the same age as the rhyolite plug.

All of the faults exhibit some indications of oblique-slip movement and displace alluvial fans and other alluvial deposits that probably range in age from late Tertiary to Quaternary. Although the faults appear to be quiescent at present, the fault scarps in alluvium are more youthful along the easterly faults than they are along the westerly faults. In fact, there appears to be a general increase in the age of alluvial scarps from east to west along the five faults. The most easterly fault in one locality displaces three levels of alluvium; the fault trace appears as a knife-sharp line on aerial photographs, and, although they are dissected, the scarps are easily identified on the ground and have slope angles averaging about 25° (P. P. Orkild, written commun., 1975). Scarps along the faults farther west are not easily identified on the ground where they cut through alluvial areas, although they show as fairly distinct lines on aerial photographs.

Because the faults cut through ranges as well as valleys, the associated gouge and breccia zones are well exposed for many kilometers. These zones vary in width along individual faults from 10 to 300 m. Where granite of Mesozoic age is cut by a strike-slip fault, it is commonly pulverized to the consistency of coarse conglomeratic sandstone for as much as 100 m from the principal fault trace. Except for a total lack of sorting and stratification, the pulverized material resembles conglomeratic arkose. Within a few meters of the principal fault trace, the mechanically disintegrated granite commonly grades to the consistency of fine sand and silt. The actual fault traces, whether in granite or other rocks, are everywhere marked by slickensided clay gouge zones that vary in width from 1 to 10 m. The gouge zones localize several springs.

Where a fault cuts through volcanic rocks of Tertiary age or sedimentary rocks of Mesozoic age, the width of brecciation is much less, and, in a few localities where carbonate and clastic sedimentary rocks are present on both sides of a fault, the combined width of breccia and gouge zones may be as little as 10 m.

The faults were conduits for hydrothermal solutions that altered Tertiary strata for distances of a kilometer or more from some fault zones. In contrast, the Mesozoic rocks, including granitic rocks, were little affected by hydrothermal solutions, even where adjacent Tertiary strata are intensely altered.

Mesozoic thrusting in Nevada

Geologic mapping in northern Nye County, Nevada (loc. 5), by F. G. Poole documented post-Early Triassic and pre-Late Cretaceous east-directed overthrusting. The major thrust carried strongly deformed lower Paleozoic argillite, chert, limestone, and greenstone of the siliceous assemblage over autochthonous and parautochthonous moderately deformed Lower Triassic and upper Paleozoic argillite, quartzite, conglomerate, and minor limestone. The allochthonous and autochthonous rocks are intruded by Upper Cretaceous plutonic rocks and overlapped by Tertiary volcanic rocks.

New Devonian locality in Nevada

Devonian conodonts were identified by A. G. Epstein in a 150-m sequence of limy quartz sandstone and sandy limestone, pelletoid and fine-textured limestone, chert, and siliceous hornfels in the Miller Mountain area of western Nevada near lat 38°05′ N., long 118°07′ W. (loc. 6). Mapping by J. H. Stewart showed that the Devonian unit occurs in two structural slices tectonically interleaved with graptolite-bearing eugeosynclinal Middle and Upper Ordovician rocks. The entire Ordovician and Devonian sequence was originally assigned to the Palmetto Formation. The Devonian sequence includes indistinctly graded gravity-flow units, current-deposited ripple-laminated and cross-stratified layers, and slump deposits.

Yucca basin configuration, Nevada Test Site

According to G. D. Bath and G. L. Dixon, geologic and magnetic data from numerous drill holes in Yucca Flat at the Nevada Test Site (loc. 7) indicate that the asymmetrical configuration of the Quaternary Yucca basin was controlled principally by a major north-striking normal fault in the western part of the basin. This pre-Quaternary fault, which has a maximum displacement of 1,000 m, controlled the configuration of the Yucca basin and the thickness of Quaternary alluvial deposits that filled the basin. The deepest part of the basin and the thickest sequence of alluvial deposits occur on the downthrown or eastern side of the fault in the southwestern part of the basin.

Cenozoic tectonics of eastern Mojave Desert

W. J. Carr and D. D. Dickey found that Tertiary structure in the region of Parker, Ariz., is genetically related to a major low-angle fault, the Whipple Mountain detachment. The fault has been recognized in many ranges within a structural and topographic zone 100 km wide, here called the Sonoran-Mojave belt, that extends northwesterly for at least 300 km through northern Yuma and southwestern Mojave Counties, Arizona, and eastern San Bernardino and northeasternmost Riverside Counties, California (loc. 8). Physical connection of the fault from range to range has not been demonstrated, but the structural style of the fault is everywhere similar. In addition, the Sonoran-Mojave belt contrasts with surrounding areas and appears characterized by (1) a virtual absence of seismicity, (2) a scarcity of Quaternary faults and a lack of active faults, (3) an absence of Quaternary volcanic rocks, (4) relative tectonic stability since about 14 million years ago, (5) northeasterly or diffuse range trends, (6) a virtual absence of linear mountain fronts and deep intermontane basins, (7) a relatively low level of residual magnetic intensity, (8) abrupt metamorphic changes, (9) 70- to 100-million-year-old granitic plutons, and (10) pre-Tertiary rocks that are different from coeval rocks northeast and southwest of the belt.

Cenozoic structure and volcanism in Arizona

According to Ivo Lucchitta, the Bill Williams area in southern Mojave and northern Yuma Counties, Arizona (loc. 9), is located at a tectonic juncture marked by the intersection of major regional structural lineaments, by a change in the trend of basins and ranges, by several anomalously oriented ranges, and by proximity to inferred wrench faults (Poole and others, 1967; Miller, 1970). This highly deformed area contains high-angle dip-slip, thrust, and probable wrench faults. Tectonism probably continued into the Quaternary, as Lasky and Webber (1949) previously reported. The thrust faults carried Paleozoic rocks and locally Precambrian crystalline rocks (Lasky and Webber, 1949) over Cenozoic rocks. W. J. Carr (oral commun., 1976) mapped similar thrusts in the Parker area of Arizona farther west (loc. 8). The large areal extent of thrusting, combined with mylonitization and silicification of Precambrian crystalline rocks several meters beneath the fault surface, casts some doubt on the gravity-slide hypothesis proposed by Shackelford (1975). The northeasterly trend of anomalously oriented ranges extends into the Bill Williams area, where it is represented by fracturing that, together with the dominant northerly to northwesterly structural grain of the region, forms a grid pattern; the fracturing seems to die out northward, however. The group of anomalously oriented ranges may be terminated by northwest-trending wrench faults, as Poole and others (1967) suggested previously.

Silicic and mafic volcanic rocks are abundant and interbedded with a thick sequence of continental deposits, all of which are deformed. Study of the volcanic rocks will help establish the chronology of Cenozoic deformation and volcanism. Several volcanic centers are recognized; the most recent volcanic activity was the effusion of mesa-forming mafic lava flows.

Reclassification and interpretation of Supai Group and Hermit Shale, Grand Canyon region

Study of the Pennsylvanian and Permian shallow-water marine to continental red bed and carbonate rocks of the Supai Group and Hermit Shale indicated complex facies changes across the Grand Canyon region of northwestern Arizona (loc. 10). This sequence of rocks was systematically sampled and studied by E. D. McKee to determine vertical and horizontal sediment distribution through textural, structural, faunal, and compositional characteristics. Depositional patterns and paleontologic work indicate that sediments of Morrowan, Atokan, Virgilian, and Wolfcampian age are present and that the Grand Canyon area was the site of an embayment that extended eastward from the southern Nevada seaway during much of Pennsylvanian and Early Permian time. Periodically, this embayment was also connected to the Sonoran geosyncline to the southeast and (or) the Paradox basin to the northeast. Positive and negative tectonic elements in northern Arizona and southern Utah were mapped; these paleotectonic and stratigraphic data may be useful in subsurface petroleum exploration.

Cenozoic chronostratigraphic studies, Black Mesa region of Arizona

Vertebrate fossils collected from the Shonto and Dilkon terrace deposits in the Hopi Buttes area (Sutton, 1974) of the Black Mesa region of Arizona (loc.

11) provided provisional mammal ages of Blancan and Blancan to Irvingtonian, respectively. According to T. N. V. Karlstrom, R. L. Sutton, J. P. Schafer, Richard Hereford, B. C. Philpott, and H. E. Holt, the ages are consistent with the stratigraphic positions and correlations of these deposits to the 1A and 1B Black Point terraces along the Little Colorado River, which are dated by the K-Ar method as between 1 and 3 million years old (Damon and others, 1974). The stratigraphically younger Jeddito Formation of Hack (1942) consists of at least four major depositional units, which, according to available carbon-14 and mammal-age dating, are of middle to late Pleistocene age. Time-stratigraphic analyses of Hack's (1942) Tsegi and Naha Formations indicate a series of short-term cycles of deposition in post-Altithermal (post-5,500 years before present) time. Those depositional events in the project area that have been directly dated by carbon-14, tree rings, and archaeology corroborate the regional paleoclimatic record reconstructed from a synthesis of southwestern bioclimatic, geoclimatic, and archaeological data (Hevly and Karlstrom, 1974; Karlstrom and others, 1974).

IGNEOUS ROCKS

Mantle-derived tholeiite, Elko County, Nevada

R. R. Coats, E. H. McKee, and R. K. Mark (USGS), in collaboration with C. L. Hu (University of California at Los Angeles) and H. R. Bowman and F. Asaro (Lawrence Berkeley Laboratory), found that the youngest Tertiary volcanic rocks along the northern border of Elko County, Nevada (loc. 12), are low-alkali olivine tholeiites (Mark and others, 1975). Rubidium content and high $^{87}Sr/^{86}Sr$ ratios indicate that these rocks were probably formed by partial melting of a mantle that was depleted in rubidium and strontium at a period less than 1 billion years ago and possibly somewhat more recently. All these basalts occur where basement rocks may be as old as late Precambrian. The oldest episode of basaltic volcanism in the area is recorded by basalts and gabbroic intrusions in the generally allochthonous Valmy Formation (Ordovician).

Two-mica plutons in Nevada

In a regional study of granitoids in the Basin and Range province, D. E. Lee recognized several distinctive two-mica granites alined along a north-south trend in northeastern Nevada (loc. 13). One of these unusual two-mica plutons was studied in detail by Lee and Van Loenen (1971), who ascribed its distinctive nature to assimilation of uppermost Precambrian Osceola Argillite of Misch and Hazzard (1962). Similar plutons have since been found in the northern Snake Range, the Kern Mountains (Lee and others, 1973), and the Toana Range, and, from their geologic setting, it is possible that each may also owe its distinctive nature to assimilation of upper Precambrian argillitic rocks.

Whatever the origin of these unusual two-mica plutons, it seems significant that they are alined along a northerly trend that coincides closely with Zartman's (1974) boundary between two different lead types. The area east of the pluton alinement contains lead derived principally from the Precambrian crystalline basement, whereas the area west of the alinement contains isotopically homogeneous lead derived from sedimentary deposits whose main source was Precambrian rocks exposed nearby. The unusual two-mica granites may have resulted from actual anatexis of upper Precambrian argillitic rocks along the hinge line separating lead types I and II of Zartman.

Complete chemical analyses were obtained for muscovite and biotite concentrates from these plutons, and their compositions are remarkably similar. The muscovites are phengitic, and each of the biotites contain about 6.0 percent MgO, except for one that has only 3.83 percent MgO. These results may be of interest to experimental mineralogists studying biotite and muscovite.

Cenozoic igneous rock patterns, Nevada and Utah

J. H. Stewart, W. J. Moore, and Isidore Zietz reported that Cenozoic igneous rocks within several age increments in Nevada and western Utah (loc. 13) are exposed in arcuate, generally east-trending belts, which become successively younger southward. The pattern seems to reflect a southward-migrating front of igneous activity that began about 43 to 34 million years ago near lat 40° N. and ended about 17 to 6 million years ago near lat 37° N. Broad aeromagnetic highs with superimposed high-frequency anomalies are associated with some of these outcrop belts. Mineral deposits are alined along the east-trending belts in easternmost Nevada and western Utah. During any one time interval, igneous activity was concentrated near the leading edge of the east-trending volcanic front, which may have been related to magma generation localized along a southward-propagating transverse rupture or structural warp in a subducting lithospheric plate.

Middle Tertiary plutonism, Santa Catalina Mountains, Arizona

Geologic mapping in the region east and north of Tucson, Ariz. (loc. 14), by S. C. Creasey, N. G. Banks, R. P. Ashley, and T. G. Theodore documented extensive middle Tertiary plutonism in the Santa Catalina Mountains and nearby Tortolita Mountains. Potassium-argon dating by Creasy and fission-track dating by Ashley indicated that a composite batholith was emplaced during late Oligocene time coincident, or nearly so, with widespread penetrative deformation that produced the enigmatic gneiss of the Santa Catalina Group and related gneissic rocks in the Tortolita Mountains. Regional structural and petrologic similarities, combined with previously published geochronologic data, suggest that these rocks are part of a broad zone of middle Tertiary granitic plutonism that extends northwesterly for more than 130 km. Locally, copper mineralization was spatially related to these plutons, but generally they are remarkably unaltered.

GEOCHRONOLOGIC STUDIES

Metamorphic ages, Toiyabe Range, Nevada

Three K-Ar age determinations on Cambrian phyllites from different localities in the Toiyabe Range (loc. 15) yielded distinctively different ages. E. H. McKee determined an age of about 30 million years on phyllite south of Austin, Nev. This metamorphic age is coincident with widespread late Cenozoic igneous activity in central Nevada. Poole and McKee (1974) previously reported two different metamorphic ages on Cambrian phyllites in separate thrust plates at Wall Canyon in the southern Toiyabe Range. One sample from autochthonous lower plate rocks yielded an age of about 73 million years that coincides with Cretaceous plutonic events, and the other sample from allochthonous upper plate rocks yielded an age of about 338 million years that coincides with Mississippian orogenic events.

Age of Rubio Peak Formation, Black Range, New Mexico

D. C. Hedlund reported that andesite and hornblende latite lava flows with thin interbeds of sandstone and tuff underlie the Sugarlump and Kneeling Nun Tuffs over a large area in the Black Range and on the Santa Rita horst west of the Mimbres fault in southwestern New Mexico (loc. 16). In many parts of the Black Range, the Sugarlump Tuff is absent, and the Kneeling Nun Tuff, which has been dated as 33.4 ± 1.0 million years by the K-Ar method (McDowell, 1971), rests directly on the Rubio Peak Formation.

The Rubio Peak Formation was named by Elston (1957) after a prominent butte in the Dwyer quadrangle and was later mapped and further described by Hernon, Jones, and Moore (1964) in the nearby Santa Rita quadrangle. On the basis of floral assemblages in associated lake beds, the Rubio Peak(?) Formation was regarded as late Miocene or early Pliocene in age (Jahns and others, 1955; F. J. Kuellmer, New Mexico Bureau of Mines and Mineral Resources, written commun., 1960), and an early Miocene(?) age was accepted by Hernon, Jones, and Moore (1964) for similar latite, rhyodacite, andesite, and volcaniclastic rocks in the Santa Rita quadrangle. Potassium-argon mineral dates of 36.4 ± 2.3 million years on hornblende and 32.6 ± 2.1 million years on plagioclase determined by R. F. Marvin, H. H. Mehnert, and V. M. Merritt (written commun., 1975) indicated that andesite and hornblende latite lava flows underlying the Kneeling Nun Tuff are of early Oligocene age.

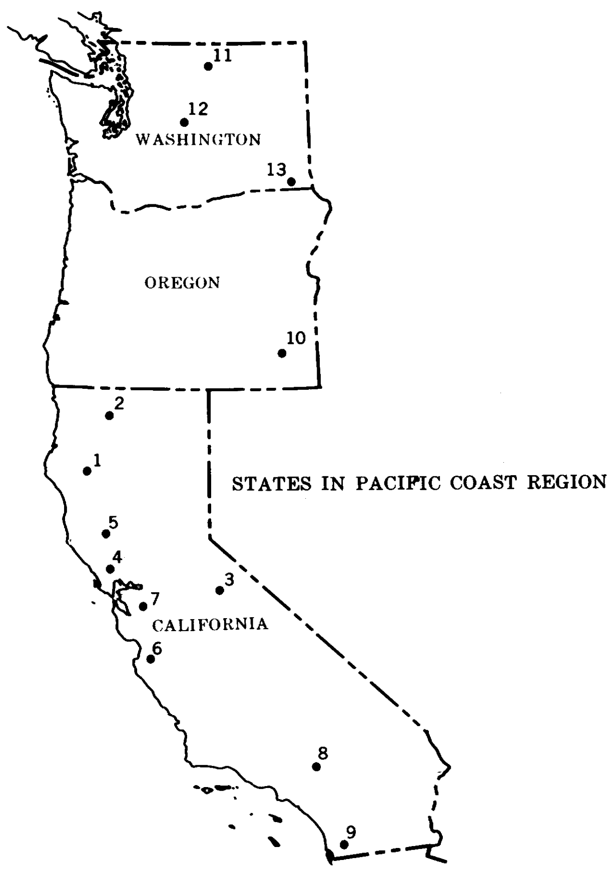
In the Black Range, there is evidence of an unconformity below the Kneeling Nun and Sugarlump Tuffs, and coarse pebbly sandstones are locally common at the contact with the underlying Rubio Peak Formation. Because the Kneeling Nun Tuff has an isotopic age of 33.4 ± 1.0 million years, the hornblende age of 36.4 ± 2.3 million years is more acceptable for the Rubio Peak Formation.

PACIFIC COAST REGION

CALIFORNIA

Early Cretaceous metamorphic age, South Fork Mountain Schist, northern Coast Ranges

New K-Ar measurements made by M. A. Lanphere, M. C. Blake, Jr., and W. P. Irwin in the northern Coast Ranges of California (index map, loc. 1) indicated that the blueschist mineral assemblages in the South Fork Mountain Schist and Chinquapin Metabasalt Member were formed during an Early Cretaceous metamorphic event. The two units were formally named by Blake, Irwin, and Coleman (1967) for exposures in the Picket Peak quadrangle and by definition are restricted to completely recrystallized rocks of textural zone 3. Ages ranging from 114 to 120 million years were measured on whole-rock samples from the Yolla Bolly and Black Mountain quadrangles by the $^{40}Ar/^{39}Ar$ technique of K-Ar dating. Ages ranging from 90 to 145 million years have been reported for the South Fork Mountain



Schist, but part of this scatter results from including rocks that are not from the South Fork Mountain Schist as it is formally defined. The age of 114 to 120 million years is compatible with the hypothesis that the South Fork Mountain Schist resulted from metamorphism of Upper Jurassic and Lower Cretaceous Franciscan rocks during the upper part of the Lower Cretaceous.

Subdivision of the Gazelle Formation

Geologic mapping by P. E. Hotz in the northwestern China Mountain quadrangle of California (loc. 2) showed that the Gazelle Formation (Middle and Upper Silurian) is divisible into a lower member and an upper member. The lower member has a highly varied lithology consisting of discontinuous bodies of spilitic volcanic rocks near its base, volcanic wackes, local arkosic wackes, shale, plentiful chert, chert-particle sandstone, chert-pebble conglomerate, chert breccia, and limestone. The upper member, which is conformably above the lower member and in part of a lateral equivalent of the upper part of the lower member, is well-bedded to massive volcaniclastic siltstone and sandstone in its upper part. Great lateral and vertical heterogeneity and pervasive faulting in some areas suggest that the lower member may be in part a tectonic mélange or broken formation.

Relative depths of plutons within the Sierra Nevada batholith

H. W. Oliver made an analysis of the gravity data in the east-central Sierra Nevada (loc. 3), where anomalies of −5 to −40 mGal are associated with the most felsic plutons. Correlation with isotopic ages, where they are available, shows the gravity anomalies to be largest and broadest over the youngest Cretaceous plutons, the suggestion being that they are significantly thicker than the older plutons.

Pliocene and Pleistocene deformation, Coast Ranges north of San Francisco

Structural studies by K. F. Fox, Jr., C. E. Meyer, and E. C. Schwarzman revealed a substantial contrast in the intensity of folding of Pliocene and Pleistocene strata in Marin, Sonoma, and Napa Counties, California (loc. 4), near the western edge of the North American plate. The average dip of that part of the deposits west of the north-trending valley between Healdsburg and Petaluma is 5.8°, whereas east of this valley the average dip is 34.5°. This difference in deformational intensity defines two structural blocks, the Sebastopol on the west and the Santa Rosa on the east. The relatively flat-lying deposits in the Sebastopol block are Pliocene marine sandstone with minor intercalated conglomerate and one widespread layer of pumice lapilli tuff dated at about 6 million years old. These beds nearly abut the N. 40° W.-trending San Andreas fault on the west and are cut by several N. 60° W.-trending dip-slip faults. The relative lack of deformation of the Pliocene rocks in this area suggests that they were deposited after the northwestward transit of the Mendocino triple junction. This hypothesis is based on the premise that the extreme deformation of Miocene and Pliocene rocks in the vicinity of Cape Mendocino was caused by northwestward movement of the triple junction and that a wake of similarly deformed rocks should lie along its path to the southeast. Consequently, the average right-lateral offset of the triple junction opposite the central Coast Ranges could not have exceeded about 4 cm/yr for the last 6 million years.

Distribution of basement lithologies shows no correlation with the Pliocene and Pleistocene structural domains; therefore, the contrasting deformational intensities probably stem from peculiarities in the pattern of regional stress distribution since the transit of the triple junction and not from a contrast in the rheological properties of the basement rocks.

Landslide complex near The Geysers steam field reinterpreted

Geologic mapping by F. E. Goff and R. J. McLaughlin in The Geysers geothermal region southeast of Cobb Mountain in California (loc. 5) suggested that an area formerly considered to be a large landslide complex is instead a tectonic feature of downfaulted blocks. These faults, together with the northwest-trending active Collayomi fault and Quaternary Cobb Mountain fault, offset contacts in the 1-million-year-old rhyodacites forming the Cobb Mountain volcanic pile as much as 244 m vertically. Because 5 km^3 or more of magma was extruded, this downdropped area southeast of Cobb Mountain may have resulted from posteruption subsidence of the emptying magma chamber.

Significance of age relationships of rocks above and below Upper Jurassic ophiolite, The Geysers-Clear Lake area

Recent field investigations conducted by R. J. McLaughlin (USGS) and dating of pre-Tertiary rocks by E. A. Pessagno (University of Texas) in The Geysers-Clear Lake region of California (loc. 5) demonstrated that deformed and metamorphosed strata of the Franciscan assemblage are significantly younger than ophiolitic rocks and overlying basal Great Valley sequence strata that override the Franciscan along the regional Coast Range thrust. Pelagic cherts containing locally abundant, well-preserved radiolaria are present in the Franciscan assemblage, and Pessagno studied radiolaria from several of these chert localities. Preliminary data indicated that some of these cherts are as young as late Hauterivian or early Barremian (McLaughlin, 1976), but more recent data now indicate an age range of early Tithonian to early Cenomanian (Late Jurassic to early Late Cretaceous); an apparent hiatus in pelagic sedimentation occurs between the Hauterivian and late Albian (middle to late Early Cretaceous).

Radiolaria from tuffaceous chert associated with pillow basalts in the ophiolitic rocks of the upper plate of the Coast Range thrust are late Kimmeridgean in age (pre-Tithonian), the indication being that the youngest and oldest Franciscan rocks in this area are clearly younger than the structurally overlying ophiolite.

The whole-rock K-Ar ages from two blueschist-grade metagraywacke samples from The Geysers area, furthermore, indicate that blueschist metamorphism occurred approximately between 112 and 119 million years ago, a date approximately corresponding to the gap in pelagic sedimentation suggested by paleontologic data. Thus, this depositional gap may indicate a period of subduction that occurred between Hauterivian and late Albian time.

Correlative late Cenozoic tephra, California and western Nevada

Results of neutron-activation analysis of volcanic glass separated from ashes and tuffs in California and western Nevada made it possible to correlate several upper Pliocene and Pleistocene formations and identify several widespread, well-dated stratigraphic markers that provide age control for late Cenozoic tectonism (uplift, subsidence, folding, and faulting) in these regions. Some recent results are:

- An ash-flow tuff in the Huichica Formation north of San Pablo Bay in the San Francisco area of California is correlated with the upper of two water-laid tuffs in the Livermore Gravel of Clark (1930) south of the town of Livermore, Calif., and with a water-laid or air-fall tuff found near the base of the Paso Robles Formation in the central Coast Ranges. A recent date by M. A. Lanphere and G. B. Dalrymple on the tuff in the Huichica Formation gave an age of 3.94 ± 0.18 million years, which, together with the trace-element correlation, dates these formations as late Pliocene. This absolute-age date is the first obtained for the Paso Robles Formation.
- A water-laid tuff situated stratigraphically near the top of the marine Etchegoin Formation in the Kettleman Hills of California is correlated with the Lawlor Tuff as ash flow interbedded with continental deposits at several localities in the east-central Coast Ranges to the north. The Lawlor Tuff correlates locally with the lower of the two tuffs in the Livermore Gravel mentioned above. A previous K-Ar age on the type Lawlor Tuff gave an age of 3.96 ± 0.18 million years. The ages are in good agreement with all observed stratigraphic relations.
- Correlatives of an ash in the type section of the marine Merced Formation south of San Francisco have been found in unnamed continental Pleistocene beds west of Hollister, Calif., in the central Coast Ranges and in unnamed continental Pleistocene sediments near the Washoe Valley in Nevada, studied by R. W. Tabor and S. D. Ellen. Recent K-Ar ages determined by Dalrymple and Lanphere on the ash in the

Merced Formation are scattered: 0.44 ± 0.18, <0.7, 0.7 ± 0.5, 1.1 ± 0.5, 2.1 ± 0.3, and <2.2 million years. The older ages probably reflect detrital contamination in the water-laid ash. A previous fission-track age on zircons from this ash determined by C. W. Naeser gave an average age of 1.1 ± 0.4 million years with a spread of 0.4 to 2.0 million years, identical to the spread obtained in the K-Ar analyses. A recent fission-track age on the ash in the Washoe Valley determined by Naeser gave an age of 0.86 ± 0.24 million years.

A Pelona-Orocopia Schist correlative(?) in the Salinian block

Field investigations in the basement terrane of the Salinian block of California (loc. 6) by D. C. Ross delineated a schist (metagraywacke) terrane of several hundred square kilometers stretching across parts of the Santa Lucia and Gabilan Ranges and presumably cut off by the San Andreas fault on the southeast. These rocks, although intruded locally by granitic rocks of presumably middle Cretaceous age, are tentatively interpreted to be a dislocated fragment of the Pelona-Orocopia Schist terrane of southern California. The metagraywacke belt puts restrictions on postgranitic slivering of the central Salinian block but, if the correlation with the Pelona-Orocopia Schist is valid, does suggest significant pregranitic dislocation to allow insertion of what is most likely a Mesozoic belt (the metagraywacke) into what has generally been guessed to be a Paleozoic terrane (the other metamorphic rocks of the Salinian block).

Relation of oil accumulations to tectonics of San Andreas fault system

An analysis of the regional geology of the Coast Range province of central and northern California (loc. 7) as interpreted by T. W. Dibblee, Jr., indicated that the accumulations of petroleum and gas in the basins of Upper Cretaceous and Tertiary marine sedimentary sequences are probably directly related to (1) long-continued horizontal (right-slip) movements on the San Andreas fault and related parallel northwest-trending faults that transect this province and (2) related clockwise distortion of the whole province. The deep sedimentary basins are elongated in a more westerly direction than the faults and appear to have formed between upwarps of the same trend adjacent to or between the faults. The oil and gas accumulated where the sedimentary series is being deformed into anticlinal or other closed structures en echelon near or adjacent to the faults and where the sedimentary series has not yet been severely eroded.

Youthful-appearing fault scarps, San Bernardino Mountains

Fault scarps occur intermittently for about 80 km along the base of the northern side of the San Bernardino Mountains in California (loc. 8). Mapping by F. K. Miller indicated that the scarps are in varying degrees of preservation ranging from highly dissected to extremely youthful in appearance. They range in height from ½ to 60 m. In general, the larger scarps are more highly dissected. They are commonly lobate in form, concave toward the mountain range. The zone is roughly linear along the eastern half of the range but has a northward bulge in the western half. At its western end, the zone trends south-southwest and then almost east-west to within about 1.5 km of the San Andreas fault zone. The $17{,}000 + C^{14}$-year-old Blackhawk landslide appears to cover one of the more dissected scarps, but the age of the youngest looking features has not been determined. Because of the youthful appearance of many of the scarps, the zone should probably be considered active.

Age of metamorphic and plutonic rocks, San Diego County

Potassium-argon ages on biotite and hornblende from 18 metamorphic and plutonic rocks in the Cuyamaca Peak and Mount Laguna 15-min quadrangles (loc. 9) of southern San Diego County, California, by V. R. Todd and W. C. Hoggatt ranged from 91 to 99 ± 3 million years. All plutons have a strong, steeply dipping, north-northwest-striking foliation that is both synintrusive and postintrusive in age. It is parallel to walls of plutons emplaced along the north-northwest structural grain but crosses east-west-trending interplutonic contacts at high angles. This foliation has been folded on a large scale. In thin section, the plutonic rocks show evidence of postmagmatic, synkinematic recrystallization of all minerals, including biotite and hornblende. The same metamorphism affected both plutonic rocks and a sequence of deep-water sedimentary and volcanic rocks previously called the Julian Schist and thought to have been metamorphosed in a prebatholithic (Jurassic?) event. The main metamorphic episode in this part of the Peninsular Ranges batholith accompanied intrusion and continued for some time after emplacement of the youngest intrusive units. The K-Ar data indicated that the rocks cooled through the range of hornblende and biotite closure no earlier than 99 million years ago, but this figure probably does not indicate the age of emplacement.

OREGON

N. S. MacLeod and E. H. McKee reported that the K-Ar ages of rhyolites in southeastern Oregon (loc. 10) and published histograms of dated volcanic rocks from the Cascade Range in Oregon and the Snake River Plain in Idaho show similar peaks of volcanism at about 15 million years, between 5 and 10 million years, and from 0 to 2 million years. Periods of very low volcanic activity are centered at about 13 and 2.5 million years in the three areas. The calc-alkaline volcanic rocks of the Cascade Range differ from the bimodal basalt-rhyolite association of the Snake River Plain and southeastern Oregon. Furthermore, rhyolitic rocks in the Snake River Plain become progressively younger toward the east, in contrast to those in Oregon, which are younger toward the west. In southeastern Oregon, initiation of the westward progression of rhyolitic vents began about 10 million years ago at about the start of the middle peak of volcanism, and the rate of progression decreased 2 to 3 million years ago; this period corresponds to the period of decreased volcanism over the entire region from the Cascades to the Snake River Plain. The volcanic rocks in the three areas are not likely to be related in their mode of genesis, but the common peaks of volcanism suggest a regional tectonic control that influenced ascension or generation of magmas. These peaks probably correspond to periods of east-west extension.

WASHINGTON

Pre-Eocene emplacement of the Okanogan gneiss dome documented

The Okanogan gneiss dome of Washington (loc. 11) for some time was considered to be pre-Eocene in age on the basis of a number of moderately discordant radiometric ages and indirect evidence. Incontrovertible field documentation, however, was not forthcoming until recently. Near the eastern margin of the dome about 16 km west of Republic, Wash., cobbles of lineated cataclastic granitoid gneiss—a rock type that is characteristic of and is extensively exposed throughout the dome—were found by C. D. Rinehart in basal conglomerate beds of the Klondike Mountain Formation (Eocene). Nearby, fossiliferous correlatives of the conglomerates are middle Eocene in age, and biotite and hornblende from overlying lavas in the same formation yielded K-Ar ages of about 47 million years, also middle Eocene.

Early Pleistocene faulting in Kittitas Valley

According to R. B. Waitt, Jr., three east-trending, north-facing fault scarps in a dextral, en echelon arrangement disrupt lower Pleistocene terrace gravel as well as the unconformably underlying Ellensburg Formation and Yakima Basalt (Miocene and Pliocene) of Washington. The fault zone is 6 to 9 km south of, and antithetically related to, the steeply south-southwest-dipping lower part of the Yakima Basalt that defines the northern side of the Kittitas Valley (loc. 12). The Kittitas Valley faults resemble much larger structures on the northern flanks of several large anticlines to the south and east—faults that are down to the north, that individually strike east, but that collectively form a vague, northwest-trending, dextral, en echelon pattern (R. D. Bentley, personal commun., 1975). At least some of these anticlines show evidence of Quaternary activity (Bingham and others, 1970), as does a probably related structure, Badger Mountain, farther north (Hanson, 1970). The Kittitas Valley fault zone also parallels the interregional Olympic-Wallow lineament (Raisz, 1945; Wise, 1963), whose interpolated trend is 19 to 23 km to the southwest.

The gravel cut by the faults is side-stream debris that is graded to and overlies Yakima River mainstream gravel, which Porter (1976) interpreted as outwash and named Thorp Drift. Preliminary paleomagnetic data (Porter, 1976) suggest that the upper part of the Thorp gravel accumulated during the Matuyama reversed geopolarity epoch, 0.69 to 2.43 million years in age (Cox, 1969). Side-stream terraces graded to the next youngest outwash—Kittitas Drift of Porter (1976) (0.12 million years in probable age)—are not disrupted by the faults. The faulting, therefore, evidently occurred between 0.12 and 2.5 million years ago.

Magnetostratigraphic units in the Yakima Basalt

Stratigraphic subdivision of the lower part of the Yakima Basalt (Miocene and Pliocene) of Washington is difficult because of the scarcity of widespread, petrographically distinct flows. D. A. Swanson and T. L. Wright used a portable fluxgate magnetometer to delineate four mappable magnetostratigraphic units along the Snake River and in the Blue Mountains of southeastern Washington and adjacent Oregon (loc. 13). Only samples from oxidized parts of flows were found to give consistent polarity determinations; nonoxidized samples from flow interiors commonly gave ambiguous results. The four magnetostratigraphic units, generally consisting of 20 to 30 flows, are designated from oldest to youngest—R_1, N_1, R_2, and N_2 (R indicates reverse polarity and N normal polarity). Unit R_1 overlies the Imnaha Basalt as used by Hooper (1974) in the Lewiston downwarp. A saprolite commonly separates N_2 from the overlying Frenchman Springs Member of the Yakima (normal polarity), but the two units are locally interbedded, the indication being that both belong to the same polarity interval. The gradual westward thickening of the magnetostratigraphic units, and of the overlying units, suggests the filling of a broad basin centered near Pasco throughout much of Yakima time. Offset contacts between magnetostratigraphic units indicate a maximum displacement of about 325 m along the previously mapped Hite fault, a northeast-trending normal fault east of Walla Walla, Wash. A newly recognized south-facing monocline near Oregon Butte has a structural amplitude of 235 m, as deduced from the magnetostratigraphy. Mapping of magnetostratigraphic units should prove to be an important means of subdividing and correlating the Yakima Basalt across the entire Columbia Plateau.

ALASKA

Significant new scientific and economic geologic information has resulted from many regional and topical investigations conducted in Alaska during the past year. Discussions of the recent findings of these studies are grouped under four major geographic regions and a general statewide category.

GENERAL

New Bouguer gravity map of Alaska

A new Bouguer gravity map of Alaska at a scale of 1:2,500,000 was prepared by D. F. Barnes (1976). The map was compiled from about 30,000 Alaskan land gravity measurements plus approximately 40,000 km of surface ship gravimeter traverses over the bordering continental shelves. Gravity datum for the map was obtained from the 1971 International Gravity Standardization Net, and the data reduction used the 1967 International Reference Ellipsoid and a density of 2,670 kg/m^3. The map may eventually aid in solving several types of problems in different physical sciences such as geodesy, geophysics, and geology. It provides a method for calculating the gravitational acceleration in various parts of Alaska and for removing regional gradients from local gravity surveys. Preliminary interpretations provided by a short text and an inset on the map include 5-km contours of crustal thickness estimated from the gravity data; locations of interior structural basins filled with Cenozoic sediments and sedimentary rocks; and linear to arcuate gravity highs locally associated with mineralization and (or) former plate boundaries.

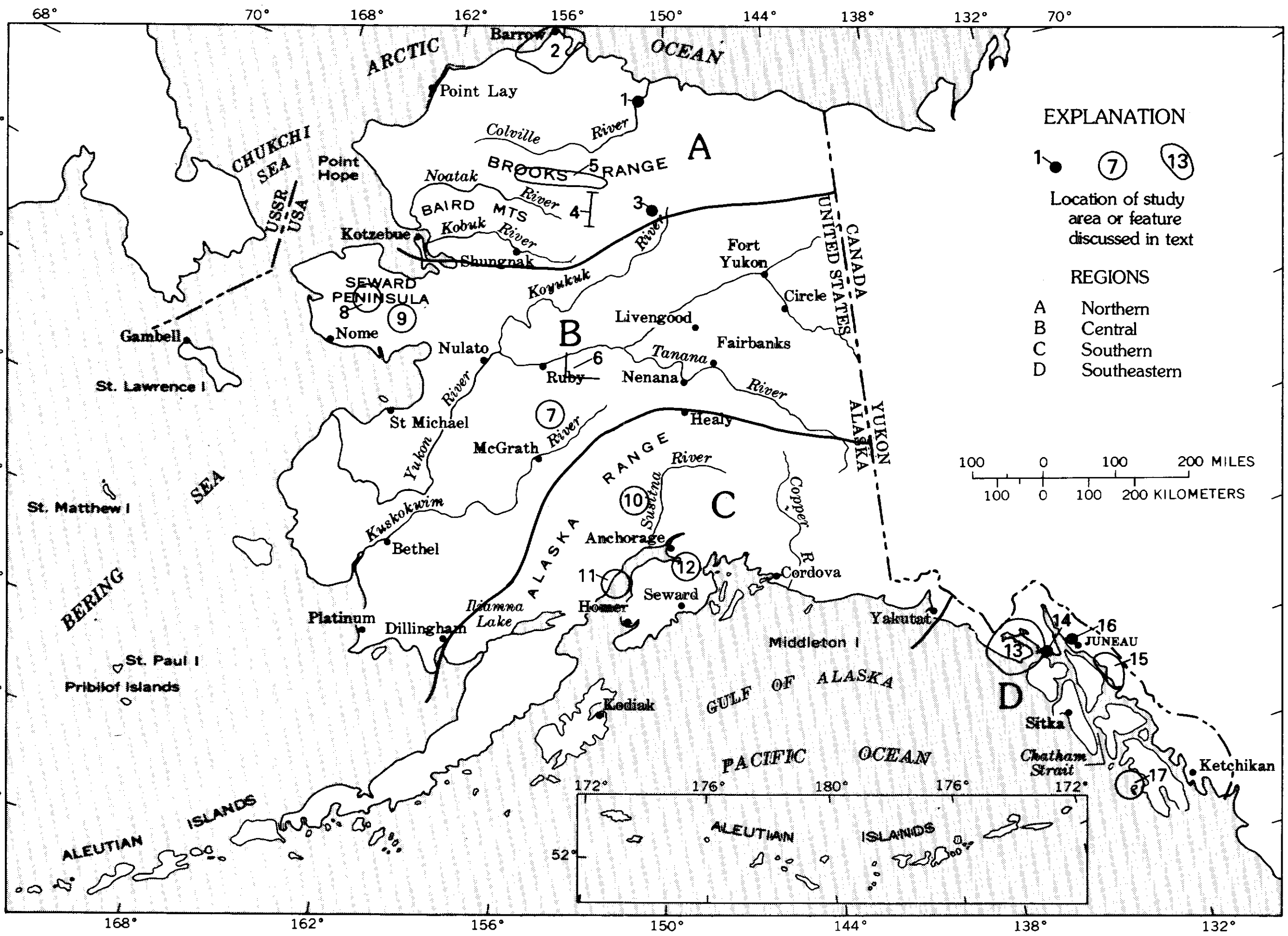
New geologic map of Alaska

A new geologic map of Alaska at a scale of 1:2,500,000, which will supersede the map previously published in 1957, is being prepared by H. M. Beikman. The map is an entirely new compilation that synthesizes and summarizes all available data from Federal, State, and other agencies. Uncolored geologic maps at a scale of 1:1,000,000, which are preliminary compilations upon which the final multicolor map is based and which were published as soon as they were completed, include MF–611 (Beikman, 1974b), covering the southwestern part of the State; MF–612 (Beikman, 1974a), covering the south-central part; MF–673 (Beikman, 1975a), covering the southeastern panhandle; and MF–674 (Beikman, 1975b), covering the Alaska Peninsula and the Aleutian Islands. Compilation of the geology of the northern part of the State is now completed. A preliminary uncolored geologic map of the entire State at 1:2,500,000 is available, and the multicolored map is being prepared. This new geologic map of Alaska will be accompanied by a report in which the stratigraphic units are briefly described.

NORTHERN ALASKA

Neogene marine clay recognized at Ocean Point, arctic coastal plain

At Ocean Point, Alaksa (loc. 1, index map), an exposure on the lower Colville River yielded mollusks indicative of the Beringian transgression (Pliocene). These mollusks are generally thought to have come from the Gubik Formation (MacNeil, 1957; Hopkins, 1967). The underlying clays have been assigned to the Sentinel Hill Member of the Schrader Bluff Formation (Brosgé and Whittington, 1966; MacBeth and Schmidt, 1973). A recent detailed reexamination by L. D. Carter showed, however, that the com-



pact clay is much younger than Cretaceous and could more appropriately be assigned to the Nuwok Member of the Sagavanirktok Formation of Detterman and others (1975). The clay contains foraminifera and ostracodes indicative of a Neogene age, along with a few tests redeposited from Cretaceous beds. Reexamination of Schrader's (1904) original description of the Gubik Formation at Ocean Point shows, furthermore, that the original collection of Beringian or Pliocene mollusks came from the clay and not from the overlying Gubik Formation, as MacNeil indicated. The discovery is important because continuing study may show that this section has recorded the first arrival of Pacific marine organisms and thus provided a record of the first opening of Bering Strait; it will also force a reconsideration of the late Cenozoic tectonic history of the arctic coastal plain.

Reinterpretation of part of the Gubik Formation, arctic coastal plain

New collections of molluscan fossils from Skull Cliff, Alaska (loc. 2), and reexamination of many older collections from the Gubik Formation between Peard Bay, Point Barrow, and the Meade River coal mine resulted in a greatly changed age assignment for and a reinterpretation of ancient deposition and climatic conditions. These beds, originally believed to be early Pleistocene (Hopkins, 1967), are now shown to be of late Pleistocene age, deposited during the Pelukian (last interglacial) transgression. Peculiar features such as the presence of erratic boulders, zones of muddy gravel and peaty sand, and local folded zones are shown to be typical diagnostic features of arctic beach and shallow-marine sediments. However, the faunas indicate that the water temperatures were warmer than they are at present. The discovery of a fossil sea otter skull more than 1,000 km north of the present range of the sea otter indicates that the winter ice cover was less complete and of a shorter duration than it is at present. The Pelukian shoreline now lies more than 50 km inland, and the unusually high position of the Pelukian beds above present sea level provides evidence of substantial uplift of the westernmost arctic coastal plain during the last 125,000 years.

This study, carried out by D. M. Hopkins (USGS) and O. M. Petrov (Geological Institute, Academy of Science, Moscow, U.S.S.R.), is one of the results of the U.S.A.-U.S.S.R. Academy of Science Exchange Program.

Doonerak structural high, central Brooks Range

Rocks in the Doonerak antiform (loc. 3) resemble correlative sequences in the northeastern Brooks Range of Alaska, according to J. T. Dutro, Jr., W. P. Brosgé, M. A. Lanphere, and H. N. Reiser. Mafic dikes in the antiform have K-Ar ages of about 380 million years (Devonian) and 470 million years (Ordovican). They intrude low-grade metamorphic rocks and associated volcanic rocks that are probably of Cambrian or Ordovician age. These lower Paleozoic units are unconformably overlain by Carboniferous to Triassic strata. The antiform is bounded on both the north and the south by faults. One hypothesis calls for two separate faults. The southern fault is believed to have thrust Middle and lower Upper Devonian rocks northward onto phyllites on the southern flank of the antiform. A separate northern fault is interpreted as a south-directed thrust that moved rocks of Late Devonian age and younger southward over Carboniferous rocks on the northern flank. This interpretation implies that the rocks of the north-central Brooks Range are mainly autochthonous and that the rocks directly beneath them would be similar to strata of Middle Devonian age and older now found in the core of the Brooks Range south of the Doonerak antiform.

Central Brooks Range structural transect

A structural transect of the central Brooks Range (loc. 4) from the Schwatka Mountains across the Endicott Mountains in the Killik River area of Alaska was made by C. G. Mull, I. L. Tailleur, and C. H. Mayfield (USGS) and G. H. Pessel (Alaska Division of Geological and Geophysical Surveys). The transect provides evidence that the northern Endicott Mountains are allochthonous. North-dipping metamorphosed clastic carbonate rocks of the Endicott and Lisburne Groups (Devonian and Mississippian) in the northern Schwatka Mountains are concordantly overlain by a north-dipping thrust sequence. This apparently allochthonous complex forms most of the Endicott Mountains and consists mainly of the Hunt Fork Shale and Kanayut Conglomerate (Devonian) and the Kayak Shale (Mississippian) of the Endicott, the Lisburne Group (Mississippian), and the Siksikpuk Formation (Permian). A distance of 80 km between the subthrust Lisburne in the south and the northern limit of allochthonous Lisburne outcrops in the Killik River area represents the minimum tectonic transport of the allochthon. Regional stratigraphic relationships date the large-scale thrust transport as Early Cretaceous. Evidence that the rocks of the northern Endicott Mountains are allochthonous and originally lay south of the subthrust rocks in the middle of the Brooks Range will substantially alter the regional isopach and facies maps of many of the rock units of the central Arctic Slope.

Brooks Range olistostrome

C. G. Mull's examination of exotic blocks of older competent rocks enclosed in Lower Cretaceous mudstone provided evidence that many of those rocks are chaotics developed depositionally rather than tectonically. These deposits indicate an olistostrome that may be recognized in areas extending from the De Long Mountains (loc. 5) eastward into the Killik River quadrangle and possibly the Chandler Lake quadrangle of Alaska. These olistostrome deposits occur with fossiliferous lowermost Cretaceous turbidites and polymict conglomerates deposited on differing sections that have been subsequently telescoped together by thrust faulting. Some of the olistoliths appear to have come from rocks in structurally higher allochthons. The penecontemporaneous tectonism indicated by these deposits confirms previous indications that large-scale tectonic shortening of the Brooks Range began in earliest Cretaceous time. In some areas, recognition of the olistostrome as a sedimentary unit rather than a complex tectonic chaos clarifies structural relationships that previously seemed anomalous and simplifies the structural interpretation.

CENTRAL ALASKA

Rampart Group, northeastern Ruby quadrangle

The Rampart Group and associated intrusive mafic rocks of Permian and probable Triassic age were mapped by R. M. Chapman and W. W. Patton, Jr., in the northeastern quarter of the Ruby quadrangle of Alaska (loc. 6). Basaltic rocks (probably both extrusive and intrusive), chert, and intrusive diorite-diabase-gabbro are most common; rhyolitic and tuffaceous rocks and rare thin-bedded limestone are present in minor amounts. Phyllitic and schistose metasedimentary rocks, apparently older Paleozoic rocks that underlie the Rampart Group unit, have been found in a few places. This area generally has low relief and is heavily mantled by vegetation, silt, and vegetated silt-sand dunes; thus, only scattered exposures of the more resistant bedrock are found on ridge tops and in small cutbanks.

The Rampart Group unit in this area extends eastward 56 to 80 km from the Nowitna River to the eastern limit of bedrock exposures and is a continuation, interrupted by the wide Nowitna River lowland, of a similar large belt of these rocks in and to the west of the Ruby-Poorman area. Relationships of these rocks to the older Paleozoic metamorphic rocks in both areas substantiate the anticlinal nature of the Ruby geanticline in the Ruby quadrangle south of the Kaltag fault. The southern contact of the Rampart Group unit in this discontinuous belt may be a fault contact that lies along the Big Mud River and trends southwest through the Poorman area. This tentative interpretation is based on field observations of sheared older rocks close to the contact and a preliminary evaluation of the aeromagnetic survey map of the western half of the Ruby quadrangle.

Newly discovered Upper Triassic and Lower Cretaceous strata, northern Kuskokwim Mountains

An unreported section of Upper Triassic and Lower Cretaceous strata was discovered in the Medfra quadrangle in the northern Kuskokwim Mountains of Alaska (loc. 7) by W. W. Patton, Jr., J. T. Dutro, Jr., and R. M. Chapman. The Upper Triassic and Lower Cretaceous section is exposed in a narrow band around the eastern and northern perimeter of the Kuskokwim geosyncline. It overlies Paleozoic carbonate and clastic rocks of the Ruby geanticline and underlies middle and Upper Cretaceous clastic rocks of the Kuskokwim geosyncline. The Upper Triassic sequence is 100 to 150 m thick and composed of calcareous sandstone, limestone, conglomerate, and chert with abundant *Monotis*. The Lower Cretaceous sequence conformably overlies the Upper Triassic and consists of about 100 m of calcareous sandstone, grit, shale, and coquinoidal limestone with *Buchia*.

This newly discovered Mesozoic section appears to have important implications for the tectonic history of central Alaska. Lithologically, it has strong affinities for coeval rocks in northern Alaska but contrasts sharply with the Permian to Lower Cretaceous island arc and oceanic volcanic assemblages that lie immediately to the north in the Yukon-Koyukuk province (Patton, 1973). The high content of carbonate and quartz detritus and the absence of volcanogenic debris suggest that the provenance of these strata was confined to the carbonate-quartzite-pelitic schist terrane of the Ruby geanticline.

It has been suggested that the Precambrian(?) and Paleozoic terrane of the Ruby geanticline represents a sliver of the Brooks Range-Seward Peninsula continental crust, which was rifted away at the end of the Paleozoic (Patton, 1970). From late Paleozoic to Early Cretaceous time, the wedge-shaped Yukon-Koyukuk province, situated between the Brooks Range-Seward Peninsula area and the Ruby geanticline, was a marginal sea or mini-ocean basin. Following this model, the nonvolcanic Upper Triassic and Lower Cretaceous section in the northern Kuskokwim Mountains may be interpreted as a clastic wedge that was deposited along the trailing edge of the rifted fragment.

Seward Peninsula not part of Alaska in Ordovician time

R. J. Ross, Jr. (USGS), and A. R. Ormiston (Amoco Production Co., Tulsa, Okla.) suggested that the distribution of the Ordovician trilobite *Monorakos* and its close relatives defines a zoogeographic province in the Siberian Platform, the Kolyma Platform, the Okhotsk Massif, and the Seward Peninsula of Alaska (loc. 8). In Ordovician time, these areas probably formed a single crustal plate distinct from North America and in a somewhat more northerly latitude. Subsequently, this continent broke apart and was later reconstituted along Mesozoic or Cenozoic sutures. The Seward Peninsula was not part of Alaska in Ordovician time.

Plutonic rocks, southeastern Seward Peninsula

Chemical analyses were done on samples collected by T. P. Miller from the Darby and Bendeleben plutons in the southeastern Seward Peninsula of Alaska (loc. 9). These analyses show that, although the plutons have about the same total iron content, their Fe_2O_3:FeO ratios are quite different. The Darby pluton has an Fe_2O_3:FeO ratio of 1.08, in comparison with a ratio of 0.16 for the Bendeleben pluton; the Darby pluton's higher ratio suggests that it had a higher oxygen pressure and thus a higher degree of water saturation than the Bendeleben pluton. This difference may reflect the water content of the granitic source rocks.

SOUTHERN ALASKA

Kenai Group, Talkeetna quadrangle

According to I. F. Ellersieck and Clyde Wahrhaftig, the Kenai Group in the Talkeetna quadrangle of Alaska (loc. 10) can be divided into two formations. The lower formation, which correlates with the "middle Kenai member" of Barnes (1966), can be divided further into two interfingering members: a conglomeratic facies and a sandy facies. The conglomeratic facies is a braided stream deposit, and the sandy facies is a cyclic meandering river deposit.

Subbituminous coal seams in the conglomeratic facies are generally thick (1.5 to 5 m) and relatively free of shaly partings. They are not likely to be continuous along a northeast-southwest direction for more than about 2 km. Coal seams in the sandy facies are thin (10 cm to 3 m), and contain many silt and bone partings. No seams were found that would be economically feasible for mining.

The upper formation of the Kenai Group, which correlates with the "upper Kenai member" of Barnes (1966), lies with slight unconformity on the lower formation of the Kenai and overlaps it to the northwest. The upper formation is a coarse conglomeratic braided stream deposit having a source area immediately northwest of the present edge of the Susitna River basin. It probably correlates with the Sterling Formation of Calderwood and Fackler (1972).

Rate of uplift, western side of Cook Inlet

Additional carbon-14 analyses were made on samples obtained by R. L. Detterman, T. L. Hudson, and J. M. Hoare from beach deposit material resting on top of bedrock terraces along the western shore of Cook Inlet, Alaska (loc. 11). A total uplift of 13.5 to 14.5 m over the last 2,500 years confirms an average uplift rate of 0.6 cm/yr.

Duration of sedimentation at Portage

Portage, Alaska (loc. 12), subsided about 2 m during the Alaskan earthquake of 1964 (Kachadoorian, 1965; McCulloch and Bonilla, 1970), and an area of approximately 18 km^2 was lowered into the intertidal zone of Turnagain Arm (Ovenshine, Lawson, and Bartsch-Winkler, 1976). Marine waters killed the forest, shrub, and grass in the area and rapidly deposited silt. By 1974, nearly 20×10^6 m^3 of silt had accumulated in a layer averaging 1.5 m thick on the seaward side of the Seward Highway and 0.9 m on the landward side (Ovenshine, Lawson, and Bartsch-Winkler, 1976). This change in the environment of the Portage area was dramatic and profound, but, in the last few years, there have been indications that sedimentation has slowed to the point that revegetation is beginning: grasses of several types have returned, and a few willows thought dead have sprouted new growth.

The sequence of events observed and inferred (subsidence → inundation → vegetation kill → deposition → revegetation) suggests that natural processes are restoring the Portage landscape to its pre-1964 condition, according to A. T. Ovenshine and Reuben Kachadoorian. Available geologic data on preearthquake sediments suggest that the cycle of subsidence and restoration has occurred at least twice previously during late Holocene time (Ovenshine, Lawson, and Bartsch-Winkler, 1976, fig. 3D).

Data available for estimating the rate of sedimentation in the Portage area are: 2 m (total subsidence that occurred in 1964), 5 cm/yr (rate of sedimentation measured over the interval August 1974 to August 1975), and 1.55 m (total thickness of sediment accumulated up to 1974). The thickness of the sediment deposited between March 1964 and August 1974 (1.55 m) and the thickness added during 1974–75 (5 cm) indicate a nonlinear buildup of sediment that should continue until a total of 2 m of sediment has accumulated.

A model for sedimentation derived from these data is shown in figure 5. The model is a curve giving the total thickness of sediment accumulated at any given time after the onset of deposition in 1964. The formula for the curve is:

$$A = S\ (1 - e^{kt}),$$

where A is the total thickness of sediment accumulated at time t, S is the total subsidence, $e = 2.718$, $k = -0.1492$, and t is the time in years since 1964. The constant K was determined at $S = 2$ m, $A = 1.55$ m, and $t = 10$ years. According to the formula, A for 11 years is 1.61 m, or 6 cm of deposition for the 1-year period 1974–75. This value compares favorably with the field measurement of 5 cm for the same 1-year period. The curve of figure 5 indicates that sedimentation in the Portage area will cease by 2014. However, the sedimentation will be approximately 98 percent complete by 1989.

A better estimate of the time required for sediment to accumulate to the preearthquake level would require: determination of sedimentation rates for at least 25 additional locations scattered over the Portage area (the present estimate is derived from

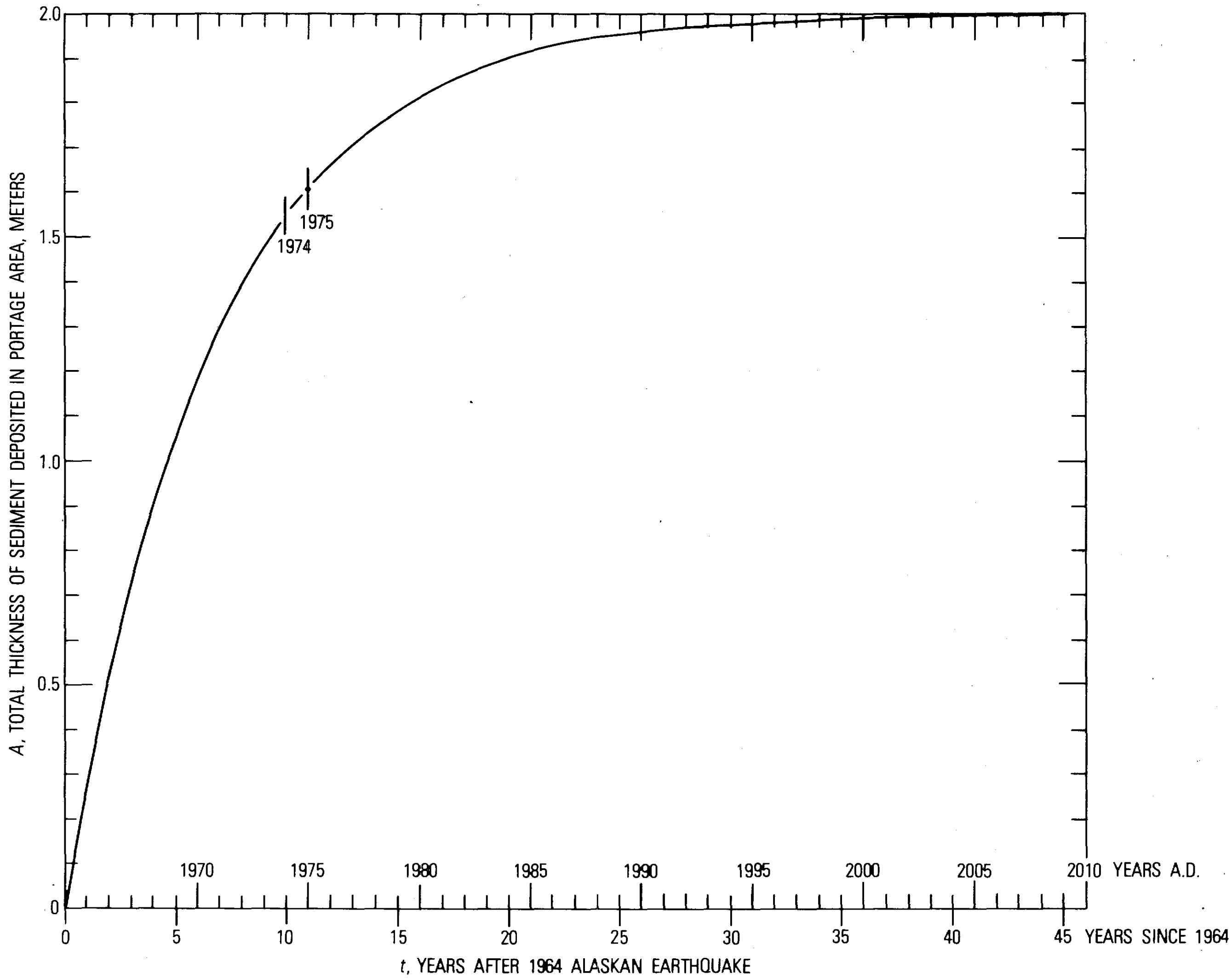


FIGURE 5.—Curve depicting the rate of buildup of the intertidal sediment surface at Portage, Alaska. The portion of the curve between the years 1974 and 1975 is based on field measurements; the remainder of the curve is calculated from the formula developed in this report. Sedimentation should cease in the early part of the next century as the total thickness of the deposit approaches 2.0 m, the amount that the land subsided during the 1964 Alaskan earthquake.

measurements made at only two sites); consideration of the increased effects of vegetation density on trapping sediment; an evaluation of the shift of depocenters landward as filling progresses; and a refinement of analysis and modeling. Without these refinements, Ovenshine and Kachadoorian suspect that their estimate of 45 years until the cessation of sedimentation is correct only within a factor of 2.

Although this analysis has developed only an estimate of the time required for natural restoration of the Portage area, it clearly shows that the pulse of sedimentation caused by the earthquake will be of very short duration in comparison with the scale of geologic time.

SOUTHEASTERN ALASKA

Glacier Bay National Monument study

Studies in Alaska's Glacier Bay National Monument (loc. 13) reported by MacKevett and others (1971) were recommenced as a result of a U.S. National Park Service plan to include the monument in the National Wilderness Preservation System. The current project is a joint effort of the USGS and the U.S. Bureau of Mines (USBM) involving D. A. Brew, Donald Grybeck, B. R. Johnson, K. M. Blean, Christine Carlson, and C. J. Nutt (USGS) and A. L. Kimble, Jan Still, Jean Rataj, and Al Clough (USBM).

Studies were directed mainly toward a resampling of selected areas to test the applicability of previously obtained geochemical data and toward reconnaissance geologic mapping and sampling of previously unvisited areas.

Geologic mapping in the area southeast of the Mount Crillon-La Perouse layered gabbro body (Rossman, 1963) and southwest of the Brady Glacier confirmed Rossman's unpublished descriptions of metamorphosed graywacke and slate in that area. Rossman (1963) correlated the unit with the Sitka Graywacke (Upper Jurassic and Lower Cretaceous) of northeastern Chichagof Island (Rossman, 1959). Previous studies (MacKevett and others, 1971; Brew and Ovenshine, 1974) indicated that the unit extends northwestward throughout the Fairweather Range and that it is unfossiliferous. T. L. Hudson (oral commun., 1975) suggested that the unit correlates with Paleozoic rocks still farther to the northwest. In the area southeast of the Mount Crillon-La Perouse body, this unit was found to be cut by leucocratic granitic bodies of inferred middle Tertiary age surrounded by well-defined low-pressure metamorphic facies series aureoles up to a few hundred meters wide and by at least one newly recognized, small layered gabbro body.

Geologic mapping in the upper Wachusetts Inlet area, which was exposed by the recent rapid recession of the Plateau Glacier, revealed that the highly fractured and altered granitic rocks characteristic of the upper Muir Inlet area extend farther south than had been previously assumed and that at least one thin (10 m) layered hornblende gabbro still cuts those rocks. This gabbro still is the first to be recognized in this part of the monument.

Excursion Inlet fault, Glacier Bay National Monument

The Excursion Inlet fault is one of a complex of faults that make up the Chatham Strait and Fairweather fault systems of Alaska (Overshine and Brew, 1972; Loney and others, 1975). Near the southeastern corner of Glacier Bay National Monument (loc. 14), it cuts mainly lower Paleozoic graywacke, slate, and some volcanic and carbonate rocks (MacKevett and others, 1971; Lathram and others, 1959). The fault has been traced for about 90 km from its northernmost exposure, where it is apparently truncated by a large granitic body of middle Tertiary age, south-southeast to the waters of Excursion Inlet and Icy Strait. The fault apparently does not extend into the lower and middle Paleozoic rocks of Chichagof Island on the southern side of Icy Strait (Loney and others, 1975) and is thus inferred either to be truncated by another northwest-striking fault beneath the strait or to change strike rather abruptly and continue southeastward to join the Chatham Strait fault (Ovenshine and Brew, 1972).

The present position of an east-west-striking dike swarm exposed to the east on the western side of Excursion Inlet and to the west on the northeastern side of Icy Strait in the vicinity of triangulation stations MUD and DAY (Lathram and others, 1959) indicates about 14 km of right-lateral offset. The dikes are 10 cm to 1.3 m wide, occur in thin-bedded graywacke and slate country rock, and consist of locally composite, locally magnetite-bearing augite-hornblende and hornblende-augite andesite and diabase.

Studies were planned or in progress by D. A. Brew, Christine Carlson, and C. J. Nutt to reexamine the apparent northward truncation of the fault and date the dikes; close bracketing of the age of movement on the fault should result. The available regional and local evidence suggests that the movement was probably of early Tertiary age (Loney and others, 1967; Ovenshine and Brew, 1972; Brew and Ovenshine, 1974).

Wilderness studies, Tracy Arm-Fords Terror area

The southwestern boundary of the Coast Range batholithic complex southeast and east of Juneau, Alaska (loc. 15), including the Tracy Arm-Fords Terror Wilderness Study Area, is marked by a 3- to 8-km-wide foliated biotite-hornblende quartz diorite sill that is now believed to be exposed for at least 225 km along strike. What are probably the northernmost exposures were mapped as the Mount Juneau pluton (Ford and Brew, 1973; Sainsbury, 1953); they are inferred to connect southeastward with the Speel River-Fords Terror pluton (Brew, 1974; Brew and others, 1975), and that body may in turn connect with a generally similar body in the Port Houghton-Thomas Bay area. Investigations in the Tracy Arm-Fords Terror Wilderness Study Area were being conducted by D. A. Brew, A. B. Ford, Donald Grybeck, B. R. Johnson, C. J. Nutt, and Christine Carlson.

The sill is generally bordered on the southwest by amphibolite-grade schists that are part of the Barrovian sequence of the Wrangell-Revillagigedo metamorphic belt; their original age is late Paleozoic through Early Cretaceous, and the age of metamorphism is probably middle or Late Cretaceous.

The sill was metamorphosed along with these rocks and was probably emplaced during the deformation-metamorphism episode. Northeast of the sill are gneiss, schist, and marble of the Coast Range gneiss complex, which are also amphibolite facies. The original age of the rocks of the gneiss complex is uncertain, but sparse evidence suggests that they are at least in part late Paleozoic in age. The age of the metamorphism is also uncertain, but, lacking contrary evidence, it is tentatively considered to be Cretaceous also.

The studies completed to date of the sill and its surroundings show that the sill is close to and consistently parallel to the Coast Range megalinear, an enigmatic and probably younger structure that extends the length of southeastern Alaska. The association of these two features and the slight contrast in rock units on either side of the sill suggest that the zone that they occupy may have been a significant structural discontinuity for a large part of Mesozoic and Cenozoic time.

Further extension of middle Tertiary granitic rocks, Juneau Icefield area

Detailed geologic studies in the upper Gilkey Glacier area of Alaska (loc. 16) by D. A. Brew, A. B. Ford, Christine Carlson, and C. J. Nutt revealed that the extensive middle Tertiary granodiorite complex of the Juneau Icefield area extends to the west beyond a broad zone of inclusions that runs through the Vaughan Lewis Glacier and that was suspected to mark a major boundary of the complex. The complex is now believed to extend well to the west of its originally predicted location. This finding reinforces the hypothesis (Brew and others, 1975) that Tertiary granitic rocks are the main component in this part of the Coast Range batholithic complex.

Early Paleozoic volcanic center and associated iron-copper deposits

In the Heceta Island area of Alaska, along the western coast of Prince of Wales Island (loc. 17), the Upper Silurian through Lower Devonian interval is represented by two formations, the Heceta Limestone and the Karheen Formation, the latter being a predominantly clastic unit with red bed affinities (Eberlein and Churkin, 1970). Field geologic mapping by G. D. Eberlein and Michael Churkin, Jr. (USGS), in conjunction with paleontologic studies by N. M. Savage (University of Oregon), showed that east of Heceta Island, toward the interior of Prince of Wales Island, the lithologies of the Heceta Limestone and the Karheen Formation are interlayered and that fossils characteristic of each occur together in a sequence that is cyclically repeated. This sequence is considered to be a new, as yet unnamed, formation.

It is believed that the indicated dramatic facies change reflects sedimentation off the flank of a large volcanic center, dominated by andesite and basalt, that radiometric and paleontologic dating indicate was active during Late Ordovician to earliest Silurian time.

Volcanic rocks identified with the center were first recognized in the nearby Kogish Mountain-Staney Cone area of Prince of Wales Island (Churkin and Eberlein, 1975) and consist mainly of breccia with subordinate amounts of volcaniclastic sedimentary rocks and minor carbonate. Recent mapping demonstrated that this assemblage underlies most of the Craig C–3 and D–3 1:63,360 subquadrangles as well as most of Kasaan Peninsula, where it constitutes the host for formerly productive copper-bearing magnetite and associated copper deposits. The relations in general give rise to the interesting speculation that at least some of the deposits in question may owe their origin to submarine volcanic exhalative processes operative in Late Ordovician and Early Silurian time rather than to pyrometasomatic replacement related to Jurassic or Cretaceous(?) plutonism, as was postulated by previous investigators.

PUERTO RICO

Serpentinite associated with basalt, southwestern Puerto Rico

Mapping by R. D. Krushensky in the Yauco quadrangle of southwestern Puerto Rico showed that serpentinite is associated with two-pyroxene-olivine basalt. Two small bodies of serpentinite appear to be enclosed in the two-pyroxene-olivine basalt, and a third, larger body (300 m across) that underlies the southwestern part of the town of Yauco shares an extensive contact with the basalt and limited contacts with the Yauco Mudstone; other contacts of the serpentinite are covered by younger alluvium and the Juana Díaz Formation (Oligocene and Miocene).

The two smaller bodies may be xenoliths carried upward by the intruding basalt, but, more likely, they and the larger body are examples of cold intrusion that postdates the Maestrichtian Yauco Mudstone. As such, they postdate by a significant factor the apparently Jurassic and Early Cretaceous serpentinite in the Punta Verraco quadrangle to the south and other bodies of serpentinite in southwestern Puerto Rico.

Igneous rocks, western Puerto Rico

Geologic mapping by R. D. Krushensky in the Yauco quadrangle of southwestern Puerto Rico and by Krushensky and A. F. Curet in the Monte Guilarte quadrangle of west-central Puerto Rico indicated that a hypersthene-augite-olivine basalt previously mapped as the Rio Loco Formation of Slodowski (1956) is, in fact, intrusive. The Rio Loco was described (Slodowski, 1956, p. 60) northeast of the town of Yauco as a unit of pillowed basalt flows, which is overlain by the interbedded Yauco Mudstone and Maricao Basalt (Turonian-Maestrichtian). More than 15 separate mappable bodies of two-pyroxene basalt intrude and crosscut bedding in the Yauco-Maricao in that area, and bedding in the Yauco-Maricao both north and south of the largest stock, as well as in all others, dips moderately (30°–45°) southward. Such field relations preclude deposition of the Yauco-Maricao on top of the basalt pile. Moreover, the rocks that Slodowski (1956) described as pillowed are brecciated and recemented with quartz but lack all features associated with pillowed lava flows, such as pillow forms, glassy or fine-grained outer margins, and radial fractures or vesicles. Extrusive hypersthene-augite-olivine basalt a few kilometers to the east shows aa tops and is interbedded with volcaniclastic breccias of the Lago Garzas Formation. These flows appear to be extrusive equivalents of the intrusive body beneath the town of Yauco. Pillowed basalt of the Rio Loco Formation flows in the Monte Guilarte quadrangle are enclosed in volcaniclastic breccias of the Maricao Basalt, a unit interbedded with the Yauco Mudstone and Lago Garzas Formation.

Faulting in the Sierra Bermeja Range, southwestern Puerto Rico

Field studies by R. P. Volckmann showed that the southern flank of the Sierra Bermeja Range in the Parguera quadrangle of southwestern Puerto Rico is underlain by amphibolite and serpentinite exposed in a series of imbricate high-angle fault slices. These fault slices are displaced from the south against the Mariquita Chert of Mattson (1973) that forms the bulk of the range.

The fault zones consist of a chaotic association of highly sheared amphibolite and serpentinite. It is thought that the serpentinite has been remobilized periodically and intruded into these zones of weakness.

It was suggested (Mattson, 1973) that the Sierra Bermeja is a nappe formed by gravity gliding on low-angle glide planes lubricated by bodies of serpentinite. However, at no place is evidence found to support this suggestion. To the contrary, all fractures and most structural attitudes in the Sierra Bermeja are high angle; thus, a major vertical orientation, rather than a horizontal orientation, of the tectonic stresses responsible for the structure and distribution of rock types on the Sierra Bermeja is suggested.

Magnitude of strike-slip faulting, eastern Puerto Rico

The Cerro Mula fault zone, which has at least 20 km of left-lateral movement in north-central Puerto Rico, has a westward trend and separates the volcanic province of northeastern Puerto Rico from that of central Puerto Rico. Few stratigraphic units can be correlated across the fault zone. In the Humacao quadrangle, the fault zone splits into the Naguabo fault, which trends easterly, and the Mambiche fault, which trends southeasterly through the center of the quadrangle.

Recent mapping and stratigraphic studies by J. W. M'Gonigle on the Naguabo fault zone demonstrated a left-lateral displacement along the fault of at least 2 km but probably no more than 4 km. The greater left-lateral movements of the region are therefore thought to have occurred along the Mambiche fault zone. Predictably, stratigraphic units that lie north and south of the Mambiche fault in the Humacao and Naguabo quadrangles do not correlate.

GEOLOGIC MAPS

Much of the work of the USGS consists of mapping the geology of specific areas, mostly for publication as quadrangle maps at scales of 1:24,000, 1:62,500, and 1:250,000. Mapping the geology of the United States is a mandate of the Organic Act establishing the USGS; a long-range goal is the completion of geologic maps of the entire country at scales that will fulfill forseeable needs and uses. Table 1 shows published geologic mapping by area (in square kilometers) for each State. Figure 6 shows the status of published geologic mapping in the United States by different scales.

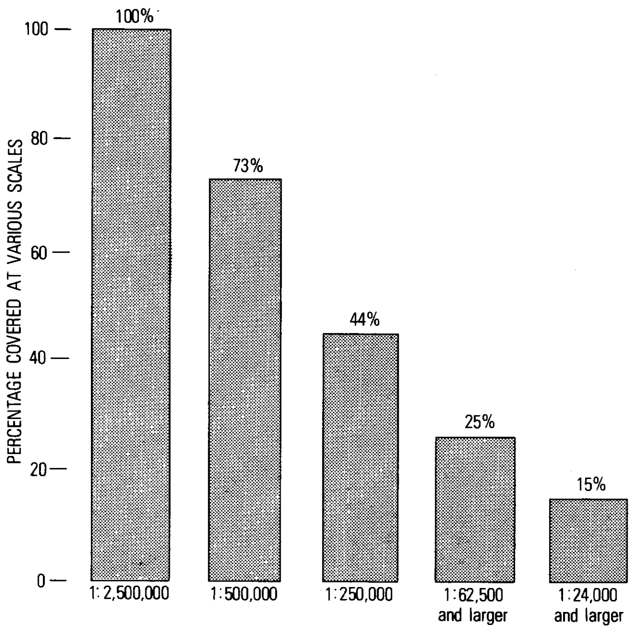


FIGURE 6.—Status of geologic mapping in the United States, 1976, by scales.

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 extend geologic knowledge in areas of known interest; some provide detailed knowledge for engineering planning or construction. The primary objective of some mapping studies is to provide solutions to problems in paleontology, sedimentary petrology, or a wide variety of other specialized topics.

LARGE-SCALE GEOLOGIC MAPS

Large-scale geologic mapping, principally at scales of 1:24,000 and 1:62,500, constitutes about four-fifths of the geologic mapping program of the USGS. Such large-scale maps are available for about one-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; extensive cooperative programs are underway in Connecticut, Kentucky, Massachusetts, and Puerto Rico. Other areas where mapping is underway include the Pacific Northwest, California, Delaware, Georgia, Maine, Maryland, Michigan, Minnesota, Nevada, New Hampshire, North Carolina, Pennsylvania, South Carolina, Tennessee, Virginia, Wisconsin, and the Rocky Mountain States.

Large-scale geologic maps play a vital role in increasing scientific knowledge of the Earth and also have many applied uses. Maps of mineralized areas not only help determine the scientific principles that govern formation and distribution of ore deposits but also serve as the basis for exploration of economic mineral deposits and assist in 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. These maps are becoming more numerous and more important in planning for more logical land use and for such large-scale engineering works as damsites, highway alinements, and subway routes. Geologic maps aid the actual construction process by locating vital construction materials and by providing the basis for site-preparation cost estimates. These maps are also extremely valuable as an aid in avoiding hazards such as landslides and swelling clays and in identifying 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-scale and smaller geologic maps generally are compiled from available large-scale geologic maps and supplemented by reconnaissance geologic mapping at intermediate scales. Mapping at 1:250,000 has now expanded to constitute more than one-third of the geologic mapping program of the USGS. Many State geological surveys also have 1:250,000-scale geologic mapping programs underway or completed. These efforts by Federal and State surveys as a nationwide program promise to provide geologic map coverage of two-thirds of the United States by 1985; at the present time, more than 40 percent is covered. Figure 7 shows the areas of the conterminous United States for which 1:250,000-scale maps have been published. Figure 8 shows areas of Alaska, Hawaii, and Puerto Rico for which 1:250,000- and 1:125,000-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 and Colorado within a few years. Single-sheet $1° \times 2°$ geologic maps have been started in parts of Arizona, Idaho, Montana, New

TABLE 1.—*Status of geologic mapping by State*

State	Geologic mapping at 1:63,360 and larger								Geologic mapping at 1:250,000							
	Published before 1930		Published 1930–75 by Federal agencies		Published 1930–75 by State and other agencies		Total		Published before 1930		Published 1930–75 by Federal agencies		Published 1930–75 by State and other agencies		Total	
	km²	Percentage of State	km²	Percentage of State	km²	Percentage of State	km²	Percentage of State	km²	Percentage of State	km²	Percentage of State	km²	Percentage of State	km²	Percentage of State
Alabama	0	0	7,343	6	54,825	41	62,168	47	0	0	0	0	0	0	-------	---
Alaska	3,569	--	58,013	4	1,784	--	63,366	4	0	0	784,766	53	29,785	2	814,551	55
Arizona	3,590	1	115,361	39	4,569	2	123,520	42	14,245	5	10,153	3	2,538	1	26,936	9
Arkansas	1,305	1	47,782	35	1,955	1	51,042	38	8,546	6	0	0	0	0	8,546	6
California	6,690	2	105,703	26	51,383	13	163,776	40	0	0	0	0	405,366	100	405,366	100
Colorado	5,558	2	79,611	30	1,305	--	86,474	32	25,382	9	126,909	47	0	0	152,291	57
Connecticut	163	1	6,449	51	3,755	29	10,367	82	0	0	0	0	12,683	100	12,683	100
Delaware	163	3	559	11	489	10	1,211	24	0	0	1,813	35	0	0	1,813	35
District of Columbia	0	0	158	100	0	0	158	100	0	0	0	0	158	100	158	100
Florida	0	0	3,916	3	2,611	2	6,527	5	0	0	0	0	0	0	-------	---
Georgia	0	0	9,790	6	13,978	9	23,768	16	0	0	8,702	6	0	0	8,702	6
Hawaii	0	0	2,284	14	4,569	28	6,853	41	0	0	0	0	0	0	-------	---
Idaho	5,711	3	25,294	12	24,802	12	55,807	26	0	0	16,576	8	0	0	16,576	8
Illinois	19,417	13	816	1	18,764	13	38,997	27	516	--	0	0	20,083	14	20,599	14
Indiana	1,468	2	816	1	3,100	3	5,384	6	0	0	0	0	93,683	100	93,683	100
Iowa	653	--	326	--	0	0	979	1	2,072	1	0	0	0	0	2,072	1
Kansas	1,142	1	50,419	24	23,711	11	75,272	35	0	0	21,601	10	0	0	21,601	10
Kentucky	5,180	5	87,024	84	4,255	4	96,459	93	0	0	8,029	8	0	0	8,029	8
Louisiana	0	0	25,291	22	35,081	30	60,372	52	0	0	0	0	0	0	-------	---
Maine	1,119	1	14,939	19	6,527	8	22,585	28	0	0	44,030	55	0	0	44,030	52
Maryland	7,832	31	2,774	11	9,137	36	19,743	77	0	0	0	0	25,564	100	25,564	100
Massachusetts	163	1	10,562	52	653	3	11,378	56	20,368	100	0	0	0	0	20,368	100
Michigan	4,403	3	13,706	9	1,468	1	19,577	13	0	0	6,993	5	8,910	6	15,903	11
Minnesota	7,343	4	3,753	2	3,753	2	14,849	7	0	0	119,139	58	0	0	119,139	58
Mississippi	0	0	25,563	21	2,608	2	28,171	23	0	0	0	0	9,246	8	9,246	8
Missouri	15,175	8	5,594	3	7,995	4	28,764	16	0	0	42,476	24	0	0	42,476	24
Montana	8,158	2	66,596	18	28,135	7	102,889	27	7,770	2	150,219	40	0	0	157,989	42
Nebraska	0	0	4,732	2	1,795	1	6,527	3	0	0	62,937	32	0	0	62,937	32
Nevada	979	--	43,167	15	13,442	5	57,588	20	0	0	0	0	235,171	82	235,171	82
New Hampshire	0	0	326	1	17,622	76	17,948	77	0	0	0	0	23,337	100	23,337	100
New Jersey	8,322	43	2,611	13	1,142	6	12,075	62	0	0	0	0	19,472	100	19,472	100
New Mexico	3,753	1	65,387	21	31,556	10	100,696	32	10,360	3	24,760	8	32,686	10	67,806	22
New York	31,328	25	7,669	6	28,477	23	67,474	54	0	0	0	0	124,114	100	124,114	100
North Carolina	979	1	11,585	9	4,890	4	17,454	14	7,340	6	21,963	17	0	0	29,303	23
North Dakota	2,284	1	25,431	14	9,953	6	37,668	21	0	0	0	0	2,849	2	2,849	2
Ohio	4,908	5	3,427	3	27,340	26	35,675	34	0	0	0	0	21,111	20	21,111	20
Oklahoma	11,914	7	2,447	1	49,114	28	63,475	36	0	0	15,799	9	80,859	45	96,658	54
Oregon	326	--	39,976	16	13,900	6	54,202	22	0	0	128,981	52	10,878	4	139,859	56
Pennsylvania	8,322	7	2,611	2	1,142	1	12,075	10	0	0	0	0	116,523	100	116,523	100
Rhode Island	0	0	2,739	100	0	0	2,739	100	2,739	100	0	0	0	0	2,739	100
South Carolina	0	0	3,427	4	4,079	5	7,506	10	0	0	31,080	40	0	0	31,080	40
South Dakota	1,795	1	12,727	6	46,993	24	61,515	31	17,871	9	5,504	3	0	0	23,375	12
Tennessee	653	1	9,407	9	57,899	54	67,959	63	0	0	0	0	108,121	100	108,121	100
Texas	25,781	4	30,849	5	51,888	8	108,518	16	0	0	0	0	375,548	55	375,548	55
Utah	5,711	3	84,454	40	16,586	8	106,751	50	0	0	0	0	213,175	100	213,175	100
Vermont	489	2	2,611	11	17,949	75	21,049	88	0	0	0	0	24,024	100	24,024	100
Virginia	5,711	6	4,895	5	22,354	22	32,960	32	0	0	10,360	10	0	0	10,360	10
Washington	2,611	2	32,844	19	10,443	6	45,898	27	0	0	14,905	9	0	0	14,905	9
West Virginia	57,118	92	2,611	4	2,611	4	62,340	100	0	0	0	0	62,340	100	62,340	100
Wisconsin	2,447	2	10,606	7	3,590	3	16,643	12	4,662	3	3,108	2	0	0	7,770	5
Wyoming	6,853	3	92,861	37	13,911	6	113,625	45	33,670	13	181,299	72	0	0	214,969	85
Puerto Rico	0	0	5,385	61	0	0	5,385	61	0	0	0	0	0	0	-------	--
Total	281,086	8	1,275,227	14	759,888	8	2,316,201	25	7,770	2	150,219	40	0	0	157,989	42

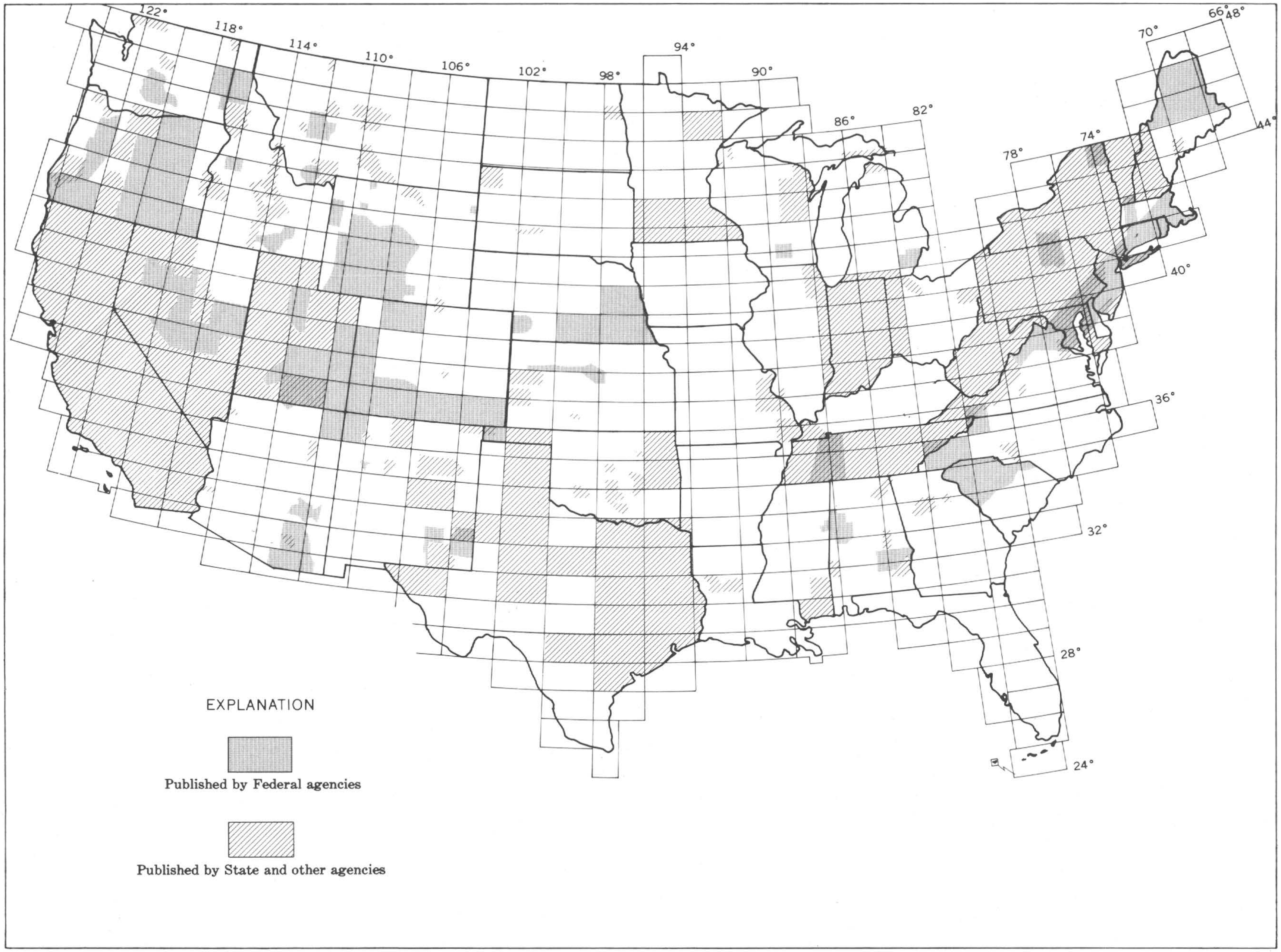


FIGURE 7.—Index map of the conterminous United States showing 1:250,000-scale geologic maps published as of December 31, 1975.

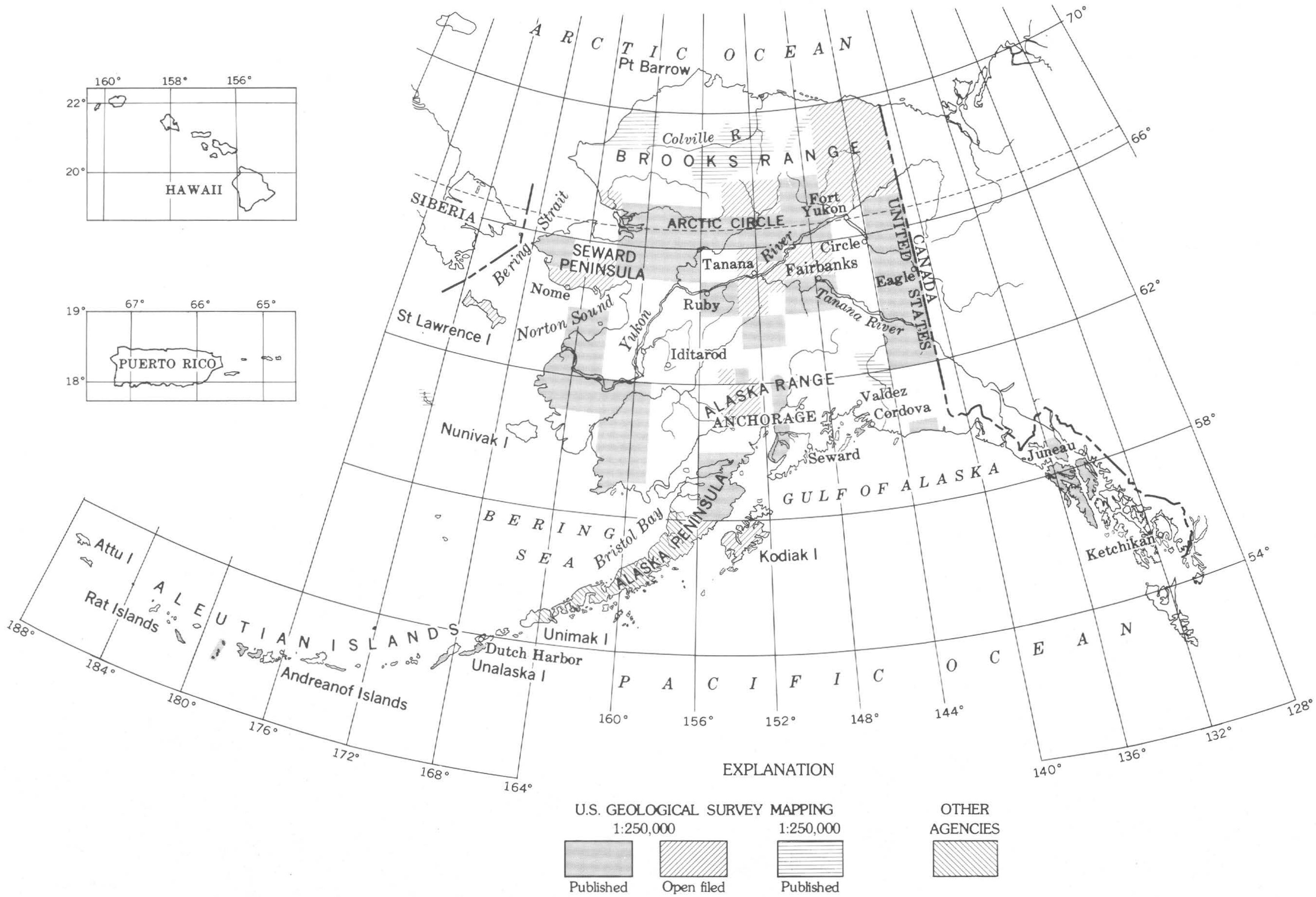


FIGURE 8.—Index map of Alaska, Hawaii, and Puerto Rico showing geologic maps published or on open file as of December 31, 1975.

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 potential 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, review various geologic features of the Nation in forms that show overall characteristics of the features in detail commensurate with the scales. Most are intended as wall maps for contemplative reviewing and as working maps for further specific studies.

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 International Geological Congress and the International Union of Geological Sciences. The map is being prepared in cooperation with the Geological Survey of Canada, the Institute of Geology of the 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 is computer storage of data on deposits to facilitate rapid retrieval.

National Environmental Overview maps, 1:7,500,000, J. B. Epstein, program manager.

The National Environmental Overview Program was established to summarize the characteristics and geographic distribution of Earth materials and the nature and extent of geologic processes in the United States. The maps and reports being compiled will provide a geologic data base useful to the understanding of environmental problems on a national scale. This data base will be useful for generalized decision-making on land use, energy and mineral-resource development and associated environmental impact, and public health. These maps will help to identify problems, isolate critical areas of potential geologic constraints, and provide topics for future research.

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

This State geologic map, begun in 1968 as a cooperative project, is in press. The map uses 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 90 percent complete, will reflect the increased knowledge of Colorado's geology acquired 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 the map is being prepared for publication. A preliminary black-and-white map has been published (Stewart and Carlson, 1974a), and color copy is also available (Stewart and Carlson, 1974b). The compilation draws on data from about 500 large- and small-scale maps, many of which have been used previously in the compilation of 1:250,000-scale county maps. Field checking and remapping have been done in areas where county maps are incomplete or out of date. The new map will show nearly 100 geologic units.

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

Compilation of this map, which includes more than 50 geologic units, has been completed, and a map of the State east of the 121st meridian is being prepared for publication. A map of the western part of the State was published previously (Wells and Peck, 1961), and a preliminary black-and-white version of a map of the eastern part of the State has been published (Walker, 1973). The data are based partly on available published and unpublished maps and partly on extensive new reconnaissance and photogeologic mapping.

Geologic map of Wyoming, scale 1:500,000, J. D. Love and A. C. Christiansen, compilers.

This new map is being compiled in cooperation with the Geological Survey of Wyoming. It will replace the State map published 20 years ago and is based 75 percent on new data. Initial compilation at 1:250,000 scale on topographic bases is more than half completed, and the map will be published by the State.

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

This map is a contribution to the Map of the Metamorphic Belts of the World, sponsored by the Commission for the Geological Map of the World of the International Geological Congress and the International Union of Geological Sciences, 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 International Union of Geological Sciences (Zwart and others, 1967) suggested metamorphic facies map explanation. Progress includes preliminary compiling and reviewing of regional metamorphic facies maps at 1:1,000,000 scale for all of the State, coding of background metamorphic mineral locality information, and beginning of the final combination of 1:1,000,000 regional maps.

Paleotectonic investigations of the Pennsylvanian System in the United States, scale 1:5,000,000, E. D. McKee and others.

Paleotectonic maps in press show the total thickness of rocks of the Pennsylvanian System, the thickness and lithofacies of divisions of the system, and the distribution of rocks underlying and overlying the system. In addition, interpretive maps show the transport direction of sediments, the restored thicknesses, and the tectonic development of the country during the period. Some maps show paleogeography, and some show environments of deposition at selected times during the period.

Paleotectonic maps: Analysis of the Mississippian System, scale 1:10,000,000, by L. C. Craig and others.

Paleotectonic maps are being prepared that show the total thickness of rocks of the Mississippian System, the thickness and lithofacies of divisions of the system, and the distribution of rocks underlying and overlying the system. In addition, interpretive maps show the transport direction of sediments, the restored thicknesses, and the tectonic development of the country during the period. Some maps show paleogeography, and some show environments of deposition at selected times during the period.

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 assessments of water requirements for industrial, domestic, and agricultural purposes; (3) determinations of the chemical, physical, and biological characteristics of water resources and the relation of water quality and suspended-sediment load to various parts of the hydrologic cycle; and (4) studies of the interrelation of the water supply with climate, topography, vegetation, soils, and urbanization. One of the most important activities of the USGS is the systematic collection, analysis, and interpretation of data for evaluating the Nation's water resources. These data are computer processed for storage, retrieval, and dissemination of water information.

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

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

Subjects currently under investigation or researched recently by the USGS include the following: (1) Properties of water—geochemistry, temperature, and water chemistry; (2) drainage, runoff, and watersheds—flood plains, floods, frozen ground, playas, and storm runoff; (3) evaporation, meteorology, and precipitation—droughts, evapotranspiration, glaciers, glaciology, ice and icing, snow, and transpiration; (4) flow, hydraulics, and streams—availability of water, base flow, channel morphology, culverts, drainage, floodflow formulas, flood hazards, flood-inundation maps, fluid mechanics, gaging, geomorphology, highway drainage, hydraulic engineering, hydrodynamics, low flow, measurement of streamflow and time of travel under ice, acid mine 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-resource 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 terranes, 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 resource research, interpretations, investigations, mapping of ground water, model studies, processing, publication, remote sensing, reports, research, stochastic hydrology, techniques for hydrologic studies and resource 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 FY 1976, data on streamflow were collected at about 7,600 continuous-record discharge stations and at about 9,000 lake- and reservoir-level sites and partial-record streamflow stations. About 12,000 maps of flood-prone areas in all States and Puerto Rico have been completed to date, and about 850 pamphlets covering areas susceptible to flooding have been published. Studies of the quality of surface water were expanded; there were approximately 5,300 water-quality stations in the United States and in outlying areas where surface water was analyzed by the USGS. Parameters measured include 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 4,200 of the water-quality stations. Sediment data were obtained at almost 1,300 locations.

Annually, about 500 USGS scientists report participation in areal water-resource studies and research on hydrologic principles, processes, and techniques. There are about 2,000 active water-resource projects. Nearly 700 of the studies in progress are classed as research projects. Of the current water-resource studies, about 160 are related to urban hydrology problems.

In FY 1976, 878 areal appraisal studies were carried out. Maximum and mean areas of the studies were 3.078 million square kilometers and 79,750 km^2, respectively. Total areal appraisal funding was about $21 million. Ground-water studies were made or are currently in progress for about two-thirds of the Nation. In 1976, 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 studies of the hydrologic principles governing the occurrence of brackish water in estuaries. Land subsidence due to ground-water depletion and the possibilities for induced ground-water recharge are under investigation in areas where the land surface has settled significantly. The effects of coal-mining activities on both ground- and surface-water resources are being studied intensively.

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 FY 1976. Records of about 290,000 station-years of streamflow acquired at about 10,000 regular streamflow stations are stored on magnetic tape, and data on about 250,000 wells and springs have been entered in a new automated system for storage and retrieval of ground-water data. Digital-computer techniques are used to some extent in almost all the research projects, and new techniques and programs are being developed continually.

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

Requests for data on water use in the United States and in relatively small areas increased in 1976. The need to develop energy sources of various kinds in areas where industrial development has been nonexistent or minimal requires estimates of future water requirements in these areas and evaluation of the adequacy of water resources to meet the demand. Studies are underway to improve methods for expanding the scope, intensity, and accuracy of water-use investigations.

Investigations describing the occurrence of water as a natural resource are given in the following sections for the four regions of the United States (fig. 9) used since 1973 by the USGS for administering the water-resource program.

NORTHEASTERN REGION

Torrential rains during late June and early July 1975, combined with antecedent wet conditions, caused severe flooding in the Buffalo River and Wild Rice River basins in Minnesota. The valley of the Red River of the North between Moorhead and Halstad, Minn., was also severely flooded. The 1975 floods exceeded the maximums previously recorded at 18 of 47 sites having 10 years or more of record. Damage, mostly agricultural, was widespread and was estimated to exceed a quarter of a billion dollars.

Intense rainfall during the evening of July 20 and the early morning hours of July 21, 1975, caused flooding of unprecedented magnitude in highly urbanized Mercer County, New Jersey. Over 150 mm of rain was recorded during a 10-hour period at Trenton. The peak flow of Assunpink Creek at Trenton had a recurrence interval greater than 100 years. Damages to highways and bridges, to industrial, business, and residential buildings, to farmland and crops, and to water-supply systems were severe.

A study to develop a procedure for estimating low-flow-frequency characteristics for streams in

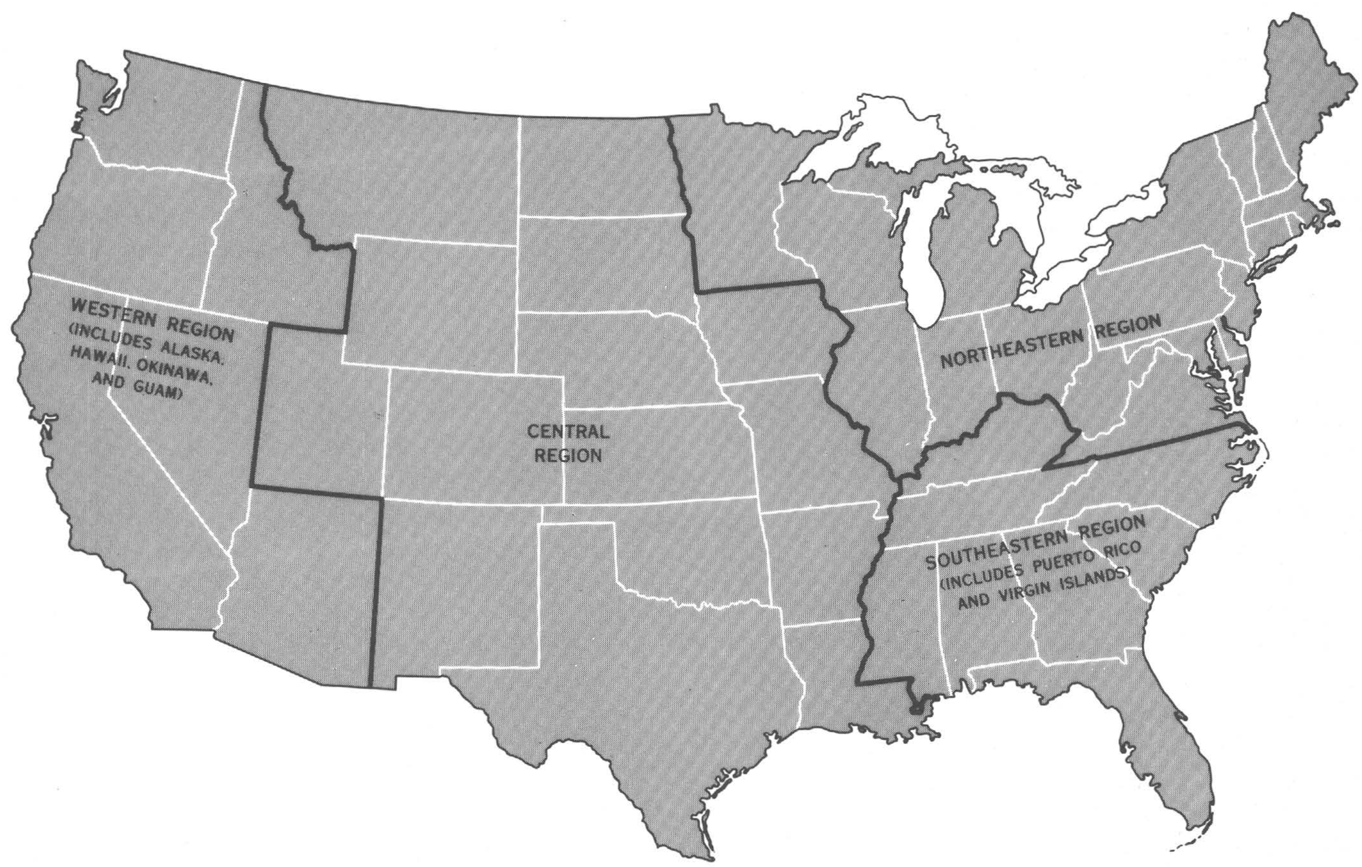


FIGURE 9.—Index map of the conterminous United States showing areal subdivisions used in the discussion of water resources.

New York, Pennsylvania, and Maryland in the Susquehanna River basin was completed. Multiple-regression techniques were used to develop relations for estimating the 1-, 3-, 7-, 30-, and 183-day-duration low flows at recurrence intervals of 10, 20, 50, and 100 years for annual series data and the 1-, 3-, 7-, and 30-day-duration low flows at the same recurrence intervals for each of six months, May through October.

Test drilling revealed the presence of two freshwater zones on Nantucket Island, Mass., beginning 64 and 116 m below the base of the overlying freshwater lens; these depths roughly correspond to those indicated by the Ghyben-Herzberg principle. Relatively impermeable clay beds protect the deeper freshwater zones from saltwater infiltration. If the deep freshwater zones were emplaced during periods of lower sea levels in Pleistocene time, similar reserves of freshwater can be expected in deep aquifers off many parts of the North Atlantic coast.

An electric-analog analysis of ground-water conditions in the Indianapolis area of Indiana indicated that an additional 2.6 to 4.5 m^3/s of water can be pumped to meet the city's projected water needs. The range in pumpage indicated by the model reflects the range of uncertainty in some model-input parameters.

The former site of the Metallurgical and Argonne National Laboratory in northeastern Illinois, where radioactive materials were buried from the late 1940's through the mid-1950's, was being studied to determine the source, route, concentration, and rate of movement of radioactive materials in the subsurface.

Since the beginning of the nuclear era, low-level radioactive waste has been buried in shallow trenches. The Riceville, N.Y., burial ground has been so used for about 10 years. Although no large-scale migration of radioisotopes from this site is known, abnormal amounts of tritium have been found in streams draining the site. The USGS has been studying the area to develop geohydrologic criteria for the location of future burial grounds in similar terrane —an elevated plain of clay-rich till locally capped by thin outwash gravel and severely dissected. A predictive digital waste-transport model is a possible result of the study.

Mining of low-grade copper-nickel ore in the Duluth Complex (gabbro) has been proposed in northeastern Minnesota. The proposed development sites lie in or near the Superior National Forest and near the Boundary Waters Canoe Area. The hydrology of the area, including streamflow, surface-water quality, and ground-water resources, is being studied by the USGS to establish predevelopment conditions. Results of the study will form a basis for an assessment of the effects of mining and related activities on the hydrology of the area.

Indiana is the first State for which statewide information concerning the traveltime of a contaminant spilled into a stream has been published (S. E. Eikenberry and L. G. Davis, 1976).

CONNECTICUT

Test drilling in the Quinnipiac, Pequabuck, Eightmile, and Farm River valleys was completed by F. P. Haeni and R. L. Melvin. More than 4,700 m of stratified-drift sediments was drilled and sampled by hollow-stem auger and mud-rotary equipment. The maximum saturated thickness in these valleys ranges from 30 m in the Farm River valley to at least 130 m in the Pequabuck River valley.

DELAWARE

Hydraulic properties of an aquifer and a confining bed in the Dover area

P. P. Leahy determined the hydraulic properties of the Piney Point (Eocene) aquifer (a fine to medium sand) and the overlying silty confining bed by conducting a 23-day aquifer test at a well field near Dover, Del. During the test, head changes were monitored continuously in the Piney Point aquifer, the overlying Cheswold (Miocene) aquifer, and the intervening confining bed. Based on a leaky artesian aquifer analysis, the transmissivity and storage coefficient of the aquifer are 380 m^2/d and 3×10^{-4}, respectively. The confining-bed hydraulic properties were determined by a combination of the following methods: (1) Analyses of drawdown data in the aquifer by the Hantush leaky-artesian-type curves, (2) determination of hydraulic diffusivity based on the ratio of head changes in the aquifer to head changes in the confining bed, and (3) analyses of head changes in the confining bed using theoretical response curves to determine hydraulic diffusivity. Vertical conductivity cannot be determined directly by any of these techniques. However, their combined use indicates that the vertical conductivity of the confining bed ranges from 1.2 to 2.7×10^{-5} m/d. The range of values for specific storage is 1.0 to 2.0×10^{-5}/m.

Aquifer model studies

Model studies were used by R. H. Johnston to analyze the flow system in the lightly pumped, unconfined sand aquifer of central and southern Delaware. A two-dimensional digital model was used to simulate flow in an approximate sense—only recharge by precipitation and discharge to surface-water bodies were represented. After calibration, the model was able to duplicate observed water-table contours with good accuracy, and agreement was excellent between measured base flow and model-computed values of ground-water discharge, except in an area near Dover, where leakage to the underlying Cheswold artesian aquifer is substantial. The model was used to (1) delineate an area of 65 km^2 northwest of Dover, where most of the leakage occurs; (2) estimate base flow in ungaged streams and particularly ground-water discharge to tidal rivers; and (3) project water-level declines and depletion of base flow in five areas where pumping is expected to increase.

INDIANA

Ground-water resources near Fort Wayne

The Fort Wayne area of northwestern Allen County, Indiana, is covered by 60 m or more of glacial material. Little deep drilling has been done in this area to determine aquifer thickness and areal extent. In 1975, 16 test holes designed to help determine aquifer geometry were completed. Michael Planert and L. D. Arihood reported that aquifer material thicker than 30 m was found at several locations, and the possibility of developing large supplies of ground water seems good.

Leachate from landfills moving toward industrial well fields

Leachate from two landfills in Indianapolis, Ind., continued to move toward industrial well fields. R. A. Pettijohn constructed digital flow and transport models of the two areas to determine the rate of movement of the leachate.

MARYLAND

Observation wells show effect of pumpage and leakage

F. K. Mack reported that observation wells were installed in the Patapsco, Magothy, and Aquia aquifers to monitor the effects of pumping at Chalk Point in Prince Georges County, Maryland. The observation wells are about 2 km north of a well field yielding 1,900 to 3,800 m^3/d from the Patapsco and Magothy aquifers. Water levels in each of the monitoring wells were affected by pumping or by interaquifer flow. Water levels in the Magothy aquifer have declined as much as 13 m since 1962. Long-term records for the Patapsco are unavailable; however, it seems that water levels there are influenced by pumping, even though the sand beds screened in the production and observation wells are not laterally continuous. Although the Aquia aquifer is not tapped by pumping wells, water levels in the aquifer are about 2.4 m lower than they were in 1962 because of leakage through the underlying confining bed into the Magothy aquifer.

Ground water in Harford County

Results of a study by L. J. Nutter indicated that water is available in moderate to large quantities in sand-and-gravel aquifers of the Coastal Plain in Harford County, Maryland, and in small to moderate quantities in the much more widespread metamorphic-rock aquifers of the Piedmont. The water in both types of aquifers is of good chemical quality and is generally suitable for domestic, commercial, and most industrial uses without treatment. Approximately 20 percent of the ground-water samples collected contained iron concentrations exceeding U.S. Public Health Service (USPHS) recommended limits; less than 5 percent contained nitrate concentrations exceeding USPHS recommended limits.

Geohydrology of Carroll County

The geohydrology of six 7½-min quadrangles in Carroll County, Maryland, was studied by E. G. Otton. Yields of wells in crystalline schist, phyllite, and marble range from good to poor, and water supplies are generally adequate for ordinary purposes. However, there are a few places, generally underlain by phyllite and schist, where adequate domestic supplies of ground water are unobtainable. Criteria have been developed that describe the relative suitability of terrane for shallow underground disposal of domestic sewage. In general, valley-flat areas having a shallow water table and steep rocky hillslopes are unsuitable for effluent disposal, whereas upland areas underlain by thick saprolite seem to be suitable disposal sites.

MASSACHUSETTS

Deep test drilling on Cape Cod

Three test holes were drilled and sampled on Cape Cod, Mass., and geophysical logs were made to determine aquifer lithology and lower boundary, according to D. R. LeBlanc and J. H. Guswa. Granitic bedrock was penetrated at altitudes of −56 m in the town of Bourne and −78 m in the town of Barnstable.

About 1,220 m from the southern shore of Cape Cod in the town of Mashpee, a test hole entered saltwater at an altitude of −95 m. An altitude of −91 m for the saltwater-freshwater interface was calculated with the Ghyben-Herzberg density model. The electrical-resistivity logs indicate that the transition zone from freshwater to saltwater is approximately 6 m thick.

Supply of ground water on Nantucket Island adequate for current needs

Ground water occurs under water-table conditions in the sand and gravel of glacial origin that forms Nantucket Island, Mass. Locally, ground water may be perched on thin layers of till. Depth to the water table ranges from 1 m to as much as 15 m beneath the higher parts of the island.

Driven wells of small diameter provide adequate supplies of water for domestic needs. Fields of shallow wells or screened and gravel-packed wells can yield enough water for public supply or irrigation.

Ground water in most parts of Nantucket Island contains from 18 to 25 mg/l chloride and less than 100 mg/l dissolved solids. Wells close to the shore may penetrate much saltier water at shallow depths.

Recent test drilling by E. H. Walker and F. A. Kohout showed that freshwater extends to a depth of 158 m under the center of the island. Freshwater was also found in two deeper zones, 222 to 249 m and 274 to 283 m. Presumably, the freshwater entered these deep zones during the glacial period, when sea level was lower, and has not yet been displaced by salty water.

Ground-water assessment in the Aberjona-Mystic River basin

D. F. Delaney and F. B. Gay reported that the Aberjona-Mystic River basin in eastern Massachusetts has an aquifer system composed of stratified unconsolidated materials deposited by melt waters during the last glaciation. The unconsolidated deposits have sufficient volume and transmissivity (370 m^2/d) to sustain yields of at least 19 l/s to individual wells.

Ground-water quality is generally good throughout the basin, and the water is suitable for most uses. However, hardness tends to be moderately high (120 to 180 mg/l) in comparison with that of ground water in other parts of eastern Massachusetts, and iron and manganese generally exceed the limits for drinking water (0.3 and 0.05 mg/l, respectively) recommended by the National Academy of Sciences (1973).

The aquifer system is recharged from precipitation and induced infiltration from the two main streams draining the basin. For at least three decades, most of the basin has been sewered, and sewage has been discharged outside the basin. Ground-water withdrawals and out-of-basin discharge significantly deplete streamflow and result in a mean annual runoff that is 0.26 to 0.31 m^3/s lower than that from surrounding basins of similar size.

MICHIGAN

Ground water in southeastern Michigan

Results of a study in southeastern Michigan by F. R. Twenter indicated that ground-water supplies are sufficient to meet domestic needs in most rural areas and to supply many smaller communities and industries.

Both the bedrock and the glacial deposits yield water. Of the bedrock aquifers, those in the Saginaw, Marshall, Berea, and Sylvania Formations generally yield the greatest quantity—in some places as much as 20 l/s. In the glacial deposits, good sand-and-gravel aquifers may yield as much as 190 l/s in some places.

Water from shallow wells is generally of good chemical quality. Mineralization of ground water increases with depth; water from many deep wells has a dissolved-solids concentration of 1,000 mg/l or more.

Erosion in the St. Joseph River basin

T. R. Cummings reported that the quantity of substances transported by water in the upper reaches of Michigan's St. Joseph River basin is being measured to establish baseline conditions. Currently, 4 daily sediment stations and 38 periodic sediment and chemical-quality stations are being operated to relate agricultural land-use practices to erosion. Color and color-infrared photographs of the basin were obtained, and the first of several research projects was begun. Wastes from a small dairy operation will be pumped into a concrete-lined pit, stored for approximately 6 months, and then sprayed on an adjacent crop. The spraying will be monitored to determine its effect on the quality of water in a nearby small stream. On the basis of data now being obtained, a subbasin will be chosen later in the year for a more intensive study of erosion.

Digital modeling involving the Muskegon County waste-water system

A three-layered three-dimensional digital model was developed by W. B. Fleck and M. G. McDonald to study the ground-water flow regime of a 1,600-km^2 area that includes the 40-km^2 Muskegon, Mich., waste-water facility. Hydraulic conductivity values determined from field data range from 0 to 240 m/d in the water-table aquifer and are about 80 m/d in the confined sandstone aquifer. A recharge of 200 mm/yr determined from base-flow data was used to run the model under steady-state conditions. The resulting heads determined by the model closely match those determined from field measurements.

MINNESOTA

Water resources of the St. Louis River watershed

G. F. Lindholm, D. W. Ericson, W. L. Broussard, and Marc Hult reported that water in the Biwabik Iron-formation of Minnesota and in glacial drift in the eastern part of the St. Louis River watershed is of good quality and can be made suitable for private and municipal use with minor treatment. Dissolved-solids concentration is usually less than 500 mg/l.

Water in the St. Louis River and its major tributaries and in lakes above Cloquet, Minn., can be made acceptable for domestic use by color removal and disinfection. Below Cloquet, municipal and industrial wastes make the water unsuitable for all domestic uses.

Average annual runoff from an 8,883-km^2 basin upstream from Scanlon is 230 mm, one of the highest runoffs from large basins in Minnesota. Five hydroelectric powerplants are located on the St. Louis River between Cloquet and Fond du Lac, where the river descends 174 m in 22.5 km. At the steepest gradient, below Thomson Dam, the river drops almost 113 m in 5.3 km. Five storage reservoirs in the Cloquet and Whiteface River basins having a combined capacity of 410 hm^3 regulate streamflow for powerplant operation.

Buried aquifers in the Brooten-Belgrade and Lake Emily area, west-central Minnesota

An evaluation by R. J. Wolf of test drilling in the Brooten-Belgrade and Lake Emily area of Minnesota indicated that buried glacial-outwash and Cretaceous sand aquifers as thick as 15 m occur to depths of 91 m and, in places, are capable of yielding enough water for irrigation. The buried aquifers are narrow, elongate, truncated bodies enclosed by clay till. The Precambrian surface, ranging from 58 to 107 m below land surface, is the lower limit of high-yield buried aquifers.

Maps of buried sand beds were drawn to show their vertical distribution. Water in the buried-drift aquifers is of the hard, calcium-magnesium bicarbonate type, similar to that in the surficial outwash, and is generally suitable for irrigation. It is expected that water samples from the Cretaceous aquifers will be higher in dissolved-mineral concentration than those from the drift aquifers.

Possible problems in the study area are the probable slow rate of recharge to the buried aquifer, loss of head because of well interference, multiscreening of wells, and uncontrolled flowing wells.

Water resources of the Lake Superior watershed

P. G. Olcott, D. W. Ericson, P. E. Felsheim, and W. L. Broussard determined that sand-and-gravel zones in drift, interflow zones in the North Shore Volcanic Group, and sandstone in the southern part are the most favorable sources of ground water in Minnesota's Lake Superior watershed. Well yields are several liters per minute from crystalline bedrock and thin glacial deposits, but 6.3 l/s or more can be obtained from thick glacial deposits and sandstone in the Nemadji River basin. Lake Superior has provided a large supply of good-quality water to municipalities, but asbestoslike particles in the water are presently threatening its use.

Surface water is soft to moderately hard and has a maximum of about 125 mg/l dissolved solids. Water in drift aquifers is hard to very hard and has a maximum of about 150 mg/l dissolved solids. Water in crystalline rock aquifers, especially in the North Shore Volcanic Group, is variable in quality, ranges from good to saline, and has a maximum dissolved-solids concentration in excess of 50,000 mg/l.

Of the 710-mm average annual precipitation in the area, about 330 mm runs off to Lake Superior and 380 mm is evaporated and transpired. Most of the approximately 880 hm^3 of water used in the watershed in 1973 came from Lake Superior. Nearly 98 percent of the water was used by industry.

Ground water in the Park Rapids area

J. O. Helgesen's study of a 1,940-km^2 surficial outwash aquifer in the Park Rapids area of Minnesota continued. The saturated part of the sand-and-gravel deposit is generally thickest (12–30 m) and coarsest in the northern part of the area. Estimated transmissivity is as much as 2,800 m^2/d. A data analysis, aided by a preliminary digital model, indicates that the aquifer is recharged mainly by precipitation; the aquifer discharges mainly to streams, although discharge to lakes in the northern half of the area and evapotranspiration in the southern half of the area are significant. Ground water is of the calcium bicarbonate type. The dissolved-solids concentration is commonly 200 to 300 mg/l, but it is less in wetland areas.

Ground-water supply and demand

Ground water is a very important source of water supply in Minnesota; according to G. F. Lindholm and R. F. Norvitch, about 22 m^3/s was withdrawn in 1970. Nearly equal amounts are withdrawn for public-supply, rural-domestic and stock, and self-supplied general industrial uses. Surface water, however, is the principal source of cooling water for thermoelectric powerplants.

Drift aquifers supply water in a large part of the State, but bedrock aquifers in southeastern Minnesota are the most favorable for further development of large water supplies.

In the central part of the State, surficial outwash, a readily available source of large water supplies, is being tapped in increasing amounts for irrigation. Few buried outwash aquifers have been defined.

Effect of copper and nickel mining on surface water in northeastern Minnesota

According to P. G. Olcott and D. W. Ericson, initial chemical analyses made in USGS and private laboratories showed that trace metals are present in the surface waters of the proposed copper- and nickel-mining area of northeastern Minnesota in concentrations ranging from 0.1 to 30 μg/l. Higher concentrations have been noted in samples from small streams draining near-surface orebodies. Available analyses indicate that shallow ground water adjacent to a 9,074-t bulk-ore sample pit contains a maximum of 350 μg/l Cu and 2,600 μg/l Ni. Similar concentrations were found adjacent to a mineralized outcrop.

The extensive low-grade orebody occurs near the base of the Duluth Complex. It is at or within a few thousand meters of the bedrock surface in a 0.8- to 1.6-km-wide strip extending about 64 km northeastward from Hoyt Lakes to the border of the Boundary Waters Canoe Area, where mining has been prohibited.

The glacial deposits in the area consist mostly of clayey ground and terminal moraine having some ice-contact sand and gravel. Glacial deposits range from 0 to 15 m in thickness in the northern half of the area, where outcrops of Duluth Complex and Giants Range granite are numerous. Glacial deposits in the southern half of the area are more continuous and thicker and contain a higher percentage of ice-contact sand and gravel.

The area, bisected by the Laurentian Divide, is drained by the Kawishiwi and South Kawishiwi Rivers in the Hudson Bay drainage area and by the St. Louis River and its tributaries in the Lake Superior drainage area.

Limnological aspects of lakes in Eagan and Apple Valley

Selected physical, chemical, and biological parameters were used to assess the quality of 20 lakes in the towns of Eagan and Apple Valley, Minn. M. R. Have (1975a) reported that all of the lakes are eutrophic except Holland and Fish Lakes, which are mesotrophic. Some lakes (including Fish Lake) have storm-sewer inlets but are not discernibly different in quality from lakes with no such inlets.

Water quality of Burnham Creek

A water-quality assessment of the Burnham Creek watershed in Minnesota was made in May 1975 by M. R. Have (1975b). Surface waters were calcium-magnesium bicarbonate types having 0.11 mg/l or less of nitrite plus nitrate nitrogen and 0.10 mg/l or less of total phosphorus. Fecal coliform bacteria concentrations were between 3 and 720 colonies/100 ml, and fecal streptococci concentrations ranged between 19 and 1,600 colonies/100 ml. Pesticide concentrations were low in all stream-bottom materials, but slightly increased concentrations were apparent downstream. The benthic community was dominated by blackfly larvae.

MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA, AND MONTANA

H. O. Reeder analyzed ground-water resources and their possible future development and management in the Souris-Red-Rainy region. The region includes the basins of the Souris River within Montana and North Dakota; the Red River of the North in South Dakota, North Dakota, and Minnesota; and the Rainy River within Minnesota. The total study area of 154,480 km^2 is mostly in North Dakota and Minnesota.

Sand-and-gravel deposits in the drift are the most important freshwater aquifers. Other major aquifers are in the Precambrian, Paleozoic, Cretaceous, and Tertiary rocks in parts of the region. Regional ground-water movement is toward the Red River of the North.

Ground water having less than 3,000 mg/l dissolved solids is available throughout the region. Also, there is an abundance of more highly mineralized water, which should also be considered a usable resource. Yields of wells in individual aquifers are generally less than 6.3 l/s but may be more than 31 l/s locally.

Ground water is the sole or primary source of water supply in much of the region and is used for irrigation, rural-domestic and livestock needs, public supplies, and industrial needs. Although only 20,300 ha was irrigated in 1975, ground- and surface-water supplies, if they are fully developed and used, are adequate to irrigate a total of approximately 627,000 ha.

NEW JERSEY

Potomac-Raritan-Magothy aquifer-model study

J. E. Luzier reported that head decline averages about 0.5 m/yr nearly everywhere in the Potomac-Raritan-Magothy aquifer system of New Jersey downdip (southeast) from the relatively narrow outcrop band that parallels the Fall Line. Except for a small region near the outcrop northeast of Trenton, N.J., heads are at or below mean sea level out to and beyond the coastline. The very large and coalescing cones of depression that have developed exhibit pronounced elongation parallel to the outcrop and to the Delaware River. Heads within these cones range from 5 to more than 25 m below mean sea level because of the relatively continuous increase in pumpage for public-supply and industrial use. For the 18-year period of the model simulation, pumpage has ranged from about 5 m^3/s (1956) to about 10 m^3/s (1973).

Calibration of the model, which is nearly complete, is based on matching the 1973 measured potentiometric surface with 10 long-term hydrographs. Preliminary results suggest that the Delaware River is a major source of recharge to the large cone of depression underlying Burlington, Camden, Gloucester, and Salem Counties. In this region, preliminary results from the model indicate that more than 40 percent of the 6.3 m^3/s extracted in 1973 was derived from induced recharge from the Delaware River, and more than 30 percent was from leakage through the overlying confining layer; the remainder came from precipitation on the outcrop and from storage within the aquifer system. Salty ground water to the south and southeast is well within the cone of depression, and it is being induced to move updip under the influence of heads depressed well below sea level. Low gradients and low rates of decline suggest that, over the long term, the presence of this salty ground water so close to areas of pumping can result in eventual contamination of the fresh ground-water supply.

Digital model of the Farrington Sand Member of the Raritan Formation in Middlesex, Monmouth, and Mercer Counties

G. M. Farlekas used a digital-computer model to simulate past and future water-level declines of the Farrington Sand Member of the Raritan Formation of the Coastal Plain in Middlesex, Monmouth, and Mercer Counties, New Jersey. Since 1897, ground-water withdrawals have caused as much as 34 m of water-level decline. The average 1973 withdrawals from the Farrington Sand Member exceeded 1.0 m^3/s.

The 1959 potentiometric surface is incorporated into the model. Calibration of the model for the 15-year period 1959–73 is based on the comparison of computed and actual 1973 potentiometric surface and observation-well hydrographs. The digital model, formulated by P. C. Trescott to include a water table and an artesian aquifer, was modified to simulate the effect of the declining potentiometric surface of the overlying Old Bridge Sand Member of the Magothy Formation.

Almost all ground-water diversions from the Farrington Sand Member were from wells within 9.6 km of the outcrop of the Farrington Sand Member and thus caused gradients in excess of 5.7 m/km. The center of the cone of depression, at Sayreville in Middlesex County, was more than 21 m below sea level in 1973. The center of the cone of depression in the overlying Old Bridge Sand Member is at Freehold in Monmouth County, 9.3 km to the southeast. The altitude of the potentiometric surface at the center of the cone was more than 15 m below mean sea level in 1973. No wells tap the Farrington Sand Member in the Freehold area, although a recent (1974) test well indicated that at least 21 m of sand is available for development. The digital model will be used to predict future water-level declines in the Farrington Sand Member near the outcrop area and the presently untapped part of the aquifer in the area from Freehold to the coastal areas of Monmouth County.

NEW YORK

Effects of urbanization on ground-water quality

Urbanization was shown by H. F. H. Ku and D. J. Sulam to be a major cause of progressive change in ground-water quality in southeastern Nassau County, New York. Increases in the concentration of selected constituents in the shallow ground water correspond to population increases and attendant increases in individual waste-water disposal systems that discharge to the water-table aquifer in the area. This finding is based on numerous analyses of shallow ground water pumped over the past 70 years from two infiltration galleries that trend east-west and are at right angles to ground-water flow. The study also shows a considerable downward movement, from 1950 to 1973, of water high in nitrate, chloride, and dissolved solids to the underlying Magothy aquifer, the major source of water for the area. Downward movement is most pronounced near the ground-water divide.

Pleistocene geology of the South Fork of Long Island

Studies by Bronius Nemickas and E. J. Koszalka (William Nieter, Bronius Nemickas, E. J. Koszalka, and W. S. Newman, 1975) indicated that the stratigraphy of the South Fork of Long Island, N.Y., is complicated by large-scale glacial tectonic structures. The study area underwent multiple glaciations, and the morainal features may be, in part, time transgressive. The Ronkonkoma Drift, which is as wide as 4.8 km and has more than 30.5 m of relief in some areas, is not a stratigraphic unit but seems to be a composite of many different lithologies. The investigators believe that two tills may be present in the study area. The older Montauk Till Member of the Manhasset Formation, seen in the coastal bluffs of the southern shore east of Montauk Village, may be correlative with the till in the Port Washington sand pits of northwestern Long Island. A second (younger) till overlies the type Montauk Till Member and is found in the subsurface as massive lenses and layers in the Ronkonkoma Drift. Geophysical logging of wells and test borings has been successful in identifying the till in the subsurface. A knowledge of the distribution of the two till beds is needed to evaluate ground-water resources in the area.

Prediction of effects of sewerage on water levels

The effect of planned sewerage in southwestern Suffolk County and southeastern Nassau County, New York, on water levels and streamflow was evaluated by G. E. Kimmel and A. W. Harbaugh (1975), using a three-dimensional electric-analog model of the Long Island ground-water system. They estimated that, during the 20-year period 1975–94, declines of 1.5 m in the water table and as much as 1 m in head will occur in the Magothy aquifer as a result of Suffolk County sewerage alone. Declines of as much as 6 m in the water table and 5 m in head in the Magothy aquifer were forecast as a result of the combined sewerage of Suffolk and Nassau Counties. A 40-percent decline in streamflow was forecast in and around the area of sewerage as a result of the combined sewerage. These declines will result from discharging to sea the waste water previously returned to the ground-water system through cesspools and septic tanks.

PENNSYLVANIA

Estimated trout population of Sacony Creek

J. L. Barker and K. P. Kulp made a survey of Sacony Creek in Pennsylvania and its major tributaries from July 1974 to May 1975. The survey revealed that the water was of good to excellent quality and that there was a sizable wild-trout population in the upper basin. A good trout habitat in the upper basin was estimated to support 590 trout (133 kg/hm^2). A standing crop of 626 kg/hm^2 was measured in the more productive lower reaches.

Limnologic investigations

Limnologic investigations at 53 recreational lakes in Pennsylvania were made during July and August from 1971 to 1975. Necessary scientific data were acquired for appraising the effects of geology, land use, and pollution on the water quality of each lake's ecosystem.

J. L. Barker reported that, in the absence of mine drainage or any other significant source of pollution, the dissolved-solids concentrations in lakes ranged from 17 to 130 mg/l. Dissolved solids in lake waters and the trophic state of lakes decreased with geologic terrane in the following (descending) order: (1) weathered carbonate rocks, (2) unconsolidated water-sorted deposits, (3) igneous and metamorphic rocks, (4) noncarbonate sedimentary rocks, and (5) till.

Ground water in southeastern Pennsylvania

Results of a study of the ground-water resources of Chester County, Pennsylvania, from 1973 to 1976 by L. J. McGreevy and R. A. Sloto (1976) indicated that yields of more than 6.3 l/s can be obtained from most units of the predominantly metamorphic and igneous rocks. Most of the ground water contains less than 150 mg/l dissolved solids, but acidity, iron, manganese, and nitrate cause water-quality problems for some users. Calcareous rocks, which cover about 7 percent of the county, have generally higher yields. The water from these units is generally hard and has a higher concentration of dissolved solids than that from the metamorphic rocks.

About 27 hm^3 of ground water was withdrawn in Chester County in 1974. Almost 60 percent of this water was for self-supplied domestic users. Public supplies accounted for another 30 percent. Almost two-thirds of the 310,000 residents of Chester County depend on ground water for household use.

RHODE ISLAND

Drilling and aquifer tests in the Beaver River-Pasquisset Brook area of the Pawcatuck River basin in Rhode Island resulted in identification of seven sites, from which yields of 44 l/s or more of water may be obtainable from large-diameter wells, according to H. E. Johnston and D. C. Dickerman. The sites were located by drilling thirty-five 63.5-mm-diameter exploratory wells to depths of 12 to 40 m in stratified drift. At each site, a 200-mm-diameter test well, 23 to 29 m deep, and an array of 6 to 10 small-diameter observation wells were drilled. The 200-mm wells were pumped at 35 to 38 l/s for 48 or 72 hours. Preliminary analyses of the data indicated that aquifer transmissivity is between 600 and 1,300 m^2/d at six sites and as much as 1,750 m^2/d at one site.

This investigation is one of five planned for the principal ground-water reservoir areas in the Pawcatuck River basin; it is part of a Rhode Island Water Resources Board program to locate, test, and acquire sites from which large quantities of ground water can be withdrawn in southern Rhode Island.

WEST VIRGINIA

A reconnaissance of the hydrology of the Coal River basin in southern West Virginia was made by J. S. Bader, J. L. Chisholm, S. C. Downs, and F. O. Morris. Data collected indicate that runoff in the lower part of the basin is less than that farther upstream. The quality of stream water improves downbasin. Highly mineralized water from places in the headwaters is diluted downstream by the inflow of less mineralized water. The stream water is generally alkaline, and, although much coal is mined in the area, acid mine drainage is not a widespread problem. A total load of about 820,000 t is transported out of the basin annually; about 540,000 t is suspended sediment, and about 280,000 t is dissolved minerals. The occurrence of fecal bacteria indicates that raw sewage is a major source of stream contamination.

Fracture systems are the most significant channels for ground-water flow. The rocks underlying the basin are poorly permeable and, except where they are fractured, transmit little water. Ground-water quality varies with well depth. Water from deep wells is alkaline and more mineralized than that from shallow wells.

WISCONSIN

Low-flow estimation by streamflow routing

A digital model was used by W. R. Krug to route daily discharges of Wisconsin's Flambeau River from Flambeau Flowage to Park Falls. Thirty-two years of simulated discharges at Park Falls had a 7-day, 10-year low flow ($Q_{7,10}$) of 7.4 m^3/s. The standard error of estimate was about the same as that for 16 years of gaging-station records. The 32 years of simulated discharge at Park Falls will be used by the Wisconsin Department of Natural Resources to establish regulations for papermill-waste discharge to the Flambeau River and to determine the economic impact of these regulations on mill opperation.

Flood-plain delineation and water-quality reconnaissance in the St. Croix National Scenic Riverway

S. M. Hindall determined, by slope conveyance methods, the 2-, 5-, 50-, and 100-year flood elevations at two proposed development sites along the St. Croix National Scenic Riverway in Wisconsin. The flood plain will be delineated at additional sites during the next several years.

Two water-quality reconnaissance studies of the entire riverway also were completed—one was made during high flow, and one was made during low flow. Only physical characteristics were measured. The major significant difference was that the low flow had higher water temperatures and lower DO concentrations. DO concentrations decreased during the summer low flow, whereas saturation percentages increased because of the differences in water temperature and weed growth. Water quality is generally good in the St. Croix Riverway; no problem areas or potential problem areas were discovered. A nine-site network established to monitor chemical quality will permit a more detailed assessment of the water quality of the riverway.

Irrigation chemicals produce only minor changes in chemical quality of ground water

In an investigation of irrigation and the water quality of the central sand plain of Wisconsin, S. M. Hindall found that, although irrigation and farming practices have affected water quality, especially in areas of intensive irrigation, the overall effect has been minor. Analyses of data collected during a 2-year period indicate that nitrate concentration in the irrigated areas was about twice that in the nonirrigated areas, whereas the opposite was true for phosphorus concentration. The average nitrate (as N) concentration in irrigated areas was about 8 mg/l, in comparison with an average of about 4 mg/l in nonirrigated areas. Phosphorus concentration ranged from 0.04 mg/l in irrigated areas to 0.09 mg/l in nonirrigated areas. Although these concentrations are high enough to promote algae blooms, they are substantially below the upper limit recommended by the USPHS for drinking water. The fact that all of the concentrations remained nearly constant during the data-collection period indicates that water quality has essentially stabilized in the irrigated areas.

Fifteen of 86 samples contained minor amounts of pesticides. All concentrations were well below upper limits for drinking water. The most prevalent contaminants were DDT and its derivatives, DDD and DDE, although DDT has been banned for several years in Wisconsin.

Sandstone aquifer in Door County

The sandstone aquifer system (Ordovician and Cambrian sedimentary rocks) was investigated as a possible alternative to the Silurian dolomite aquifer in Door County, Wisconsin. Exploratory drilling indicated that the sandstone aquifer in this part of Wisconsin is much more carbonaceous and less productive than was previously believed, according to M. G. Sherrill. Water from the sandstone aquifer has dissolved-solids concentrations of about 1,900 mg/l, sulfate concentrations greater than 500 mg/l, and chloride concentrations greater than 400 mg/l.

Soil mapping used in conjunction with surface and subsurface geology to map areas of potential ground-water contamination

Depth to bedrock may be a key factor in investigating the contamination of ground water. In M. G. Sherrill's study of Wisconsin counties bordering Lake Michigan, plotting depths to dolomitic bedrock was greatly facilitated by using soils data. Soils formed from bedrock at depths of 1.5 m or less exhibit characteristics of the rock. Soil characteristics were plotted, together with well and outcrop data, to develop a reasonably accurate depth-to-bedrock map for an extensive area.

Effects of a flood-control structure on the hydrology of the Trout Creek basin

A 5-year study by R. S. Grant and S. J. Field was begun in August 1975 to determine the effects of a dry-dam flood-control structure on the hydrologic characteristics and trout population of Trout Creek in Iowa County, Wisconsin. Hydrologic characteristics being studied are the amounts, types, and areas of sediment aggradation and degradation; changes in channel morphology; and streamflow characteristics. Four gaging stations were established to monitor streamflow, suspended sediment, and sediment-particle size. Eight stream reaches are measured twice yearly to observe channel changes.

The Wisconsin Department of Natural Resources is making related studies of fish and other biological phenomena.

Hydrology of the wetland of the Nevin Fish Hatchery

R. P. Novitzki defined the hydrologic system supporting the wetland at the Nevin Fish Hatchery in the Madison area of Wisconsin. The wetland functions as a ground-water discharge zone. Total outflow from the area is three times as great as precipitation within the wetland's watershed. Discharge enters the wetland from discrete springs along its edge and from seeps. The wetland is drained mainly by a stream, but underflow through underlying sand-and-gravel beds may be significant.

WISCONSIN AND ILLINOIS

R. S. Grant, using the radioactive tracer method, measured reaeration coefficients on the Rock River from Indian Ford, Wisc., to the Illinois border. The reaeration coefficients were less than 0.5 per day (base e at 25°C) on three long reaches affected by backwater from dams, whereas the coefficients for free-flowing reaches ranged from about 2 to 4 per day. The reaeration coefficient on another reach was apparently increased by winds to about 40 times the coefficient of reaches where there was little or no wind. The study, done in cooperation with the Wisconsin Department of Natural Resources, should provide reliable estimates of the reaeration coefficient for a water-quality model of the Rock River. The model will be used to evaluate the effects of a proposed nuclear powerplant.

SOUTHEASTERN REGION

The increasing demand for water in the southeastern region is reflected by continuing investigations of modeling techniques, artificial recharge, and water storage to provide water managers with the tools necessary for maximum utilization of known water resources. Accompanying these efforts are studies to delineate untapped sources of water for industry, agriculture, and public supply. Interest is increasing in the use of brackish- or saline-water aquifers for the storage of surplus freshwater to be used in times of shortage. Saline-water aquifers are also being considered for storage of liquid industrial wastes, treated sewage effluent, and storm-water runoff. Energy-related projects are being initiated in the fields of coal hydrology, cooling water for powerplants, and disposal of nuclear wastes.

Several studies involving the use of brackish- or saline-water aquifers are underway in Florida. In the Fort Lauderdale area, tests are being conducted to determine the feasibility of storing freshwater in a brackish-water aquifer; across the State, in Pinellas County, tests are being conducted to determine the feasibility of storing storm-water runoff in a saline aquifer. In the panhandle and in southern Florida, the monitoring of industrial-waste injection in a saline-water aquifer is continuing.

Monitoring in the vicinity of coastal well fields in Florida has shown several areas where a saltwater front is moving inland—probably as a result of increased ground-water pumping and the lack of rainfall during the 1975 rainy season. Increased demand and reduced recharge have led to more intensified investigations of potential well fields in the Miami and Tampa-Sarasota areas.

Subsurface correlation has delineated four major aquifers in the Upper Cretaceous of the Georgia Coastal Plain. In Mississippi, an aquifer model has shown that it may be feasible to dewater Cretaceous aquifers in the divide-cut section of the Tennessee-Tombigbee Waterway by trenching.

Investigators have delineated four areas near Beaufort, S.C., where saltwater may have contaminated the principal limestone aquifer. Northward, in the vicinity of Myrtle Beach, the use of the induction resistivity probe in the geophysical logging of wells has been valuable in delineating the water-bearing sands of the Black Creek aquifer.

FLORIDA

Hydrologic framework of the Santa Fe River subbasin

J. D. Hunn reported that the Santa Fe River subbasin, a part of the Suwannee River basin in north-central Florida, has a large, good-quality water resource. The Floridan aquifer, the area's principal source of ground water, crops out in the lower quarter of the subbasin, but elsewhere the aquifer is overlain by the Hawthorn confining bed. There appears to be an unmapped confining bed of limited areal extent in the Floridan outcrop area. Streams, lakes, ponds, and swamps are numerous throughout the area where the aquifer is confined, but they are sparse where there are no confining beds. The Santa Fe River and other streams that approach the western boundary of the Hawthorn confining bed disappear into sinks. Only the Santa Fe River reappears at the surface—about 5 km downstream. Spring discharge along the Santa Fe River below the confined area is as much as 28 m^3/s.

Water-resource management in Broward County

Competition for water supplies in the densely populated coastal areas of Broward County, Florida, is intensifying the need for improved water management and water-use practices by local and regional regulatory agencies, according to C. B. Sherwood, Jr., and H. W. Bearden. Major emphasis is on the distribution of water in the highly controlled regional canal system and on the control of well-field locations. Preliminary data indicate that feeder canals designed to convey water from the regional water-management system into well fields for induced infiltration are effective in reducing drawdowns and in retarding seawater intrusion.

Bearden (1972, 1974) reported that monitoring of saltwater in the Biscayne aquifer indicates a slight movement of the salt front toward the southern part of the city of Hollywood's well field and also a slight inland movement of the salt front in the Hallandale area. Movement of the salt front is attributed to increased municipal pumpage and below-average rainfall during the 1975 wet season.

In a companion study, extensive core-hole drilling by H. J. McCoy in central Broward County indicated a large area suitable for a major well field. Preliminary data indicate that the quality of water in the area is good. Also, there is a potential for aquifer replenishment by induced infiltration from canals belonging to the regional water-management system.

Water quality in the South New River Canal basin and in western Broward County

Because of the possibility of increasing urbanization along the western reach of Florida's South New River Canal, runoff characteristics—particularly loads of nitrogen, phosphorus, dissolved solids, and organic carbon—were analyzed by B. G. Waller. Hydraulic measurements and samples of surface and ground water for chemical analyses were being collected to determine the sources of these constituents. By utilizing these data, regulatory agencies will be able to establish criteria for the acceptable loads of nitrogen and phosphorus that may enter the canal as runoff from expanding urban developments. The waters within the canal are backpumped into Conservation Area 3 for storage and for drainage of the subbasin. The maintenance of high-quality water within the South New River Canal and the adjacent conservation area, which was formed out of the ecologically fragile Everglades, depends on preventing contaminated runoff from entering the canal.

Quarterly diurnal data for DO and chemical analyses of water samples from canals adjacent to water-conservation areas of the regional water-management system in western Broward County indicate little influence from encroaching urbanization; data also show the same to be true in eastern Broward County (B. G. Waller, W. L. Miller, and T. R. Beaven, 1975). Because of the rapid expansion of urban development, precautionary water-quality-control measures have been implemented by local and regional regulatory agencies. Water-quality data chiefly indicate changes caused by seasonal rainfall, releases from the conservation areas, agricultural runoff, and ground-water inflow.

Ground-water-level ranges in the Fakahatchee Strand

L. J. Swayze found that water levels in the Fakahatchee Strand of Florida had a seasonal range of nearly 2 m. The Faka Union Canal on the western border of the strand created a gradient to the canal during dry periods, but the extent of the canal's influence on the strand has not been determined.

Freshwater-saltwater interface in Collier County

W. J. Haire reported that the coastal aquifer in Collier County, Florida (H. J. McCoy, 1975), was again severely stressed during the dry season of 1975. For the first time, saltwater moved up the Golden Gate Canal and topped the saltwater control. More than 250 mm of rainfall in May restored the normal freshwater-saltwater interface.

High permeability at proposed well fields in Dade County

Exploratory core borings that completely penetrate limestone of the Biscayne aquifer at five proposed municipal well-field sites in Dade County, Florida, indicated caverns as large as 0.75 m in diameter. Howard Klein reported that the saturated thickness of the aquifer ranges from 18 to 24 m. Analog models indicated that, when pumping occurs at the proposed sites, infiltration from canals in the vicinity will contribute from 25 to 50 percent of the total quantities withdrawn; the remainder will be from ground-water storage and from water salvage due to reduced evapotranspiration.

Seawater intrusion in Dade County

Continuing studies of seawater intrusion by J. E. Hull indicated landward movement of the salt front during 1975 to within 1 km of Miami-Dade well field in Miami Springs, Fla., and into the Homestead Air Force Base well field. A new well field has been established west of the air base.

De Soto County connector well tested

Tests made on a connector well in northeastern De Soto County, Florida, by W. E. Wilson III and C. B. Hutchinson showed that the rate of flow through the well is directly proportional to the depth to the potentiometric surface of the Floridan aquifer. Ground water flows by gravity from the unconfined sand aquifer through the well bore and into the underlying confined limestone Floridan aquifer. During the first 6 weeks of the test, the flow rate ranged from 2.8 to 4.1 l/s, and the depth to potentiometric surface ranged from about 13 to 15 m below land surface. Fluctuations in the potentiometric surface resulted from periodic pumping by nearby irrigation wells.

Saline-water intrusion

According to G. W. Leve, water-quality monitoring of wells tapping the Floridan aquifer indicated that saline-water intrusion is occurring in the Jacksonville area of Florida along the coast and about 24 km west of the coast, adjacent to the St. Johns River. In these areas, the chloride concentration of water in some of the deeper wells (penetrating more than 150 m of the aquifer) has increased from less than 40 mg/l to about 100 mg/l in the last 2 years.

A preliminary investigation indicated that, in the area adjacent to the St. Johns River, the increase in chloride concentration may be caused by the upward movement of highly mineralized water from deeper zones in the aquifer through fractures in relatively impermeable confining beds underlying the shallower freshwater zones.

Digital model of the sand-and-gravel aquifer in central and southern Escambia County

Application of the Trescott-Pinder digital model (P. C. Trescott, 1973) to the sand-and-gravel aquifer of central and southern Escambia County, Florida, indicated that discharge under conditions of no pumping from the main producing zone was 0.0013 $m^3 s^{-1} km^{-2}$, which is within the range of values for base runoff of streams maintained by the zone. Total ground-water discharge (or the approximate perennial yield) within the 614-km^2 area of principal interest was 7 m^3/s. In applying the model, Henry Trapp, Jr., made the following assumptions concerning the main producing zone: (1) It is continuous throughout the area, and it is laterally isotropic; (2) it is the zone now tapped by all large-capacity wells in the area; (3) it is a separate, leaky, confined aquifer; (4) it is bounded by constant-head boundaries; (5) its recharge and discharge take place through the constant-head boundaries and the overlying confining bed; and (6) its head above the overlying confining bed equals the water table, which remains constant.

Water resources of Manatee County

D. P. Brown reported that water levels in wells penetrating the Floridan aquifer in Manatee County, Florida, were measured in May and September of 1975. In May, when ground-water withdrawals were at a maximum, water levels were at or below sea level in about half of the county; water levels ranged from 3 m below sea level in the central part to over 10 m above sea level in the southeastern part. In September, when ground-water withdrawals were minimal, water levels ranged from about 6 m above sea level along the western coast of Manatee County to over 13 m above sea level along the eastern border of the county.

Saltwater intrusion at Fernandina Beach

R. W. Fairchild reported that continuous withdrawals of ground water from the Floridan aquifer in the Fernandina Beach area in northeastern Florida have resulted in a steady decline of artesian pressure in the aquifer. The decline in pressure created a cone of depression, which first developed in the late 1930's and has since enlarged. The center of the cone has declined about 5 m since 1940. The chloride concentration of water in some of the wells that tap the deeper zones of the aquifer has increased considerably; chloride content in one well increased from about 100 mg/l to more than 900 mg/l between 1952 and 1975.

Saltwater intrusion into the shallow water-table aquifer, Palm Beach County

The shallow water-table aquifer that furnishes water for all purposes in Palm Beach County, Florida, is a prolific source of supply, according to L. F. Land and J. J. Schneider (H. G. Rodis and L. F. Land, 1976). In many coastal communities, however, public-supply wells are threatened by saltwater intrusion during the dry season.

Recent test drilling by W. B. Scott showed that saltwater underlies the Tequesta well field at depth and is advancing into the well field from the west as well as from the east.

Digital model traces path of pond wastes to Palm Beach County well field

L. F. Land used a digital model to trace the path of tertiary treated wastes from a percolation pond toward an existing well field in Palm Beach County, Florida. Results indicated that the wastes would arrive at the well field in about 6 years. Modifications to the hydraulic system are now being simulated to determine whether proposed changes will control the pond outflow. Simulations will include pond sealing, lowering of ground-water levels at the ponds, and ditching.

Identification of transmissive zone at an injection-test site

An exploratory hole was drilled at the Bear Creek storm-water storage site in Pinellas County, Florida, to determine the hydrologic effects of injecting storm runoff in deep, underground strata. The hole was completed to a depth of 393.2 m. A 356-mm casing was set and cemented in place at 152.4 m below land surface. J. J. Hickey reported that analyses of the data (lithologic log, water quality, short-term pumping tests, borehole television, and geophysical logs) indicate that transmissive zones in the open hole are between 159 and 179 m, 229 and 253 m, 283 and 326 m, and 360 and 387 m below land surface. About 80 to 90 percent of the measured inflow in the test hole occurs between 283 and 326 m, and most of that inflow occurs between 283 and 305 m.

Hydrologic evaluation of Cypress Creek well field

A digital ground-water model of the Cypress Creek well-field area north of Tampa, Fla., was developed by P. D. Ryder. The model is being calibrated by simulating steady-state conditions based on a September 1974 potentiometric-surface map. The results thusfar indicate that the leakance of the confining layer in the 414-km^2 modeled area may range from a high of 1.0×10^{-2} (m/d)/m to a low of 1.2×10^{-4} (m/d)/m.

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

A 3,000-km^2 area incorporating parts of Hillsborough, Pinellas, and Pasco Counties contains nine well fields that supply the urban centers of the Tampa and gulf coast areas of Florida. C. B. Hutchinson and L. R. Mills reported that, at times during 1975, total pumpage from the Floridan aquifer was as much as 5 m^3/s. To keep pace with the demands for fresh ground-water supplies for Pinellas County and the City of Tampa, two additional well fields, each with a withdrawal capacity of 1.3 m^3/s, are under construction within this area. Maps prepared semiannually show a maximum of 9 m of drawdown in the potentiometric surface of the Floridan aquifer at the well fields. The maps also show cones of depression developing in the water-table aquifer. The potentiometric surface of the Floridan aquifer in southern Hillsborough County, mapped in detail for the first time in May 1975, was below sea level over much of the area owing to pumpage for crop irrigation. Data for September 1975 indicated that water levels had recovered.

Geohydrologic information for water-use planning

C. B. Bentley reported that 18 aquifer tests and analyses of the Floridan aquifer were completed in a three-county area in northeastern Florida to determine the transmissivity and storage coefficient of the aquifer and the leakance through the confining beds. Observed transmissivities versus depth-of-well penetration indicate a hydraulic conductivity of about 43 m/d and an actual transmissivity of about 5,600 m^2/d. The storage coefficient is about 0.8×10^{-3}, with some local variations, and the leakance varies from about 0.1×10^{-2} to 0.2×10^{-1} (m/d)/m throughout the area.

Quality of surface water in the Suwannee River basin

J. E. Dysart observed that the characteristics of surface water in the Suwannee River basin of Florida are controlled by the geology of the basin and by phosphate mining and processing operations. Differences in bedrock geology and types of terrane and in the number of springs in the basin are reflected by changes in the major dissolved constituents and several other physical and chemical characteristics of the surface water. The phosphate mining and processing operations are a source for phosphorus, sulfate, and fluoride in the water of the basin (L. G. Toler, 1967).

Data on aquifers of southern Florida

A series of maps of the primary aquifers of southern Florida, compiled by K. E. Vanlier and others, showed the following: (1) Recharge areas of the Floridan aquifer; (2) potentiometric surface of the Floridan aquifer in east-central Florida in May 1974 (dry period); (3) chloride in the upper Floridan aquifer; (4) altitude of the base of potable water in the Floridan aquifer; (5) depth to the Floridan aquifer; (6) hardness of water in the Floridan aquifer; (7) altitude of the top of the Floridan aquifer; (8) altitude of the base of the shallow aquifer system; (9) top of the shallow aquifer system; and (10) potentiometric surface of the shallow-aquifer high in 1974 (wet period). The maps are used by the Central and Southern Florida Flood Control District to obtain the ready information needed in issuing water-withdrawal permits.

GEORGIA

The Upper Cretaceous formations of the Georgia Coastal Plain can be separated in the subsurface into four major aquifers of Eagle Ford-early Austin, late Austin, Taylor, and Navarro age. These aquifers, in their outcrop area east and northeast of Macon, Ga., form a single aquifer, which also includes formations of Eocene age. The Cretaceous aquifer systems were correlated from their outcrop area into the subsurface by L. D. Pollard, who used geophysical well logs and lithologic descriptions.

Of the major aquifers, the one of Eagle Ford-early Austin age is the most consistent in areal extent and yield characteristics. All of the aquifers have increasingly higher concentrations of clay downdip to the south and southeast.

Where the aquifers are water table or confined at shallow depths, they yield water low in dissolved solids and pH. Ground water from deeper zones of the aquifers is generally higher in sodium and bicarbonate ions and has higher dissolved-solids concentrations.

KENTUCKY

D. V. Whitesides reported that ground-water levels have risen as much as 6 m in the Louisville-Jefferson County area of Kentucky since 1960. Water levels rose about 3 m between 1960 and 1970 and an additional 3 m between 1970 and 1975. Ground-water levels are only 6 m below land surface in some areas of the county and are at or near record highs in some observation wells. The rising water levels and near-record-high water table in the area can be attributed to (1) decreased use of ground water; (2) recharge from the Ohio River, septic tanks, and leaking sewers and water mains; and (3) above-average precipitation. The rise in water levels represents a valuable increase in the ground-water storage available for future use. However, if present trends continue, the rising water table could cause drainage problems, wet basements, and damage to sewers.

MISSISSIPPI

In a recent study to determine alternative means of dewatering the divide section of the proposed Tennessee-Tombigbee Waterway, S. A. Leake concluded that the trenching method is a viable alternative or adjunct to dewatering by wells.

The divide section of the proposed waterway in northeastern Mississippi is about 64 km long, and the depth of the cut at the Tennessee Valley Divide will be about 52 m. The project requires dewatering a saturated thickness of more than 15 m in most of the section.

The approach used to evaluate the effects of dewatering by trenching was to develop a two-dimensional cross-sectional digital model that simulates flow to a trench and considers the effects of partial penetration and anisotropy.

NORTH CAROLINA

Water budget and water quality of a small Coastal Plain swamp watershed

A water budget for the 70-km^2 Creeping Swamp watershed in eastern North Carolina was part of an analysis of natural hydrologic conditions made prior to a stream channelization project. According to M. D. Winner, Jr., total water input measured in 1974 was 1,151 mm of rainfall. During that year, outflow consisted of 10 percent surface runoff, 21 percent base flow, 8 percent ground-water outflow, and 61 percent evapotranspiration. Changes in storage were considered to be near zero on an annual basis, and there was no ground- or surface-water inflow to the watershed.

Average annual suspended-sediment yield from the watershed, which is predominantly rural, was about 12 t/km^2. Stream temperatures ranged from 5.5 to 26°C. C. E. Simmons reported that increased concentrations of most of the chemical constituents in a downstream direction are due primarily to base flow of water from the Castle Hayne Formation. Dissolved-solids loads of major constituents during an 11-month period ranged from 7.3 tonnes of nitrate to 220 tonnes of bicarbonate.

Flow model of the Cape Fear River

A daily streamflow and reservoir-routing model of North Carolina's Cape Fear River, developed by F. E. Arteaga, was used to predict the effects of two proposed reservoirs on minimum downstream flows. It was shown that, if the B. Everett Jordan and Randleman Lakes are controlled by the operating rules now proposed, enough water will be available from reservoir releases to insure a minimum flow of 17 m^3/s downstream at the Cape Fear River at Lillington, N.C.

The technique used for streamflow modeling utilized the diffusion-analogy model for one-dimensional flow routing. Attempts to model the effects of a third proposed reservoir, Howards Mill, were not successful because the effects of large ungaged areas could not be accounted for by the model.

Spring-site studies along Blue Ridge Parkway

Twenty-three springs at 15 sites along the Blue Ridge Parkway in western North Carolina were evaluated during 1974–75 to determine their suitability for continued use as water supplies. All springs are developed as water supplies and are enclosed by spring boxes constructed of cast concrete and (or) stone and mortar. Springs along the parkway are dependable sources of water. Records show no long-term decline in discharge between 1959 and 1963 and between 1974 and 1975. According to C. C. Daniel III, most of the existing springs could be redeveloped or modified to provide more water than the present structures capture. On the basis of hydrogeologic characteristics, the springs can be classified in the following three general groups: (1) Springs that flow from thick permeable deposits (discharge not influenced by underlying formations), (2) springs that flow from a permeable veneer resting on impermeable material, and (3) springs that flow from fractured rock.

Because of the remote locations of these springs, chances of their being contaminated by sewage or animal wastes are slight. The greatest potential source of contamination is overland runoff entering spring boxes. The chemical quality of the ground water is generally excellent. Chemical analyses show that the water is soft, slightly acidic, and low in dissolved solids.

SOUTH CAROLINA

Successful use of induction logs in ground-water investigation

The standard long and short normal electrical-resistivity probes widely used to estimate water quality in freshwater aquifers have only limited application for this purpose in Horry and Georgetown Counties, South Carolina. According to A. L. Zack, many of the important Black Creek aquifer sands are too thin to allow accurate resistivity measurements to be made, even after adjustments are made for thin-bed effects. Also, where sands are thicker, they are usually interrupted by impervious rock layers, which have deleterious adjacent-bed effects on the resistivity measurements.

Apparently, measurements of the low resistivities (less than 40 Ω, even for sands containing 25 mg/l Cl^-), which are encountered throughout the geologic section, require the use of an induction-resistivity tool. This tool has certain focusing properties that minimize the effects of adjacent beds and allow resistivities of individual beds to be accurately measured. The value of this log has been demonstrated at Myrtle Beach, Georgetown, and Plantersville, S.C.

Capacity use study in the "low country"

L. R. Hayes reported that a preliminary inventory of existing wells in the "low country" of South Carolina led to the identification of four major areas where there is saltwater contamination of the primary limestone artesian aquifer: Parris Island in Beaufort County; Brickyard Point, also in Beaufort County; the area in Beaufort County bounded to the north by State Highway 77 and to the south by the Atlantic Ocean; and Edisto Beach in Colleton County; the area in Beaufort County bounded to been identified as a potential problem area. Although the high chloride content in the water from some wells is due to faulty well construction, geologic, hydrologic, and quality-of-water data from seven test holes and data from existing wells strongly support the conclusion that contamination resulted from the intrusion of seawater into the aquifer. Data from test holes and existing wells indicate that in some cases the permeability of the aquifer where saline water is present is much less than that where contamination has not taken place. Geologic and hydrologic data show significant changes in the lithologic and hydraulic characteristics of the aquifer over relatively short distances. The aquifer ranges in thickness from a few meters with a transmissivity of less than 190 m^2/d at Harbor Island to a thickness of several hundred meters with a transmissivity of more than 4,500 m^2/d at Hilton Head Island.

TENNESSEE

The New River basin is comprised of three counties that produce more than 50 percent of the coal mined in Tennessee. Strip mining has more than doubled in recent years. A. E. Coker, A. L. Higer, and E. F. Hollyday used Landsat–1 digital tapes to map 10 land-cover categories related to hydrology in 15 topographic quadrangles (scale 1:24,000) covering this mining basin.

Within the 1,020-km^2 basin, land-cover types for each 4,500-m^2 unit had been classified as of April 14, 1973. According to this analysis, 88.6 percent of the basin is forest, 6.5 percent is rock and bare earth (predominantly strip mines, spoil banks, and access roads), and 4.9 percent is agricultural land. These data are needed for planning the development and use of water and related resources as well as for determining the effects of mining on small watersheds.

CENTRAL REGION

Hydrologic activities in the central region during the past year again strongly emphasized studies related to the environment and to energy development. Long-established programs for the collection and publication of diverse water-resource data continued. Intensive water-resource investigations related to coal and oil-shale development continued in North Dakota, Montana, Wyoming, Utah, Colorado, and New Mexico. Reconnaissance-level studies of the water resources of coal areas in Oklahoma were begun during the year.

Additional emphasis was given to hydrologic studies of small basins that are representative of potential surface coal-mining areas. Results of these studies are expected to be applied to leasing decisions, environmental impact statements, mining procedures, and specifications for reclamation of mining areas.

Water-quality studies are underway throughout the central region. USGS scientists, in cooperation with personnel of other agencies and with Canadian scientists, are studying the effects of the Garrison Diversion plan on the Souris River in North Dakota and Manitoba, Canada. Intensive water-quality studies are being made in coal areas, especially in Colorado, Montana, New Mexico, North Dakota, Utah, and Wyoming. The energy-related water-quality investigations include studies of sediment, bed material, water chemistry, and aquatic biota in selected streams.

Lake and reservoir studies concerned with algal production and identification and with salt leaching are underway in several reservoirs on the North Platte River in Wyoming and in the Flaming Gorge Reservoir in Utah. A study of strip-mine reclamation and the effects of spoil-pile drainage on receiving streams is underway in Missouri. The study includes determining the concentrations of selected trace metals in surface and ground waters.

Surface-water activities were again an important part of the regional program. Gaging-station networks were expanded in Colorado, Montana, Utah, and Wyoming because of increased activity in energy-related projects; monitoring the quality and quantity of surface water in the energy areas constitutes a large share of the effort. Because of deficient surface-water supplies in many coal and oil-shale areas, studies are underway to determine the possibility of importing water from other sources into these areas and to evaluate the effects of such a procedure on the existing hydrologic system. Digital-model systems analyses are widely used for planning energy studies and for providing additional knowledge of the systems.

Throughout the region, many additional flood-prone areas were mapped, and all flood-prone-area mapping has been completed for some States. Increased numbers of HUD type-15 flood-insurance studies at specific cities were made during the year; several additional States added these studies to their programs. Flood-frequency studies were completed in Colorado, Montana, North Dakota, and South Dakota and were nearing completion in Nebraska and Texas. A new program to study scour in rivers at and near bridges was begun in Arkansas, Kansas, and New Mexico. In Wyoming, a study was made for the National Park Service to determine the possibilities of flooding of the Snake River if a devastating earthquake were to destroy Jackson Lake Dam near Jackson.

Emphasis on the development and use of digital models for ground-water studies continued. Changes in ground-water conditions in the alluvial valley of the Red River in Louisiana, which may result from the installation of lock-and-dam structures in the river, were projected with the aid of a digital model. Ground-water levels were projected as a function of precipitation, potential evapotranspiration, lithology of the alluvium, depth to the water table, and changes in stream stages.

Studies of artificial recharge to aquifers by spreading ponds continued near Lubbock, Tex., and in El Paso County, Colorado. An investigation of the feasibility of artificial recharge to an alluvial aquifer by means of naturally filtered river water in an injection well was begun in south-central Nebraska.

Hydrologic research in the central region included many activities related to energy development, such as investigations of the hydrochemistry of surface and ground water in oil-shale and coal-bearing terrane, the development of modeling techniques for the prediction of solute transport in ground water, and the development of techniques for estimating numerical values for parameters and boundary-condition values for ground-water systems. Also included was research in sediment transport, channel geometry changes, and fluvial processes in coal areas.

An investigation of special significance to coal development is an evaluation of the water-yielding potential of the Madison Limestone—an important, deeply buried aquifer underlying large areas in the Powder River basin in Wyoming, Montana, North Dakota, and South Dakota. A preliminary numerical model of the aquifer system is being tested for use in planning further studies and for designing a data-collection program. The location of the first deep exploratory well to be drilled through the Madison Limestone was selected, and specifications were developed for drilling and hydraulic testing.

Field investigations of the hydrology of geothermal systems are continuing in Colorado, Montana, and Utah. Also, instruments, tools, and interpretative techniques for use in the extreme heat of geothermal systems are being tested.

In Nevada, water-resource investigations continued at the Nevada Test Site, where tracer tests were made in a thin fractured-dolomite aquifer to determine permeability distribution, and pumping tests were begun at Yucca Flats to determine aquifer characteristics and ground-water flow rates.

MULTISTATE STUDIES

Extensive aquifers underlie Fort Union coal region

M. G. Croft reported that the Fox Hills-basal Hell Creek aquifer underlies all of the Fort Union coal region. In the center of the Williston Basin in North Dakota, the rocks forming the aquifer are at a maximum depth of 670 m; the aquifer has a transmissivity of about 28 m^2/d; the dissolved-solids content of the water ranges from 1,000 to 2,200 mg/l. In the Powder River basin in Montana and Wyoming, the rocks forming the aquifer are exposed on the basin's eastern and western flanks and are at a maximum depth of about 2,400 m in the center of the basin. The aquifer has a transmissivity of 28 to 100 m^2/d; the dissolved-solids content of the water ranges from 800 to 1,200 mg/l.

The aquifer is one of the area's major sources of water for small municipalities or communities that do not obtain surface water from the Yellowstone or Missouri Rivers. Water is also pumped from the aquifer to repressurize oil fields, and many flowing wells tap the aquifer for livestock and farm supplies. A potentiometric map of the aquifer suggests that a water-level decline of several hundred meters has occurred in flowing wells along the Yellowstone River near Miles City, Mont. Water-level declines of more than 30 m have occurred in many areas beneath small cities and in areas adjacent to the Missouri and Little Missouri Rivers, owing to ground-water discharge by many flowing wells.

Model of ground water in Madison Limestone

Withdrawal of ground water from the extensive Madison Limestone aquifer has been proposed to meet the increasing water demands that will accompany the future development of energy resources in the Powder River basin of Wyoming and Montana. Most recharge to the aquifer originates in or near the outcrop areas of the Madison in the Bighorn Mountains and Black Hills, and most discharge occurs through springs and wells. A digital model designed by L. F. Konikow (1976) simulated the flow of ground water in the Madison aquifer in a 163,000-km^2 area that included the Powder River basin. Although the model was used to make a preliminary estimate of the range of effects that might result from major ground-water withdrawals, the model analysis clearly indicated that more accurate descriptions of the hydrogeologic properties of this aquifer are needed. Preliminary results indicated that the total flow through the aquifer in the modeled areas was approximately 5.7 m^3/s.

Geohydrology of the Madison Group

W. R. Miller (USGS) and J. L. Peterson (Montana State University) reported that preliminary analyses of geophysical and lithologic logs indicate that the Madison Group in the northern Powder River basin and in the area around the Black Hills of South Dakota can be divided into four distinct units on geophysical logs. Maximum porosity appears to be associated with dolomitization. Zones having high dolomitization and high apparent porosity trend roughly east-west, the thickest and most widespread zones extending along the Montana-Wyoming boundary and east of the Black Hills. Dolomitization is thought to be a function of the paleogeography, not of modern structural features. All large-capacity production wells are in areas of high dolomitization.

Summary appraisal of ground water in the Missouri River region

According to O. J. Taylor, ground water in the Missouri River region occurs principally in unconsolidated to semiconsolidated sand and gravel, in sandstone formations that lie near the land surface or in deep structural basins, and in limestone or dolomite formations at various depths. Additional water can be obtained by conjunctive use of ground and surface water, reuse of available supplies, artificial recharge, and salvage of evapotranspiration. More productive use of the sandstone aquifers will result from artificial recharge, induced interaquifer leakage, conjunctive use of surface water, and temporary mining of ground water. Limestone and dolomite aquifers have a potential for development of large ground-water supplies, by salvage of rejected recharge and by inducing interaquifer leakage.

COLORADO

Hydrologic studies of Steamboat Springs and Vail areas

Basic hydrologic and geologic data were collected by R. E. Brogden and T. F. Giles in areas near Vail and Steamboat Springs, Colo., to identify the availability and chemical characteristics of ground water in various aquifers. Both areas are experiencing rapid population growth coupled with rapid increase in water use. Knowledge of the occurrence of ground water will allow the State to allocate the resource more efficiently.

Parts of the Steamboat Springs study area include a region of potential coal development. Identification of hydrologic baseline conditions prior to mining will help to determine the impact of strip mining on the availability and chemical characteristics of water in the study area. Well yields in the coal-development area are low, generally less than 0.6 l/s. Stripping the land to mine the coal can affect the quality of the ground- and surface-water resources in parts of the study area. Analyses of water from wells and springs in the coal-rich Williams Fork and Isles Formations have indicated that dissolved-solids, copper, and selenium concentrations are in excess of limits recommended by the USPHS for drinking water. Dissolved-solids concentrations range from 407 to 1,930 mg/l. Copper concentrations as high as 3,800 μg/l and selenium concentrations as high as 29 μg/l were detected.

Ground-water resources of the Southern Ute Indian Reservation

The availability and chemical characteristics of ground water on the Southern Ute Indian Reservation near the Four Corners area of southwestern Colorado were studied by R. E. Brogden and E. C. Hutchinson. The reservation is in an arid region, and surface-water supplies are limited to a few major rivers. Most of the stock- and domestic-water supplies are from private wells.

The primary aquifers on the reservation are fractured sandstones and shales. Well yields are low, generally less than 0.3 l/s. Alluvial deposits are restricted to the major river valleys and are mostly less than 4.6 m thick. Most wells drilled in the alluvium are completed in the underlying bedrock.

The quality of water on the reservation is variable; dissolved-solids concentrations range from less than 150 mg/l to more than 4,400 mg/l. In aquifers in the Animas and San Jose Formations, selenium occurs in amounts exceeding those recommended by the USPHS for drinking water; concentrations of selenium range from less than 1 μg/l to more than

6,200 μg/l. Cases of selenium poisoning have been reported by the U.S. Bureau of Indian Affairs and the Southern Ute Tribal Council.

Artificial-recharge experiments in El Paso County

Infiltration rates were monitored in nine spreading ponds to determine the artificial-recharge potential of three alluvial aquifers in El Paso County, Colorado. P. J. Emmons reported that the infiltration rates of three spreading ponds on the alluvial aquifer in the upper Black Squirrel Creek basin ranged from 0.3 to 0.5 m/d; the infiltration rates of two spreading ponds on the alluvial aquifer in Jimmy Camp Creek valley ranged from 0.8 to 2.4 m/d; the infiltration rates of four spreading ponds on the Widefield aquifer in Fountain Valley ranged from 0.4 to 2.9 m/d. On the basis of infiltration rates only, the artificial-recharge potential for the aquifers is good. Other factors, however, such as the chemical quality of the water to be recharged and the interaction of the receiving aquifer with the recharge water, must be evaluated before a final determination of the recharge potential of the aquifers can be made.

Shallow ground water, Front Range urban corridor

The rapidly increasing population and the industrial growth in the Front Range urban corridor of Colorado, which extends from the Fort Collins-Greeley area to the Colorado Springs area, have resulted in an increasing need for water. Ground-water use, which in the past has been small in comparison with surface-water use, is now rapidly increasing. To provide information to State and local officials, land-use planners, and developers, D. E. Hillier and R. E. Brogden conducted an investigation into the occurrence of shallow ground water in the Front Range urban corridor.

Well yields vary considerably, depending on the aquifer. Yields as high as 125 l/s can be developed in the alluvium of the South Platte and Cache la Poudre Rivers. Yields of wells in bedrock, dune sand, and alluvial fans are considerably lower than those of wells in stream-channel alluvium and are generally less than 1.5 l/s. The shallow ground-water system is in equilibrium with the general availability of water in the area. Fluctuations of water levels are directly related to precipitation, irrigation practices, and ground-water withdrawals.

Quantity and quality of ground water in northeastern Larimer County

The quality of ground water in the alluvial aquifers of northeastern Larimer County, Colorado, is controlled by irrigation practices in the area. According to R. T. Hurr and P. A. Schneider, Jr., selenium, sulfate, hardness, and dissolved-solids concentrations are controlled by the quality of applied irrigation water, by the amount of water lost to evaporation during irrigation, and by the solution of material in the alluvium and in the bedrock at the base of the alluvium rather than by any single source or area. Three locally significant alluvial aquifers that have a combined ground-water storage capacity of 195 million m^3 and that supply water to 273 irrigation and municipal wells, as well as to numerous stock and domestic wells, have selenium concentrations ranging from 0 to 44 μg/l, sulfate concentrations ranging from 20 to 1,800 mg/l, hardness ranging from 230 to 1,900 mg/l, and dissolved-solids concentrations ranging from 304 to 3,260 mg/l.

Water management in the South Platte River valley

During the period 1947–70, surface-water diversions for irrigation in the South Platte River valley of Colorado averaged 1,210 hm^3 annually, and ground-water diversions averaged 518 hm^3 annually, according to R. T. Hurr, P. A. Schneider, Jr., and D. R. Minges (1975) (R. T. Hurr, 1975).

About 45 to 50 percent of the applied irrigation water recharges the ground-water system; a large part of the water in the system ultimately seeps into the river. Owing to the consumptive losses, however, the recharged ground water is higher in dissolved solids than the applied irrigation water, so that there is a general increase in dissolved-solids concentration in a downgradient and downvalley direction. There also tends to be an increase in dissolved-solids concentration in the river in a downvalley direction.

Withdrawals by wells between 1947 and 1970 reduced ground-water discharge to the river by about 308 hm^3 annually. The flow of the South Platte River was not significantly changed, however, because the effect of other management practices—an increase in transmountain diversions and a decrease in direct diversions from the river—offset the reduction in ground-water discharge. An analysis of streamflow data indicated that the return flow from the application of the increased imported water amounts to 179 hm^3 annually. Diversion records show a decrease in direct diversions of 160 hm^3 annually. The sum of these two quantities is within 10 percent of the observed reduction in ground-water discharge; thus, there is almost no change in the streamflow of the South Platte River as it leaves Colorado.

Federal Center storm-runoff management model

A storm-runoff management model for the Federal Center in Denver, Colo., designed to monitor present conditions and to provide effective evaluation of the future development of storm-runoff characteristics was studied by R. D. Jarrett and J. F. McCain. The management model is to be used by the General Services Administration in near-future and long-range planning for the Federal Center. Nine digital rain gages and seven nonrecording rain gages have been installed in the 11.7-km^2 study area to determine the areal distribution of precipitation. Nine stream-stage recorders have been installed to determine the net flow from the Federal Center. Dual digital precipitation and stage gages are used at key locations to correlate precipitation and runoff.

Water-level decline projected for parts of Cheyenne and Iowa Counties

G. W. Kapple reported that a digital model was constructed to quantitatively evaluate the ground-water potential of the Ogallala aquifer in parts of Cheyenne and Kiowa Counties, Colorado. A finite-difference technique with grids of 2.6 km^2 was used for the 2,395-km^2 area.

Using 1972 pumpage data (T. J. Major, Lynda Kerbs, and R. D. Penley, 1975), the model predicted that regional declines will be as much as 12.2 m by the year 2000. Most simulated depletion occurred in the thicker parts of the aquifer.

Hydrology of oil-shale lands

A study of the semiarid Parachute Creek and Roan Creek basins in northwestern Colorado was made by G. H. Leavesley to inventory water resources and describe the hydrologic system prior to oil-shale development. Data on discharge, chemical and biological quality, and sediment were obtained to define the surface-water system. Snowmelt is the major source of surface runoff, although peak flows may result from either snowmelt or high-intensity summer thunderstorms. Irrigation of farmland on the valley floors accounts for large consumptive losses to evapotranspiration. Surface-water, irrigation, and climatic records were compiled to compute a water balance for each basin. Surface-water quality is affected by irrigation return flows and ground-water discharge. Dissolved-solids concentrations increase from less than 400 mg/l in the headwaters to more than 1,000 mg/l near the basins' mouths.

The ground-water system consists of three principal aquifers. The upper two are in the Green River Formation and are separated by the Mahogany zone; the third is in the upper part of the Wasatch Formation. A network of deep and shallow observation wells was established to measure potentiometric-surface levels and ground-water quality. Discharge and chemical-quality data were collected for major springs to determine their sources and contributions to total basin hydrology. Springs from the upper aquifer of the Green River Formation have a calcium bicarbonate-type water with dissolved-solids concentrations of about 300 mg/l. Springs from the Wasatch Formation have a sodium sulfate-type water with dissolved-solids concentrations exceeding 3,500 mg/l at some locations.

Hydrology of coal lands in the Yampa River basin

G. H. Leavesley and R. E. Brogden reported that the water resources and the hydrologic system of selected proposed coal-development sites in the Yampa River basin of northwestern Colorado were being defined prior to proposed mining. Discharge, chemical and biological quality, and sediment data were measured at 10 surface-water sites. Water-level and chemical-quality data were collected from a network of deep and shallow observation wells throughout the region. Precipitation, air and soil temperatures, humidity, solar radiation, and wind were measured at selected sites to define regional climate. Analyses of data from the Taylor Creek study site (U.S. Bureau of Land Management, 1975) indicate that the greatest impacts from mining will be increased sediment and dissolved-solids loads to streams. Dissolved-solids concentrations presently range from 500 to 1,100 mg/l.

Changes in the hydrologic system during mining will be monitored, and these data and the baseline information collected before mining will be used to develop models that will predict the effects of coal mining on the hydrology of unmonitored areas of the Yampa River basin.

Water resources of El Paso County

R. K. Livingston, J. M. Klein, and D. L. Bingham studied the water resources of El Paso County, Colorado, an area experiencing a rapid population increase. The annual water supply consists primarily of precipitation, most of which is lost through evaporation and evapotranspiration. Mean annual precipitation ranges from less than 300 to more than 760 mm and is a function of land-surface altitude; much of the county is a semidesert region.

Surface waters were studied by examining recorded mean annual discharge, flow duration, low-flow and high-flow frequencies, flood frequency at gaged sites, and estimated mean annual flow and peak discharges at ungaged sites. Gain-and-loss investigations of Monument and Fountain Creeks defined interactions between surface water and ground water. The chemical quality of surface water is generally good, except for locally high fluoride concentrations that exceed USPHS recommended limits for drinking water. Dissolved-solids concentrations during low-flow conditions range from less than 100 mg/l in small mountain streams to more than 1,000 mg/l in Jimmy Camp Creek, a plains stream. The water quality of Fountain Creek deteriorates with the addition of sewage effluent between the cities of Colorado Springs and Fountain.

Ground water occurs primarily in the alluvium in Fountain Creek valley (including the Widefield aquifer), Jimmy Camp Creek valley, and upper Black Squirrel Creek basin. Ground water also is obtained from the Dawson Formation in the northern part of the county. Alluvial aquifers contain an estimated 620 hm^3 of ground water, whereas the Dawson aquifer contains an estimated 46,360 hm^3 of ground water in the upper 150 m of saturated thickness. Using estimated data for ground-water withdrawals from the Dawson aquifer and a mathematical model of the aquifer, a water-level decline map for the year 2000 indicates three areas with a decline greater than 46 m and a depletion of flow in Monument Creek of 105 l/s. The dissolved-solids content of ground water ranges from less than 250 mg/l in upper Black Squirrel Creek basin to more than 3,500 mg/l in Jimmy Camp Creek valley. The chemical quality of ground water generally is good.

Ground-water quality near a cattle feedlot

Ground-water quality is being monitored at a large cattle feedlot near Greeley, Colo., in order to determine the effects of the feedlot on the water quality samples collected from January 1974, when 19 wells in or near the feedlot has enabled ground-water sampling upgradient and downgradient of the lot as well as at several depths within the aquifer. The feedlot is located on alluvium near the South Platte River where the water table is about 9 m below land surface. Analyses of about 250 water-quality samples collected from January 1974, when the feedlot operation began, to February 1976 indicate that minimal water-quality changes have occurred in all but one of the observation wells. Chloride and nitrate concentrations in background samples range from about 80 to 140 mg/l and 5 to 15 mg/l, respectively. A 14-m-deep well located near the eastern (downgradient) edge of the feedlot contains chloride and nitrate concentrations ranging from about 110 to 150 mg/l and 10 to 50 mg/l, respectively.

Effects of waste disposal on ground-water quality near Denver

Land application of sewage sludge, a solid-waste landfill, and associated liquid-waste disposal pits have had minimal effect on the quality of ground water in an area 26 km east of Denver, Colo., according to S. G. Robson. Ground water in the area occurs in flat-lying sandstone layers in the Dawson Formation or in small alluvial deposits along creeks. Disposal operations generally occur along the upper parts of the hilly topography where depth to ground water ranges from 15 to 37 m. The 380 mm of annual precipitation produces minimal local runoff into stream channels in the area. Although water-level measurements in wells indicate that the study area is part of a recharge area for the Dawson Formation, the quantity of water moving down through the predominant shale and mudstone layers of the formation is small and probably will not have a rapid or pronounced effect on ground-water quality in the area.

Drilling of geohydrologic test holes in an oil-shale formation in Rio Blanco County

G. J. Saulnier, Jr., and F. A. Welder reported that 20 geohydrologic test holes were drilled in the upper and lower aquifers of the Green River Formation in Rio Blanco County, Colorado. Eleven holes in the upper aquifer were completed to an average depth of 309 m, and 9 holes in the lower aquifer were completed to an average depth of 459 m. The total footage drilled was 6,455 m.

Water discharge during drilling was as much as 38 l/s. Specific conductance of the discharged water was generally less than 3,000 μmho/cm at 25°C.

Hydrologic evaluation of oil-shale mine sites in the Piceance Creek basin

The hydrologic characteristics of four possible sites for the location of an experimental oil-shale mine in the Piceance Creek basin of Colorado were evaluated by J. B. Weeks and G. H. Leavesley, using existing data. On the basis of the evaluation, the U.S. Bureau of Mines selected a site near Ryan Gulch, a tributary to Piceance Creek, for test drilling. Hydrologic data were collected during drilling by F. A. Welder and G. J. Saulnier, Jr. The field data indicate that the aquifer system at the test site is more permeable and contains water with lower dissolved-solids concentrations than initial estimates indicated. The aquifer test data show that the transmissivity of the permeable section at the test site is about 260

m^2/d and that the concentration of dissolved solids in the water in the aquifers is about 1,500 mg/l.

A digital model of the aquifer system was used to make estimates of mine-shaft dewatering rates for the site before test drilling. The data collected during drilling will be used to revise the model parameters. The model will then be used to provide new estimates of mine-shaft dewatering rates.

KANSAS

Increased rate of water-level decline in southwestern Kansas

E. D. Gutentag and M. E. Pabst reported that the rate of water-level decline is increasing in southwestern Kansas. Measurements in 538 observation wells in the Ogallala Formation and undifferentiated deposits of Pleistocene age showed that the average annual decline was 0.52 m during the period 1966–75. In 1974–75, however, the average decline was 1.6 m. The increased rate of decline is attributed primarily to increased withdrawals of ground water for irrigation during the drought in 1974–75. In 1940–74, water withdrawals for irrigation increased from 74 to 2,470 hm^3.

Ground-water withdrawals exceed recharge in alluvial valleys of Ness County

New wells were drilled in the alluvium of the Pawnee River and Walnut Creek valleys in Ness County, Kansas, to maintain irrigation supplies late in the season when well yields decrease because of interference between wells and declines in water levels. According to E. D. Jenkins, ground water stored in the alluvial valleys is depleted gradually, and it is replenished principally in years of excess precipitation such as 1950–51 and 1957–60. Since 1961, water levels have declined steadily at a rate of about 0.3 m/yr in response to significant increases in the amount of ground water pumped.

LOUISIANA

Soft-water zone defined in St. James Parish

Test drilling near Hester, La., on the Mississippi River in St. James Parish, defined an area where water in the Gramercy aquifer is of very good quality, according to D. C. Dial. The approximately 2.6-km^2 crescent-shaped area parallels the Mississippi River. The water is unusually low in hardness (<30 mg/l) and iron (<0.3 mg/l) and is a potential source for public-supply use. In the surrounding area, water in the Gramercy aquifer is generally hard to very hard (100–300 mg/l) and high in iron (>0.3 mg/l). North of the zone of soft water, the aquifer contains slightly saline water. Additional testing will be required to evaluate the yield potential of the area and to clarify quality relationships and the origin of the soft water.

High sediment yield in coastal lowland watershed

L. D. Fayard reported that a 58.5-km^2 area in the sugarcane belt of southern Louisiana was gaged for runoff and suspended-sediment discharge. The average slope of the area is estimated to be less than 0.1 percent. Data from eight selected storms show that the sediment yield is somewhat higher than what would be expected in a lowland area. Total rainfall at the gaging station during these storms was 419 mm, and total runoff was 300 mm. The suspended-sediment yield from the storms was 194 t/km^2.

Quality of water of the lower reach of the Red River

The lower reach of the Red River in Louisiana carries a heavy suspended-sediment load much of the time. According to R. F. Martien, the mean suspended-sediment discharge at Alexandria, La., for the 1974 water year was 192,000 t/d. Several large municipalities use the Red River for the disposal of sewage, much of which receives only primary treatment and therefore places an increased BOD load on the river. Oxygen supersaturation, however, occurs throughout the Louisiana reach during low flow and overcomes BOD loads. Light- and dark-bottle measurements indicate that the oxygen supersaturation is due primarily to photosynthesis by algae.

Areas in eastern Rapides Parish remapped

Physiographically, most of the area in eastern Rapides Parish, Louisiana, is the Prairie Terrace of Pleistocene age. All of this area was mapped previously as terrace deposits and thus was considered to be the outcrop of the terrace aquifer. However, J. L. Snider, who was completing a study of the terrace aquifer in central Louisiana, found that clays of Miocene age occur at the land surface at a number of test-well sites drilled in 1975. The new data show that the terrace aquifer is not as extensive as was previously believed and that the clays act as hydrologic boundaries that retard ground-water movement in the area. Additional test drilling will be necessary to determine the extent of the Miocene clays.

Water quality of the Atchafalaya Basin Floodway

The Atchafalaya Basin Floodway in Louisiana is the largest distributary of the Mississippi River. The water quality of the floodway was studied from

September 1973 to August 1975 by F. C. Wells and C. R. Demas. They found that the chemical quality of the Atchafalaya River varies with discharge in the Red, Black, and Mississippi Rivers. Dissolved-solids concentrations were found to be equal to or less than 285 mg/l 90 percent of the time. Dominant anions present in the Atchafalaya River are bicarbonate, sulfate, and chloride. Similarly, the dominant cations are calcium, sodium, and magnesium. Bicarbonate and calcium concentrations were found to be equal to or less than 112 mg/l and 36 mg/l, respectively, 50 percent of the time. Concentrations of nitrogen and phosphorus compounds, pesticides, and heavy metals are relatively low. The primary sources of oxygen to swamps and backwater areas of the basin are overflow and distributary flow of the Atchafalaya River. Time-of-travel data indicated that traveltimes in distributaries on the western side of the floodway are much slower than traveltimes in the main channel of the Atchafalaya River.

Water quality of the Red River alluvial aquifer

M. S. Whitfield, Jr., reported that numerous local areas in the Red River alluvial aquifer have chloride concentrations exceeding 250 mg/l. Some of these occurrences, particularly in the Shreveport area of Louisiana, may be caused by man's activities. However, many of the bodies of saline water lie near or parallel to the strike of underlying sand beds of Tertiary age that also contain saline water. Thus, most of the larger areas of saline water appear to result from the discharge of saline water from underlying sands.

Near Clarence, in Natchitoches Parish, chloride concentrations in water from the base of the alluvium are as great as 4,300 mg/l, and near Colfax, in Grant Parish, chloride concentrations are as great as 4,600 mg/l. Because of local recharge from infiltration of rainfall at both sites, however, chloride concentrations in water from the upper part of the alluvial aquifer are less than 20 mg/l.

MONTANA

Test drilling in Glacier National Park

Test drilling by D. L. Coffin, R. G. McMurtrey, and A. J. Boettcher in campgrounds and near ranger stations in Montana's Glacier National Park revealed that wells tapping glacial and lake deposits yield from 0.06 to 13 l/s of water. The seven test holes are from 12 to 35 m deep and yield water of excellent quality. The glacial deposits are primarily till and poorly sorted outwash. The lake deposits are well-sorted sand and gravel. Both types of deposits are composed mainly of rounded to well-rounded fragments of argillite and limestone from the Belt Supergroup.

Geohydrology of Madison Group in part of northern Montana

R. D. Feltis prepared structural maps of the top of the Madison Group of Mississippian age north and northeast of the Little Belt and Big Snowy Mountains of central Montana; these maps show that the regional dip of the Madison is toward the northeast.

Drill-stem-test pressure data from oil test holes in the Madison indicate that the regional hydraulic gradient from the mountain recharge areas is northwest toward Giant Springs at Great Falls, north and northeast toward the Bearpaw and Little Rocky Mountains, and eastward toward the Williston Basin. Water is discharged from the Madison at Giant Springs, at Big Springs and Warm Spring near Lewiston, and at several warm springs near the Little Rocky Mountains. The dissolved-solids concentration of the water ranges from about 280 mg/l at Big Springs to 1,600 mg/l at the springs near the Little Rocky Mountains. The dissolved-solids concentration of water from oil test holes in the Madison ranges from about 1,500 to 4,000 mg/l in the Judith Basin area; it is more than 200,000 mg/l in northeastern Montana.

Coal-aquifer reclamation study in Bear Creek area

W. R. Hotchkiss and J. D. Stoner studied the reclamation potential of an area of strippable coal deposits in southeastern Montana, about 14 km south of the confluence of the Bear and Otter Creeks. The 4.9-m-thick Anderson, the 3-m-thick Dietz, and the 6-m-thick Canyon coal units of the upper part of the Tongue River Member of the Fort Union Formation of Paleocene age are major shallow aquifers in the area. Ground water generally flows northwestward in the coal units and discharges outside of the Bear Creek area. The yields from composite coal aquifers are less than 0.7 l/s, and specific capacities are less than $0.02\ l\ s^{-1}\ m^{-1}$ of drawdown. Dominant constituents in water from the coal are sodium and sulfate; bicarbonate is also abundant. The dissolved-solids concentration is about 3,500 mg/l.

A digital-computer model will be used to estimate the response of local hydrologic conditions to various degrees of strip mining.

Effects of surface coal mining on ground-water supplies in Big Horn County

Hydrologic studies by N. J. King and D. R. Rima of two proposed surface coal mines in the Decker area of southeastern Big Horn County, Montana, identified the principal ground-water problems associated with mining as (1) removal of shallow coal beds, which are the main aquifers in the area, (2) excessive ground-water inflow to the mines from the nearby Tongue River Reservoir through permeable alluvium and clinker, and (3) deterioration of water quality owing to the leaching of spoils materials after mining and reclamation have been completed. Impaired ground-water supplies can be replaced with adequate yields of water of equal or better quality by drilling 30 to 60 m deeper to underlying coal beds. Excessive ground-water inflow can be controlled by trenching and constructing compacted-fill ground-water barriers between the mines and the reservoir. In contrast, little or nothing can be done to prevent leaching of the replaced spoil materials and the consequent deterioration of the shallow ground-water resources in the mined areas. The effect would be local, however, and would not significantly impair the water quality in the Tongue River Reservoir, which is used as a fish and wildlife habitat and for irrigation downstream.

Ground-water quality in Lincoln

An appraisal of the ground-water quality in Lincoln, Mont. (population about 500), was made by K. R. Wilke. Residents of this unincorporated town have individual wells and septic tanks.

The ground-water level below land surface ranged from 0.6 to 3 m in September 1974 and June 1975. Ground-water samples had low concentrations of nitrite plus nitrate, total ammonia, and phosphate. Nitrite plus nitrate (as N) ranged from 0.01 to 0.53 mg/l and averaged 0.13 mg/l for 37 samples collected in October 1974 and ranged from 0.05 to 0.75 mg/l and averaged 0.22 mg/l for 30 samples collected in May 1975.

Although near-surface ground-water levels and numerous septic tanks provide a setting for possible ground-water contamination, ground water in the Lincoln area did not appear to be significantly degraded by septic-tank effluent.

NEBRASKA

Five flood-frequency regions in Nebraska defined

E. W. Beckman's analyses of data for 258 gaging stations having 13 years or more of record on natural streams resulted in the definition of five flood-frequency regions in Nebraska. Boundaries of three of the regions are closely related to soil types, and the boundaries of the other two regions are along or near basin divides. Multivariant regression analyses of data for the stations in each region were made to determine the minimum number of physical and climatological characteristics that would define consistent and smooth frequency curves. Best results were obtained by the computation of a constant and the choice of two physical characteristics and one climatic characteristic for each of six recurrence levels in each region.

Effect of irrigation development on water supply of Upper Republican Natural Resources District

A study by E. G. Lappala indicated that, since 1952, there has been a very large increase in the use of ground water in the three-county area (Chase, Dundy, and Perkins Counties) of the Upper Republican Natural Resources District of Nebraska. At the end of 1975, there were 1,932 registered irrigation wells in the district, a 2,175-percent increase over the number of wells registered in 1952. Fourteen percent of the wells were drilled in 1975, and 50 percent of the wells have been drilled since 1970. The principal aquifer being developed consists of saturated sands and gravels in the Pliocene Ogallala Formation. Water-level declines of as much as 4.9 m occurred between 1952 and 1975. Base flows of major streams draining the area underlain by the aquifer have been reduced by as much as 19 percent since 1967. The amount of recoverable ground water in storage has been reduced by about 1 percent (518 hm^3). Net withdrawal of ground water in 1975 was about 308 hm^3, in comparison with an estimated recharge of 217 hm^3 from precipitation.

Organic nitrogen in ground water

L. R. Petri and R. A. Engberg reported that concentrations of organic nitrogen make up a substantial percentage of the total nitrogen content of water samples collected from nine 3.18-cm-diameter shallow observation wells installed in areas near the Platte River in central Nebraska. The depth to water is 9 m or less in each observation well, and all wells are screened so that only water from the upper 0.5 to 1.0 m of the water table can be sampled. Very little organic nitrogen was observed in water samples from nine domestic wells, each of which is within 0.5 km of one of the observation wells. In many localities, nitrogen in the organic form apparently moves rapidly into the aquifer, and substantial oxidation to inorganic forms takes place within the aquifer.

NEW MEXICO

Approximately 190 l/s of ground water is being pumped from two uranium mines completed in the Jurassic Westwater Canyon Member of the Morrison in the Church Rock mining district about 20 km northeast of Gallup, N. Mex. The water generally contains less than 400 mg/l of dissolved solids and, except for a small amount of dissolved uranium, is of better quality than the water now available in the municipal supply. Some of the water will be required for use in oil-processing plants. Additional waste water, however, will probably be available from other mines that reportedly will be located nearby. After mining ceases, the mines will comprise large underground collection systems from which water can be pumped as needed. According to W. L. Hiss (1975a), water salvaged from the mines constitutes a potential source of high-quality ground water for the city of Gallup.

NORTH DAKOTA

Ground-water resources of Morton County

Ground-water investigations by D. J. Ackerman in Morton County, North Dakota, concentrated on refining previous concepts of the hydrology of bedrock and drift aquifers. The variability of the occurrence and of the persistence of sandstones within various bedrock units has been related to the depositional environment of the units. On a smaller scale, the hydraulic conductivities of cores of bedrock sandstones that are similar in appearance may differ by more than seven orders of magnitude; anisotropic variations may be of about one order of magnitude. The lowest conductivity values appear to be related to the increase in the montmorillonite content of the clay fraction.

Movement and quality of ground water in western North Dakota counties

L. O. Anna reported that Skylab photography shows dominant northwest-southeast-trending lineaments in southwestern North Dakota. The lineaments may be along major Earth-fracture systems. The fractures possibly control both vertical ground-water movement between deep and shallow aquifers and surface-water drainage patterns.

The marine Cannonball Member of the Fort Union Formation and its continental equivalents, the Ludlow and Lebo Shale Members, are traceable in the subsurface. These members, which consist of sandy siltstone and claystone, are major confining beds in the area. The Hansen lignite bed of the Tongue River Member is about 4 m thick; it is traceable in the subsurface throughout most of a three-county area. The lignite dips 4.7 m/km to the northeast.

Recent test drilling identified two major aquifer systems, the Fox Hills-basal Hell Creek and the upper Hell Creek-Ludlow. They range in depth from 0 to 600 m and 0 to 500 m, respectively. Flowing wells in both aquifer systems have created major cones of depression along the Little Missouri River. Water levels have declined about 60 m in the upper Hell Creek-Ludlow aquifer system. Transmissivities of the two aquifer systems average 20 m^2/d. Both aquifer systems yield sodium bicarbonate water with approximately 1,000 mg/l dissolved solids.

Ellendale aquifer extends into LaMoure County

C. A. Armstrong reported that the Ellendale aquifer extends northward from its discovery area about 10 km east of Ellendale in Dickey County, North Dakota (Naplin, 1973), to the James River flood plain about 5 km south of Grand Rapids in LaMoure County. The aquifer generally ranges from 4 to 8 km in width and is as much as 18 m thick. The materials forming the central part of the aquifer grade from coarse, gravelly sand in the north to fine to medium sand in the south-central part of the aquifer. Estimates of probable well yields range from about 18 to 50 l/s.

Analyses of water samples from the aquifer show that the water is very hard and generally is a sodium sulfate bicarbonate type containing from 500 to 1,200 mg/l dissolved solids. Sulfate, iron, and manganese concentrations generally exceed the limits recommended for drinking water (U.S. Department of Health, Education, and Welfare, 1962).

Excessive concentrations of sulfate found below mine area

About 2.7 million t/yr of lignite is strip mined at Gascoyne, N. Dak., for electric-power generation. About one-third of the lignite is mined below the original level of the water table. A recent ground-water investigation conducted at the mine by M. G. Croft indicated that the shallowest aquifers down-gradient from the mine contain excessively high concentrations of sulfate. Several water samples containing as much as 6,000 mg/l of sodium sulfate were collected from wells and a small stream draining the mine area.

Geochemical studies suggest that the sulfate is derived from pyrite contained in the lignite. The pyrite oxidizes to sulfuric acid on exposure. The acid reacts with calcium carbonate in the aquifer matrix to form calcium sulfate and calcium bicarbonate. Clay particles in the aquifer are mainly montmorillonite and calcium exchanged in ground water for sodium. It is also possible that much of the sulfate is derived from the solution of gypsum in the overburden when the overburden is redeposited in mine lakes during the stripping process.

Sand Prairie aquifer in Ransom and Sargent Counties

Test drilling by C. A. Armstrong indicated that the Sand Prairie aquifer of North Dakota extends southward from Barnes County (Kelly, 1966) to the southern part of Sargent County, where it merges with sediments of glacial Lake Sargent. The sediments comprising the aquifer were deposited in an ancient stream channel and in the adjacent, partially eroded glacial moraine. Consequently, the base of the aquifer is uneven, and aquifer thickness ranges from 0 m at the edge to about 36 m in the buried channel. Well yields from the aquifer range from about 0.5 l/s from domestic and stock wells to about 60 l/s from irrigation wells located in the thicker parts of the aquifer. Water in the aquifer generally is very hard and is a calcium bicarbonate type that contains less than 700 mg/l dissolved solids.

Hydrology of strippable lignite deposits

Results of a reconnaissance study conducted by O. A. Crosby emphasized the intermingling of strippable lignite with aquifers in North Dakota in the Sentinel Butte and Tongue River Members of the Fort Union Formation of Tertiary age. The aquifers consist of very fine to medium-grained sandstone interspersed with fractured lignite beds. The water table ranges from several meters above to several meters below the lignite at each deposit, depending on local stratigraphy and topography. Ground-water movement is generally controlled by a strong downward gradient. In some areas, the fractured coal seams are the best source of domestic and livestock water from the standpoint of quantity and quality.

Streamflow is highly variable; flow generally occurs during snowmelt periods, during periods of thunderstorm activity, and within the first few weeks after the first killing frost in the fall.

During the base-flow periods, the dissolved-solids concentration ranges from about 1,000 to 4,000 mg/l, and the predominant cation and anion are sodium and sulfate, respectively. With increased flow owing to surface runoff, the dissolved-solids concentration generally drops below 1,000 mg/l, and there is a rapid proportional increase in calcium and magnesium cations and bicarbonate anions.

Premining hydrologic conditions studied at lignite-deposit area

Preliminary data obtained by J. S. Downey indicated that the proposed expansion of lignite strip-mining activities in Dunn County, North Dakota, may result in changes in the streamflow, geochemical, and ground-water regimens. Some changes may be temporary, but others may remain even after strip mining has ceased. The purpose of Downey's investigation is to determine the premining hydrologic and geochemical conditions in a small area to provide background data with which to measure the magnitude of change caused by mining.

Buried valleys

P. G. Randich reported that test drilling in McHenry County in north-central North Dakota outlined a continuation of the New Rockford buried-valley aquifer through southern McHenry County. The aquifer ranges in width from 1 to 3 km and consists of discontinuous sand-and-gravel deposits having an average thickness of 30 m. The trend and gradient of the buried-valley aquifer indicate that it is part of a drainage system that predates the Souris River drainage system in North Dakota. The Souris River near Verendrye appears to be a gaining stream where it crosses over the New Rockford aquifer. Irrigation wells developed in the aquifer near Karlsruhe yield from 30 to 60 l/s. The chemical quality of ground water in this part of the New Rockford aquifer varies from a calcium bicarbonate to a sodium bicarbonate sulfate type containing from 400 to 2,000 mg/l total dissolved solids. The total dissolved-solids concentration and the sodium content increase in the lower and deeper parts of the aquifer. This increase is caused by recharge to the buried-valley aquifer from adjacent and underlying sandstone aquifers of Cretaceous age.

SOUTH DAKOTA

Glacial aquifers extensive in parts of northeastern South Dakota

Glacial-outwash aquifers 3 to 65 m thick were penetrated by most of the 140 test holes drilled in Clark County, an area of 2,536 km^2 in northeastern South Dakota. Studies by L. J. Hamilton (USGS) and C. M. Christensen (South Dakota State Geological Survey) showed that the aquifers generally are less than 15 m thick. They occur in irregular stringers, bands, and pockets from the surface to depths of 150 m.

A major glacial-outwash aquifer

Jack Kume reported that the Bowdle aquifer, first mapped in Edmunds and Faulk Counties, has now been mapped in eastern Walworth County in north-central South Dakota. The aquifer is under water-table conditions and consists of 3 to 6 m of saturated sand and gravel. Depth to water is commonly 2 to 3 m, but it may be as much as 8 m below land surface in some areas. This major glacial-outwash aquifer has a potential for large-capacity wells such as those used for irrigation. In 1975, development in Walworth County included only three irrigation wells and one municipal well.

Madison Group a major source of recharge

According to L. W. Howells, a preliminary analysis of data appears to support the theory that carbonate rocks of the Madison Group probably are the major source of recharge to overlying aquifers such as the Sundance Formation and the Dakota Sandstone in central and eastern South Dakota. The recharge moves successively upward from aquifer to aquifer near pinch-outs against the Precambrian high of the Sioux uplift. The water is derived from precipitation and loss of streamflow to the Madison outcrop in the Black Hills.

The Madison may contain as much as 250,000 hm^3 of water in storage. Dissolved-solids content of the water ranges from less than 500 mg/l to more than 120,000 mg/l.

TEXAS

Differences between saltwater and freshwater zones of the Edwards aquifer in the San Antonio area

Test drilling, conducted by R. W. Maclay, T. A. Small, P. L. Rettman, and Celso Puente, in the Edwards aquifer in the San Antonio area of Texas revealed significant lithologic, mineralogic, and hydrologic differences between the saltwater and freshwater zones of the aquifer.

Test-hole cores from the saltwater zone are typically dark-gray carbonates containing organic materials, including petroleum. The rocks are composed of dolomitic limestones or pure dolomite. The dolomites are typically crystalline, possess sucrosic porosity, and have intrinsic permeabilities ranging from less than 0.001 to about 1 μm^2. The total porosity of the core samples averaged about 20 percent; most of the porosity is controlled by the textural characteristics of the carbonates. The rocks are fractured, but many of the fractures are tightly closed.

Test-hole cores from the freshwater zone are typically light-gray to white limestone and show orange stains along open fractures. The intrinsic permeability of the rock matrix is commonly less than a millidarcy (0.987×10^{-11} cm^2), but secondary porosity, including vuggy and fracture porosity, is well developed. The total porosity of the rock samples averaged about 12 percent. Because of their small size, the throats connecting the pores do not allow gravity drainage from most of the porosity within the rock matrix.

Important diagenetic changes in the rocks of the freshwater zone include calcification of dolomites, recrystallization of grainstones into a chalky rock, and active dissolution along fractures and within carbonate units containing calcium sulfate minerals, reefal rocks, or highly burrowed beds. These diagenetic changes have greatly increased the overall transmissivity of the aquifer, but they have decreased the storage capacity within the freshwater zone.

Water-level, springflow, and streamflow interrelationships in the Edwards aquifer

Water-level, springflow, and streamflow data were used by Celso Puente to develop simple and multiple linear-regression equations to estimate water levels in wells and the flow of three major springs in the Edwards aquifer in the eastern San Antonio area of Texas. The equations provide daily, monthly, and annual estimates that agree closely with observed data.

Analyses of geologic and hydrologic data indicate that the water discharged by the major springs is supplied primarily by regional underflow from the west and southwest and by local recharge in the infiltration area in northern Bexar, Comal, and Hays Counties.

Exploration for fresh ground water in the basins of western Texas

W. D. Stanley and J. S. Gates used airborne-electromagnetic and Earth-resistivity methods to search for fresh ground water in the southeastern Hueco Bolson near El Paso, Tex. Airborne data were collected along 640 km of flight path, and surface-resistivity soundings were made at 67 locations along 180 km of profile. No large bodies of fresh ground water were located, but several small- to moderate-sized bodies were detected.

The material under the flood plain of the Rio Grande is predominantly clay or sand containing saline water. Along a band parallel to the Rio Grande and under the adjacent mesa to the northeast, the materials are probably deposits in an ancient channel of the river, which extends to depths of 100 to 400 m. The lower part of this resistive material is locally saturated with freshwater. The largest body of fresh to slightly saline ground water, which may have a volume of 0.5 to 1 km^3, was detected in the area between Fabens and Tornillo, from the edge of the flood plain to the edge of the mesa.

WYOMING

Resistivity study of alluvium in the Powder River basin

Direct-current resistivity measurements were made in a study by W. J. Head to define the physical properties of alluvium in the Powder River basin in Wyoming. The results of the study will be used in the water-resource evaluation of the coal areas in the basin. Results of preliminary interpretations indicate that most of the alluvium is shallow and consists mainly of silt- and clay-sized particles.

Soundings on Prairie Dog Creek, Crazy Woman Creek, and Dead Horse Creek indicated that alluvium in these areas is 4.9 to 13.4 m deep. Silt and clay are dominant, and some sand is present in minor amounts. Water-resistivity measurements indicate high dissolved-solids concentrations.

Soundings on the Little Powder and Belle Fourche Rivers indicated alluvium at depths of 3.6 to 25.3 m. The alluvium is composed of silt and clay, but some zones have higher amounts of sand and, probably, some gravel. Because of the lower concentrations of dissolved solids, the resistivity of water in these areas is slightly higher than that of water in the other valleys.

Bouguer gravity map of the Powder River basin

A Bouguer gravity map of the Powder River basin of Wyoming was made by W. J. Head and K. T. Kilty (USGS) and Warner Koslowski (Defense Mapping Agency) as part of the ground-water evaluation of the Madison Limestone. The map consists of 1,479 data points for an area of approximately 57,000 km^2. The gravity data were supplied by the Defense Mapping Agency of the Department of Defense. Terrane corrections will be added where necessary. The Bouguer gravity map agrees basically with a structural map of the Minnelusa Formation compiled by Head (unpub. data, 1975), using the Petroleum Information Company's Well History Control System data file.

The deepest part of the Powder River basin is in an area north of Casper Mountain at lat 43°7′ N., long 105°45′ W. The Bouguer gravity map indicates that the Precambrian basement may be nearer to the surface in Campbell County (lat 44° N.) than the Minnelusa structural map implies. This area has few deep-well penetrations. The initial gravity results also show a major structural zone extending northward from the Old Woman anticline in eastern Niobrara County into the Black Hills of South Dakota. Many other structural and basement features are prominent on the map.

The gravity data agree well with a compiled temperature-gradient map of the basin. Several gravity anomalies occur in areas of temperature-gradient anomalies.

Borehole geophysical study in the Powder River basin

Hydrologic characteristics of the Madison Limestone and the Minnelusa Formation in the Powder River basin of Wyoming were investigated in a study by W. J. Head (USGS) and R. H. Merkel (Exploration Data Consultants, Inc.), using formation evaluation of geophysical well logs. Geophysical logs from approximately 70 wells distributed throughout the Powder River basin were digitized, processed, and interpreted to get a regional understanding of the lithologic and ground-water characteristics of aquifers in the Madison and Minnelusa Formation (Merkel and Head, 1976). The percentage of sand, the porosity, and the apparent ground-water resistivity of the Minnelusa closely follow structural trends in the basin. All three of the above parameters were minimal along the structural axis of the basin and increased toward the basin flanks. Close correlations between the water resistivities in the Madison and Minnelusa Formation indicate several hydrological relationships between the two units. The low primary porosity determined from the geophysical logs of the Madison Limestone indicates that it is necessary to intersect a zone of secondary porosity in order to develop the Madison as an economic aquifer. Consequently, because of increased porosity and better water quality, the flanks of the basin appear to be the most favorable places for water production from both formations.

WESTERN REGION

Water-resource investigations in the western region followed trends common throughout the country; basic investigations into streamflow, water levels in wells, and the chemical, physical, and biological characteristics of both ground water and surface water continued. Similarly, much effort went into evaluations of water supplies in various areas and into basic research in hydrology. Digital modeling of runoff, of ground-water basins, of chemical dispersion and transport, and of the behavior of water in the unsaturated zone increased both in the number of models and in their complexity. One noteworthy trend was the increased attention given to the interaction between man and hydrologic phenomena.

At Menlo Park, Calif., USGS scientists and members of the planning community wrote final reports for the San Francisco Bay Region Environment and Resources Planning Study. The Tucson-Phoenix Urban Pilot Project in Arizona was also in its final stages. These two projects involved a far wider use than ever before of Earth scientists and Earth-science information in the planning process.

In Tacoma, Wash., the Puget Sound Lowland Urban Pilot Project was entering an expanded phase as the year ended. The likelihood of population growth, the presence of commercially valuable deposits of coal, and the potential impacts on the environment of a Trident submarine base and of major facilities for offloading and processing petroleum have increased the demand for Earth-science information to be used in planning and managing the expected environmental changes.

The following investigations are representative of specific programs dealing with the interaction between man and hydrology. D. K. Nordstrom, E. A. Jenne, and R. C. Averett (1976) made a preliminary report on the influx of heavy-metal leaching from abandoned mine workings to a reach of the upper Sacramento River in California's Central Valley. W. L. Burnham, in cooperation with the Environmental Protection Agency (EPA), evaluated the possible hydrologic effects of injecting treated sewage effluent into a saline aquifer a short distance seaward of a wildlife refuge on the island of Maui in Hawaii. W. J. Campbell participated in AIDJEX, a multinational study of Arctic sea ice and its effects on worldwide weather patterns and on petroleum drilling and petroleum-production platforms.

Studies of the hydrologic effects of coal mining, including erosion and sediment transport, continued in Arizona, Alaska, and Washington. In northern Washington and western Nevada, USGS investigators cooperated with the U.S. Navy in studying the effects of effluents from long-term washing of explosives.

A variety of flood studies continued throughout the western region. The hydrologic patterns of a damaging flood that inundated part of Las Vegas, Nev., on July 3, 1975, were described by T. L. Katzer, P. A. Glancy, and Lynn Harmsen (1976). Flood-inundation maps were prepared for the Department of Housing and Urban Development's use in administering the Flood Disaster Protection Act of 1973. A team of hydrologists and geologists, which included R. J. Janda (R. J. Janda, K. M. Nolan, D. R. Harden, and S. M. Colman, 1976; R. J. Janda, 1975a, b; R. J. Janda, K. M. Nolan, and D. R. Harden, 1975; R. T. Iwatsubo, K. M. Nolan, D. R. Harden, G. D. Glysson, and R. J. Janda, 1975; K. M. Nolan, D. R. Harden, and S. M. Colman, 1976; K. W. Lee, G. W. Kapple, and D. R. Dawdy, 1975; R. C. Averett and R. T. Iwatsubo, 1975), studied the stresses that natural events (floods) and lumbering in the Redwood National Park area of California have imposed on the environment; the studies related especially to mass wasting and sediment transport.

In northwestern Washington, G. C. Bortleson and R. T. Wilson (1976) tabulated data for material impairment, especially acidification, of the water in Boulder Creek, which drains from the fumarole-active Sherman Crater on Mount Baker. In eastern California, Hot Creek in Owens Valley continued to pour its load of arsenic and boron into Lake Crowley, a major link in the Los Angeles municipal water supply; L. A. Eccles (1976) reported, however, that dilution with Owens River water reduces arsenic and boron concentrations to acceptable levels except, perhaps, during major droughts. K. J. Takasaki (1976) prepared a framework that will be used by the State of Hawaii to comply with recent Congressional action and EPA regulations for ground-water-quality monitoring.

ALASKA

Water availability in the lower Ship Creek basin

The State of Alaska plans to expand its fish-hatchery operations along the lower reaches of Ship Creek near Anchorage. This expansion will require an additional supply of cold water to reduce the temperature of the heated water discharged into the water used for fish rearing. Ground water is more desirable than the water from Ship Creek, the water chemistry and sediment content of which vary seasonally. Studies by G. W. Freethey (1976) and L. D. Patrick indicated that the required additional water is available from shallow unconfined aquifers at the U.S. Army's Fort Richardson site, along a losing reach of Ship Creek (12.2 km above its mouth). The Elmendorf Air Force Base site, 4.5 km above the mouth of Ship Creek, is along a gaining reach of the stream; however, the required amount of water probably could not be withdrawn from the shallow ground-water body at the site. Two areas upstream from this site offer a better potential for development of unconfined ground water.

Ground-water quality and movement beneath the city landfill in Anchorage

A preliminary evaluation of geohydrologic and water-quality data from the Merrill Field landfill in Anchorage, Alaska, suggested that shallow, leachate-polluted ground water is not contributing appreciable amounts of pollutants to a confined aquifer lying 24 m below the fill. L. L. Dearborn reported, however, that the data are not conclusive, as several water-quality abnormalities involving arsenic, calcium, magnesium, and sulfate were not satisfactorily explained. Furthermore, the rate of vertical movement through the confining silt and clay might be either as high as 110 mm/yr (indicated by an analysis of an aquifer pumping test) or as low as 1.2 mm/yr (indicated by laboratory analyses of drive-core samples). Even though the rate of movement has not been determined, downward movement of water does occur; the potentiometric surface has been drawn down as much as 16 m below the water table since pumping began in 1958.

Channel erosion surveys

Some significant results of continuing channel surveillance by P. F. Doyle and J. M. Childers along the trans-Alaska pipeline route in central Alaska are as follows:

- A new maximum evident flood (MEF) nearly 0.6 m higher than the previous MEF was measured at Hess Creek near Livengood, Alaska.
- A bankfull flood on the Salcha River was observed to cause about 2.5 m of temporary thalweg scour at the pipeline crossing site.
- Rapid anabranch shifting on braided streams, such as the Lowe River, was documented by photography before and after high water.
- As much as 55 m of bank erosion, which has taken place within 2 or 3 years on the Middle Fork Koyukuk River near Coldfoot, Alaska, was measured.
- Photogrammetric surveys were found effective for channel erosion surveillance, especially on braided streams.

Ground-water conditions near Fairbanks

The alluvial aquifer beneath the flood plains of the Chena and Tanana Rivers receives recharge primarily from the Tanana River. Above-average discharge of the Tanana throughout much of the summer of 1975 resulted in unusually high water-table conditions in the southern part of Fairbanks, Alaska, during July and August, according to G. L. Nelson.

Ground water in the uplands north of Fairbanks is contained primarily in the fractured Birch Creek Schist. The water-bearing zones with the greatest yields appear to be in the more competent lithologies, principally quartz veins, quartzite, and siliceous schist. The less competent pelitic schist does not have sufficient permeability to provide adequate water to wells.

Ground-water levels in the uplands continued a 3-year decline, probably because of reduced precipitation, which has averaged 25 percent below normal since 1972. Declines of 2 to 5 m appear to be typical, and a decline of 11 m is the maximum recorded.

Water-supply problems near Prudhoe Bay

During the winter months, potable water is scarce near Prudhoe Bay, Alaska, because most lakes and streams freeze solidly to the bottom. In others, water remaining under the ice is commonly brackish because of freeze concentration and is unfit for consumption. The major source of water is deep pools in the larger rivers; these pools are commonly depleted by heavy usage. According to G. L. Nelson, however, ample potable water is available during the summer to satisfy year-round requirements if it can be stored for winter use. Although artificial storage is expensive, it appears to be the most reliable means of insuring an adequate winter water supply.

Water-resource appraisal of coalfield areas in Alaska

One continuously recording discharge station and several miscellaneous sites were selected for measurement of discharge, sediment transport, and water chemistry in the Beluga River, Peters Creek, and Healy Lake coalfield areas of Alaska. Surface water in the Beluga River and Peters Creek areas is of the calcium bicarbonate type and is of good quality; D. R. Scully reported that dissolved-solids concentrations range from 25 to 40 mg/l, alkalinity (HCO_3) ranges from 10 to 30 mg/l, pH ranges from 6 to 8, and DO is at or near saturation. Surface water in the Healy Lake area has a higher dissolved-solids concentration and apparently carries a greater sediment concentration.

Oilspill risk analysis for northern Gulf of Alaska Outer Continental Shelf area

At the request of the Department of the Interior's Office of Program Development and Budget, R. A. Smith and J. R. Slack (USGS) and R. K. Davis (Department of the Interior) conducted an oilspill risk analysis for the northern Gulf of Alaska Outer Continental Shelf lease area. The study, the objective of which was to determine relative hazards associated with oil and gas development in different regions of the lease area, was undertaken to facilitate final selection of tracts to be offered for sale. The analysis consisted of two parts—the first involving probabilities of spill occurrence and the second dealing with likely trajectories of spills relative to the locations of vulnerable wildlife populations inhabiting the Alaskan coastal region.

On the basis of estimated quantities of recoverable oil and the anticipated level of development of the 728,460-ha sale area (that is, number of platforms, pipelines and storage facilities, and volume of tanker traffic), it was estimated that a total of from 13 to 22 major spills could be expected to occur during the production life of the field if all proposed tracts were leased and developed. A major spill was defined as the release of more than 1,000 bbl of oil. Spill-frequency estimates were similarly made for eight subdivisions of the lease area.

The Gulf of Alaska is quite active seismically, and the likelihood of a major earthquake (larger than magnitude 8) in the vicinity of the lease area over the next three decades has been put at greater than 50 percent. On the basis of this information and the location of anticipated slump areas, it was estimated that as many as 20 additional spills could result in the event of an earthquake, depending on the design specifications of platforms and pipelines.

An oilspill trajectory model based on wind and current data provided by the National Oceanic and Atmospheric Administration was constructed and used to analyze movements of hypothetical oil slicks on a digital map of the area. Short-term patterns in wind variability (6-hour transitions) were described as a first-order Markov process evaluated from weather-station records for the area. Wind-transition probability matrices as well as surface-current velocity fields were established separately for the four seasons. The locations of 13 categories of critical wildlife habitats (including waterfowl nesting and molting areas, Steller sea-lion rookeries, and Sitka deer wintering areas) were digitized in the coordinate system used in spill-trajectory simulations. Probability distributions indicated the likelihood that spills occurring at various locations in the proposed lease area would impact the wildlife populations in question. The locations of wildlife habitats were made seasonally specific so that the results of the impact analysis would reflect seasonal correlations between wind and current patterns and the migratory behavior of the species at risk.

By combining oilspill frequency estimates with the trajectory analysis, it was possible to determine the relative oilspill hazards to wildlife populations posed by sales of tracts at different locations in the lease area. Tracts lying to the west of Kayak Island, for example, were found to pose more than four times the risk to waterfowl and seabird populations inhabiting the Copper River Delta and to marine fisheries in Prince William Sound than tracts elsewhere in the lease area. Sitka deer populations, which graze kelp on certain beaches during the winter, were found to be less vulnerable to oilspills than had originally been postulated.

AMERICAN SAMOA

Total annual rainfall on Tutuila Island in American Samoa ranges from about 2,540 mm near the coastline to 6,350 mm at an altitude of 244 m. Small, steep basins generally yield perennial flow into approximately 120 streams, but the amounts are small and highly variable. According to Iwao Matsuoka, the consecutive 7-day average discharge that can be expected at 10-year recurrence intervals at the 55 streamflow stations analyzed is 0.22 m^3/s. About half of this total (0.11 m^3/s) is from the stations on the southwestern part of the island (between Amanave village and Pago Pago Harbor), where most of the water collection and distribution system is concentrated. The highest low-flow 7-day 10-year recurrence discharge determined was 0.02 m^3/s. The 5-year total runoff at five continuous-record gaging stations ranged from 61 to 78 percent of rainfall measured at a coastal rain gage and from 26 to 33 percent of rainfall measured at an altitude of 250 m.

CALIFORNIA

Models of the Antelope Valley ground-water basin

Antelope Valley is a closed basin in the western part of the Mojave Desert in southern California. A ground-water basin with a surface area of 2,300 km^2 underlies the valley floor. The ground-water system consists of two alluvial aquifers separated by fine-grained lacustrine deposits. During the last 50 years, pumpage of ground water in excess of natural recharge has resulted in the steady decline of the ground-water level in the basin. By 1972, the cumulative overdraft was about 11,000 hm^3. To help evaluate the possible impact of various water-management alternatives, T. J. Durbin constructed a mathematical model of the ground-water basin. The model was calibrated by comparing the computed hydraulic heads to the corresponding prototype water levels for both steady-state and transient-state conditions. For the steady-state model, the area-weighted median deviation of the computed hydraulic heads from the prototype water levels was 3.7 m. For the transient-state model, the median deviation was 7.6 m.

Natural arsenic not a problem for proposed lake

A reconnaissance study was made in the Dry Creek basin of northern California to determine the extent to which arsenic might affect Lake Sonoma, a proposed impoundment. Samples of sediment, water, and biota were collected and analyzed for arsenic content. According to R. F. Middelburg, Jr., the study indicated that arsenic presents a potential problem only in a small geothermal area. Samples of geothermal water from the area contained 140 μg/l of arsenic—almost 2½ times the maximum recommended by the USPHS for drinking water. However, the contribution of arsenic to the lake would be minimal because the discharge of geothermal water in the area is estimated to be only about 0.0003 m^3/s.

Changes in the distribution and abundance of benthic invertebrates in the Sacramento River

The Sacramento River was studied by the California Department of Water Resources in 1960–61 to provide guidelines for maintaining adequate levels of water quality. In 1972–73, R. C. Averett, L. J. Britton, and R. F. Ferreira assessed the water-quality conditions of the Sacramento River to determine what biological changes might have taken place. A comparison of data shows no clearly defined differences between the benthic organism samples collected in 1960–61 and those collected in 1972–73. Downstream changes in benthic invertebrate composition are consistent with the changes that occur in substrate type; however, monthly changes are not consistent.

Effects of wildfire on water quality

Following two adjacent wildfires in the Roaring River drainage basin in California's Kings Canyon National Park, a sampling program was undertaken from May to July 1974 by R. J. Hoffman and R. F. Ferreira to ascertain water-quality changes resulting from the fires.

A noticeable increase in the concentration of nitrogen was found in samples taken from the Roaring River immediately downstream from the Moraine Creek fire. The increases in nitrogen concentration, however, were not great enough to pose a serious threat to the aquatic ecosystem. The other water-quality samples were typical of dilute Sierra Nevada streams and indicated that the Roaring River was not adversely affected by the wildfires.

Ground-water degradation in the Santa Maria Valley

According to J. L. Hughes, ground-water quality in the Santa Maria Valley of California has steadily deteriorated since the early 1900's. Deterioration of ground water, the only readily available source of water for the area's industrial and domestic needs, is attributed mostly to agricultural practices. Agriculture is the area's principal industry and its largest user of water by a ratio of 3:1. The deterioration of ground-water quality is evident from nitrate (as N) and sulfate concentrations in excess of 40 and 2,000 mg/l, respectively. Dissolved-solids, chloride, and several trace-metal concentrations are also high.

Discharges from the area's four domestic waste-treatment facilities, two oil refineries, two stockyards, a solid-waste landfill, and a sugar refinery have also contributed to the degradation. The total impact on ground-water quality by these point sources is, however, less significant than that attributed to agriculture.

The water-quality problem is partly related to ground-water withdrawals in excess of annual recharge. An average deficit of approximately 12.3 hm^3/yr has existed since the 1940's. The ground-water gradient is toward the west and the Pacific Ocean. Decreased natural ground-water discharge to the ocean and increased salts in the coastal part of the valley reflect both usage and accumulation. Apparently, there has been no seawater intrusion.

IDAHO

Water resources of Henrys Fork basin above Ashton

A 2-year USGS and Idaho Department of Water Resources cooperative water-resource investigation of the 2,771-km^2 Henrys Fork basin above Ashton, Idaho, neared completion. This study provides a data base from which future changes can be gaged.

Much of the basin north of the farming community at Ashton has not been affected by the increasing number of people attracted by its abundant recreational features. R. L. Whitehead, W. A. Harenberg, and H. R. Seitz reported that, generally, the basin's water is of excellent quality, as analyses of water sampled from 58 streams, 5 lakes or reservoirs, 16 springs, and 39 wells and microbiological analyses of samples from 21 wells and 18 surface-water sites indicate. Specific-conductance values for most water samples are well under 300 μmho at 25°C, except those for ground-water samples from the Ashton area, which generally exceed 300 μmho and are as high as 830 μmho. This difference is believed to result from the leaching of minerals in fertilizers and other chemicals applied to the farmlands. Streamflow measurements of selected sites were made to determine gaining or losing reaches of major streams. Ground-water and surface-water resources are closely related within the basin.

It is inferred that most of the water leaves the basin as streamflow or as evapotranspiration and that it originates from precipitation, mostly as snow, within the basin.

Water resources of the Weiser River basin

A 2-year investigation of the water resources of the Weiser River basin in Idaho was completed. H. W. Young, W. A. Harenberg, and H. R. Seitz prepared a report that included a sediment-yield map, a surface-water-runoff map, and a ground-water potentiometric-surface map. Sediment yields for the basin during the 1974 and 1975 water years were approximately 490 and 190 t/km^2, respectively. Peak runoff in the basin occurs in January in the tributaries in lower altitudes and in May in the tributaries in higher altitudes. Mean annual discharges of the Weiser River near Weiser, Idaho, for the 1974 and 1975 water years were 54 and 34 m^3/s, respectively. Ground-water movement in the basin is generally toward the Weiser River and its major tributaries.

Generally, the chemical quality of both surface water and ground water is good, their dissolved-solids concentrations being mostly less than 200 and 400 mg/l, respectively.

NEVADA

Hydrologic conditions and hazards, Washoe Lake area

In a cooperative program with the State of Nevada, P. A. Glancy, T. L. Katzer, and F. E. Rush evaluated hydrologic conditions and hazards in an urbanizing area between Reno and Carson City, Nev. Using the 7½-min Washoe City topographic quadrangle, the group mapped ground-water levels, aquifer yields, and phreatophyte distribution (F. E. Rush, 1975) and delineated potential hazard areas with respect to floods and sediment movement.

Effects of ground-water pumping in Las Vegas Valley

From 1955 to 1972, about 1,400 hm^3 of ground water was pumped from the valley-fill reservoir in Las Vegas Valley of Nevada, according to J. R. Harrill. Substantial water-level declines resulted in the northwestern part of the valley where pumping was concentrated. The maximum net decline was about 55 m. The water-level declines resulted in about 84 hm^3 of subsidence and caused storage depletions of more than 500 hm^3 in the principal aquifers, about 160 hm^3 from the near-surface reservoir, and about 43 hm^3 from consolidated rocks adjacent to the valley. The balance was extracted from the deeper aquifers. In 1972, the first full year of large-scale water importation from the Colorado River, pumpage declined and ground-water levels recovered temporarily. By 1975, although importation facilities were operating near capacity, ground-water pumpage had increased, and the annual water-level decline in the principal aquifers exceeded 3 m in nearly 65 km^2 of the northwestern part of the valley.

OREGON

Variation in ground-water quality of northern Yamhill County

Ground water near Carlton, Oreg., in northern Yamhill County is highly variable in quality and in its relative proportions of major anions and cations. Eocene marine rocks yield water of calcium bicarbonate, sodium bicarbonate, and sodium chloride types. According to F. J. Frank, wells in the area range from about 15 to 90 m in depth, but the chemical character of the water has no discernible relationship to depth. Concentrations of iron are high, ranging from 0.59 to 7.4 mg/l, but the water is otherwise suitable for domestic use. Dissolved-solids concentrations in nine samples ranged from 116 to 496 mg/l.

Change in water quality of the John Day River after a cloudburst

After an intense storm on July 10, 1975, which produced high flows on some tributary streams, the water quality of Oregon's John Day River at McDonald Ferry showed a marked change. During a 6-hour period, the discharge of the river increased from 59 m^3/s to a peak of 110 m^3/s and then fell to 65 m^3/s at the time of sampling. According to D. A. Curtiss, the sediment concentration observed just after the discharge peak was 1,310 mg/l in comparison with a concentration before the storm of less than 50 mg/l. The highest observed turbidity was 240 JTU, in comparison with a previous high of 45 JTU for that year. Total nitrogen (as N) increased to 3.1 mg/l in comparison with a previous high of 0.81 mg/l for that year. Total iron and manganese peak concentrations were 8,800 and 1,600 μg/l, respectively, in comparison with previously observed highs of 2,700 and 90 μg/l, respectively, for the year. The total phytoplankton cell count increased to 28,000 cells/ml after the peak flow, in comparison with a previous high of 11,000 cells/ml for that year.

WASHINGTON

A 2-year study of surface- and ground-water quality on the Yakima Indian Reservation in Washington by M. O. Fretwell showed that the mountain streams, which are affected by few of man's activities except logging and grazing, have water of similar quality, characterized by low dissolved-solids concentrations, nearly identical chemical compositions, and slightly high fecal coliform bacteria concentrations. The lowland streams and drains, however, receive irrigation return flow, which is largely responsible for their poorer water quality; their average dissolved-solids concentrations are 2 to 3 times higher than those of the mountain streams, their nitrate concentrations are almost 13 times higher, and their fecal coliform bacteria concentrations are 20 times higher.

Specific conductance of the ground water varied from 20 to nearly 1,500 μmho at 25°C. Concentrations of nitrate (as N) in the ground water exceeded 10 mg/l in a farmland area of about 18 km^2 near the southwestern corner of the reservation. Fecal coliform bacteria were found in water from a few isolated wells, probably as a result of direct entry along the well bore. Springs were commonly contaminated, however, by range cattle walking directly through the water.

SPECIAL WATER-RESOURCE PROGRAMS

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, recommendation of methods for water-data acquisition, and preparation of hydrologic unit maps of the Nation. Closely related activities included two river-quality assessment studies and implementation of the National Water Data Exchange.

The "Federal Plan for the Acquisition of Water Data, Fiscal Year 1977," released in the fall of 1976, 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. Twenty-one regional plans were released earlier in 1976 and formed the basis for the above-mentioned Federal plan.

The FY 1978 coordination cycle is underway. The magnitude of activity in water-data collection is growing; each year, more agencies and private organizations are involved. As these activities expand, the need to identify existing, planned, and needed water-data activities becomes correspondingly greater, not only as a coordination mechanism but also as a planning base.

Activities covered in the field coordination effort include (1) specific plans for long-term stations to gage the stage, flow, and quality of surface water; (2) studies of ground-water quality; and (3) compilation of general information for other water-data needs. The 1974 edition of the "Catalog of Information on Water Data," which was printed in 21 separate volumes corresponding to the 21 WRC regions, reflects water-data acquisition activities as of January 1, 1974. The catalog contains a cross-referenced list to tie the old hydrologic coding system (map number and area letter) to the new eight-digit hydrologic unit codes used on the State Hydrologic Unit Maps. The USGS's short-term data-collection activities, which have a record length of less than 3 years, are included for the first time in the 1974 edition of the "Catalog of Information on Water Data." Short-term data from other participating agencies probably will be included in the next (1976) edition of the catalog.

The Coordinating Council for Water-Data Acquisition Methods held two meetings during the year. Eighteen Federal agencies are now represented on the council, which provides advice on policy to the Office of Water-Data Coordination (OWDC) methods coordinator for the "National Handbook of Recommended Methods for Water-Data Acquisition" and which serves as Federal reviewer of chapters prepared by 10 work groups. About 150 technical personnel from 25 Federal agencies are assigned to these work groups, which prepare chapters covering (1) surface water, (2) ground water, (3) sediment, (4) biologic and bacteriologic quality of surface and ground water, (5) chemical and physical quality of surface and ground water, (6) soil moisture, (7) drainage-basin characteristics, (8) evaporation and transpiration, (9) snow and ice, and (10) hydrometeorological observations. During 1976, detailed outlines for all 10 chapters, as well as final drafts of several chapters, were completed.

A new series of USGS base maps entitled "State Hydrologic Unit Maps," prepared by the OWDC in cooperation with the WRC, received the approval of the National Programs and Assessment Committee of the WRC. The 1:500,000-scale maps for 43 States and the Caribbean area were published and are being sold by the USGS. Maps for the remaining States are expected to be published by October 1976. The maps show a hierarchy of the hydrologic units of the National Water-Data Network and of the 2,100 cataloging units used by OWDC in the "Catalog of Information on Water Data." Prior to printing, each map was reviewed extensively by principal Federal, regional, and State water-resource agencies throughout the country. The purpose of the project is to produce a set of nationally consistent maps on a good-quality base that accurately delineates major surface-drainage boundaries. When it is completed, the series will consist of 53 maps in 47 separate folders covering the 50 States and the Caribbean region. The maps are a standard USGS series and will be used by the OWDC for all cataloging and coordinating purposes. The drainage boundaries on this map series are also being portrayed on the USGS's new series of digitized land-use maps being prepared at a scale of 1:250,000.

The tenth meeting of the Advisory Committee on Water Data for Public Use was held November 18–20, 1975, in Reston, Va. The meeting was highlighted by the reports of five ad hoc working groups, which considered a wide range of activities, including (1) river-quality assessment, (2) recommended methods for water-data collection, (3) water-use data needs, (4) improved communications mechanisms for data coordination, and (5) urban water information needs. A step aimed directly at increasing the involvement of the non-Federal sector in the recommended-methods activity was taken early in 1975 with the impaneling of the Ad Hoc Working Group on Recommended Methods, which consists of 10 members from the Advisory Committee on Water Data for Public Use. The working group provides a non-Federal counterpart to the Coordinating Council for Water-Data Acquisition Methods, and its first task was to develop ways and means by which effective non-Federal participation in the recommended-methods activity could best be achieved. Under the auspices of this working group, detailed chapter outlines and several completed chapters for the new "National Handbook of Recommended Methods for Water-Data Acquisition" were reviewed by many non-Federal experts concerned with water-data acquisition. Also in the interest of greater non-Federal participation, discussions related to the recommended-methods activity were held with many water-oriented technical societies.

The tenth meeting of the Interagency Advisory Committee on Water Data was held December 16–17, 1975, in Reston, Va. The main purpose of the meeting was to provide a forum for the Federal agencies to discuss activities and projects related to the coordination program. The need for water-quality data on small watersheds has become increasingly evident since the completion of the report on streamflow and precipitation data needs, prepared by the Interagency Work Group on Hydrologic Data for Small Watersheds. Accordingly, organization of a work group to study water-quality-data needs for small watersheds was approved. Another work group was approved to study the availability of data on the quality of precipitation. A third new work group, whose purpose is to study ways to improve communications as related to the coordination effort, was also approved. All three of these working groups are being organized.

NATIONAL STREAM QUALITY ACCOUNTING NETWORK

During 1976, additional stream-quality stations were added to the National Stream Quality Accounting Network (NASQAN), a component of the Level I accounting element of the National Water-Data Network. As a result of recommendations made by the Ad Hoc Working Group on River-Quality Assessment, two new river-quality assessment studies were initiated in FY 1976. These projects were located in the Chattahoochee River basin in Georgia and the Yampa River basin in Colorado. The study of the Willamette River basin in Oregon was completed, and a number of reports were prepared. Additional information on NASQAN and the river-quality assessment studies can be found in the section on "Coordinated Water-Quality Programs."

NATIONAL WATER DATA EXCHANGE

In 1971, the Federal Interagency Water-Data Handling Work Group completed a study that recommended establishment of a National Water Data Exchange (NAWDEX). Following several contract design studies, NAWDEX was established in November 1975. In its final form, NAWDEX will consist of water-oriented organizations throughout all levels of Federal, State, and local government and in the private sector, affiliated and linked together by computers to make their data more readily available in a timely and efficient manner. All activities and services are coordinated by a central program office located within the USGS. Assistance in locating desired data and referral of requests to the best source will be provided by the NAWDEX Program Office. A nationwide network of local assistance centers has been established within the NAWDEX membership in nearly all States and major population centers.

The NAWDEX Program Office is currently developing a "Water-Data Sources Directory." This directory will identify organizations that collect water data, locations from which these data may be obtained, the geographic areas in which the data are collected, the types of data collected and made available, and the media in which the collected data are available. This directory is scheduled to be made available for nationwide use in November 1976.

A Master Water-Data Index is also being prepared and is scheduled to be made available for nationwide use in November 1976. This index will list individual sites for which data are available and related information such as location, collecting organization, types of data, periods of record, parameters, frequency of measurement, and media in which the data are available. More than 80,000 sites are currently being indexed from information contributed to the "Catalog of Information on Water Data" (currently being maintained by the OWDC). The data are collected by 19 Federal agencies and more than 300 non-Federal agencies. The contents of the index will grow significantly as NAWDEX membership increases. Membership in NAWDEX is voluntary and open to those who wish to take an active role in its activities.

WATER-DATA STORAGE SYSTEM

The USGS uses a digital computer to process, store, retrieve, and display water-resource data. The computer is also used in water-resource studies that require capabilities in statistical and analytical techniques, graphical display and map presentation of data, and mathematical modeling of hydrologic systems. The computer system consists of a central computer located in Reston, Va., and remote terminal facilities located in 45 States.

Data on daily discharge, collected by the USGS and cooperating Federal and State agencies at about 10,000 regular streamflow stations, are stored on magnetic tape. The volume of data holdings is equivalent to about 290,000 station years of record. More than 80 percent of all streamflow data collected under this program is covered. The data are stored in discrete units containing figures for daily water discharge for each gaging station and for each year of record; thus, the data are compatible with a variety of statistical programs for analysis on the basis of calendar years, water years, climatic years, or any other period desired.

An automated system for storage and retrieval of surface-water-quality data has been in use since 1959. All data collected since then, plus selected long-term historical records, have been entered into the system. The system contains the following types of data: (1) Chemical and physical analyses of surface water, (2) suspended sediment, (3) water temperature, (4) specific conductance, and (5) multi-item data collected by digital monitors. The results of about 1 million analyses are stored in the file.

A new automated system for storage and retrieval of ground-water data has been introduced. The Ground-Water Site Inventory data base operates under a proprietary data-base management system that allows data retrieval on the basis of about 30 key parameters. Information in the new file includes data on location, physical characteristics, construction history, geohydrology, aquifer characteristics, field quality determinations, and water levels and withdrawals for wells, springs, or other sources of ground water. By the end of June 1976, records of about 250,000 wells and springs had been converted from the older punchcard format and entered into the new system.

URBAN WATER PROGRAM

The objective of the USGS urban hydrology program is to provide generalized relationships for estimating hydrologic changes due to urbanization. It includes studies in urban areas of water-resource development, urban lakes, rainfall as opposed to runoff, erosion and sediment transport, quantity and chemical and biological quality of runoff, and ground-water recharge and contamination under various types and degrees of land development. The first step in this program is the establishment of an adequate data base; most USGS urban hydrology projects are still in the data-collection phase.

QUANTITY AND QUALITY OF STORM RUNOFF IN URBAN AREAS

Urban storm-water quality

The quality of storm-water runoff from a 19-ha area of single-family residences near Pompano Beach, Fla., was measured by H. C. Mattraw, Jr., and C. B. Sherwood, Jr. Rainfall and runoff information and samples for water-quality analyses were obtained by an automated system described by G. F. Smoot, Jacob Davidian, and R. H. Billings (1974). Between June 1974 and June 1975, only 70 of the 123 rainfall events recorded in the area produced runoff. Twenty of the rainfall-runoff events were sampled and analyzed. Bulk precipitation (rainfall plus dry fallout) was of good quality in comparison with that of other metropolitan areas. Estimated annual loads are (1) COD, 22 kg/ha; (2) total residue, 85 kg/ha; (3) total nitrogen, 1.5 kg/ha; and (4) total phosphorus, 0.2 kg/ha.

The water quality of Fanno Creek, which drains an urban area near Portland, Oreg., changed markedly during a 24-hour period after 51 mm of rain fell in 12 hours in December 1975. According to S. W. McKenzie and T. L. Miller, as water discharge increased from 0.10 m^3/s to a peak of 3.54 m^3/s, specific conductance decreased from 130 to 54 μmho, turbidity increased from 25 to 150 JTU, suspended sediment increased from 16 to 2,500 mg/l, settleable solids increased from 0.1 to 5.3 mg/l, and BOD increased from 6 to 124 mg/l.

Rainfall-runoff model application

In the Memphis area of Tennessee, C. W. Boning investigated the effects of urbanization on runoff characteristics in order to provide improved criteria for design of storm-drainage facilities. Rainfall and runoff data were collected on 29 streams with drainages ranging in size from 0.13 to 49 km^2. Development in these basins ranges from highly impervious commercial to entirely rural. The USGS rainfall-runoff model (D. R. Dawdy, R. W. Lichty, and J. M. Bergmann, 1972) is proposed for use in this study. That model was calibrated by using separate 2- and 3-year records on a 177-km^2 drainage area and used with a long rainfall record to simulate a flood-peak record. The flood-frequency curve developed by this method is similar to one developed for this stream by the U.S. Soil Conservation Service; this agreement is interpreted as indicating the applicability of the model approach in this geographic regon.

HYDROLOGIC EFFECTS OF WASTE DISPOSAL IN URBAN AREAS

A 35-well sampling system was installed in and around the NW. 58th Street Dade County, Florida, landfill to monitor the quality of the leachate. J. E. Hull found no evidence of movement of most constituents, with the exception of sodium, chloride, potassium, ammonia, COD, and specific conductance, which were higher downgradient of the landfill.

EROSION AND SEDIMENT

Hydrology and sedimentation in an urbanizing area of Montgomery County, Maryland, were studied by T. H. Yorke, Jr., and W. J. Herb. Factors found to be significant in predicting storm-sediment loads were storm runoff, peak discharge, rainfall intensity, peak runoff, and percentage of the basin under construction. Multiple-correlation coefficients for best regression equations with four independent variables ranged from 0.85 to 0.96, and standard errors ranged from 0.30 to 0.22 log units. Mean annual sediment yields from urban construction sites ranged from 16 to 226 t/ha. The most significant factors affecting annual sediment yield were the degree of sediment control and the slope conditions on construction sites; lesser but still significant factors were the proximity of construction to stream channels and the length of time that surface soils were unprotected.

WATER USE

Nuclear-fueled steam-electric powerplants becoming major water users in the United States

Although considerable study has been given to the effects on water use of the development of new coal deposits, oil shale, and other sources of energy, only minimal attention has been paid to the effects of the gradual conversion from fossil-fueled powerplants to nuclear-fueled powerplants. The Great Lakes Basin Commission (1975) pointed out that, at present, a nuclear steam-electric powerplant requires about 50 percent more condenser water for a given temperature rise than a fossil-fueled powerplant of equal size. The best actual overall plant efficiency of fossil-fueled powerplants today is approximately 40 percent. Operating at a 36-percent efficiency, a representative fossil-fueled plant with flowthrough cooling requires about 148 l of cooling water for every kilowatt-hour of power generation accompanied by an $8\frac{1}{3}$°C temperature rise in the water. At their present overall energy-conversion efficiency of about 32 percent, nuclear powerplants require about 222 l of cooling water to generate 1 kWh of electricity with an inplant temperature rise of $8\frac{1}{3}$°C.

The Federal Power Commission's preliminary data on public-utility power production are shown in the table on p. 136.

C. R. Murray applied the Great Lakes Basin Commission's water-requirement factors to the changes in U.S. power production in 1975 and estimated that cooling-water requirements increased 12 km^3 for nuclear-fueled powerplants and decreased 1 km^3 for fossil-fueled powerplants. When the net cooling-

Public-utility power production, 1974 and 1975

Year	Fossil-fueled		Nuclear-fueled		Total thermal (fossil and nuclear)		Hydroelectric		Total thermal and hydro-electric, billion kWh
	Billion kWh	Percentage of total	Billion kWh	Percentage of total	Billion kWh	Percentage of total	Billion kWh	Percentage of total	
1975	1,444.1	75.6	166.3	8.7	1,610.4	84.3	299.6	15.7	1,910.0
1974	1,451.7	77.8	112.7	6.0	1,564.4	83.9	300.4	16.1	1,864.8
Percent change, 1975/1974	−0.5		47.6		2.9		−0.3		2.4

water increase was added to the estimated 189 km^3 used for thermal powerplants in 1973 and 1974 (C. R. Murray, 1975), it was determined that 200 km^3 (52.8 trillion gallons) of cooling water was used in all thermal powerplants in 1975. If, however, no supplemental cooling methods had been used in thermal powerplants, their water requirements would have been about 250 km^3 in 1975.

The water requirement per kilowatt-hour developed by nuclear power is about the same as that required by fossil-fueled plants 20 years ago (prior to technological improvements). Because of the higher water demand (and its attendant higher cost) made by nuclear steam-electric powerplants, the trend toward siting nuclear powerplants in coastal and estuarine zones, where water is cheaper, must continue in order to keep nuclear powerplants competitive with fossil-fueled inland plants.

Water consumption by nuclear powerplants

About 63 percent of the energy input to a nuclear powerplant is discharged as heat to the cooling-water system, according to E. V. Giusti and E. L. Meyer. Using published data, Giusti and Meyer determined that water consumption varies with the cooling system adopted; water consumption is least for once-through cooling (about 0.5 m^3 s^{-1}/1,000 MWe) and greatest for closed cooling by mechanical-draft towers (about 0.8 m^3 s^{-1}/1,000 MWe). When freshwater is used for cooling, the regional water-resource economy is affected by the increased competition for water. Because of increasing water withdrawals, which are at a maximum during low-flow periods, and the necessity of constantly maintaining a cooling-water supply for reasons of safety, new models are needed to evaluate low flows in terms of (1) ground-water inflow to a basin's rivers, (2) evapotranspiration from a basin, and (3) basinwide consumptive water withdrawals.

Water use in coal conversion

The use of water and energy in the production and conversion of coal into a "pipeline-quality" gas by the SYNTHANE gasification process and in the conversion of coal into thermoelectric power was determined by I. C. James II, E. D. Attanasi, Thomas Maddock III, S. H. Chiang, and N. C. Matalas. A plant-level process analysis was used to achieve these results for four different cooling systems, two levels of residuals control, and four levels of mined-land reclamation All results were for coal of the quality found in the Williams Fork Mountains of northwestern Colorado. Computer programs have been written and are available to perform the material and energy-balance calculations for coal of other qualities.

Water-use and energy efficiencies in coal conversion are dependent on the type of cooling system and the degree of residual treatment used. For a mechanical-draft cooling tower with no constraints on residual discharge, consumptive water use for both cooling and processing the water used in electric-power generation is about 0.00804 m^3/kg of coal and for gasification about 0.00518 m^3/kg of coal; consumptive water use for gasification is about 64 percent of that for thermoelectric power generation. For facilities meeting Colorado standards, consumptive water use is somewhat less, particularly in the gasification plant, owing to treatment and reuse of process and blowdown water. If cooling ponds and residual-control practices were used, consumptive water use would be about 0.00825 m^3/kg of coal for electric-power generation and about 0.00377 m^3/kg for gasification, about 46 percent of the use in electric-power generation. Water use in natural-draft cooling towers is about the same as that in mechanical-draft towers. Once-through cooling, which requires larger water withdrawals, has considerably smaller consumptive use at the plant; however, additional evaporation from the river attributable to the increased heat load is not accounted for.

The energy efficiency of the conversion from the primary energy form (coal) to a secondary energy form is about 54 percent for gasification and between 39.2 and 38.3 percent for electric-power generation, depending on the cooling system. Surface mining of coal directly consumes only about 1 percent of the energy that is produced, but this consumption is of secondary energy forms such as electricity, diesel fuel, and ammonium nitrate.

Capital investments are greater for electric-power generation than for gasification for comparable coal inputs. Total capital investments for mining and conversion for plants with residual modification and mechanical-draft evaporative cooling towers are \$3,860,000 kg^{-1} s^{-1} of coal processed for electric generation and \$2,370,000 kg^{-1} s^{-1} of coal processed for gasification. Capital investments in surface mining account for approximately 10 to 15 percent of these total capital costs.

Estimating ground-water pumpage in the Central Valley of California

The quantity of ground water pumped annually in the San Joaquin and Sacramento Valleys of California for municipal and agricultural uses is being studied by H. T. Mitten. To date, pumpages have been estimated for the San Joaquin Valley from the Tehachapi Mountains northward to near Merced from 1962 to 1971 and for the Sacramento Valley from 1966 to 1971. Basic data, including agricultural power and pumping-plant-efficiency tests, are presented in a series of open-file reports (H. T. Mitten, 1971, 1972a, b, 1973, 1974; H. T. Mitten and William Ogilbee, 1971; William Ogilbee and H. T. Mitten, 1970) and in two basic-data reports (William Ogilbee and M. A. Rose, 1969a, b). The data are also being stored on magnetic disks.

Ground-water development for irrigation in southwestern Kansas

Geohydrologic studies in southwestern Kansas have documented the extent of ground-water development for irrigation in the area. E. D. Gutentag and D. H. Lobmeyer reported that 7,000 irrigation wells annually withdraw about 2,400 hm^3 of ground water, which is applied to about 567,000 ha of land (duty of water, 0.4 m). This extensive development has caused significant water-level declines that, in parts of the area, represent a 50-percent decrease in the original (predevelopment) saturated thickness of the aquifer.

Use of ground water for irrigation in Big Blue River basin, Nebraska

E. K. Steele, Jr., reported that pumpage records from selected irrigation wells in a five-county area of the Big Blue River basin in Nebraska indicate that ground-water withdrawals during 1975 totaled about 1,332 hm^3 for an average application of irrigation water of 0.440 m over the 303,000 ha irrigated. The resultant net lowering of the water table from spring to fall of 1975 averaged 0.86 m. Pumpage during the 1975 irrigation season was 210 hm^3 less than it was in 1974, and the fall 1975 water-level average was 0.22 m higher than it was in the fall of 1974. Water-level measurements made in the spring of 1975 indicated that a net depletion of about 542 hm^3 had occurred since the spring of 1974. The number of irrigation wells in the five-county area continued to increase. In 1975, 459 new wells were drilled, and the total number of registered irrigation wells increased to 8,037.

COORDINATED WATER-QUALITY PROGRAMS

Willamette intensive river-quality assessment study

D. A. Rickert and W. G. Hines (1975), D. A. Rickert, W. G. Hines, and S. W. McKenzie (1975a, b, c), and W. G. Hines and others (1975a, b) completed an intensive river-quality assessment of the Willamette River basin in Oregon. The study concentrated on the effects of population and industrial growth and the resulting waste discharges on the dissolved-oxygen (DO) regime of the river. The investigators concluded that basinwide secondary treatment of municipal and industrial waste water has resulted in a dramatic increase of summertime DO concentrations in the Willamette River. Rates of carbonaceous decay (k_1) are very low (0.03 to 0.06 per day), and point-source BOD loading now accounts for less than one-third of the satisfied oxygen demand. Nitrification is now the dominant DO sink. DO concentrations met the State standards in all reaches of the Willamette during the low-flow period of 1974. Mathematical modeling shows that low-flow augmentation from storage reservoirs was largely responsible for the standards' being met. Future achievement of DO standards will require continued low-flow augmentation in addition to pollution control. Summertime flows above 170 m^3/s will be needed even with increased treatment removal of oxygen-depleting materials. The greatest immediate incremental improvement in DO can be made by reducing point-source ammonia loading. The pros and cons of upgrading the treatment efficiencies for BOD removal can best be determined after ammonia loadings have been reduced to reasonable levels and the possibility of controlling a benthal-oxygen demand in Portland Harbor has been fully assessed.

National Stream Quality Accounting Network

J. F. Ficke and R. O. Hawkinson reported that the National Stream Quality Accounting Network (NASQAN), which is operated by the USGS and is the largest national program for collecting uniform information about the quality of the Nation's rivers, accumulated data from 345 stations during 1975. Monitoring of water quality through the network at this level of activity, which represents 65 percent of full-scale operation, covers a broad suite of physical, chemical (inorganic, organic, and radiochemical), and biological characteristics of water. General rules of network design used in developing NASQAN were summarized in papers by R. J. Pickering and J. F. Ficke (1975, 1976) and by J. S. Cragwall, Jr. (1976). Data from longer term network stations were furnished to the U.S. Council on Environmental Quality (CEQ) for inclusion in its annual report ("Environmental Quality—1975") to illustrate that some general improvements in water quality have taken place since 1961. The CEQ based its conclusions on observed decreases in the frequency of violations of the criteria established for the quality of water for drinking or for the protection of aquatic life. The USGS and the CEQ also cooperated during the year in developing schemes for using maps to display NASQAN data and to produce national pictures of water quality.

NASQAN-related research, performed by a contractor with cooperative support from the CEQ and the EPA, consisted of evaluating the use of water-quality indexes for describing water-quality conditions. The study grouped available indexes into 10 generic types and concluded that, at present, biological and single-constituent chemical indicators are the most useful for most types of water-quality analyses. Six other categories of indicators need to be further developed before they can be fully evaluated.

Central Laboratories System

The Central Laboratories System continued to expand the analytical services available to USGS water-resource projects during 1976. New leased facilities in Wheatridge, Colo., replaced both the Salt Lake City, Utah, and the Denver, Colo., facilities. The Atlanta Central Laboratory in Doraville, Ga., occupied in FY 1974, and the new facility in Colorado will enable the Central Laboratories System to better coordinate the methods-development activities of Federal programs with the production laboratory sections. The work load for 1976 increased about 20 percent over that for 1975.

INTERNATIONAL HYDROLOGICAL PROGRAM AND RELATED ACTIVITIES

The International Hydrological Program (IHP) is an outgrowth of the International Hydrological Decade (IHD). Like its predecessor, it is under the aegis of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The IHP now involves about 80 countries, and its activities are guided by an Intergovernmental Council made up of representatives of 30 member countries, of which the United States is one.

The IHP consists of five major categories of activities: (1) The scientific program, including studies of the hydrological cycle, assessment of water resources, and evaluation of the influence of man's activities on water regimens; (2) the promotion of education and training in hydrology; (3) the enhancement of exchange of information; (4) help with technical assistance; and (5) the enlargement of regional cooperation.

U.S. participation in the IHP is under the guidance of the U.S. National Committee on Scientific Hydrology (USNC/SH). The USNC/SH was formed by the USGS at the request of the Department of State and with the concurrence of water-oriented Federal agencies. C. A. Herter, Jr., Deputy Assistant Secretary of State for Environmental and Population Affairs, and V. E. McKelvey, Director of the USGS, approved the charter of the USNC/SH on May 13, 1975.

The functions of the USNC/SH are: (1) To formulate the U.S. program of participation in the IHP; (2) to serve as a channel of communication among those involved; (3) to promote international hydrological activities; (4) to help the Department of State prepare U.S. positions on water; and (5) to arrange for U.S. activities related to requests from other countries insofar as possible.

The committee now has 15 members; it may have as few as 10 and as many as 20. It consists of the Chief Hydrologist of the USGS, who is automatically the Chairman, and representatives of eight other Federal agencies and six nongovernmental organizations. J. S. Cragwall, Jr., Chairman, and L. A. Heindl, Executive Secretary, have served on the committee since its inception. The Associate Chief Hydrologist of the USGS, O. M. Hackett, is automatically Alternate Chairman.

The United States, along with many of the other countries that had participated in the IHD, continued studies in 1976 as part of the IHP. The network of 82 river stations that observe and record streamflow, chemical quality, and suspended-sediment load was maintained. This network provides a general index of the discharge of surface water and of 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 provide information on water-level fluctuations and on the chemical quality of lake, reservoir, and ground water.

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

During the year, USGS hydrologists participated in international meetings of working groups, intercountry exchange of experts, discussions of selected activities chosen for particular years, and hydrologic research at selected areas in the United States where the results are expected to have international interest or application.

R. L. Cory continued water-quality monitoring and studies of the epifauna in the South, Rhode, and West Rivers, small estuarine tributaries on the western side of Chesapeake Bay in Anne Arundel County, Maryland. He also measured water-quality profiles at nine stations in the Magothy River and seven stations in the Rhode River.

G. C. Taylor, Jr., continued to serve on the IHP Panel of Editors for the "Guidebook on Ground-Water Studies."

R. L. Nace continued work on a summary of available data pertinent to the world water balance, a continuation of an extended study that was begun during the IHD. It has been modified, however, to become a monograph on basic hydrology, centered around the global water balance.

A second phase of the work relates to the translation into English of a Russian monograph on the world water balance and global water resources. Translation of the chapters is being done by experts in several countries, including members of Federal agencies outside the USGS. As a U.S. contribution and on behalf of UNESCO, Nace is serving as editor of the total translated monograph, which will be published by UNESCO.

D. M. Thomas, as a member of the IHP Working Group for the Preparation of the World Catalogue of Low Stream Flow, assisted in the analysis of data requested and proposals for their use.

Thomas Maddock, Jr., prepared an analysis of the scope of activities for the IHP Working Group on the Investigation of Water Regime of River Basins Affected by Irrigation; this analysis was the basis for the group's discussion at a meeting held in November 1976 in Leningrad, U.S.S.R.

J. D. Bredehoeft participated in discussions of the IHP Working Group on Long-Term Predictions of Changes in Groundwater Resources Due to Human Activities, held in Paris, France, in June 1976 and assisted in outlining a report on the physical and mathematical models available for investigating related problems.

J. F. Poland prepared a general outline of a casebook on subsidence for the IHP Working Group on Land Subsidence Due to Groundwater Exploitation. The working group held its first meeting in December 1976 in Los Angeles, Calif.

G. H. Davis submitted an outline of a report on hydrological problems arising from development of energy resources to the IHP Secretariat in Paris. The outline will be reviewed in July 1976 and completed during a workshop scheduled for 1977.

O. M. Hackett, A. I. Johnson, J. C. Kammerer, F. P. Kapinos, S. M. Lang, R. H. Langford, and C. R. Murray prepared sections for the World Meteorological Organization (WMO) casebook "Examples of Established Solutions to Institutional and Organizational Problems Encountered by WMO Members in Setting Up Their Hydrological Services." The casebook was the subject of an international seminar held in Ottawa, Canada, in July 1976.

H. H. Barnes, Jr., participated in the meeting of the Working Group on the Guide and Technical Regulations of the WMO Commission on Hydrology in Geneva, Switzerland, in February 1976.

M. E. Moss and W. B. Langbein submitted sections to the second WMO casebook on hydrometeorological networks, and Moss revised his report to the WMO Commission on Hydrology on network design during a week of meetings in Geneva in May 1976.

The USGS also has been active in its support of the hydrological activities of the WMO and its Operational Hydrological Program. J. S. Cragwall, Jr., is the hydrologic advisor to the U.S. permanent representative to the WMO and the Chairman of the Advisory Committee for Operational Hydrology. O. M. Hackett is a member of the WMO Technical Commission for Hydrology. During the past year, USGS personnel were involved with a variety of WMO activities.

The International Standardization Organization (ISO) is another agency with which the USGS cooperates regularly. Its aims are to standardize hydrological equipment and techniques and to assure that data from equipment made in different countries are mutually compatible. G. F. Smoot, Chairman of the Technical Committee on Hydrological Practices, A. F. Pendleton, and J. K. Culbertson, members, attended the annual meeting of the ISO and its commissions in England. These members and D. E. Click, F. A Kilpatrick, and C E. Kindsvater prepared working papers on the use of various pieces of gaging and monitoring equipment for the meeting.

MARINE GEOLOGY AND COASTAL HYDROLOGY

MARINE AND COASTAL GEOLOGY

ATLANTIC COAST

Structural and geophysical studies of the northern U.S. Continental Margin

Six multichannel seismic-reflection lines collected over the past 2 years confirmed seaward-thickening sedimentary prisms, one under Georges Bank (over 8 km thick) and the other the Baltimore Canyon Trough (over 14 km thick). According to J. S. Schlee, both prisms appear to be bordered on their seaward sides by a discontinuous buried ridge inferred to be an Early Cretaceous reef complex. For the shelf, profiles can be divided into three acoustic units: (1) a horizontally layered unit of probable Cenozoic age, (2) a middle unit marked by anastomosing reflectors inshore and horizontal reflectors offshore that are up to 5 km thick and that probably correlate with Cretaceous sedimentary rocks, and (3) a bottom unit of strong horizontal reflectors thought to be carbonate rocks of Jurassic age.

J. A. Grow compared the interval velocities derived from three of the multichannel seismic-reflection lines across the Continental Margin off Maryland, Delaware, New Jersey, and Georges Bank with earlier seismic-refraction data reported by Ewing and others (1946), Ewing and Ewing (1959), and Drake and others (1959). Both techniques identify a thin (0.5–1.5 km) upper sequence that has velocities ranging from 1.6 to 2.0 km/s and that is probably Eocene to Holocene in age. The earlier shelf refraction lines show an intermediate layer with velocities between 2.9 and 3.6 km/s and thicknesses of 1 to 4 km over a high-velocity (5 km/s) "basement," whereas the new data show the presence of a 2.0- to 2.4-km/s layer as well. Velocity gradations within "consolidated sediment" layers range from 2.8 to 5.0 km/s, and thicknesses of 1 to 5 km are found; these layers overlie sedimentary rocks with velocities between 5 and 6 km/s. Because many of these high-velocity strata can be identified as sedimentary rock, it is now possible to trace the oceanic crust, which appears to correlate with the 7.1-km/s layer of Ewing and Ewing (1959), to a depth of 12 to 14 km near the base of the slope beneath 10 to 12 km of sediment.

The 1975 USGS aeromagnetic survey of the Continental Shelf and Slope from Cape Hatteras, N.C., to the Canadian border delineated thick basins of nonmagnetic rock interpreted as being of Mesozoic and Tertiary sedimentary origin. K. D. Klitgord and J. C. Behrendt compared automatic depth-to-basement computations by using a modification of the Werner deconvolution method with seismic common-depth-point (CDP) reflection and refraction data. The magnetic interpretations allow extrapolation between the widely spaced seismic lines. Depth-to-magnetic-basement maps indicate a series of troughs and ridges beneath the shelf and slope. A large trough having a sediment thickness of more than 10 km between the Chesapeake Bay and New Jersey corresponds to the Baltimore Canyon Trough shown by seismic data. Magnetic depths calculated over the Georges Bank basin indicate apparent horsts and grabens reaching depths of more than 8 km in places.

The aeromagnetic survey and surface ship magnetic data were used to investigate the nature of the "quiet zone" crust between the Mesozoic magnetic anomalies and the "East Coast" anomaly that parallels the Continental Slope. A series of right-lateral fracture zones that produce a major offset in the Mesozoic anomalies south of the New England seamounts can be traced onto the Continental Shelf between the Chesapeake Bay and Long Island, N.Y. Lineated anomalies having a north-northeast trend are found over the quiet zone between the fracture zones. The large (greater than 100 nT) anomaly noted by Emery and others (1970) within the quiet zone is shown to be parallel to the Mesozoic anomalies and is interpreted as a normal polarity event. Between this anomaly and the "East Coast" anomaly are long-wavelength (about 70 m), low-amplitude (less than 50 nT) anomalies alined parallel to the "East Coast" anomaly.

Structure of the Continental Margin off Georgia, South Carolina, and North Carolina

A wedge of sediment more than 5 seconds (two-way) thick was disclosed by CDP multichannel profiles during studies of the Continental Shelf, the Blake Plateau, and the deep sea off the Southeast Georgia Embayment. The data were collected during two joint cruises conducted by the USGS and the Institute Français du Pétrole (IFP) in 1975 and by Geophysical Service, Incorporated. W. P. Dillon (USGS) and J. P. Fail and J. Cassand (IFP) reported that acoustic basement is clearly marked beneath the Blake Basin and the Blake Ridge but is very difficult to distinguish beneath the Blake Plateau and the Continental Shelf, presumably because of small acoustic impedance differences between basement rocks and overlying sedimentary rocks. An angular unconformity beneath the Blake Plateau may be underlain by Triassic deposits accumulated in fault basins. Horizon β, identified as the top of Neocomian deposits in the deep sea by Deep Sea Drilling Project (DSDP) drilling, appears to be traceable beneath the Blake Plateau. Strata below this horizon appear to wedge out beneath the inner Blake Plateau. Post-Neocomian (?) Cretaceous deposits that dip gently seaward beneath most of the Blake Plateau show progradational features near the Blake Escarpment and faulting near Cape Fear, N.C. The top of Cretaceous deposits is marked by erosion, as DSDP drilling on the Blake Ridge indicates, and very extensive removal of material is apparent in the deep sea. Probable Tertiary deposits accumulated atop the Cretaceous platform to form the Continental Shelf. These deposits thin across the Blake Plateau and thicken again in the deep sea.

Environmental conditions of the Georges Bank area

Of the three areas in the Atlantic Outer Continental Shelf scheduled for oil and gas leasing, Georges Bank is clearly subject to the most vigorous natural stresses. Current velocities of 3 to 4 kn (150–200 cm/s) are not uncommon, high sea states accompany winter northeastern storms and fall hurricanes, and large sand waves on the bottom may constitute an unstable substrate for platform and pipeline foundations. A preliminary assessment by D. W. Folger of 3,500 km of high-resolution seismic data indicated that the northern side of the bank is underlain in places by what appears to be highly contorted glacial till. This material, where it is close to the surface, may provide unstable foundation conditions.

Sand waves in the Baltimore Canyon Trough area

Geological and geophysical studies carried out by D. W. Folger, H. J. Knebel, W. P. Dillon, M. H. Bothner, R. E. Miller, and Bradford Butman showed that most of the shelf in the Baltimore Canyon Trough area consists of a stiff clay substrate covered by a veneer of medium-grained sand, absent in places, that ranges in thickness up to an estimated few tens of meters. Sand waves are present, most commonly as small symmetric ripples 30 to 50 cm in wavelength and 5 to 10 cm high, and are probably caused by oscillating currents associated with wave motion. The sand waves are very large in some areas; near the head of Wilmington Canyon, they are 100 to 600 m in wavelength and up to 9 m high. Because these waves are asymmetric and may be in motion, they constitute a hazard to the stability of structures built on them. Studies are being carried out to determine the extent and rates of motion of the waves and the geotechnical properties of the underlying clay.

Studies of the hydrocarbon concentration in the sands were carried out by Miller and D. M. Schultz. Preliminary results showed the hydrocarbon concentrations to range from 1 to 4 ppm in the shelf sands. The n-alkane fraction forms approximately 7 to 11 percent of the total hydrocarbon extract and has a range of carbon atoms from C_{12} to C_{32}, C_{29} being the dominant species. The odd-to-even ratio of the n-alkane fraction averaged 0.285 percent. These geochemical parameters strongly suggest, but do not prove, that the hydrocarbons extracted from these shelf sediments are of biogenic origin rather than anthropogenic origin.

Sediment processes in submarine canyons

Studies of sedimentation processes in submarine canyons may give clues about sediment movements on the shelf above. During August 1975, D. A. Cacchione (USGS), Alexander Malahoff (Office of Naval Research), and G. T. Rowe (Woods Hole Oceanographic Institution) made four dives in the research submersible ALVIN into the lower Hudson Canyon as part of a Woods Hole program sponsored by the Office of Naval Research. They obtained data on sedimentation patterns, currents, and benthic faunal types and activities at water depths between 2,800 and 3,400 m.

Preliminary analyses of tube and box core samples taken from ALVIN confirmed visual observations that the axial floor at these depths consists of a fine- to medium-grained sandy substrate mantled by a thin veneer of organic debris and silty clay. The absence of thick surface accumulations of soft, unconsolidated muddy deposits, typical of the surface sediments on the shallower sections of the canyon floor, is surprising in light of the low measured flow speeds and the observed abundance of materials in suspension above the canyon floor. Rocks exposed along the canyon walls and large boulders resting in the thalweg commonly have only a very thin cover of sediment on their surfaces.

Current-meter records taken over a 3½-day period at 7 and 100 m above the canyon floor showed consistent downcanyon flow. The current speed is modulated by the semidiurnal tide, but no flow reversals occurred throughout the measurement period. Peak velocities at 7 m above the bed were 15 cm/s. No bedload transport was detected visually, and current-induced effects could be recognized at the sediment surface in only a few places. Instantaneous determinations of bed shear stress at each dive site, made by using a dye-pellet technique, consistently gave shear values that were too low to induce transport of the in-place sediment.

The surface features and bed forms observed at each dive site were caused mainly by faunal activity; only one example of current-induced sediment ripples was observed. The faunal distributions appear to be related to sediment type, but the specific nature of this relationship has not yet been fully worked out.

D. E. Drake (USGS) and G. H. Keller, P. G. Hatcher, and H. Pak (Atlantic Oceanographic and Meteorological Laboratory, NOAA) reported that intensive sampling of the near-bottom waters of Hydrographer, Hudson, and Wilmington Canyons during March and April of 1974 revealed substantial differences in the concentrations and distributions of suspended matter in the three canyons, although the surface waters in each area contained similar amounts of particulate matter (0.4–0.6 mg/l). Relative to shelf and slope concentrations, each canyon has a lens of particle-rich near-bottom water. Concentrations in the near-bottom canyon waters over a depth range of 200 to 800 m are up to an order of magnitude greater in Hudson Canyon than they are in Hydrographer and Wilmington Canyons.

Below the photic zone, the suspended matter was predominantly noncombustible biogenic and terrigenous detritus. Suspended matter from the Hudson Canyon contained the highest ash residue.

Near-bottom current-meter records obtained during the water-sampling periods suggest that the current characteristics are not sufficiently different to account for the high suspended loads in Hudson Canyon. Furthermore, other investigators have shown that the present influx of terrigenous sediment to the shelf is uniformly small from Cape Cod, Mass., to Cape Hatteras, N.C. It appears likely that the fine sediment is supplied to Hudson Canyon from mud deposits on the shelf and slope south of Nantucket Island, Mass.

Quaternary history of Cape Cod Bay

C. J. O'Hara and R. N. Oldale (1976) found that seismic-reflection profiles in Cape Cod Bay, Mass., define a fluvially carved, northeast-sloping unconformity inferred to be underlain by crystalline and sedimentary rocks of Triassic age or older. Valleys on the unconformable surface delineate a northeast-trending drainage pattern in the western part of the bay and a more north-trending pattern in the eastern part. A prominent north-northwest-trending escarpment in the middle of the bay may be fault related. Erosional remnants inferred to be Coastal Plain strata of Cretaceous to Pleistocene age commonly overlie the unconformity in the northeastern part of the bay. Elsewhere, glacial drift deposits directly overlie the unconformity. The glacial deposits in the western part of the bay are inferred to represent ice-contact stratified drift, outwash, and morainic and glaciolacustrine sediments derived from the Cape Cod Bay ice lobe. In the eastern part of the bay, the glacial deposits are inferred to be derived from the more remote South Channel ice lobe and to represent well-sorted deep-water lake-bottom sediments overlain by a nearshore shallow-water deltaic facies.

Three phases of postglacial history are recognized (Oldale and O'Hara, 1975). Valleys cut into the glacial drift are filled with sediments of probable estuarine origin. An unconformity that truncates valley fill and glacial drift indicates a period of erosion, probably during marine transgression, since marine deposits of gravelly sand are found locally overlying the unconformity at depths of up to 35 m. These features are thought to be relict bars. A veneer of sand and silty clay forms the most recent sediments above the unconformity. Silty clay in the deepest parts of the bay becomes sandy landward and can be traced into modern beach sediments.

Quaternary features of Vineyard Sound and eastern Rhode Island Sound

Subbottom profiles analyzed by C. J. O'Hara showed deeply buried valleys with thalwegs 200 m below sea level off Martha's Vineyard, Mass. Nearshore, the channels are shallow and underlain by bedrock and contain deposits inferred to be glacial drift. Further offshore, the drift-filled channels are underlain by Coastal Plain deposits of Late Cretaceous age. Well-stratified sediments in the southern part of Vineyard Sound appear to be glacial lake deposits. The Buzzards Bay moraine appears to have a submarine extension 20 km long southwest of Cuttyhunk Island.

Holocene marine deposits are thin or absent near shore, except locally where they fill channels cut in the surface of the glacial drift, and they thicken to 15 m offshore. Middleground and Lucas Shoals in Vineyard Sound appear to be the shallow-water parts of an extensive submerged beach complex.

Nantucket Island drill hole

A well drilled on Nantucket Island, Mass., as a stratigraphic and water-resource test yielded a continuously cored geologic section ranging in age from Triassic(?) to Pleistocene. According to D. W. Folger and others (1976), the deepest rocks recovered at depths below sea level of 446 to 503 m are dark maroon basalt or diabase having many amygdaloidal zones containing zeolites and veins of calcite. The rocks resemble those of the Triassic lowlands of the Eastern United States and are presumed to be of Triassic and Jurassic age. A preliminary K-Ar date by R. F. Marvin indicates a minimum age of 164 ± 3 million years. The upper 13 m of these beds has altered completely to kaolinite as a saprolitic zone in which every detail of the structure of the original igneous rock is preserved. Overlying this zone from 338 to 446 m are loose unconsolidated clayey sands and a few clay beds. Above these, from 117 to 338 m, lie stiff clays of Late Cretaceous age containing lignite and a few highly concentrated sandstone stringers. Much of the Upper Cretaceous section is mottled red, olive, and gray silty clay. About 30 m of greensand, barren of fossils, overlies the clay. Pleistocene sands and gravels containing at least two till or soil zones make up the uppermost 90 m of the section. Studies of water salinity by F. A. Kohout and others (1976) show a Ghyben-Herzberg lens about 160 m thick underlain by a brackish transition zone. Instead of changing to a saltwater zone below the transition zone, however, the water is either fresh or brackish to the total depth of the well. At least part of this freshwater may be relict from the Pleistocene low-sea-level stand.

GULF COAST AND CARIBBEAN SEA

Unstable sediments on the Mississippi Delta

Sediment failure on the submerged part of the Mississippi Delta poses a serious environmental hazard to offshore platforms and pipelines, especially as oil and gas drilling operations proceed into the deeper water of the delta front and the Continental Slope. Previous studies have shown that delta-front sediment masses move downslope in a number of ways. For example, the loss of pipeline segments several kilometers in length during storms suggests large movement over broad fronts, whereas sharp kinks in other pipeline sections suggest movement within a limited area.

In order to classify the various kinds of deformational features involved, L. E. Garrison (USGS) and J. M. Coleman and H. H. Roberts (Coastal Studies Institute, Louisiana State University) interpreted high-resolution seismic profiles, side-scan sonar records, and repeated detailed hydrographic surveys of the delta front and the shelf and slope off the Mississippi River. They identified and mapped features caused by faults and slumps on the periphery of the river mouth bar; mud diapirs caused by differential loading; radial graben and tensional faults; sedimentary features indicating mass wasting and flowage, induced by wave motion and degassing; surface mudflows and mud noses; shelf-edge rotational slumps; deep-seated contemporaneous faults; and mud volcanoes and diapirs on the upper slope. All these features are presently active and are large enough or have a rate of movement rapid enough to endanger bottom-mounted offshore structures and pipelines.

In order to measure the effect of wave pressure on the bottom as a triggering mechanism for sediment failure, an experiment known as SEASWAB (Shallow Experiment to Assess Storm Waves Affecting the Bottom) was carried out at an oil-production platform on the offshore delta. The site, in East Bay, La., was in 20 m of water in an area of known low sediment strength. A wave staff, a current meter, and a series of wave-pressure gages were hung from the platform to measure wave characteristics. An array of accelerometers was planted in the mud nearby to detect vertical and lateral motion in the sediments.

Data from several periods during which large waves occurred in the area were analyzed, and J. N. Suhayda (Coastal Studies Institute, Louisiana State University) reported that wave-induced pressures on the sea floor were up to 50 percent greater than linear theory had predicted. Pressure fluctuations associated with wave periods of about 6 seconds induced vertical displacements on the order of 1 to 1.5 cm at a point about 0.3 m below the mudline. These cyclic bottom displacements of the sea floor showed intermittent pulses of motion separated by relatively quiet periods as a response to groups of higher waves in a complex wave field. The measured displacements, however, were only about 10 percent as large as existing theoretical models would have predicted.

Two piezometers were deployed from the platform to measure the in-place pore-water pressures for calculation of effective stress. T. J. Hirst and A. F. Richards (Lehigh University) measured differential pressure at a depth of 6 m below the mudline, while R. H. Bennett (NOAA) and W. R. Bryant (Texas A&M University) measured absolute pore pressure at depths of 1.4, 8.4, and 15.3 m below the mudline. Excess pore pressures of 0.3 to 0.5 kg/cm^2 above hydrostatic were reported under normal sea conditions; increases were even greater during storm periods.

In-place vane shear tests at the platform analyzed by Bryant and W. A. Dunlap (Texas A&M University) showed low shear strength indicative of the underconsolidation of the sediments.

J. S. Booth (USGS) and Thomas Whelan (Coastal Studies Institute, Louisiana State University) investigated the type and quantity of gases present in cores from four boreholes in the submerged portion of the Mississippi Delta. The holes were drilled 30 to 60 m below the mudline in water depths of 25 to 100 m. The four sites represented a variety of bottom conditions ranging from areas with a history of failure to areas having an acoustic stratigraphy indicating stability throughout Holocene time. Booth and Whelan reported that the primary gas in modern delta sediments is methane and that, in each borehole, the maximum concentration occurred 30 to 40 m below the mudline. Total gas concentrations in all cores ranged from 5×10^{-3} ml/l (background) to as much as 365 ml/l methane. In general, low sediment shear strengths were measured where methane existed above background values. High ratios of sulfate to methane occurred in two holes where previous mass movement was evident. Inasmuch as methane is produced only after all dissolved sulfate ions in the interstitial water are converted to sulfide by bacterial action, the presence of sulfate suggests vertical mixing of the sediment during or just preceding mass movement.

Sediment patterns of the south Texas shelf

H. L. Berryhill, Jr., C. W. Holmes, G. L. Shideler, and G. W. Hill reported that sediment patterns are influenced by tectonic movement on the south Texas Outer Continental Shelf, even though the region is aseismic. The pattern of faulting has moved progressively outward across the shelf in Pleistocene and Holocene time; the outer third of the shelf has been extensively faulted during Holocene time, and sea-floor slumping is presently an active process at the shelf edge peripheral to the ancestral Rio Grande Delta. Net sediment transport for the region is southward, and rates of sedimentation during Holocene time may have been as high as 1 m/1,000 yr. During and following the passage of a hurricane, sand is carried seaward at least halfway across the shelf.

Suspended sediments of Corpus Christi Bay, Texas

The suspended-sediment particulate system of the Corpus Christi Bay estuary in Texas was investigated during a flood tide in October 1975 and January 1976. G. L. Shideler and Frances Firek reported that quasi-synoptic water samples and vertical light transmission-temperature profiles at seven bay monitoring stations suggest a general increase in turbidity toward the head of the bay; this increase may reflect the influence of the Nueces River as a prominent source of bay sediments. Gradients having increasing turbidity with depth are generally noted at individual stations. Observed light-beam transmission values, which reach a maximum of 42 percent/ 0.25 m but are generally less than 25 percent/0.25 m, indicate a relatively high turbidity within the bay in comparison with open ocean waters. The suspended sediments of the bay consist largely of inorganic clay-silt particles and phytoplankton; the phytoplankton fraction appears to be dominated by a variety of diatoms. The absence of prominent thermostratification indicated by vertical temperature profiles apparently reflects the bay's shallowness and high degree of mixing by local winds.

Trace-metal levels in biota of Corpus Christi Bay, Texas

Measurements of trace metals in water, sediment, and biota indicated that significant amounts of lead, cadmium, and zinc are being concentrated in oysters of the Corpus Christi Bay estuarine system in Texas. C. W. Holmes found the ranges of concentrations to be:

	Sediments, µg/g	Suspended sediment, µg/g	Water, µg/l	Oyster shells, µg/g	Oyster flesh, µg/g (dry wt.)
Pb	26–1200	N.D.[1]	0.6–1.0	2.6–20.5	3.0–207
Cd	0.8–190	2.0–120	0.08–0.13	0.15–0.65	0.1–2.0
Zn	130–13,600	81–1,130	50–400	2–108	1,000–32,000

[1] N.D., not determined.

When the concentration of an element in an oyster is compared with the concentration of the element in the surrounding water and suspended sediment, a considerable enrichment of zinc and lead is observed within the organism.

Metal-rich sediments within the Corpus Christi Harbor are the apparent source of the trace-metal-rich water and suspended sediment available to the organisms in Corpus Christi Bay. Remobilization of these trace metals from the harbor floor plays a significant role in this redistribution process.

Sediments of the Puerto Rico shelves

In mapping the sedimentary facies and bathymetry of the western half of the Muertos shelf south of Puerto Rico, J. V. A. Trumbull and D. K. Beach (USGS) found that the bathymetry, a product of structural movement and coral reef growth, is the chief control over the mixing rates and the areal distribution of terrigenous and biogenic sediments. Biogenic sediments dominate the outer shelf, and a significant fraction is relict. Terrigenous sediments are confined to the nearshore zone and are moved westward by coastal currents as far as the Ponce basin (a structural depression), where they are deflected south and southeastward by shallow reefs.

Unconsolidated sediments that cover the narrow insular shelf off the northern coast of Puerto Rico are chiefly terrigenous and are mixed in places with calcareous skeletal particles derived from organisms living on the shelf. Trumbull, O. H. Pilkey (Duke University), and Nahum Schneidermann and Craig Saunders (University of Puerto Rico) concluded that the terrigenous component is derived from modern river sediments. Inasmuch as most of the world's continental and larger insular shelves are covered with relict sediments, this area affords a unique opportunity to study sedimentary processes on an equilibrium shelf (Schneidermann and others, 1976).

PACIFIC COAST

Neogene structural evolution of the California continental borderland

D. G. Howell (1976) summarized various aspects of recent investigations off southern California. Mapping on the Channel Islands by Howell, Hugh McLean, and J. G. Vedder led to a better understanding of Neogene tectonic events and their influence on Miocene depositional patterns throughout the borderland. The influx of Catalina Schist debris and the nearly simultaneous initiation of widespread volcanism near the end of early Miocene time signaled a significant transformation in structural style. A similar relationship between the onset of volcanism and the uplift and erosion of basement rocks was found by J. C. Taylor and McLean in their petrographic examination of dart core and dredge samples from the outer ridges and banks. Paleontologic study of the same samples by R. E. Arnal (foraminifers) and J. D. Bukry (coccoliths, silicoflagellates, and diatoms) helped to demonstrate that borderland paleobathymetry began to change at the end of Paleogene time from a regionally sloping margin of apronlike turbidite deposition to one of evolving ridge-and-basin topography. Interpretations of seismic profiles by Arne Junger indicated that major episodes of faulting occurred during late Miocene, Pliocene, and Quaternary time and that folding developed concurrently. Junger's claycake experiments led him to conclude that the present borderland topography and shallow structure resulted from convergent right-lateral movement along deep-seated shear zones.

Together, these findings suggest that the present configuration of the borderland of southern California is genetically related to an episode of crustal right shear (approximately 22 to 12 million years ago) that developed in response to the migration of a triple point past the margin and the coupling of the Pacific and North American plates.

Geologic hazards of the California continental borderland

Four areas of the southern California continental borderland were studied by H. G. Greene, S. H. Clarke, Jr., and M. E. Field to define the nature and extent of the geologic hazards that could affect the environment as a result of petroleum-resource development in this region; these areas are the Tanner and Cortes Banks, the northern Santa Rosa-Cortes Ridge, the Mugu-Santa Monica shelf, and the San Pedro shelf. The geologic phenomena investigated include faulting, seismicity, sediment instability (for example, submarine slumping and sediment creep), sediment erosion, and oil and gas seeps. These phenomena were studied principally by means of high-resolution seismic-reflection profiles, supplemented in some places by deep-penetration seismic-reflections records, side-scan sonography, underwater television coverage, and sediment samples. Seismicity data were obtained from published studies.

Faulting and seismic activity are major hazards in all four areas. Active faults, indicated by displacement of the sea floor and Holocene sediments, are common along the northern flank of Cortes Bank, in the structural saddle between Tanner Bank and Cortes Bank, and on top of the northern Santa Rosa-Cortes Ridge. On the Mugu-Santa Monica and San Pedro shelves, numerous discontinuous faults, as well as offshore extensions of the Santa Monica and Palos Verdes Hills faults, appear active. Seismicity data also reflect activity in their shelf areas; some epicenters have been correlated with extensions of the Palos Verdes Hills fault and the Newport-Inglewood zone.

The flanks of the Tanner and Cortes Banks and the northern Santa Rosa-Cortes Ridge are overlain by unconsolidated sediments that are unstable and periodically move downslope as submarine slides, slumps, and creep. The tops of the banks and the ridge are characterized by pre-Quaternary volcanic and sedimentary rock cropping out through a thin veneer of Quaternary sediments. A low rate of sedimentation and relatively strong bottom currents are inferred for these areas. In the Mugu-Santa Monica and San Pedro shelf areas, downslope mass movements of unconsolidated sediments occur along the walls of Mugu and Santa Monica Canyons and along the seaward margin of the shelf. The limited extent of bedrock outcrops and the presence of locally thick deposits of unconsolidated Quaternary sediments in these areas suggest that foundation conditions may be hazardous.

Numerous well-documented oil and gas seeps are present on the Mugu-Santa Monica and San Pedro shelves and may be present in the vicinity of the Tanner and Cortes Banks and on the northern Santa Rosa-Cortes Ridge, although none were identified. Analyses of extractable organic material from eight samples of very fine grained foraminiferal sand from the Tanner and Cortes Banks area were made by K. A. Kvenvolden, J. B. Rapp, and G. D. Redder. The distribution of aliphatic hydrocarbons, as determined by gas chromatography, suggests an origin from at least two sources. Hydrocarbons commonly found in basinal sediments and usually attributed to terrestrial biology are present. In addition, the samples contain a complex mixture of hydrocarbons whose chromatographic record may be attributable to petroleum pollution. Kvenvolden, Rapp, and Redder pointed out, however, that diagenetic processes in the sediments might also yield such a complex mixture and that the results therefore do not show conclusively whether the hydrocarbons result from diagenetic processes or from contamination by petroleum either through seeps or spills.

Sedimentation and erosion on the Monterey Fan, central California

The deep-sea Monterey Fan is cut by three related fan valleys: the Monterey fan valley; the Ascension fan valley, a tributary; and the Monterey East fan valley, a "hanging" distributary. Geophysical and sedimentological studies by W. R. Normark and G. R. Hessed show changes in the activity of the canyon valley system following the Holocene rise in sea level. The Ascension fan valley is now relatively inactive owing to loss of sediment supply. Differential accumulation of mud between the valley floor and the levee crest indicates that fine-grained turbid-layer flows (turbidity currents) play a major role as carriers of mud to the fan. Sands present on the floor of the Monterey fan valley and 150 m higher in the floor of the Monterey East fan valley show that some of the turbid-layer flows are more than 150 m in height. On the other hand, the lack of sands on levee crests 400 m above the valley floor indicates that no flows of that height have occurred during the Holocene. Hummocks on the backsides of fan valley levees appear to be depositional dune-like features that migrate toward levee crests during growth.

Tectonic framework of the Strait of Juan de Fuca and the Pacific Continental Shelf

The onshore geologic framework of the northwestern part of the Olympic Peninsula of Washington, established by P. D. Snavely, Jr., N. S. MacLeod, and J. E. Pearl, can be extrapolated into the Strait of Juan de Fuca and onto the adjacent Pacific Continental Shelf by using offshore gravity and magnetic data, seismic-reflection profiles, and limited subsurface information. The major thrust fault mapped at the base of a sequence of submarine volcanic rocks, which forms the Crescent Formation (lower and middle Eocene), extends offshore west of Cape Flattery and probably lies along the southwestern flank of the linear northwest-trending Prometheus magnetic high in the Tofino Basin. Two test wells drilled by Shell Canada along this magnetic high penetrated Crescent volcanic rocks at about 1,600 and 1,900 m (Shouldice, 1971). Northeast of the Prometheus high, test wells encountered Eocene to lower Miocene sedimentary rocks, which are coeval with the thick, deep, marginal basin sequence that crops out along the northern flank of the Olympic Mountains. A test well drilled southwest of the Prometheus high, however, penetrated upper Eocene and Oligocene strata that unconformably overlie a structurally complex sequence of diagenetically altered sandstone and siltstone. This latter unit probably correlates with the middle Eocene and lower upper Eocene mélange and broken formation mapped near the coast south of the Crescent thrust in the Cape Flattery area.

Gravity and magnetic data obtained by NOAA in 1972 in the Tofino Basin show that a linear gravity low is superimposed on the Prometheus linear magnetic high. This relationship of magnetic high and gravity low can be interpreted as indicating that a thick sequence of Eocene mélange and broken formation is thrust under the volcanic rocks at the Prometheus high anomaly, just like the Crescent thrust onshore in the Olympic Peninsula, where sedimentary rocks are thrust below the Crescent volcanic rocks.

The northwest-trending Calawah fault, which has an inferred left-lateral separation, extends offshore just south of Cape Flattery. This fault probably marks the northeastern boundary of the Prometheus magnetic high and is assumed to form the interface offshore between the oceanic-type crust beneath the Prometheus high and the continental-type crust of Vancouver Island and the adjacent inner shelf.

The Leech River fault of southern Vancouver Island trends southwestward across the western part of the Strait of Juan de Fuca to a point just north of Cape Flattery. The Leech River fault is interpreted as the major zone of underthrusting in early Eocene time between the oceanic-type crust in western Oregon and Washington and the pre-Tertiary crustal rocks of Vancouver Island. The Crescent thrust also is interpreted as a major underthrust zone but is of middle to late Eocene age.

The Calawah fault, which is interpreted as a transform fault with left-lateral separation, probably formed in late middle Miocene time and offset both the Crescent fault and the Leech River fault. Movement of the Calawah continued at least through the Pleistocene.

Tidal channels of Willapa Bay, Washington

Side-scanning sonar surveys, diving observations, and coring were the techniques used by R. L. Phillips and H. E. Clifton to delineate bed forms of differing morphology, orientation, and internal structure within the estuary channel system in Willapa Bay, Wash. The side-scanning sonar recorded bed forms oriented normal to the flow of the tidal currents in nearly all parts of the channel. Sand waves up to 1 m high dominate the channel bottom, whereas dunes up to 2 m high form on the sides of the channels. Fields of ebb- and flood-oriented bed forms coexist within the channel system. During the maximum tidal exchanges, most of the bed forms reverse their orientations. Oriented cores up to 2 m long through the channel-bottom sediments show sets of medium-scale cross-strata containing reactivation surfaces interbedded with ripple lamination. Shell concentrations, wood fragments, and bioturbation are common in the channel bottom. Sediment on the channel sides occurs as large-scale cross-strata with reactivation surfaces. Bioturbation is slight on the channel sides but increases on the shallow subtidal or tidal sand flats adjacent to the channel.

Estuarine facies of Willapa Bay, Washington

H. E. Clifton and R. L. Phillips developed a model for an estuarine fill deposit based on a comparative study of facies in modern sediments and Pleistocene terrace deposits in and adjacent to Willapa Bay, Wash. The model incorporates both vertical sequences and lateral changes in facies extending from the estuary mouth to the tidal rivers that feed the estuary. The vertical sequences are produced by the lateral accretion of tide-flat facies over tidal-shoal and point-bar facies and tidal-channel floor facies. The subtidal deposits tend to change laterally from medium- to fine-grained sand near the mouth of the estuary to mixed sand and mud in the central estuary to mud in the upper estuary. The coarse, poorly sorted sand and gravel deposited by rivers in the upper estuary differ markedly from the well-sorted sand deposited by tidal currents. Historical sequences in the Pleistocene terrace deposits suggest that the estuary will ultimately convert to a broad tidal marsh crossed by narrow tidal rivers. The juxtaposition of well-sorted sand and organically rich mud under an impermeable mud seal suggests that ancient estuarine deposits should be excellent traps for hydrocarbons.

ALASKAN-ARCTIC INVESTIGATIONS

GULF OF ALASKA

Structural elements of the offshore Gulf of Alaska Tertiary province

A preliminary interpretation of recently acquired USGS geophysical data by T. R. Bruns and George Plafker indicated that the offshore Gulf of Alaska Tertiary province comprises at least three areas, each with a markedly different tectonic style and history. In general, structural development becomes more intense from east to west.

The eastern area between Cross Sound and Icy Bay is characterized by a basin filled with as much as 9 km of relatively undeformed sediment presumed to be of late Cenozoic age. The seaward flank of the basin is formed in part by a shelf-edge arch at Fairweather Ground; the axis of the basin is near the coast and generally parallel to it. The next area begins roughly at an imaginary line drawn between Pamplona Spur and Icy Bay and extends to Kayak Island. It contains an upper Cenozoic section at least 7 km thick characterized by multiple angular unconformities that indicate active deformation during deposition. Many large folds are found in the region of the Pamplona Spur-Icy Bay boundary; some of these structures are covered by a kilometer or more of relatively undisturbed sediment. The western half of this area is a broad shelf-edge arch. The third area, between Kayak Island and Montague Island, is characterized by complex, tightly folded structures, severe deformation, and continuing active tectonism. Faults and folds have divergent trends that may indicate multiple periods of deformation. The upper Cenozoic sediment thickness is extremely variable.

The structural development of the Gulf of Alaska Tertiary province appears to have been caused by a combination of wrenching and compression that reflects late Cenozoic interactions between the North American and Pacific Ocean plates. The Pamplona Spur-Icy Bay and Kayak Island boundaries may be major compressional tectonic zones formed by this interaction.

Hydrocarbon assessment of the lower Cook Inlet, Alaska

The lower Cook Inlet section of the Outer Continental Shelf (OCS) is 150 to 350 km southwest of Anchorage, Alaska. This area contains 5,600 km^2 of submerged lands in less than 200 m of water. The geology of the submerged area was extrapolated from onshore data by L. B. Magoon III.

The sedimentary rocks are as old as Triassic and as young as Pleistocene. The Mesozoic strata include volcanic, volcaniclastic, and marine clastic sediments. Tertiary rocks, from which the oil and gas in the upper Cook Inlet are produced, consist of nonmarine conglomerate, sandstone, siltstone, and coal. The Tertiary rocks fill a northeast-trending structural trough flanked by the Bruin Bay fault on the northwest and the Borden Range fault on the southeast and are deformed by anticlinal structures and faults that may provide traps for hydrocarbons.

The section of the OCS area having oil and gas potential ranges from Middle Jurassic through Tertiary in age. E. G. Sable estimated that this area could contain from 0.3 to 1.4 billion barrels of oil and from 17 to 76 billion m^3 of natural gas, depending on the statistical level of confidence accepted. R. A. Smith and F. B. Chemlik pointed out that the time frame for significant development will be relatively long, owing to high costs and environmental conditions. They estimated that it will be 1 to 2 years after the lease sale before substantial exploratory drilling will occur, 5 to 8 years before initial production will begin, and 6 to 10 years before maximum production will be reached.

Resource assessment of the western Gulf of Alaska

The Kodiak Tertiary province in the western Gulf of Alaska contains three major sedimentary basins that are as yet unsampled.

Using seismic-reflection profiles and analogy with the sedimentary rocks exposed on land, R. E. von Huene inferred that the basins contain an upper Tertiary sequence as much as 6 km thick overlying a deformed lower Tertiary sequence of high seismic velocity.

The upper Tertiary sequence should have the greatest potential for petroleum. The thickness of the section should allow conditions of temperature and pressure sufficient for hydrocarbon maturation; anticlinal and possible stratigraphic traps as well as possible reservoir rocks can be inferred (von Huene and others, 1975).

BERING SEA

Volcanic and fault hazards on the Pribilof Islands

The Pribilof Islands in the southern Bering Sea are centers of persistent basaltic volcanism controlled by tensional fractures along the crest of a broad structural high, the Pribilof Arch of D. W. Scholl and D. M. Hopkins (1969). An environmental hazard study of the islands by Hopkins and M. L. Silberman revealed that the St. George Island eruptive center was initiated about 3 milion years ago and that eruptive activity ceased about 1 million years ago. St. Paul Island became active about 0.3 million years ago and is still an area of active volcanism with a recurrence interval of about 10,000 years. There are also several smaller and less long lived volcanic foci, now marked by islets and shoals.

Both islands show evidence of faulting during the period of volcanic eruptions, and extensive faulting has taken place on St. George Island since eruptive activity ceased. Faults of two kinds are recognized on St. Paul Island; extremely complex and ramified systems of closely spaced faults that are confined to certain ancient lava flows probably resulted from the intrusion of sill-like bodies at shallow depth. Other, more extensive faults are evidently of tectonic origin. The tectonic faults have moved repeatedly over periods of several thousand years. One of two Holocene lava flows shows fracture traces, which indicate that faulting is a continuing process on St. Paul Island. Shallow geophysical records show very young faults defining a shallow graben offshore between St. Paul and Otter Island.

Hopkins and Silberman concluded that St. George Island is not an active volcanic center but that St. Paul Island is. Chances of an eruption on St. Paul during any single century are about 1 in 100. Future tectonic movements that will break the surface of the land and the sea floor must be expected on and near both islands.

Structural features in the southern Bering Sea

Mapping on the Bering Sea margin by geophysical techniques revealed a horst that bifurcates the northwestern end of the St. George basin. According to M. S. Marlow, the horst may be a southwestern continuation of the Pribilof Ridge, which is exposed on the Pribilof Islands. Numerous normal faults bound the basin, and mapping in 1975 extended the known fault zones nearly the entire length of the basin. A number of faults were found to rupture the sea floor, and several anticlinal folds were also detected.

Umnak Plateau, between the Aleutian Ridge and the Pribilof Islands, was mapped by J. I. Howell. Seismic-reflection data from Umnak Plateau show numerous diapiric features, slump structures, and several normal faults. A contour map of magnetic basement shows a large, north-trending offset in the basement that is possibly a fault zone.

Recent tectonic activity on the Yukon Delta

A study of environmental hazards in the area of the Yukon-Kuskokwim Delta by W. R. Dupré (Wesleyan University) indicated that the region is tectonically active; evidence of Quaternary faulting and volcanism is abundant. A portion of the Holocene delta south of Cape Romanzof appears to have been uplifted at least 10 m, the indication being that tectonic movements have taken place during the last few thousand years; the age of the most recent faulting is uncertain, however, because radiocarbon dates have not yet been obtained.

Dispersal of mercury in the Kuskokwim River, southwestern Alaska

Mercury from lode sources in the Kuskokwim River drainage of Alaska is rapidly dispersed in the sediments a short distance downstream from each source by physical mixing and dilution, according to Hans Nelson, B. R. Larsen, E. A. Jenne, and D. H. Sorg. In this moderately large river (discharge about 45 km^3/yr), mercury in bottom sediments returns to normal—generally less than 1 ppm—a short distance downstream from each lode source. Channel deposits and overbank deposits near lode sources are important depositional sinks. No significant mercury concentrations are found in sediment samples from the lower river and estuary, including samples from tidal flats and organic-rich delta deposits.

In the Kuskokwim drainage basin, mercury is dispersed the greatest distance in the silt and smaller size fractions (<0.062 mm) and extends farther downstream from sources in tributary streams than it does from sources in the main river, where more water and sediment are available for dilution. The dispersal distance for sediment having a high mercury content is greater downstream from mining sites than from equal-sized mercury deposits that are eroding naturally.

An estimated 17 t Hg is discharged into the marine environment each year from the Kuskokwim River drainage. Of this amount, about four-fifths is carried in solution and one-fifth by suspended sediments; only a percent or so is carried by bed-load sediments. The estimates are based on the average mercury content in sediments, suspended sediments, and water measured in this study and on estimates of discharge at the river mouth.

CHUKCHI AND BEAUFORT SEAS

Seismic stratigraphy of the southern Chukchi Sea

A detailed analysis of seismic-reflection data in the Chukchi Sea by Stephen Eittreim, O. T. Whitney, and Arthur Grantz revealed an offshore basement scarp separating the Paleozoic and Mesozoic terrane of the western Brooks Range from the 3,000-m-thick Tertiary section in the Hope Basin of the southeastern Chukchi Sea. Cenozoic sedimentation in the Hope Basin can be divided tentatively into Neogene and Paleogene units, the division being defined by a prominent conformable reflector that can be mapped over the southern Chukchi Sea. A marked change in sediment distribution is apparent from Paleogene time to Neogene time. The Neogene depocenter occupies a triangular wedge of crust bounded on the northeast by the above-mentioned basement scarp and on the south by the Kotzebue Ridge, an east-west basement ridge projecting westward from Kotzebue. Paleogene depocenters are located to the north and south. The southern boundary of the Neogene depocenter along the Kotzebue Ridge is marked by a series of antithetic and normal fault blocks, rotated to tilt toward the basin. The faults affect the entire sedimentary column, although the offset decrease higher in the section indicates some movement contemporaneous with sedimentation. The triangular east-west basin and its associated boundary faults indicate on the order of 2,500 m of relative subsidence, probably restricted to Neogene time.

Determination of sediment density at the Barrow Seavalley from analysis of gravity and bathymetry

The near-surface average sediment density in the area of the Barrow Seavalley was determined by Gary Boucher with marine seismic records (Grantz and others, 1974) and free-air gravity data collected with the seismic data (Hanna and others, 1974). A two-dimensional bathymetry correction applied to a profile crossing the seavalley used a range of values of subbottom density and incorporated a variable time lag to account for the averaging filter of the LaCoste-Romberg marine gravimeter. By varying the density and the time lag together, it was possible to minimize both the correlation between bathymetry and gravity along the profile and the local second derivative of the gravity in the vicinity of the most rapid variation of the bathymetry. The resulting subbottom density is near 2.4 g/cm^3, and the filtering effect of the gravimeter system is equated to an effective time lag of about 6.5 minutes, which corresponds to a distance lag of about 1.6 km. The approach of minimizing both the local curvature of the gravity profiles and the correlation with bathymetry was dictated by the regional gravity field, which indicated that the Barrow Seavalley is located within a structure of considerably greater areal extent. The Barrow Seavalley is a useful feature in this context because it is deep enough to have a significant gravity effect and yet is near to the surface, well-defined, and suitable for two-dimensional analysis.

Sedimentary processes in the Beaufort Sea

P. W. Barnes used drifters to study surface currents on the inner shelf of the Beaufort Sea. The results of his study revealed a consistent pattern. East of the Sagavanirktok River, the drifters predominately moved eastward, whereas all recoveries west of the Sagavanirktok invariably were to the west of their release points. It appears that a divergence in surface current drift existed in 1972 on the inner shelf off the Sagavanirktok River Delta. The onshore surface water east of the delta flowed toward Barter Island, and water west of the delta flowed toward Barrow. Curiously, the oceanographic values reported by Hufford and others (1974) showed a change in character in this same area. The salinity and temperature minimums and the ice and dissolved-oxygen maximums are located off the Sagavanirktok River Delta. A change in sediment character also took place in this area (Barnes and Reimnitz, 1974). Although this divergence appears to be documented for 1972, some question remains as to its long-term stability.

Effect of shoals on pack-ice movement

Accurate bathymetry from U.S. Coast and Geodetic Survey work done in 1949–51 (Reimnitz and others, 1972) was resurveyed in 1975 by Erk Reimnitz and L. J. Toimil from the R/V KARLUK, which has excellent navigational control and a precision fathometer. Shoals survived 25 years of ice dynamics along the shear zone between pack ice and shore fast ice, but all have shifted landward for distances of 100 to 400 m. Reimnitz and Toimil believed this shift to be related to shear-zone processes. On the basis of their studies of Landsat imagery, they concluded that the pronounced linear topographic highs on the inner shelf between Prudhoe Bay and Harrison Bay control shear-zone dynamics. This discovery is the first solid evidence for a relationship between the bathymetric anomalies in the overall profile of an arctic shelf and the boundary processes of the Beaufort Gyre pack ice. Much of the pack-ice energy appears to be expended in these shoals. These findings have important implications for offshore development in the Arctic, especially for the construction of artificial islands, for it appears that one can now make predictions regarding the longevity of such structures and the effect that they will have on pack-ice dynamics. It even seems possible to make the inner-shelf ice environment less hostile to man's endeavors by properly placing such structures.

OCEANIC STUDIES

Manganese nodule investigations

Future use of ocean mineral resources requires detailed geologic information on the ocean-bottom sediments, both for sound appraisal of the mineral-resource potential and for careful analysis of the environmental hazards that might be caused by mining. Bottom cores from two regions of the Pacific Ocean were studied by J. L. Bischoff and B. J. Rosenbauer. Cores from the Galapagos spreading center and the Bauer Basin of the equatorial eastern Pacific were obtained aboard the Soviet vessel R/V MENDELEEV, and those from the proposed manganese nodule mining area of the equatorial central Pacific, centered at 14° N., 126° W., were obtained aboard the U.S. vessel R/V OCEANOGRAPHER as part of the Deep Ocean Mining Environmental Study, conducted by the USGS in cooperation with NOAA. Bischoff and Rosenbauer found that sediments from both areas show strong evidence for the presence of hydrothermally derived metalliferous sediment. Hydrothermal activity is thus not limited to active spreading centers but can occur within oceanic plates. The manganese nodule mining area is about 2,400 km from the East Pacific Rise, the nearest zone of sea-floor spreading.

Dispersion experiments performed on the sediments from the central Pacific area, where future mining activity is likely, indicate that suspension of such sediments into the water column during mining will have little or no effect on the chemistry of the seawater. No measurable toxic heavy metals are released into the water column, and no detectable alteration of nutrients takes place.

Experiments on seawater-basalt interaction indicate that, at temperatures above 100°C, seawater picks up enough heavy-metal ions to be designated an ore fluid and to account for the observed deep-sea heavy-metal deposits.

C. C. Woo examined the mineralogic and chemical composition of manganese nodules, crusts, and pavements from different oceans to determine their origin. He found that nodules from the Pacific Ocean generally show characteristics suggesting growth from solutions within the sediments. The nodules are partially buried in sediment; the top layers are either smooth or leathery in texture, whereas the bottom layers are thicker (indicative of faster growth) and have botryoidal or cauliflowerlike growth structures with sediment between the botryoidal stalks. About a centimeter below the burial line is a belt of maximum thickness called the interface girdle, which gives the nodule a discoidal shape. The bottom layers, the interface girdle, and the crack fillings of the nodule are composed of todokorite, whereas the top layers consist of birnessite. The differences between top and bottom suggest rapid growth under low eH conditions of the lower, buried part of the nodule and slow growth under higher eH conditions of the exposed top.

Nodules from the Blake Plateau in the Atlantic Ocean are round and smooth and have no distinctive bottom or top, nor do they have the distinctive discoidal shape characteristic of Pacific nodules. Manganese pavements on the Blake Plateau show distinct growth features on the bottom of the crust. Lumps and crusts from the Mid-Atlantic Ridge, formed from hydrothermal emanations, have a very high manganese content and practically no iron. Growth of both lumps and crusts is rapid, and the content of transition elements such as Cu, Zu, N, Co, and Ba is low. In contrast, the Pacific nodules grow slowly and accumulate 3 to 4 percent of transition elements. Nodules from the Blake Plateau have intermediate compositions. The proportion of minor elements appears to be governed by the rate of growth of the nodule.

Miocene coccoliths in Mid-Atlantic Ridge igneous crust

Coring of sediment and basalt near the Project FAMOUS (French-American Mid-Ocean Undersea Study) site at DSDP Hole 334, about 104 km west of the median valley of the Mid-Atlantic Ridge, shows the sediment-basalt contact to be at 259 m subbottom, directly below an upper Miocene *Discoaster bellus* Subzone coccolith ooze. J. D. Bukry (1976) reported that even older coccoliths from limestone and chalk-breccia horizons within the basaltic section (which also contains gabbro and serpentinite breccia) can be correlated with middle Miocene coccolith zones. A limestone at 303 m subbottom contains a moderately overgrown diverse assemblage of the *Catinaster calyculus* Subzone. The deepest sample examined, from 322 m, is a gabbro-peridotite-chalk breccia containing thickly overgrown coccoliths that indicate the middle Miocene *Catinaster coalitus* or *Discoaster hamatus* Zones. The coccolith evidence suggests about a 2-million-year difference in age between the assemblage at 259 m subbottom, which is just above the youngest basalt flow, and the assemblage at 322 m, which is within a breccia possibly formed at a former wall of the rift valley.

ESTUARINE AND COASTAL HYDROLOGY

ATLANTIC COAST

F. A. Johnson investigated South Carolina's Intracoastal Waterway (ICWW) from ICWW mile 342 in the north near the Little River Inlet to ICWW mile 378 at Bucksport in southern Horry County. Preliminary analyses of the water indicate that saltwater intrusion at high tide does not move south of mile 352 except under extreme drought conditions. The null point of the considered stretch of the ICWW is at mile 375 under average freshwater inflow conditions—the tidal movement is from opposite directions at that point. Traveltime of the water northward from mile 375 to Little River Inlet averages about 1 km/d.

PACIFIC COAST

Suspended-particle transport and circulation in San Francisco Bay

T. J. Conomos and D. H. Peterson (1976) reported that differences in the relative magnitude and timing of wind stress and river inflow in the northern and southern reaches of California's San Francisco Bay create different sedimentary conditions. The northern reach is a partially mixed estuary that receives most of the bay's total annual freshwater and suspended sediment; most sediment is received during the winter. Density-driven nontidal estuarine circulation maintains a turbidity maximum that changes seasonally in particle concentration. Strong tidal currents and wind-generated waves resuspend sediment from the shallow bay floor. Some of the riverborne sediment deposited during the winter is resuspended and transported landward to the turbidity maximum during the summer. The long-term sediment data (extrapolated from bathymetric charts) indicate that the northern reach is an effective sediment trap. In contrast, the long-term sediment data also suggest that the southern reach is experiencing net erosion. The southern reach receives little river inflow or riverborne suspended sediment, and the average nontidal circulation is weak. The principal source of suspended sediment in the southern reach is the shallow bay floor.

Phytoplankton-micronutrient distributions in San Francisco Bay

Northern San Francisco Bay has a single summer-fall peak in phytoplankton-cell abundance and productivity. According to D. H. Peterson, T. J. Conomos, and E. P. Scrivani, the distribution of micronutrients in the main channel is controlled primarily by the distribution of phytoplankton; the highest abundance of phytoplankton persists in the inner regime (null zone) of the estuary, and the lowest concentrations of micronutrients occur there. Under present conditions, if summer river discharge decreases and water-residence time increases, the phytoplankton population should increase and the dissolved micronutrient concentrations should decrease. Nitrogen can be depressed to growth-rate-limiting concentrations only during periods of high phytoplankton abundance (during late summer). Increased isolation may increase the productivity per unit area in both winter and summer, but increased availability of nitrogen may increase the productivity per unit area only in the summer.

Dissolved-oxygen distributions in San Francisco Bay

D. H. Peterson and T. J. Conomos reported that seasonal surveys indicate that high dissolved-oxygen concentrations are maintained in the main channels of the northern part of San Francisco Bay and that dissolved-oxygen variations are minor. Apparently, the river and the ocean are the dominant sources of dissolved oxygen, particularly in the winter; it is thus implied that, if incoming river or ocean waters had low dissolved-oxygen concentrations, similar low concentrations would exist in the bay.

Stagnant-film model calculations indicated that the atmosphere is an important source of dissolved oxygen in the summer. This source may be exceeded by phytoplankton activity in the upper estuary (null zone) if river discharge is low (less than 200 m^3/s).

During winter periods of peak discharge, dissolved-oxygen saturation levels are highest and water-residence time is lowest; apparently, respiration effects (oxygen use by phytoplankton, bacteria, and other benthic organisms) are diminished. With decreasing winter discharge, respiration exceeds atmospheric- and phytoplankton-oxygen sources.

Modeling pH in a salt-wedge estuary in Washington

E. A. Prych and W. L. Haushild (1975) reported that an existing numerical model of the salt-wedge reach of the Duwamish River estuary in Washington was augmented by adding pH to the list of modeled water-quality parameters. The pH is affected mainly by the addition and withdrawal of dissolved CO_2 from the water, by phytoplankton, by exchange with the atmosphere, and by biochemical degradation of organic matter. Phytoplankton blooms in the layer above the wedge cause pH increases of as much as 1 unit. In the wedge, where light is much less intense, changes in pH are only a few tenths of a unit and are due mostly to biochemical oxygen demand.

MANAGEMENT OF NATURAL RESOURCES ON FEDERAL AND INDIAN LANDS

The Conservation Division is responsible for carrying out the USGS's role in the management of mineral and water resources on Federal and Indian lands, including the Outer Continental Shelf; that role includes, in particular, the conservation, evaluation, and development of the leasable mineral resources and waterpower potential of these areas. Primary functions are (1) mapping and evaluation of mineral lands, (2) delineation and preservation of potential public-land reservoir and waterpower sites, (3) promotion of orderly development, conservation, and proper use of mineral resources on Federal lands under lease, (4) supervision of mineral operations in a manner that will assure the protection of the environment and the realization of a fair value from the sale of leases and that will obtain satisfactory royalties on mineral production, and (5) cooperation with other agencies in the management of Federal mineral and water resources.

CLASSIFICATION AND EVALUATION OF MINERAL LANDS

The organic act creating the USGS gave the Director the responsibility of classifying and evaluating the mineral resources of public-domain lands. There are about 101 million hectares of land for which estimates of the magnitude of leasable mineral occurrences have been only partially made. Such appraisals are needed so that the rights to valuable minerals can be retained in the event that the land surface is disposed of and so that the extent of our mineral resources can be determined. Estimates are based on data acquired through field mapping and the study of available geologic reports, in addition to spot checks and investigations made in response to the needs of other Government agencies. As an aid in this assessment of certain minerals, guidelines have been prepared setting forth limits of thickness, quality, depth, and extent of a mineral occurrence that are necessary before land is considered mineral land.

CLASSIFIED LAND

As a result of USGS investigations, large areas of Federal land have been formally classified as "mineral land." Mineral-land classification complements the leasing provisions of the mineral-leasing laws by reserving to the Government, in disposals of public land, the title to energy resources such as coal, oil, gas, oil shale, asphalt, and bituminous rock and fertilizer and industrial minerals such as phosphate, potash, sodium minerals, and sulfur.

These reserved minerals on public lands are subject to development by private industry under the provisions of the Mineral Leasing Act of 1920. All minerals in acquired lands and on the Outer Continental Shelf are subject to development under comparable acts.

KNOWN GEOLOGIC STRUCTURES OF PRODUCING OIL AND GAS FIELDS

Under the provisions of the Mineral Leasing Act of 1920, the Secretary of the Interior is authorized to grant to any applicant qualified under the act a noncompetitive lease to prospect for oil and gas on any part of the mineral estate of the United States that is not within any Known Geologic Structure (KGS) of a producing oil or gas field. Lands within such known structures are competitively leased to the highest bidder. During FY 1976, over 95,408 ha of onshore Federal land were determined to be in KGS's.

KNOWN GEOTHERMAL RESOURCES AREAS

The Geothermal Steam Act of 1970 provides for development by private industry of federally owned geothermal resources through competitive and noncompetitive leasing. During FY 1976, 169,762 ha were included in Known Geothermal Resources Areas (KGRA); 5,073 ha were added to and 74,663 ha were deleted from lands classified as valuable prospectively for geothermal resources.

A total of $1,079,169 was received for 67,929 ha leased through competitive bidding in 12 lease sales. During FY 1976, 422 noncompetitive leases totaling 286,534 ha were issued.

KNOWN LEASING AREAS FOR COAL AND POTASSIUM

During FY 1976, eight Known Coal Leasing Areas (KCLA) totaling 923,745 ha were defined in Colorado, Montana, New Mexico, and Wyoming. An addition of 6,939 ha was made to a KCLA in Wyoming. An addition of 29,875 ha was made to the known potash leasing area in New Mexico. A known phosphate leasing area containing 664 ha was defined in Idaho.

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 water-resource development 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 streamflow 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 sites are no longer considered suitable for reservoir development, the affected Federal land is released for return to the unencumbered public domain for other possible disposition. During FY 1976, about 18,000 ha of previously classified lands were released, and the review program was carried on in 11 river basins in the Western States and Alaska.

The trend toward the development of pumped-storage hydroelectric projects is increasing. Pumping power produced by thermal plants during low-demand periods can usually provide peaking capacity at a much lower cost than the addition of an equivalent thermal capacity. During FY 1976, USGS engineers continued studies on several of the most favorable pumped-storage sites affecting Federal lands in Idaho and Oregon.

SUPERVISION OF MINERAL LEASING

Supervision of competitive and noncompetitive leasing activities for the development and recovery of leasable minerals in deposits on Federal and Indian lands is a function of the USGS, delegated by the Secretary of the Interior. It includes (1) geologic and engineering examination of applied-for lands to determine whether a lease or a permit is appropriately applicable, (2) approval of operating plans, (3) inspection of operations to insure compliance with regulations and approved methods, and (4) verification of production and the collection of royalties (see table 2).

Before recommending a lease or a permit, USGS engineers and geologists consider the possible effects on the environment. Of major concern are the esthetic value of scenic and historic sites, the preservation of fish and wildlife and their breeding areas, and the prevention of land erosion, flooding, air pollution, and the release of toxic chemicals and dangerous materials. Consideration is also given to the amount and kind of mining-land reclamation that will be required.

OUTER CONTINENTAL SHELF LEASE SALES FOR OIL AND GAS

Four sales of Federal Outer Continental Shelf (OCS) leases for oil and gas were held in FY 1976. Two sales held in July 1975 and February 1976 in the Gulf of Mexico OCS offered 984,225 ha for lease. High bids totaling $339,190,499 were accepted for 409,389 ha in 100 tracts. In December 1975, 503,276 ha were offered for lease in the southern California OCS. High bids totaling $417,312,141 were accepted for 124,020 ha in 56 tracts. The first lease sale in the Frontier OCS area of the Gulf of Alaska, held in April 1976, offered 403,400 ha. High bids totaling $599,836,087 were accepted for 165,577 ha in 76 tracts. USGS geologists, geophysicists, and engineers evaluated each tract offered to insure that the Government received fair market value.

COOPERATION WITH OTHER FEDERAL AGENCIES

The USGS acts as a consultant to other Federal agencies in land-disposal cases. In response to their requests, the USGS determines the mineral character and water-resource-development potential of specific tracts of Federal lands under their supervision that are proposed for sale, exchange, or other disposal. About 15,000 such reports were made during FY 1976.

TABLE 2.—*Mineral production, value, and royalty for FY 1976* [1]

Lands	Oil (tonnes)	Gas (1,000 m³)	Gas liquids (liters)	Other [2] (tonnes)	Value (dollars)	Royalty (dollars)
Public	22,250,000	16,524,000	1,451,188,000	44,809,000	$2,017,764,000	$218,146,000
Acquired	845,000	1,034,000	14,410,000	734,000	202,208,000	13,550,000
Indian	4,054,000	2,735,000	170,605,000	34,536,000	387,805,000	49,054,000
Military	37,000	594,000	69,523,000	----------	8,433,000	1,403,000
Outer Continental Shelf	44,453,000	95,012,000	7,462,578,000	1,142,000	3,991,558,000	626,065,000
Naval Petroleum Reserve No. 2	208,000	99,000	48,043,000	----------	14,428,000	1,570,000
Total	71,847,000	115,998,000	9,216,347,000	81,221,000	6,622,196,000	909,788,000

[1] Estimated in part.
[2] All minerals except petroleum products; includes coal, potassium, sodium minerals, and so forth.

GEOLOGIC AND HYDROLOGIC PRINCIPLES, PROCESSES, AND TECHNIQUES

EXPERIMENTAL GEOPHYSICS

ROCK MAGNETISM

Geomagnetic polarity reversal in Pleistocene sediments

A paleomagnetic record of the Brunhes-Matuyama geomagnetic polarity transition that occurred 0.7 million years ago was found by J. W. Hillhouse in the sediments of Lake Tecopa in California. During the transition, the intensity of the Earth's magnetic field was only approximately one-tenth of its normal value. The time of low magnetic intensity was at least 2½ times longer than the time of direction reversal. Virtual geomagnetic pole paths for this transition, observed in California, are completely different from similar data reported in Japan. This discovery indicates that the dipole part of the Earth's field decayed and returned during the reversal. If the residual magnetic field during a polarity reversal is a stationary nondipole field, other reported data, combined with this result, show that the nondipole field must be different in form during other transitions.

Stability of natural remanent magnetization in sediment

The effects of diagenetic alteration and grain size on the direction and stability of natural remanent magnetization in Pleistocene sediments were investigated by J. W. Hillhouse. In the deposits of Lake Tecopa in California, the Brunhes-Matuyama geomagnetic polarity transition is well recorded in relatively fresh sediment near the original lake margin. In the central part of the lake basin, where authigenesis of zeolite and potassium feldspar has occurred, paleomagnetic directions are scattered, and the dispersion is not entirely removed by alternating-field demagnetization. In the Koobi Fora Formation of Lake Rudolf in Kenya, the magnetic stability is greatest in clays and silts having grain diameters less than 20 μm, whereas coarser grained sediment is magnetically unstable. In the Koobi Fora sediments, the compositions of the magnetic minerals are the same regardless of grain size.

Paleomagnetic dating of early man

The sediments of the Koobi Fora Formation (Pliocene and Pleistocene) on the northeastern shore of Lake Rudolf in Kenya contain fossils of earliest man and many Paleolithic stone artifacts. An extended magnetostratigraphic study of these sediments was completed by J. W. Hillhouse (USGS) and Joab Ndombi (Stanford University). Earlier interpretations of K-Ar ages and magnetic polarity zones had indicated 2.6 to 3.7 milion years as the age of the fossils, but this age seemed improbably old. Hillhouse and Ndombi's extension of the magnetostratigraphy permitted a younger age assignment of 1.6 to 3.1 million years, in agreement with newer K-Ar ages and with the chronology of similar fossiliferous sites at Omo River to the north.

Magnetization of Pleistocene volcanic rocks, Long Valley caldera, California

Paleomagnetic measurements were used by E. A. Mankinen and C. S. Grommé, in conjunction with R. A. Bailey, to help analyze the volcanic history of the Pleistocene Long Valley caldera in California. All 38 volcanic units studied have normal polarity, including many with ages ranging from 0.10 to 0.14 million years. The Blake reversed polarity event, tentatively dated at 0.12 million years, was not found and thus must have been very brief. Very close grouping of magnetic directions in rocks ranging from basalt to rhyolite in the western moat of the caldera indicates that all rocks were erupted during a short time interval. A block containing three volcanic units younger than 0.22 million years in the innermost part of the western moat has been tilted northward, but there is little or no magnetic evidence for the outward tilting of the early rhyolites (0.7 million years) that occurred during the resurgent doming of the central part of the caldera. Differences in paleomagnetic directions in basalts of the southern moat of the caldera provide a means for distinguishing between lava flows of similar lithologies but different ages.

In-place measurements of apparent Curie temperature

C. J. Zablocki and R. I. Tilling made in-hole magnetic susceptibility and temperature measurements in holes drilled through the crust and into the still-molten lens of tholeiitic basalt in Kilauea Iki lava lake in Hawaii. The minimum temperature at which the magnetic susceptibility essentially drops to zero, the apparent Curie temperature of the lava, is about 540°C. These measurements are the first in-place determinations of the Curie temperatures of a cooling basaltic lava.

Holocene intensity of the geomagnetic field at Hawaii

Ancient geomagnetic field intensities were obtained by C. S. Grommé, R. S. Coe, and E. A. Mankinen from seven radiocarbon-dated basalt flows on the island of Hawaii. The intensities for the four youngest flows (2,500 to 4,500 years B.P.) are 20 to 35 percent higher than the published worldwide average derived from archeomagnetic data would predict for that latitude. This result is interpreted as indicating a significant nondipole field in the general area of Hawaii during that time, in contrast to customary interpretations of paleomagnetic directional data from Hawaii. A 10,000-year-old lava gave a paleointensity in agreement with the worldwide average. The two oldest lavas (17,000 and approximately 23,000 years) gave low paleointensities and also shallow magnetic inclinations, which again indicate the presence of a relatively large nondipole field.

Magnetic measurements of Keweenawan rocks

Remanent magnetization of samples collected from upper Precambrian Keweenawan lava flows in Baraga and Houghton Counties, Michigan, analyzed by K. G. Books, showed a reversed direction of magnetization like that previously found in other South Range lava flows. This unique polarity is found in lower Keweenawan rocks around Lake Superior, and its presence in the lavas of Baraga and Houghton Counties indicates that the lavas are Keweenawan in age.

Paleomagnetic correlation of Precambrian rocks in Arizona and the Lake Superior region

The Precambrian Unkar Group and the Nankoweap Formation in the Grand Canyon of Arizona are red beds and basaltic lavas having a total thickness of 2,000 m. A detailed paleomagnetic polar wandering path obtained by D. P. Elston and C. S. Grommé from these rocks covered the time interval from about 1,300 to 1,100 million years ago. Distinctive changes in the geomagnetic field, consisting of a rapid southerly shift in the paleomagnetic pole, a period of very rapid magnetic variation, and a reversal that is not antipolar, are recorded in the Dox Sandstone and the Cardenas Lavas, the upper part of the Unkar Group. These features are similar paleomagnetic records reported for the lavas of the lower and middle parts of the Keweenawan Supergroup, which have a time interval from 1,140±10 to 1,120±10 million years. Thus, there is a paleomagnetic correlation between the upper part of the Unkar Group of Arizona and the Keweenawan of Lake Superior. Similarities in the details of polar wandering paths have also shown that diabase sills in central and northern Arizona were emplaced during an interval of Keweenawan volcanism and that strata of the upper part of the Apache Group and the Troy Quartzite in central Arizona are correlative with the middle part of the Dox Sandstone and thus were deposited just before and during the early stages of Keweenawan volcanism.

Correlations of basal Cambrian and Devonian sedimentary rocks, central and northern Arizona

Combined stratigraphic and paleomagnetic studies of basal Cambrian and Devonian strata in central and northern Arizona were carried out by D. P. Elston and S. L. Bressler. Distinctive paleomagnetic directions, having both normal and reversed polarity, in the Tapeats Sandstone (lowermost Cambrian) of the Grand Canyon indicated that this formation can be identified across central Arizona. A different and equally distinctive paleomagnetic direction, with entirely reversed polarity, was found in overlying strata of Devonian age in the Grand Canyon and central Arizona. Two unconformities, one above the Tapeats Sandstone and one above the Beckers Butte Member (upper Middle or lower Upper Devonian) of the Martin Formation, have been recognized in central Arizona. In Grand Canyon, the Devonian Temple Butte Limestone unconformably overlies Cambrian strata and is subdivided into two members separated by a subtle unconformity. New conodont data have shown that the lower member is of late Middle or early Late Devonian age and thus is the same age as the Beckers Butte. The unconformity above the Beckers Butte and the lower member of the Temple Butte Limestone now appears to be a regionally significant hiatus separating strata of latest Givetian or earliest Frasnian Age from strata of younger Frasnian Age in this region.

GEOMAGNETISM

Geomagnetic observatories

Recordings of the temporal variations in the three components of the Earth's magnetic field (horizontal intensity, vertical intensity, and direction) were made at a worldwide network of 77 geomagnetic observatories. Absolute measurements of the Earth's magnetic field are periodically made at each of these observatories to provide baseline control and to provide data for long-term geomagnetic secular change studies.

The data are collected, processed, and deposited in the World Data Centers for worldwide distribution. Scientists throughout the world use these data in mineral exploration, space physics, solar-terrestrial relationship studies, navigation, surveying, telecommunications, and studies of the Earth's crust and mantle, as well as in determining geomagnetic secular change. The USGS uses the data primarily for magnetic charting and for studying secular change. J. D. Wood is responsible for the operation of the observatory network, and R. J. Main is responsible for data processing and quality control.

Repeat magnetic surveys

Repeat magnetic surveys involve making measurements and recordings of the absolute values and variations of the direction and the horizontal and vertical intensities of the Earth's magnetic field at periodically occupied field sites. The data collected are used in the compilation of U.S. and World Magnetic Charts and in studies of geomagnetic secular change.

Repeat surveys made in Alaska during the past year were used to determine secular change in that area over the past decade and will form part of the data base for the next issue of the U.S. and World Magnetic Charts.

The repeat survey program, which calls for periodic measurements at some 200 field sites in the conterminous United States, Alaska, and the Pacific islands, is managed by J. D. Wood.

The repeat survey data, which are deposited in the World Data Centers for worldwide use, are the major magnetic variation input to nautical and aeronautical navigation charts. The yearly circulation of these charts approaches 50 million copies.

Geomagnetic instrumentation

Efforts continued to automate the USGS geomagnetic observatories. To date, five automated systems have been installed in observatories at College, Sitka, and Barrow, Alaska; Newport, Wash.; and Boulder, Colo.

The new systems, designed by R. W. Kuberry and A. W. Green, Jr., use a three-component fluxgate magnetometer as well as a proton magnetometer. Variations of the components of declination, horizontal intensity, vertical intensity, and total field intensity are available in both analog and digital forms in real time. Permanent records are made on digital magnetic tape and on analog paper charts (in world standard observatory format). These new systems are now providing a computer-compatible product to investigators in the USGS and in the world scientific community.

Geomagnetic secular change

L. R. Alldredge completed a harmonic analysis of the annual means of geomagnetic components from selected observatories. He showed that 11-year solar-cycle effects appeared at all observatories and that these variations could be explained by an external ring current that varied with the sunspot cycle. Variations with periods ranging from 13 to 30 years were also found; these did not fit the simple pattern displaced by the 11-year-period variations. Alldredge concluded that these variations were from internal sources and that both types of variations could be used to improve on the component secular change predictions achieved by older methods.

U.S. and world magnetic charts

Under the direction of E. B. Fabiano, magnetic data representing surface, marine, and aeromagnetic measurements made from 1939 to 1974 were used to prepare magnetic charts of the United States and of the world for the epoch 1975.

Four maps of the United States depicting the distribution of the normal magnetic field at epoch 1975 will be published. The series, which consists of maps showing magnetic inclination, horizontal intensity, vertical intensity, and total intensity, was previously published in 1966. Comparisons between the 1965 and 1975 maps show significant differences in the absolute level of the field as well as in the patterns of secular change. Southern Florida shows an apparent decrease in vertical intensity of 1,400 nT (gammas) in the past decade. During this time, the annual rate of change in total intensity in North Dakota has varied from −60 nT/yr in 1965 to 0 nT/yr in 1975. In fact, the focus of −60 nT/yr in the north-central States has vanished and is now replaced by east-west trend lines that show the secular variation in total intensity ranging from 0 to

−30 nT/yr. Although there is some evidence of westward drift, the patterns of change appear to indicate that regional effects are significant. From studies of secular change, it is quite clear that magnetic maps and associated mathematical models can become obsolete within a few years because of our inadequate knowledge of the processes within the Earth's core that drive the secular variation.

Modeling of the Earth's main magnetic field

C. D. Stearns modeled the Earth's magnetic field, using 21 vertical magnetic dipoles as sources. This study yielded two conclusions that need further verification. One conclusion is that the secular change magnetic field can be predicted with moderately better results by Stearn's method than by the spherical harmonic coefficient method used by most investigators. The other conclusion is that the sources of the Earth's magnetic field are related to the location of the tectonic plate boundaries.

Magnetotelluric source field studies

A. W. Green, Jr., studied a class of geomagnetic pulsations (Pi2) commonly used in magnetotelluric profiling. This study resulted in the discovery of large-amplitude power peaks at periods much longer than the "visual" period of the pulsation. These long-period peaks have eluded other investigators, who used the so-called "Blackman-Turkey" power spectrum method, which limits analysis to periods shorter than one-tenth the record length. The present analysis treats Pi2's as aperiodic transients that permit the use of the more fundamental Fourier integral transform method, which is not subject to the above limitation. The frequencies of the power peaks thus determined are in excellent agreement with a theoretical model of Pi2 generation at the inner edge of the magnetotail plasma sheet that calls for fundamental oscillation periods in the range of 300 to 500 seconds (Green, Stearns, and Troitskaya, 1975). A significant result of this work is the possibility of using the newly discovered long-period energy in the Pi2 events for magnetotelluric profiling. Information already gained about the nature of the waveform and its propagation (from theoretical analysis) should result in techniques for reducing scatter in magnetotelluric work.

Satellite magnetic anomaly studies

Work done by R. D. Regan and J. C. Cain suggested that a global magnetic anomaly map derived from satellite measurements offers a new perspective on regional and global geologic studies. Preliminary correlation with tectonic and geologic maps indicates that, in addition to reflecting obvious large-scale features such as continental shields, the map also reveals many unexplained structures. Most striking are (1) the lack of anomalies in the Pacific Ocean, with the exception of a pair of anomalies near the 180° meridian in the area where the Emperor Seamount and the Hawaiian Island chains intersect; (2) a broad magnetic low over the Gulf of Mexico; and (3) several highs in the central United States.

Also evident is a major anomaly in central Africa that does not directly correlate with any known tectonic feature. This anomaly, termed the Bangui anomaly, was discovered in the satellite data and confirmed by aeromagnetic measurements. The anomaly is located over an area of thick continental crust and has been interpreted as a massive crustal intrusion that may be related to crustal thickening. Many major mineral deposits are associated with this body.

Although much more work is needed to completely interpret the map and to determine the causes of all the anomalies, the initial results show the utility of a satellite magnetometer as a geological-geophysical tool.

The global magnetic anomaly map and a complete discussion of its derivation were published in the "Journal of Geophysical Research" (Regan and Cain, 1975).

PETROPHYSICS

Establishment of new petrophysical laboratory

G. R. Olhoeft assembled facilities in the petrophysics laboratory for investigating the electrical properties of rocks as a function of frequency from 10^{-5} to 10^{6} Hz and near 10^{9} Hz and also as a function of current density down to 10^{-9} A/cm^2. Continuing investigations have been initiated into the physical properties of a wide variety of materials, including lunar samples, the American Petroleum Institute standard clay mineral series, Deep Sea Drilling Project core samples, and other materials. Particular emphasis is being placed on the physical properties of materials and the environmental variation of such properties in relation to ongoing geophysical projects in areas of regional geophysics and to the geothermal, uranium, lithium, and oil-shale programs.

Magnetic properties of natural and synthetic minerals

Two new techniques developed by D. E. Watson should lead to unique advancements in the investigation of magnetic properties. The first was the discovery of a new way to grow single-domain crystals of magnetic minerals. This process involves doping a pure metal such as copper, gold, or silver with an extremely small grain-size powder (<0.1 μm) of iron or some such element and heating it in controlled atmospheres for various periods of time. The magnetic properties of pure crystals can now be studied in great detail. The second technique was to use the scanning electron microscope with energy-dispersive X-ray attachments to identify the magnetic grains by structure and elemental composition.

A single magnetic grain can be identified optically and elementally and its complete magnetic properties investigated by using these new techniques and a cryogenic magnetometer.

Creep of synthetic quartz

Creep experiments were conducted by S. H. Kirby at atmospheric pressure on a suite of synthetic quartz crystals oriented for compression at 45° to a and **c**. The experiments were generally carried to 4 to 5 percent axial strain; petrographic examination indicated that all the crystals deformed principally by {1210}[0001] slip. There was clear evidence that molecular water precipitated into bubbles during loading and that the extent of precipitation was increased by deformation. Samples loaded shortly after test temperatures were reached showed sigmoidal or S-shaped creep curves having an initial stage of increasing strain rate followed by a period of decreasing strain rate (a hardening stage). In samples that were heat treated before testing, the hardening stage was not observed or was poorly developed. The fact, together with direct transmission electron microscope evidence, suggested that much of the hardening stage was due to the effects of precipitation of molecular water. The effects of OH concentration, stress, and temperature on strain rates were determined, and a flow law for the creep of synthetic quartz was formulated. Evidence was presented that creep rates are controlled by recovery rates. The role of water in assisting bulk diffusion and recovery in quartz was emphasized.

Mechanical twinning in diopside

A structural analysis undertaken by S. H. Kirby and J. M. Christie of crystal defects in experimentally deformed clinopyroxene led to the determination of the space-group symmetries of twin boundaries in diopside and the nature of the dislocations that are responsible for mechanical twinning. Thus, the difference in the natural occurrences of the two modes of mechanical twinning is given a simple physical explanation.

Rocks as internally balanced force systems

A two-dimensional analytical model was formulated by A. T. F. Chen for a dual-phase particulate composite that approximates the internal structures of certain rock types. The finite-element method was used to analyze the elastic response of this model to various static loading conditions. The state of internally balanced forces was achieved by prestressing only one material of the composite and subsequently releasing the load after the other material of the composite is introduced. Distributions of residual stresses resulting from these internally balanced forces were found to depend primarily on Poisson's ratio of the prestressed material. The creation of new free surfaces through coring was found to have little effect on the residual stress distribution in the remaining host. Although it had not been analyzed, the displacement field resulting from coring was believed to cause possible complications in interpreting surface stress measurements.

APPLIED GEOPHYSICAL TECHNIQUES

Magnetotelluric study, Snake River Plain-Yellowstone region

W. D. Stanley (USGS), in cooperation with W. H. Smith, F. X. Bostick, and J. R. Boehl (University of Texas), obtained 15 magnetotelluric soundings along a profile extending along the axis of the Snake River Plain from the Raft River geothermal area to Yellowstone National Park. Interpretation of the sounding data showed that a conductive zone with resistivities of less than 10 ohm-m exists at depths of 7 km beneath the Raft River geothermal area, 18 km near the axis of the Snake River Plain near Blackfoot, Idaho, and 5 km in the eastern part of the Yellowstone caldera system. However, the conductive zone appears to be absent or at much larger depths below the Island Park caldera system. The zone is probably related to high temperatures, posibly exceeding 500° to 600°C. In addition to the deep conductive zone, other units mapped include the surface basalt, which was found to be 2 km thick north of Blackfoot, and a conductive zone underlying the basalt. The latter conductive zone, which has resistivities of about 3 to 10 ohm-m, is believed to be Tertiary sedimentary rocks.

Geomagnetic variometer array development

J. N. Towle and D. V. Fitterman developed a digitally recording magnetometer array consisting of 10 recording stations for use in the study of geomagnetic induction anomalies in the crust and upper mantle. These geomagnetic variometers were designed for unattended operation over extended periods of time. The stations use three-component fluxgate magnetometers having a resolution of about 0.5 gamma. Data are recorded on magnetic cassettes having a capacity of 1 million 12-bit words. With a sampling interval of 4 seconds, the stations can run unattended for 10 days. At lower sampling intervals, the stations can record without servicing for over a month. The large data capacity and low power consumption are unique to this geomagnetic variometer array. The digital format in which the observations are recorded will permit rapid analysis of geomagnetic variation events.

Audio-magnetotelluric and self-potential techniques in geothermal exploration

Audio-magnetotelluric and self-potential techniques were tested by D. B. Hoover and C. L. Long in geothermal exploration at shallow to medium depths. Scalar audio-magnetotelluric equipment developed by the USGS proved to be a fast and cost-effective means of obtaining reconnaissance resistivity information in geothermal areas. Exploration depth using this technique typically ranged from 0.2 to 2 km (Hoover and Long, 1975). Common field techniques used in self-potential exploration were found to be inadequate, particularly in arid areas. The principal problem was identified with capillary pressure potential, which is related to soil moisture. Improved field techniques were developed and used with success near Steamboat Springs, Nev. (Hoover, Batzle, and Rodriquez, 1975).

Electrical anisotropic oil shales

D. L. Campbell completed a series of surface vertical electrical soundings of oil shales in the Piceance Creek basin of Colorado. Comparison of the sounding interpretations having well-logged depths indicated electric macroanisotropy coefficients as high as 9. This value was among the highest ever reported in the geophysical literature for oil shales in the lower part of the sequence. This macroanisotropy coefficient increased from 2 to 9 from the basin center toward its flank. A microanisotropy coefficient of 2.1 was found in laboratory measurements on a hand sample of rich oil shale from the region. The additional anisotropy that was observed is thought to be due to a complex of splintered aquifers radiating out from the basin center within the oil-shale sequence. It is estimated that about 7 percent of the oil-shale sequence must consist of thin water-bearing horizons in order to produce the observed effect. These horizons may have to be sealed with grouting when they are intersected by mine openings. Surface electrical soundings, therefore, relate directly to problems of water control in shaft and pit mine design for the region.

Electromagnetic methods in uranium exploration

B. D. Smith and V. J. Flanigan demonstrated that subtle geophysical anomalies are associated with uranium roll fronts in both hard- and soft-rock terranes. Electrical methods often can detect small changes in the percentage of sulfide minerals associated with roll fronts and may detect an associated change in the type of clay minerals. Magnetic methods have been successfully applied to locating this type of uranium deposit where there are associated magnetized zones. Interpretation of these anomalies can aid in mapping the roll fronts and contribute to understanding the geochemical and geological environment of the uranium ore deposits.

Resistivity soundings, Upper Raft River Valley, Idaho

Schlumberger resistivity soundings made by A. A. R. Zohdy and R. J. Bisdorf (1976) in southern Idaho in the Upper Raft River Valley and in parts of the Raft River Valley complemented soundings made previously in the Raft River Valley. The thicknesses and resistivities of various sedimentary layers, as well as the depths to the high-resistivity electric basement (granite and metamorphic rocks), were determined by the resistivity soundings and partially confirmed by two intermediate-depth drill holes. The absence of layers with resistivities of less than 5 ohm-m in the Upper Raft River Valley indicated that there is not likely to be a major geothermal reservoir in the basin sediments. Survey results will be useful in the development of a hydrogeologic model for the geothermal system in the Raft River Valley.

Relationship between water content and resistivity

An examination by R. D. Carroll and D. C. Muller of the applicability of Archie's law to over 170 samples of zeolitized volcanic tuff situated in a freshwater environment indicated that, when the tuff is saturated with 16-ohm-m water, the relationship between water content and resistivity yields a correlation coefficient of only 0.61. This poor correlation may be attributed to double-layer charge effects. However, when water having enough salinity (0.15 ohm-m) to overcome these effects is used to saturate the pores, the correlation coefficient of Archie's law rises dramatically to 0.94.

A self-potential anomaly over Kaoiki fault zone

The Kaoiki fault zone, which is seismically active, is the approximate surface boundary between Hawaii's Mauna Loa and Kilauea Volcanoes. Self-potential profiles obtained across a part of the fault zone by L. A. Anderson defined a very large anomaly with an apparent source depth that approximately coincides with the zone of seismicity. One interpretation is that the self-potential anomaly reflects a deeply buried magma body within the Kaoiki fault zone. A self-potential anomaly over the southwestern rift zone of Kilauea indicates underlying hot material at relatively shallow depths.

Gravity change at Kilauea Volcano

The applicability of high-precision gravity instrumentation and techniques to the study of deformations and mass changes associated with geological processes was demonstrated in a study of the gravity changes associated with the eruption and subsequent deflation of Hawaii's Kilauea Volcano on November 29, 1975. R. C. Jachens and G. P. Eaton (USGS) obtained multiple gravity observations having an average standard error of about 5 μGal at 19 sites in the summit area of Kilauea Volcano during two surveys that bracketed the November 29 event. The first survey was conducted 3 weeks before the event, and the second was conducted during the 2 weeks following the event. A maximum gravity increase of about 230 μGal was detected at a point about 1 km southeast of Halemaumau Pit crater. This gravity change indicates a decrease in elevation of about 1.1 m, in good agreement with the releveling results, which indicate a maximum elevation decrease of about 1.2 m. The spatial distribution of the gravity increase in the summit area corresponds to a roughly radially symmetric pattern north of the maximum. Similar patterns of vertical displacement were found to accompany other eruptions of Kilauea (Kinoshita and others, 1974). A continuous record of a 50-μGal gravity increase was obtained at a point 3 km northwest of the location of maximum change by a continuously recording gravity meter operated in cooperation with J. T. Kuo (Lamont-Doherty Geological Observatory). These results indicate that the combined use of discrete time and continuous gravity observations can be an effective method for studying active ground deformation and, in combination with elevation change information, for studying mass changes at depth.

Gravity and magnetic anomalies, northeastern Washington

A 40-mGal gravity high over Permian and Triassic metamorphic rocks in the Spokane area of Washington was discovered in gravity data assembled by J. W. Cady. Part of the gravity high correlates with a gneiss dome having a dense mafic core. The high may indicate a large, dense, mafic metamorphic terrane of crustal dimensions. It has not been determined whether a genetic relationship exists between the high-density rocks and the uranium deposits exploited at the Midnite and Daybreak mines. Several small magnetic highs over quartz monzonite southeast of the Midnite mine may indicate foundered roof pendants, zoned plutons, or zones of anatexis. One of these highs occurs adjacent to the Midnite mine, and, by analogy, the others are potential exploration targets.

Gravity terrain correction using new digital data

Donald Plouff, D. F. Barnes, and Andrew Griscom reported favorable results from preliminary tests of new cost-saving techniques for gravity terrain corrections. The techniques involved the use of magnetic tapes that provide elevations determined at intervals of 0.254 mm on available 1:250,000-scale maps of the United States. The digital terrain tapes were initially made by the Defense Mapping Agency Topographic Center and are being gradually turned over to the USGS National Cartographic Information Center in Reston, Va., for public distribution. A computer program written by A. A. Elassal and Plouff averaged these elevations for geographic compartments ¼-minute square or larger; these average elevations can then be used as input to an earlier digital terrain correction program written by Plouff. Preliminary tests suggested that 95 percent of the terrain corrections are as accurate as those obtained by classical techniques from 1:62,500-scale maps, and about 90 percent are within 0.5 μGal of those obtained by classical techniques from 1:24,000-scale maps.

Iterative three-dimensional gravity inversion program

A gravity inversion program allowing the input of both vertical and horizontal density contrasts, surface topography, and other geologic information was developed and tested by R. R. Wahl. The program uses the ratio of observed residual anomaly to computed residual anomaly to adjust each prism thickness (Cordell and Henderson, 1968). Data from Yellowstone National Park and The Geysers region of California were studied by G. P. Eaton and W. F. Isherwood, respectively. Data analysis for Long Valley, Calif., is not yet completed. Analysis of the data from Yellowstone Park suggests that a large part, but not all, of the major gravity low arises from the caldera fill. Inversion of gravity data from The Geysers tends to confirm that a magma chamber roughly spherical in shape underlies the area of geothermal energy production.

Gravity surveys in ice-covered areas

R. D. Watts and A. W. England used an electromagnetic ice-depth sounder in a gravity survey of the Mount Drum area in the Wrangell Mountains of Alaska. A significant portion of the survey area is covered by glaciers. Glacier-depth measurements were used to determine terrain corrections for the gravity data. Without the terrain corrections, accurate Bouguer anomalies could not have been computed. The use of a depth sounder makes gravity surveys practical in many previously nonsurveyable, glacier-covered areas in Alaska.

Geophysical characterization of lithium brine deposits

B. D. Smith investigated the application of geophysical methods to the exploration for lithium brine. In Clayton Valley, Nev., the lithium brine is associated with a gravity low, and direct-current resistivity measurements define the extent of the brine, which occurs within a thick sequence of conductive sediments. Near Willcox, Ariz., where anomalous amounts of lithium occur in sediments, direct-current resistivity data define a basin containing thick conductive sediments, and airborne electromagnetic data suggest that this basin of conductive sediments is closed. The sediments are located within a gravity low subsidiary to the major gravity low in the Sulphur Springs Valley of Nevada. Airborne magnetic field data suggest that subsurface volcanic rocks underlie the conductive sedimentary sequence. These geophysical observations, combined with geologic evidence, suggest that the Willcox area has a high potential for the occurrence of a brine body that may contain lithium.

Geoelectric and gravity studies of the Purcell geanticline

A series of audiofrequency magnetotelluric and gravity measurements was made by M. D. Kleinkopf and J. C. Wynn across the Purcell anticlinorium in northwestern Montana. The region is underlain principally by rocks of the Belt Supergroup of late Precambrian age. The study was initiated to gain information about the electrical properties of the Belt strata prior to the use of more expensive and time-consuming sounding techniques such as vertical electrical and magnetotelluric soundings. A principle objective was to determine subsurface structure and the depth to the crystalline basement. The Bouguer gravity traverse indicated an anomaly of about 20 mGal centered over the crest of the anticlinorium. A crustal model computed to account for the gravity anomaly consisted of a block of crystalline rock uplifted 11 km above a flat basement surface that lies at a depth of 17 km. The block is about 25 km wide and is generally positioned beneath the Prichard Formation, which crops out along the crest of the anticlinorium. Although the audiofrequency magnetotelluric measurements probably did not penetrate to the crystalline basement, they delineated several intermediate structural discontinuities that include a deep layer of less than 1 ohm-m in resistivity. This layer is approximately coincident with an inferred pyritic or pyrrhotitic unit within the Prichard Formation. The thickest (or most conductive) part of this conductor lies on the northeastern side of the gravity high, just southwest of a known normal fault that appears to abruptly terminate the conductor.

Aeromagnetic anomalies over the west-central Columbia Plateau

D. A. Swanson, T. L. Wright, and Isidore Zietz found that a low-altitude total-intensity aeromagnetic map of the west-central Columbia Plateau of Washington, underlain principally by the Yakima Basalt, shows linear positive and negative anomalies reflecting interbedded flows of normal and reversed magnetic polarity. One set of anomalies is related to anticlinal ridges, another follows the traces of known or inferred faults, and a third set coincides with a swarm of feeder dikes for the Ice Harbor flows of Swanson and others (1975), the youngest unit of basalt in the area. A fourth set of narrow, sinuous anomalies is related to flows that filled ancient valleys during the late stage of Yakima volcanism. The magnetic map suggests that the Ice Harbor dike swarm is offset by left-lateral strike-slip displacement along the Rattlesnake-Wallua fault, a segment of the Olympic-Wallowa lineament.

Colored geophysical maps from digital data

A technique was developed by R. H. Godson and T. E. Townsend to produce colored geophysical maps from digital data. The procedure transforms the original data onto a grid with values ranging from 0 to 255. These transformed data on digital tape are then processed to produce three gray density-sliced photographic images of the data. These are then processed to create three colored images (magenta, cyan, and yellow). The colored images are then overlayed to produce a 17-color presentation of the original data, approximately the size of a superslide. This composite can then be photographically enlarged to map scale.

Germanium gamma-ray spectrometer systems

An intrinsic planar germanium spectrometer system was used by F. E. Senftle to evaluate its potential in uranium exploration. The germanium detector has very high energy resolution (approximately 530 eV) in the 25- to 260-KeV region of the spectrum, where the most diagnostic gamma lines from uranium and its daughters are found. Laboratory tests indicate that the line from ^{234}Th can be used to measure quantitatively the uranium content of samples; similarly, spectral lines from ^{231}Pa, ^{210}Pb, ^{230}Th, ^{235}U, ^{223}Ra, and ^{214}Pb can be used to measure their state of equilibrium with the parent uranium isotopes. Field investigations show that there is no perceptible loss of resolution when a truck-mounted spectrometer is operated through a 61-m cable and that most of the isotopes listed above can be identified at the outcrop. Laboratory tests have shown that the ratio of ^{238}U to ^{235}U can be determined with a precision of about ± 4 percent. A borehole sonde has been designed and built for uranium exploration. The sonde includes two new features not previously used in borehole logging equipment, namely, an intrinsic germanium detector and a cryostat that uses prefrozen canisters of propane. The sonde can be used to measure uranium concentrations directly without relying on assumptions about equilibrium with radiogenic daughter products.

Use of magnetic surveys in coal exploration

When some sedimentary rocks are slowly baked in an oxygen-starved environment, they can become highly magnetic. M. L. Botsford and W. P. Hasbrouck ran magnetic surveys at four widely separated clinker areas in Wyoming to see if this effect could be used to locate the edge of a burned coal bed. At each location, magnetic anomalies of several hundred nanoteslas were observed. Mapping at these places indicated that the location of the burn-zone edge may differ by as much as 150 m, on the basis of changes in soil color and magnetic survey data. Thus, resource estimates based only on rock color in these burned areas may be too high.

GEOCHEMISTRY, MINERALOGY, AND PETROLOGY

EXPERIMENTAL AND THEORETICAL GEOCHEMISTRY

Thermodynamic properties of minerals

Calorimetric measurements of $KAlSi_3O_8$, $NaAlSi_3O_8$, and $CaAlSi_2O_8$ glasses were measured between 10 and 850 K by combined cryogenic adiabatic and differential scanning calorimetry. These data were combined with the enthalpies of fusion of analbite, high sanidine, and anorthite to derive the standard entropies of the glasses and their residual entropies at 0 K.

Low-temperature heat capacity measurements on gibbsite enabled R. A. Robie and B. S. Hemingway to determine the Gibbs free energy of formation of both gibbsite and the Al^{3+} ion.

J. V. Chernosky determined two univariant equilibria:

$$\text{talc} = 3 \text{ enstatite} + \text{quartz} + H_2O$$
$$\text{talc} + \text{forsterite} = 5 \text{ enstatite} + H_2O.$$

Using these data, E-an Zen and Chernosky derived the Gibbs free energy (G°_f, 298,1) of talc (-5516.3 ± 10.5 kJ) and enstatite (-1457.27 ± 4 kJ). The talc data, although less negative than standard compilations, are in accord with other recent work. The enstatite value contrasts with that of clinoenstatite and is in approximate accord with new high-temperature values for the heat of fusion. When these data are combined with earlier work on chrysotile and anthophyllite (Greenwood, 1963), it appears that a consistent set of values exists for talc, enstatite, clinochrysotile, forsterite, quartz, brucite, and anthophyllite.

Diffusion and mineral growth rates

J. S. Huebner studied the rimmed olivine, pyroxene, and plagioclase xenocrysts in lunar pigeonite basalt 77115, originally described by Chao and others (1975). The nature of the compositional zoning and the morphology of the grains suggest that the rims were formed by diffusive cation exchange between xenocrysts and matrix. Experiments on the major-element distribution between crystals and melt of the matrix composition preclude rim formation by reaction between xenocrysts and magma; rather, the xenocrysts are interpreted as having formed during simple subsolidus cooling. Calculations based on the olivine compositional profiles suggest a cooling time equivalent to no more than several weeks at 1,050°C. Modeling of the growth of pigeonite rims from augite xenocrysts indicates that, at high but subsolidus temperatures, augite can exsolve 50-μm pigeonite lamellae in several weeks or less. Data of this kind, when they are coupled with temperature data deduced from the compositions of coexisting pyroxenes, will permit description of the time-temperature relationships that prevailed during subsolidus cooling or metamorphic recrystallization of rocks containing common pyroxenes.

Melting experiments in the system K_2O-Na_2O-Al_2O_3-SiO_2-H_2O-F_2

S. D. Ludington conducted hydrothermal experiments at temperatures between 585° and 800°C at a total pressure of 1,000 bars. Cationic composition is that of the 1-kbar "granite" minimum in the fluorine-free system; fluorine contents are 1.8 ± 0.1 percent by weight. The work is aimed at quantitatively determining the fluorine fractionation between crystals, melt, and aqueous fluid. Preliminary results indicate that fluorine is concentrated strongly in the melt; fluorine contents of the quenched melts produced at low temperatures are as high as 7 percent by weight. Thus, if a fluorine-rich (greisen-producing?) aqueous fluid is to be produced by a crystallizing granitic magma, it must come when the last melt crystallizes and volatiles, including fluorine, are driven from the system, to be incorporated later in F-OH minerals, pegmatites, and (or) hydrothermal fluids.

Experimental studies on the origins of lunar basalts

B. R. Lipin's work on phase relations in the system $CaAl_2Si_2O_8$-$(Mg_{0.59}Fe_{0.41})_2SiO_4 - SiO_2$ proved useful in deducing the genesis of lunar highland rocks, especially Fra Mauro-type basalts. The coexistence of olivine, orthopyroxene, anorthite, and liquid over a wide range of temperatures and compositions raises the possibility that the noritic Fra Mauro basalts are residual liquids of the parent magma that produced the anorthosites, dunites, troctolites, spinel troctolites, and anorthositic norites that comprise most of the lunar highlands.

Iron-magnesium distribution coefficients for orthopyroxene-liquid, olivine-liquid, and spinel-liquid $[K_D = (X_{Fe})_{crystal}(X_{Mg})_{liquid}/(X_{Mg})_{crystal}(X_{Fe})_{liquid}]$ were determined to be 0.33, 0.30, and 0.41, respectively. If the bulk composition of the parental highlands magma was that proposed by Ganapathy and Anders (1974) (70 percent olivine, Fe/(Fe–Mg) $=0.05$, 27 percent anorthite, and 2 percent silica), then 90 percent crystallization (64.8 percent olivine and 25.2 percent anorthite) would occur before pyroxene became stable. One can calculate the effect of the separation of olivine on residual liquids by using the above K_D^{Fe-Mg} (crystal-liquid). The Fe/(Fe+Mg) ratio of a residual liquid at the time that the orthopyroxene became stable would be 0.39, well within the range of the Fra Mauro basalts.

Differentiation of Mid-Atlantic Ridge basalt—evidence from Leg 37

Lavas and associated glasses collected from Leg 37 of the Deep Sea Drilling Project show a great diversity in chemical composition, which T. L. Wright explained as a result of melting from slightly different mantle sources combined with extensive fractionation and accumulation of phenocryst minerals in shallow reservoirs. Four processes involving redistribution of phenocryst minerals are found to be important:

- Accumulation of olivine.
- Accumulation of plagioclase.
- Fractionation and accumulation of intergrown olivine-plagioclase.
- Fractionation and rare accumulation of augite and plagioclase with and without olivine.

The results of petrochemical studies imply the existence of an extensive complex of shallow magma reservoirs located beneath the axis of the Mid-Atlantic Ridge. The fact that the redistribution of phenocrysts is far more common in these rocks than it is in terrestrial lavas indicates that differentiation is probably enhanced by eruption under water, the absence of vesiculation promoting the relative movement of phenocrysts and liquid.

MINERALOGIC STUDIES IN CRYSTAL CHEMISTRY

CRYSTAL STRUCTURE ANALYSIS

Crystal structure refinement of covellite

The crystal structure of covellite (CuS) was first solved by Oftedal (1932) and confirmed and somewhat refined, on the basis of limited photographic intensity data, by Berry (1954) and Kalbskopf, Pertlik, and Zeeman (1975). H. T. Evans, Jr., and J. A. Konnert redetermined this unusual structure by means of modern techniques using an extended data set (corrected for absorption) measured with MoKα radiation on an automatic single-crystal diffractometer. Bond lengths were determined to ± 0.004 A or better, and the thermal motions were completely defined. The final reliability factor was $R=0.054$.

As shown by Oftedal (1932), the hexagonal unit cell ($a=3.7938(5)$ A, $c=16.341(1)$ A, space group $P6_3/mmc$) contains two disulfide S_2^{2-} groups, two sulfide S^{2-} ions, two copper atoms in triangular coordination, and four copper atoms in tetrahedral coordination. The S_2 bond length is 2.071(4) A. The Cu-S bond length is 2.1905(3) A in the triangle and 2.302(1) ($\times 3$) and 2.331(2) in the tetrahedron. These bonds are consistent with a valence of 4/3 for both copper atoms, which satisfied Pearson's (1964) modification of the 8–N rule.

Crystal structure of sherwoodite

Thompson, Roach, and Meyrowitz (1958) described sherwoodite, a new mineral from Montrose County, Colorado, which they formulated as $Ca_3V_8O_{22}\cdot 15H_2O$. J. A. Konnert and H. T. Evans, Jr., determined the crystal structure of this tetragonal crystal and found that it is a heteropoly complex containing discrete polyanions $(AlV_{14}O_{40})^{n-}$. The polyion has an AlO_6 octahedran at its center, surrounded by 14 VO_6 octahedra. The 15 octahedra are condensed by edge sharing into an $(AlV_{14}O_{40})^{n-}$ molecule that (ideally) has $4/mmm$ symmetry. If vanadium were fully oxidized, n in the molecular formula would be -7, but the presence of appreciable V^{4+} in the chemical analysis (and the dark color of the crystals) shows that the molecular carries one, two, or three extra electrons. If the number of Ca^{2+} ions can be counted accurately, n can be determined, but this procedure may be difficult because of the zeolitic character of much of the intermolecular Ca and H_2O. The molecules are bound by one group of Ca^{2+} ions into a rather ridgid framework containing large tunnels and cavities in which the remaining cations and water molecules are loosely held. The best formulation of this unusual mineral is $Ca_5(AlV_{14}O_{40})\cdot 28H_2O$, eight units of which are in the tetragonal unit cell ($a=28.03(3)$ A, $c=13.70(1)$ A, space group $I4/amd$).

PYROXENE STUDIES

Shear transformation of orthoenstatite to clinoenstatite

In several different experiments, S. H. Kirby (USGS) and R. S. Coe (University of California, Santa Cruz) produced clinoenstatite by deforming single-crystal specimens of orthoenstatite. Examination with light and transmission electron microscopes shows that (1) the transformation is coherent and involves a macroscopic shear on (100) [001] through an angle of $12.8° \pm 1.2°$, in good agreement with the theoretically expected value of 13.3°, and (2) the transformation is accomplished by glide on (100) of partial dislocations with $\vec{b}=0.83[001]$. Structural analysis provides further insight into the transformation mechanism. Reversion occurs in specimens annealed under a variety of conditions, and thin lamellae of clinoenstatite in unconstrained low-strain specimens recover their original shape during transformation back to orthoenstatite. Kirby and Coe's experiments and thermodynamic estimates both suggest that the equilibrium transition temperature is raised roughly 300°C per kilobar of shear stress on (100) [001]. This suggestion provides the basis of a method by which it may be possible to determine the magnitude as well as the orientation of the principle stresses that produce clinoenstatite in nature during deformation of enstatite-bearing rocks.

Clinopyroxene exsolution lamellae

G. L. Nord, Jr., and Malcolm Ross (USGS), together with Peter Robinson and H. W. Jaffe (University of Massachusetts) and J. R. Smyth (Lunar Science Institute), determined that the crystallographic orientations of the interfaces between host augite and exsolved pigeonite are indicative of the temperature of exsolution and thus are a potential geothermometer. The main reason that the boundary orientation of an exsolved phase changes with the temperature of formation is the large nonlinear change in pigeonite lattice dimensions relative to the linear change in augite upon cooling. The greatest change occurs as the pigeonite passes through the $C2/c \rightarrow P2_1/c$ transition. The boundary orientation is determined by the best fit (that is, the lowest energy configuration) between the host and the exsolved phase; this fit is a direct function of the lattice constants as well as of the elastic stiffness anisotropy of each phase. Smyth measured the lattice dimensions of both augite host and exsolved pigeonite as a function of temperature. As an example, augites from South Africa's Bushveld main-zone gabbro were found to contain three sets of "(001)" pigeonite lamellae of different sizes and orientations. It was determined, by comparison with the experimentally determined lattice constants, that one set ("001" $\wedge c=103°$) exsolved above the $C2/c \rightarrow P2_1/c$ transition, the second set ("001" $\wedge$ $c=106°$) dissolved in the vicinity of the transition, and the third set ("001" $\wedge$ $c=112°$) dissolved well below the transition, as is the case in many metamorphic augites. Single-crystal X-ray studies have shown that the differing boundary orientations are achieved by a slight rotation of the pigeonite about *b*, usually by a few minutes. Electron microscopy studies have shown that the stress induced by the shape change of a pigeonite formed in the high-temperature configuration is relieved by the formation of stacking faults on (100). A direct correlation was made between the density of faults and the temperature of lamella formation.

MINERAL STUDIES

Magnetic measurements of lunar and terrestrial ilmenites

X-ray diffraction and anisotropic magnetic measurements were made by F. E. Senftle, A. N. Thorpe, and C. C. Alexander on single crystals of lunar ilmenite and on terrestrial ilmenite from Bancroft, Ontario, Canada, and the Ilmen Mountains in the U.S.S.R. The large *c* dimension of lunar ilmenite, previously reported, is confirmed by new measurements. The shorter *c* dimension found in terrestrial specimens is ascribed to the substitution of Fe^{3+} for Ti^{4+} in the titanium crystallographic positions. Magnetic measurements on the same specimens show that, in agreement with the model of Ishikawa (1962) and Shirane and others (1962), the initial shortening of the *c* axis by the above substitution of small amounts ($<\sim5$ percent) of Fe^{3+} causes an increase in the $Fe^{2+}-Fe^{3+}$ exchange coupling through Fe^{3+} in the titanium layer that lowers the Néel transition temperature. Further, additions of greater than 5 percent Fe^{3+} are accompanied by the formation of superparamagnetic clusters of antiferromagnetically coupled Fe^{3+} in the titanium layer with Fe^{2+} in the iron layer. The Weiss temperatures and other magnetic parameters confirm this model proposed by Ishikawa (1962) and Shirane and others (1962).

New mineral from Tsumeb, Namibia

A white micaceous mineral from Tsumeb, Namibia (Southwest Africa), was identified by R. C. Erd as a new species, $ZnAs_2O_4$, the chemical analog of trippkeite, $CuAs_2O_4$. The mineral is monoclinic and has a space group *P*2/*n* or *Pn*, $a=17.615(2)$ A, $b=5.0008(2)$ A, $c=4.534(2)$ A, $\beta=90°53'(2)$. The indices of refraction are very high (well above 1.80) but have not yet been determined. The mineral has a perfect (100) cleavage, which introduces strong preferred orientation effects in the X-ray diffractometer pattern. The six strongest lines, based on intensities shown by the X-ray power photograph, are (in angstroms) 2.934 *100* (600), 3.135 *85* (401), 2.179 *50* (121), 4.823 *40* (110), 3.306 *40* (410), and 1.682 *30* (911). Two electron microprobe analyses by G. K. Czamanske gave values for zinc (23.6, 23.6 percent by weight) and arsenic (53.4, 53.7 percent by weight) very close to those for the calculated composition $ZnAs_2O_4$. The mineral is soft, dissolves easily in cold 1:1 HCl, and is nonfluorescent. Heated in a closed tube, it gives off As_2O_3 as a white sublimate and then fuses to a clear glass. There is no information available at present as to its geological occurrence or paragenesis.

VOLCANIC ROCKS AND PROCESSES

HAWAIIAN VOLCANOES

1975 activity at Kilauea Volcano

Events at Hawaii's Kilauea Volcano in 1975 were observed and recorded by the staff of the Hawaiian Volcano Observatory, headed by R. I. Tilling, Scientist-in-Charge. Other professional members of the observatory staff during part or all of the year included L. A. Anderson, E. T. Endo, R. Y. Koyanagi, P. W. Lipman, J. P. Lockwood, D. W. Peterson, and C. J. Zablocki.

Kilauea activity was dominated by the magnitude 7.2 Kalapana earthquake of November 29 and related ground deformation, a tsunami, and summit eruption. Before this event, the volcano was quieter than it had been in many years; there had been no eruptive activity and a relatively low level of seismicity. Ground-deformation studies showed a gradual slow swelling of the summit area following the subsidence associated with the December 31, 1974, eruption on the southwestern flank.

The Kalapana earthquake, the largest in Hawaii since 1868, struck at 0448 Hawaiian Standard Time on the morning of November 29; its location was approximately 5 km southwest of Kalapana on Hawaii's southeastern coast at a depth of about 5 km. In the 3 weeks before this large quake, 12 earthquakes with magnitudes of 4 to 5 occurred along the eastern rift and southern flank of Kilauea; in hindsight, these events clearly were foreshocks. The largest foreshock, a magnitude 5.7 quake located approximately 11 km east of Makaopuhi Crater at a depth of about 7 km, occurred on November 29 only about 1 hour before the magnitude 7.2 Kalapana earthquake.

The Kalapana earthquake was associated with seaward motion of the southern flank of Kilauea. New fault scarps having offsets of 1 to 2 m developed along a 25-km sector of the Hilina fault system, and widespread ground cracking and landsliding occurred in the Kilauea summit area. A maximum of 3.5 m of subsidence occurred along the coast line, and horizontal changes of as much as 6 m were detected along individual geodimeter lines.

Local tsunami waves generated by the earthquake struck the southern coast a few minutes after the earthquake reached heights of as much as 14 m above sea level. Fortunately, much of the area of highest wave action was uninhabited, but two campers were killed and more than a dozen injured at one beach site (Halape). Several buildings were destroyed or damaged by waves at Punaluu, southwest of Kilauea, and total property damage from the tsunami and earthquake was estimated at more than $3 million.

Probably as a direct effect of the earthquake, about 1 hour later, a small eruption broke out within Kilauea caldera. A fissure on the caldera floor erupted about 250,000 km^3 of lava, and two vents within the Halemaumau pit crater also produced minor amounts of lava. All eruptive activity ceased by late evening on November 29. The summit area deflated at rates of 3 to 5 μrad/hr during the eruptive activity and at gradually lower rates for about 2 weeks afterward, with an aggregate inward tilt of about 190 μrad at the Uwekahuna tiltmeter. This summit deflation was the largest since that associated with the eruption of the Kapoho eastern rift in 1960. The volume of the subsidence, which was at least 50 times greater than that of the erupted lava, indicated major subsurface movement of lava away from the summit area.

Eruption rates and evolution of basaltic landforms

A general qualitative relationship between eruption rates and landform evaluation can be established for the recent activity of Kilauea and Mauna Loa Volcanoes in Hawaii. R. I. Tilling, R. T. Holcomb, J. P. Lockwood, and D. W. Peterson (1975) noted that short-lived events, lasting a few days or less, are characterized by relatively high eruption rates and thin, fountain-fed pahoehoe flows. These very fluid flows spread rapidly until they stagnate, pond, or undergo transitions to aa. During long-lived activity, characterized by average eruption rates considerably less than those characterizing short-lived events, flow processes and landforms associated with lava channels generally dominate. If the long-lived activity is continuous and the lava supply stable, lava-tube systems develop and permit lava to travel great distances from the feeding vents; the tube-fed flows spread to form extensive hummocky fields of pahoehoe near the coast or enter the sea to form lava deltas and hyaloclastite beaches. However, if the long-lived activity is episodic, lava-tube development is minimal; repeated but brief overflows travel only short distances and tend to accrete around the source to form volcanic shields.

Potential-field surveys, Kilauea Volcano

Self-potential and electromagnetic surveys conducted by C. J. Zablocki and L. A. Anderson continued on the summit and flanks of Kilauea Volcano to monitor magma movement within recent eruptive fissures and to define the alinements and attitudes of these fissures. On the eastern rift, where the incoming very low frequency (VLF) field is poorly alined to allow detection of northeasterly trending conductors, vertical electric soundings and resistivity profiling (using a VLF resistivity unit) were conducted to determine depth to ponded lava or related hot mineralized water.

Repeated self-potential (SP) measurements made across the eastern rift indicated a change in the SP level in the vicinity of Kalanaokuaiki Pali, part of the Koae fault system (Duffield, 1975b). Local compression was noted following the November 29, 1975, earthquake, along with a subsequent increase in the SP level. This increase may reflect an upward squeezing of magma caused by compression or an increase in the fracture porosity of the rock or both. Similar SP increases were observed northwest of Kilauea's southwestern rift zone in an area of considerable earthquake-related ground cracking.

Mauna Loa eruption predicted

Increased seismic activity on Hawaii's Mauna Loa Volcano beginning in the spring of 1974 prompted the Hawaiian Volcano Observatory staff to greatly expand its geodetic and seismic monitoring network on Mauna Loa in anticipation of possible eruptions. Significant changes detected by the expanded monitors led the observatory to inform the local press about the possible reawakening of Mauna Loa, which had been dormant for the past 24 years.

The summit eruption of July 5–6, 1975, lasted only about 15 hours, but the continuing posteruptive swelling of the volcano revealed by the observatory's monitors indicate that Mauna Loa could erupt again in the not-too-distant future. Mauna Loa's historic (post-1970 A.D.) patterns of activity suggest that summit eruptions are commonly followed by flank eruptions within 3 years.

The expected eruption could send lava flowing toward population centers on the island of Hawaii; the Hawaiian Volcano Observatory is evaluating the threat and providing scientific information and advice to the local and Federal agencies that will be responsible for lava-diversion efforts, should any population center be threatened.

Geochronology and petrology of Lanai

G. B. Dalrymple and M. H. Beeson (USGS) and Norbert Bonhommet (University of Rennes) completed the first geochronologic and petrochemical study on the Hawaiian island of Lanai. Chemical analyses of four samples confirm petrographic observations that the lavas of Lanai are typical Hawaiian tholeiites, slightly more similar to the alvas of Mauna Loa than to those of Kilauea. Thirteen K-Ar measurements on six samples give a weighted mean age of 1.30 ± 0.07 million years and a $^{40}Ar/^{36}Ar$ versus $^{40}K/^{36}Ar$ isochron of 1.25 ± 0.04 million years (intercept, 298.8 ± 1.4). These age data confirm Wentworth's (1925) geomorphic observations that Lanai should be about the same age as west Maui (1.30 million years), younger than east Molokai (1.48 million years), and older than Haleakala ($\sim$0.8 million years); these data are also consistent with the hypothesis that the volcanoes of the Hawaiian Islands become progressively older from the active volcanoes of Kilauea and Mauna Loa to Kauai.

ALASKAN VOLCANOES

A flat-topped volcano formed by subglacial eruption is defined as a "tuya," after Tuya Butte in northern British Columbia (Matthews, 1947). During the course of mapping in Togiak Valley, in the Kuskokwim Mountains of southwestern Alaska, W. L. Coonrad and J. M. Hoare discovered an isolated volcanic butte, which they now recognize as a tuya, apparently the first to be discovered in Alaska.

Lower Togiak Valley is a 25- to 30-km-wide graben, locally floored by upper Cenozoic basalts that predate the last glacial advance. About 12,000 to 15,000 years ago, when the valley was filled with glacial ice to a depth of 500 to 650 m, Togiak Tuya erupted on or near the Togiak-Tikchik fault, about 3 km from the eastern wall of the valley. Togiak Tuya is oval shaped, 6 km north-south by 3 km east-west, and rises 300 m to a flat summit that slopes gently south. The slopes are steep to precipitous except on the south, where they are moderate. At the northern end is a tuff breccia cone consisting largely of black vitreous basaltic glass (sideromelane) and yellow and brown palagonite (hydrated sideromelane). The tuff breccia crops out in the broken rim of a saucer-shaped depression, which the attitude of crude bedding suggests is a crater remnant in the top of the cone. The cone is overlain on the south by olivine basalt flows that dip southward and extend only a short distance from the tuya. Their fine texture, abundant interstitial glass, and small, poorly formed columns suggest that they cooled and congealed quickly after extrusion. Construction of the tuya apparently began as a subglacial eruption that quickly became subaqueous as the Togiak Valley glacier melted and formed a lake. During this subaqueous stage, a 300-m-high cone of brecciated basaltic glass was built; after draining of the lake, eruption continued with effusion of olivine basalt flows to the south. A litter of glacial erratics on the tuya and the oversteepening of its northern end suggest that the Togiak Valley glacier later overrode the tuya from the north.

CASCADE VOLCANOES

Hydrothermal activity at Mount Baker, Washington

In March 1975, hydrothermal activity at Mount Baker in Washington increased abruptly and stimulated great scientific interest as well as concern over potential hazards. The new activity is confined to the partly ice-covered Sherman Crater and encompasses several clusters of fumaroles in which temperatures as high as 131°C have been recorded. In addition, a crater lake having a volume of 1,000 to 3,000 m^3 formed, and at least 2,000 m^3 of fine ash has been emitted from the fumaroles. Photographs of Sherman Crater, studied by D. G. Frank and A. S. Post (USGS) (1976), indicated that the activity represents the greatest amount of visible steam emission and the largest area of heated, snow-free ground observed during this century. Published accounts of eruptions at Mount Baker in the 1840's and 1850's, the subsequent fumarolic activity, and the increased fumarolic activity in 1975 were reviewed by S. D. Malone (University of Washington) and D. G. Frank (USGS) (1975).

Monitoring of the volcano, begun in 1975 by USGS scientists, includes periodic tilt surveys by D. A. Swanson (USGS), tiltmeter studies by R. V. Allen (USGS), aerial photographic surveys by Post and R. M. Krimmel (USGS), studies of fumarolic gases by Motoaki Sato (USGS) and others (1976), investigations of water chemistry by M. O. Fretwell (USGS) (1976), and analyses of ash from the fumaroles by J. E. McLane, J. W. Babcock, and R. E. Wilcox (USGS). In addition, seismic monitoring has been undertaken by Malone, and other studies have been carried on by scientists at the University of Washington, Oregon State University, Central Oregon Community College, Eastern and Western Washington State Colleges, and the Los Alamos Scientific Laboratories. Increased fumarolic temperatures and gas emissions suggest that some aspect of the hydrothermal plumbing system has changed, but, by the end of 1975, there was no clear evidence, particularly in the form of earthquakes or ground deformation, that an eruption is imminent.

Studies of postglacial events at Mount Baker by J. H. Hyde and D. R. Crandell (USGS) (1975) indicated that avalanches and mudflows of hydrothermally altered rock debris from the volcano constitute the greatest potential threat to developments in valleys that drain the volcano. The unusual thermal activity during 1975 suggests that the chances of such an avalanche or mudflow have increased substantially. The most likely route of an avalanche or mudflow is down Boulder Creek on the eastern flank of Mount Baker, which drains into the Baker Lake hydroelectric reservoir. Because of the possible risk, the U.S. Forest Service and the Puget Sound Power and Light Company (a private utility company) temporarily closed the Boulder Creek valley, Baker Lake, and the lake shoreline to public access.

Remote monitoring of fumarolic gases, Mount Baker, Washington

As part of the effort to monitor the activity of Washington's Mount Baker, Motoaki Sato and J. E. McLane (USGS), assisted by R. H. Moxham (USGS) and S. D. Malone (University of Washington), installed a specially designed thermistor and an electrochemical sensor at the western rim of Sherman Crater to monitor the temperature and the chemical composition, respectively, of the fumarolic gases. This equipment, designed by Sato and previously tested at Kilauea Volcano in Hawaii, automatically transmits information by radiotelemetry to a receiver in Seattle, 128 km distant; it is the first known attempt at such automatic remote monitoring of fumarolic gases. Data received in July and August 1975 showed that fumarole temperatures vary daily between 89° and 92°C, the highest temperatures being attained at midday. Variations in gas composition appear to be independent of the time of day. According to Sato, the imminence of a volcanic eruption may be detected by a change in the reducing capacity of the fumarolic gases (Sato, Malone, Moxham, and McLane, 1976).

Particulate matter from the fumaroles of Sherman Crater, Mount Baker

J. E. McLane, R. B. Finkelman, and R. R. Larson examined the particular matter ejected from the fumaroles of Sherman Crater on Mount Baker in Washington. The samples were collected periodically by D. G. Frank and Motoaki Sato from the surface of fresh snow beginning in April 1975. In the samples collected prior to September 1975, the most abundant particles were spherules of orthorhombic sulfur, most of which were coated with a layer of euhedral pyrite crystals. These spherules constituted about 30 to 40 percent by volume of the samples and accounted for the bulk of the sulfur present. Other constituents, in approximate order of abundance, included fragments of angular to subangular altered rocks, quartz, pyroxene (mostly hypersthene and augite, rarely diopside), sulfur chips, dacitic glass, plagioclase, and subhedral to euhedral crystals of anatase. These fragments accounted for 15 to 20 percent by volume of the samples. The remaining 40 to 55 percent by volume was undetermined altered materials (McLane, Finkelman, and Larson, 1976).

Mount Shasta—a compound, probably active volcano

Preliminary results of studies being conducted by R. L. Christiansen and C. D. Miller (1976) at Mount Shasta in California showed that Mount Shasta has a compound origin. Four successive andesitic stratocones have been built around central vents, the youngest lavas and pyroclastic deposits of each having become more silicic. Studies of geologic mapping, detailed stratigraphy, and petrology showed that the oldest cone is more than 100,000 years old; the second cone is younger and last erupted less than 12,000 years ago; the third cone (Shastina) dates from between about 12,000 and 9,000 years ago; the fourth cone (the present summit and the northern and northeastern flanks of Mount Shasta) is younger than 4,000 years—perhaps younger than 2,000 to 3,000 years. An active silicic magma chamber probably exists beneath the volcano, and cooling silicic intrusive bodies probably are still quite hot.

VOLCANIC ROCKS IN THE WESTERN UNITED STATES

Struggle between Pleistocene lava flows and Owens River

The Coso Range in Inyo County, California, lies at the southern end of Owens Valley, adjacent to the eastern escarpment of the Sierra Nevada. During Quaternary time, a major river, which carried water from Owens Lake southward into a series of interconnected basins, including China Lake, Searles Lake, Lake Panamint, and Lake Manly (Death Valley), intermittently flowed through a narrow trough between the Sierra Nevada and the Coso Range. The discharge of this river was primarily a function of the fluctuating Quaternary climate but was also affected by lava flows from nearby parts of the Coso Range. A fossil falls nearly 15 m high carved into a lava flow near the town of Little Lake, Calif., provides impressive evidence of the river that once flowed south through the area. Recent mapping by W. A. Duffield (USGS), renewing an earlier study of the area begun by W. C. Putnam (University of California, Los Angeles) (1955), showed that three successive basaltic lava flows partly or completely filled the river channel during Quaternary time. The lavas are sufficiently distinctive and remnants are widespread enough to reconstruct the history of eruption and erosion. The fossil falls near Little Lake is carved into the youngest of the three flows, near a contact with the intermediate-aged flow; the story of the struggle between lava flow and river, however, began at an earlier time, downstream.

The oldest of the three lavas erupted from a vent, now a partly eroded cinder cone, about 2 km south-southeast of Little Lake. At least two flows erupted, each about 3 to 5 m thick, but the lack of intervening soil or erosional features suggests that the two were virtually contemporaneous. The flows advanced at least 12 km downslope into a basin now called Indian Wells Valley (Pleistocene China Lake). Subsequent major stream erosion cut through these flows and into underlying Mesozoic granitic basement rocks a minimum of 175 m and formed a nearly vertical erosional cliff that is still well preserved.

The next lava to clog the river erupted from a vent, now marked by a slightly eroded cinder cone about 5 km northeast of Little Lake. Only a single flow from this vent has been recognized; it spread north and west until it reached the river and then followed the channel at least 15 km downstream into Indian Wells Valley. This flow banked against the lofty erosional scarp cut into the earlier lava and underlying bedrock but probably never rose more than about halfway up the scarp. Ensuing erosion carved a 65-m-high cliff into the new flow about 1.5 km upstream from Little Lake where the flow had ponded in or near the preflow river channel.

The final lava to fill the river channel erupted still further upstream; the vent area is now marked by a little-eroded cinder cone some 5.5 km north-northwest of Little Lake. Lava ponded around the vent area and flowed a minimum of 18 km downstream into Indian Wells Valley. This flow banked against the erosional escarpment cut into the intermediate-aged lava and into the oldest lava and underlying bedrock but probably never rose more than halfway up either cliff. The ensuing erosion was not as great as that following the earlier eruptions, but the river carved at least 10 m into the youngest flow and scoured impressive potholes several meters deep into the area of the fossil falls. Much of the 15 m of relief at the falls formed when the youngest flow partly banked against the erosional cliff in the intermediate-aged flow. Judging by vertical downcutting into rocks of similar resistance, the erosion rate following the younger flows was less than half that following the earlier eruptions.

Approximate ages of lava flows can be established by examining ages of glaciation in the Sierra Nevada and ages of lake filling in basins downstream from the Little Lake area. The Tioga Glaciation (about 20,000 years B.P.) is the youngest that could have produced enough water for the Owens River to erode the youngest lava. The Tahoe (about 60,000 to 75,000 years B.P.) and Mono Basin (about 130,000 years B.P.) Glaciations might be correlated with the more extensive erosion of the older lavas (M. M. Clark, oral commun., 1976). The same conclusion may be drawn from examining water-level fluctuations in Searles Lake as reconstructed by a study of lake deposits (G. I. Smith, oral commun., 1976). The oldest lava may be considerably older than Mono Basin in age, but, like the other lavas, it exhibits normal magnetic polarity, the indication being that it is no older than about 700,000 years B.P., the time of a substantial magnetic reversal. The relative states of preservation of primarily surface structures on all three lavas suggest rather short time spans between eruptions; therefore, it is concluded that the oldest lava is closer to 130,000 years old than to 700,000 years.

The presence of many petroglyphs chipped into all three lavas and the discovery of homesites and hundreds of artifacts as much as 3,000 and possibly 6,000 years old indicate that Indians found the river valley a pleasant place to live. Some of the earliest inhabitants in this region might have seen the eruption of the youngest of the three flows or a still younger eruption that occurred nearby in the Coso Range.

Mafic phonolites in the Sierra Nevada, California

Tertiary volcanic rocks of the Merced Peak quadrangle in the Central Sierra Nevada of California belong mostly to a mildly alkaline series that includes abundant olivine-bearing trachybasalt and less abundant trachyandesite and mafic trachyte-volcanic rocks similar to those described in nearby areas by Hamilton and Neuerburg (1956) and Huber and Rinehart (1967). Several flows and small intrusives in the Grizzly Creek drainage and near Merced Pass (Peck, 1964), however, were found recently by D. L. Peck to be mafic phonolites, similar to the highly potassic flows and intrusives found in the Navajo region (Williams, 1936) but previously not reported in the Sierra Nevada. The flows contained about 10 percent phenocrysts of biotite, or of biotite and olivine, and sparse phenocrysts of apatite in a groundmass composed of poikilitic sanidine enclosing rods of diopsidic clinopyroxene and less abundant grains of biotite, opaque minerals, and apatite. The sanidine also contained abundant minute blobs of an isotropic mineral having a low refractive index; M. E. Mrose (written commun., 1976) identified this mineral by X-ray techniques as leucite. Sparse interstitial phillipsite in one sample was similarly identified. Two rapid-rock analyses showed that the volcanic rocks contained 51 to 52 percent SiO_2, 2 percent Na_2O, and 7 to 8 percent K_2O. The analyses showed that the volcanic rocks were similar to biotite lamprophyres (minettes), which form dikes in other granitic terranes.

Rhyolite volcanism on the axis of the eastern Snake River Plain, Idaho

Juniper Buttes, about 10 km northwest of St. Anthony in Fremont County, Idaho, is a complex, normal-faulted area exposing strongly banded, crystal-poor rhyolite, obsidian, and breccia. This rhyolite, according to M. A. Kuntz, may be correlative with similar-looking rhyolite lava flows ($\sim$4.5 million years) below the Heise B welded tuff in the Kelly Mountains, 45 km to the southeast. The rhyolite is exposed in the lower parts of two parallel, southward-tilted fault blocks, which are bounded by east-west normal faults. North-trending faults form grabens in each block. The rhyolite is overlain by seven basalt flows and, locally, by Huckleberry Ridge tuff. Five of the basalt flows have been affected by faulting, and two postdate faulting. Basalt vents that postdate block uplift, tilting, and faulting are located along east-west faults or at the interactions of east-west and northwest faults. The structural patterns and distribution of rhyolite lithologies suggest that the Juniper Buttes are similar to a resurgent caldera.

The area between Big Southern Butte and Little Grassy Ridge, along the axis of the eastern Snake River Plain, is the locus of basalt eruptions and rhyolite plugs. Mapping to date confirms LaPoint's (1975) premise that rhyolite and basalt volcanism occurs where the axis is intersected by crosscutting structures such as extensions of Basin and Range faults from the flanks of the plain. Much of the area between Big Southern Butte and East Butte is underlain by rhyolite with a thin veneer of overlying basalt. Exposures of the rhyolite occur at Big Southern Butte, the pyroclastic cone atop Cedar Butte, and East Butte. Big Southern Butte and East Butte are probably resurgent, remobilized plugs or projections of the underlying rhyolite, also localized at the intersection of the plain axis and crosscutting structures. Coarse bedded ash and pumice, exposed at the margin of the breccia core of Big Southern Butte, are believed to represent vent products of a rhyolite magma that was generated during resurgence and that caused remobilization and intrusion of the plug.

New interpretation of Eocene volcanic rocks, Butte, Montana

Quartz latite of the Eocene Lowland Creek Volcanics west of Butte in Silver Bow County, Montana, was previously interpreted by H. W. Smedes as sheets of welded tuff that collapsed chaotically into a graben in the underlying Butte Quartz Monzonite. This interpretation was supported by gravity data collected by W. T. Kinoshita. Analysis of W. F. Hanna's paleomagnetic data and more recent large-scale geologic mapping by Smedes precipitated a reexamination of the data and the model. These studies, materially aided by new exposures at a critical area, indicate that the rock mass is instead a complex shallow intrusive source for the voluminous welded tuffs of the region. Key exposures display complete gradations ranging from massive and flow-banded dike rock to zones in which vesiculations have produced a brecciation along selected flow layers to massively vesiculated and brecciated rock in which the clasts closely resemble the collapsed pumice lapilli of the extrusive welded tuffs. This new interpretation is also in harmony with the previous gravity data. Elsewhere in the volcanic field, some younger dikes appear to have fused the welded tuff along the dike contacts.

Archean rhyodacite and tholeiite, Teton Range, Wyoming

The Webb Canyon Gneiss of the Teton Range in Teton County, Wyoming, consists of closely and conformably interlayered plagioclase-quartz-biotite-hornblende gneiss and amphibolite. J. C. Reed, Jr., and R. E. Zartman (1973) dated this unit at 2.8 to 2.9 billion years and first suggested its volcanic origin. Geochemical studies by Fred Barker, H. T. Millard, Jr., and Reed suggested that initially the gneiss was high-silica rhyodacite with a very low Mg/(Mg+Fe) ratio and that the amphibolite was tholeiite with a low to intermediate Al_2O_3 content.

The gneiss (rhyodacite) has rare-earth element (REE) distribution patterns (chondrite normalized) with shallow slopes and REE abundances that are 200 to 350 times greater than those of chondrites. Europium shows pronounced negative anomalies ($Eu/Eu^*=0.204$ to 0.392). Heavy REE have distribution patterns with moderate slopes; gadolinium-lutetium ratios are 1.8 to 2.0, and lutetium abundances are 63 to 84 times greater than those of chondrites. The amphibolite (tholeiite) has REE distribution patterns with flat slopes and REE abundances that are 10 to 20 times greater than those of chondrites.

The rhyodacite probably was generated in two stages: (1) Partial melting of a basaltic source rich in REE and (2) subsequent crystal fractionation at shallow depths in the crust. The tholeiitic lavas probably formed by partial melting of the ultramafic mantle.

Ore deposits and volcanic centers, Drum Mountains, Utah

Geologic and petrographic studies by H. T. Morris indicated that the volcanic rocks of the Drum and Little Drum Mountains in Juab County, Utah, are correlative. The common eruptive center of these rocks is probably a volcanic neck in the central Drum Mountains, which has base and precious metal and manganese ores associated with it. Although earlier studies suggested eruptive centers in the Little Drum Mountain, none were found. The common association of ore deposits with volcanic centers and the lack of such centers in the Little Drum Mountain now cast doubt on the likelihood that ore deposits will be found there.

VOLCANIC ROCKS IN THE EASTERN UNITED STATES

Geochemistry of subsurface basalts, Charleston, South Carolina

Geophysical studies indicated that mafic volcanic and associated plutonic rocks may be important components of the basement beneath the Coastal Plain of the southeastern United States. A drill hole sited on a magnetic and gravity high near Charleston, S.C., penetrated 750 m of Coastal Plain sediments and bottomed in 42 m of basalt. Petrographic and major-element data on 10 samples of basalt, selected from the drill core and representing at least two flow units, indicated that the basalts have undergone slight to extreme oxidation, hydration, and hydrothermal alteration. Petrochemical studies by David Gottfried, C. S. Annell, B. B. Higgins, and L. J. Schwarz on the least altered samples indicated that the basalts are of the quartz-normative tholeiitic magma type and closely resemble the Mesozoic high-titanium quartz-normative dolerites of eastern North America.

Eight samples were analyzed for 22 minor and trace elements, including rare-earth elements (REE), Rb, Ba, Sr, Th, Pb, Zn, Ni, Co, Cu, Cr, Zr, Hf, and Nb, by neutron activation, emission spectrography, and spectrophotometry. Concentrations of rubidium, barium, and strontium were highly variable and reflected the mobility of these elements during postmagmatic processes. Potassium-rubidium ratios on the least altered samples fell in the range of 200 to 300. The abundances of REE, titanium, zirconium, and niobium, which were virtually the same in all samples regardless of the degree of alteration, indicated that the different flow units were originally of the same chemical composition. The abundances of REE, titanium, zirconium, and niobium and the light rare-earth enrichment patterns were similar to those obtained by other investigators on Mesozoic continental quartz-tholeiites from eastern North America, South Africa, Tasmania, and Antarctica.

Jointing in the Watchung Basalt flows, New Jersey

G. T. Faust completed mapping the joint systems of Second Watchung Mountain in a continuing study of the Watchung Basalt of Passaic and Somerset Counties, New Jersey. A complete set of systematic cooling-joint zones, including the vesicular base, the curvilinear zone, the blocky zone, the columnar zone, and the vesicular top, was observed in temporary excavations on the mountain scarp near Totowa Borough. Key exposures of the vesicular top and the columnar zone were found in two ancient and obscured quarries operated at the turn of the century and only sporadically thereafter. On Third Mountain, at Millington quarry, tectonic and cooling joints observed in drill cores could be correlated with those exposed in the quarry walls nearby. In the curvilinear zone, the cooling joints were nearly parallel to or within 30° of the axes of the cores, whereas the tectonic joints were usually normal to the core axes.

CHEMISTRY AND MINERALOGY OF VOLCANIC ROCKS

Uranium in rhyolitic lavas and ash flows

R. A. Zielinski measured the abundance and distribution of uranium in a number of rhyolitic lava and ash flows by using a delayed-neutron technique and fission-track mapping. Samples consisted of coexisting obsidian, hydrated obsidian (perlite), and crystallized obsidian (felsite) from the Western United States; ages ranged from Oligocene to Pleistocene, and compositions ranged from calc-alkaline to peralkaline. Within the analytical precision of ± 5 percent, all perlites had uranium concentrations identical to those of the coexisting obsidians, an indication that little or no uranium was lost during hydration. Felsites showed relative uranium depletions of up to 80 percent; these depletions appeared to increase with age. Distinctly different rates of depletion were observed for calc-alkaline (slowest) and peralkaline (fastest) compositions. Uranium distribution was homogeneous in obsidian and perlite but highly inhomogeneous in felsites. Uraniferous loci in felsites were identified by electron microprobe as primary iron-titanium-manganese oxides and accessory zircon and sphene. Evidence for the mobilization of uranium during felsite alteration was seen in the association of uranium with secondary oxides of iron and manganese observed as fissure fillings and grain coatings.

Minor-element variations in hydrated and crystallized calc-alkalic rhyolites

Minor-element compositional variations among glassy, hydrated glassy, and crystallized parts (felsites) of four unaltered Cenozoic lava flows from the Rocky Mountain region were evaluated by R. A. Zielinski, P. W. Lipman, and H. T. Millard, Jr. Hydrated glasses showed consistent loss of lithium, addition of strontium and barium, and variable fluorine relative to nonhydrated glasses, all of which reflected the influence of low-temperature solution and ion exchange with ground water. The greater variability of trace elements in the crystallized samples reflected the more complex crystallization and alteration history of multiphase assemblage. Fluorine, rare-earth elements, and cesium variations in felsites were induced early in the rocks' history. Older felsites showed increasing losses of uranium and molybdenum. Strontium and barium variations in felsites were the most difficult to model and probably were caused by both early and long-term processes.

Chemistry and mineralogy of Mid-Atlantic Ridge basalts

Fifty well-located samples of fresh basalt were collected by the submersible ALVIN from the median valley of the Mid-Atlantic Ridge during Project Famous (French-American Mid-Ocean Undersea Study). J. G. Moore (USGS) and W. B. Bryan (Woods Hole Oceanographic Institute) found that the samples show regular compositional variations from the center of the rift valley (central lavas) out to the rift-valley walls (flank lavas). The central lavas show higher ratios of olivine relative to clinopyroxene and plagioclase phenocrysts and contain chrome spinel. Glasses of the flank lavas are enriched in SiO_2, TiO_2, K_2O, H_2O, and FeO/MgO relative to the central lavas.

Studies of the thickness of palagonite and manganese crusts indicated that the crust on which the flank lavas occur has a considerably older inferred spreading age than the lavas themselves. Flank lavas are generally older than central lavas, but notable exceptions occur.

The composition of the flank-lava glass can be derived by removing approximately 29 percent by weight of analyzed phenocrysts (in the ratio 5.7 plagioclase, 2.5 olivine, and 1.8 clinopyroxene) from the central-lava glass. Other processes (probably involving volatile transfer) must enrich the flank lavas in K_2O, TiO_2, and H_2O.

This crystal fractionation is believed to occur in a shallow, narrow (5 to 6 km wide) magma chamber underlying the median valley. The chamber is compositionally zoned, and central lavas are fed from dikes tapping its hotter axial zone, whereas flank lavas are fed from the cooler, differentiated melt on the margins. The nature of the chemical variations in the lavas permits an estimate of the composition and thickness of the cumulates forming at the base of the chamber.

Alteration and massive sulfide deposits in pillow lavas of Oman

R. G. Coleman reported that studies on the alteration minerals within the Cretaceous pillow lavas and sheeted dikes of Oman reveal a very steep thermal gradient. Zeolite assemblages characterize the pillow lavas, the key minerals being laumontite, analcite, and minor prehnite, whereas the underlying sheeted dikes are characterized by greenschist assemblages of albite, epidote, chlorite, actinolite, and sphene. Metamorphism of the Oman ophiolite dies out downward into the gabbros, an indication that the alteration could have resulted from circulating hot oceanic water of the sort postulated for the ophiolites of

Cyprus. Such alteration would have taken place shortly after the formation of the ophiolite at a spreading ridge where high heat flow would be expected. Heated downward-circulating ocean water would have produced the alteration. Leaching of iron, manganese, copper, and other metals during the downward migration of the ocean water presumably would have changed the ocean water to a potential ore-forming fluid. The presence of massive sulfide deposits within the pillow lavas, as well as interlayered metal-bearing pelagic sediments, indicates that the deposits may have formed from the ocean-water brines developed near the spreading ridge within the Tethyan Sea during Late Cretaceous time.

DATING OF VOLCANIC ROCKS

Obsidian hydration dating

Obsidian hydration dating performed by Irving Friedman on a group of rhyolite flows near Milford, Utah, showed them to be 150,000 to ~300,000 years old. Potassium-argon dates for the same units range from 520,000 to 750,000 years. The glasses contain no fission tracks, although they have normal uranium contents. The discrepancies in the ages given by the various techniques are being investigated. One possibility is that the glasses have unusually high water contents (they have a distinctive luster commonly associated with high-water obsidians) due to intrusion into wet sediments. In such an environment, "excess" water and perhaps excess argon may have been incorporated into the glass. The high water content has little effect on hydration ages but can cause rapid annealing of fission tracks owing to the decreased viscosity of the glass.

Dating Quaternary deposits by weathering rinds

More than 3,700 measurements of the thickness of weathering rinds on andesitic and basaltic cobbles at 70 sites in the Western United States made by S. M. Colman and K. L. Pierce demonstrated the usefulness of this technique as an age indicator for Quaternary deposits. Weathering rinds on andesitic or basaltic cobbles in the soil profile generally average 0.1 to 0.5 mm thick for deposits on the order of 10,000 to 50,000 years old; 0.2 to 1.0 mm thick for deposits on the order of 50,000 to 150,000 years old; 1.0 to 3.0 mm thick for deposits several hundred thousand years old; and as much as 8.0 mm thick for deposits greater than 1 million years old. Climate and rock properties, in addition to time, appear to be the most important variables affecting weathering-rind development. At present, weathering rinds are most useful in discriminating different ages of deposits and providing an approximate estimate of age. Their potential as a higher resolution dating technique awaits the quantitative determination of the effects of climate and rock properties and numerically dated sites.

PLUTONIC ROCKS AND MAGMATIC PROCESSES

Archean sequence, Bighorn Mountains, Wyoming

Geologic mapping by Fred Barker of Archean rocks in the Lake Helen 7½-minute quadrangle in the southwestern Bighorn Mountains of Wyoming revealed two major episodes of magmatism, deformation, and metamorphism.

Rocks formed in the older episode consist largely of a bimodal suite of fine- to medium-grained trondhjemitic and tonalitic gneisses and minor amphibolite. These rock types are closely and conformably interlayered and may be a volcanic dacite-tholeiite pair. Synkinematic intrusion of tonalite, metamorphism to upper amphibolite facies, partial melting to produce pegmatite stringers, intense folding, and intrusion of late kinematic dikes of dark tonalite ended this episode. The age of this event is not yet known.

The second episode included synkinematic intrusion of trondhjemite and then of calc-alkaline rocks, metamorphism to middle amphibolite facies, mild deformation, and intrusion of late kinematic basalt dikes. This event may have occurred 2.8 to 2.9 billion years ago.

K-Ar age of the San Marcos Gabbro, southern California batholith

G. B. Dalrymple completed a small K-Ar dating project on the San Marcos Gabbro, thought to be the oldest in the sequence of plutonic rocks that form the southern California batholith. Apparent ages from five sites in four widely separated gabbro and norite bodies range only from 103 ± 3 to 111 ± 4 million years. Concordant biotite-hornblende pairs indicate either that the later, more silicic intrusive bodies were emplaced very shortly after the gabbro or that they did not reheat the gabbro sufficiently to significantly disturb the K-Ar system. The K-Ar ages, however, are 5 to 10 million years younger than previously published U-Pb zircon ages on other units from the batholith; thus, the K-Ar ages may reflect the time of cooling rather than the time of emplacement.

METAMORPHIC ROCKS AND PROCESSES

Metamorphic forsterite and diopside in serpentinite

Nearly pure forsterite and diopside have been formed within intensely sheared zones in serpentinite from the large ultramafic complex near Sonora, Calif., according to investigations made by B. A. Morgan. Bladelike grains of forsterite are elongate, parallel to *c* with prominent (010) cleavage. Metamorphic diopside occurs as small, inclusion-free grains in rocks containing forsterite. The formation of forsterite and forsterite+diopside in serpentinite probably took place by the reactions:

antigorite+magnesite=2 forsterite+fluid
3 antigorite+calcite=4 forsterite+diopside+fluid.

Iron derived from the primary olivine and chromite has been oxidized and is almost entirely present in magnetite. On the basis of stratigraphic reconstructions, total load pressures are unlikely to have exceeded 3 kbar. At these pressures, the reactions should have taken place at about 400°±25°C and with a fluid composition ranging from nearly pure H_2O to less than 10 mole percent CO_2. The restriction of forsterite and forsterite+diopside to shear zones may be attributed to the presence of carbonate in the rock prior to metamorphism and to the dilution of the fluid phase by water external to the area of the reaction.

Stability relations of anthophyllite and antigorite

Mineral stability relationships at high temperatures for talc, antigorite, anthophyllite, forsterite, and enstatite were defined, according J. J. Hemley. The temperature at which antigorite undergoes thermal decomposition to talc+forsterite at 1 kbar H_2O is 514°±10°C, in comparison with a temperature of 435°C, or slightly higher, for chrysotile. This study clarifies a number of geologic relationships involving the formation and metamorphism of serpentinites. Anthophyllite is shown to have a relatively narrow field of stability (636°–670°C, 1 bar H_2O) between talc and enstatite, but this field expands as P_{H_2O} increases. Talc-forsterite-enstatite and talc-enstatite-quartz are seen to be low-pressure equilibria, metastable at 1 kbar. The pressure-temperature relationships delineated from this study are considerably different from earlier interpretations.

Anthophyllite-bearing assemblages are largely of theoretical interest in metamorphic petrology, but they have interesting implications with regard to ore genesis. They sometimes are the accessory assemblages in the so-called massive sulfide deposits (copper-lead-zinc) of metamorphic terranes.

GEOCHEMISTRY OF WATER AND SEDIMENTS

The primary objectives of geochemical studies in hydrogeology are:

- To understand the hydrochemical processes that control the chemical character of water and the mineralogic changes in sediments and rocks.
- To increase understanding of the physics of flow systems by application of geochemical principles.
- To understand the rates of chemical reactions and the rates of transport of physical and chemical masses within the geohydrologic system.
- To understand the concomitant chemical changes between water and sediments.

DIAGENETIC STUDIES

Trace-metal releases from sediments

R. H. Fuller (1975a) studied sediments from Lake Perris in Riverside County, California, to determine trace-metal releases under aerobic and anaerobic conditions. The study involved analyses of sediments for trace metals and equilibrations of sediments and water under aerobic and anaerobic conditions. Under anaerobic conditions, sediments released large quantities of manganese but only small quantities of iron and other trace metals; the apparent paucity of iron available from the sediments may be an important factor in limiting algal growth. Studies by others also indicated that iron may be the constituent that limits algal growth in reservoirs.

Oxygen-isotope ratios of diagenetic silica minerals

The oxygen-isotope ratios of diagenetic silica phases (opal, cristobalite, and quartz) in the Monterey Shale of California were studied by K. J. Murata, Irving Friedman, and J. D. Gleason (1976). Each phase has a characteristic value of $\delta^{18}O$ throughout its respective diagenetic zone, an indication of the absence of any isotopic exchange with ambient interstitial water. The phase transformation at the zone boundaries, however, occurs through a solution-deposition process in which the silica dissolved from the precursor phase equilibrates isotopically with interstitial water before it precipitates as the new phase with a 6- to 8-permil smaller δ^{18}. The isotopically indicated temperatures of the opal-cristobalite and the cristobalite-quartz transformations are 50° and 80°C, respectively.

Changes resulting from transition of terrestrial environment to marine environment

Changes in sedimentary diagenetic processes resulting from the transition of a terrestrial environment to a marine environment were studied by M. B. Goldhaber (USGS) and C. S. Martens (University of North Carolina), using a series of riverbed cores from the White Oak River in North Carolina. In the stretch of river under periodic marine influence, sulfate reduction is a major process owing to the availability of seawater-derived sulfate. Upstream, methane generation becomes more important. Consistent with this trend is a decrease in sedimentary pyrite in methane-rich sediments. In the terrestrial setting, total dissolved inorganic carbon decreases by nearly an order of magnitude, and pH is lower.

Relationship of sedimentary diagenesis to associated ferromanganese deposits

Edward Callender and R. J. Shedlock analyzed the manganese and copper content of northern Pacific Ocean pelagic-sediment pore water in order to evaluate the extent of sedimentary diagenesis and its relationship to the geochemistry of associated ferromanganese deposits. The vertical distribution of interstitial manganese showed considerable variation with depth, whereas the vertical distribution of interstitial copper showed a more regular decrease with depth in the cores. A possible explanation for the significant difference between manganese and copper distributions is that equilibrium between interstitial Mn^{+2} and precipitated manganese oxides in surface sediments is being approached; sedimentary biogenic phases, which contain much of the copper transported to these sediments, release copper to the interstitial water. This copper is subsequently incorporated into manganese oxide phases that form micronodules in the sediment.

Determination of provenance by study of fine-sand fraction of lake sediments

In a study of Abert Lake in Oregon, R. G. Deike, B. F. Jones, and R. E. Smith examined microscopically the fine-sand (75–105 μm) fraction of lake-sediment samples to determine provenance. The sand is composed of (roughly, according to abundance) (1) both euhedral and cryptocrystalline calcite, (2) lithic matrix fragments, mainly from fine-grained textures; (3) feldspar (generally An_{50-70}), (4) pyroxene (mostly augite), (5) clear- and brown-glass shards (some apparently zeolitized), (6) iron oxides (mainly magnetite), (7) diatom frustrules, and (8) minor amounts of amphibole, biotite, clay aggregate, phillipsite, clinoptilolite, and garnet (andradite). Centrifuged separates, 0.1 to 2.0 μm and less than 0.1 μm, analyzed by X-ray diffraction and transmission electron microscopy, are composed of mixed-layer smectite-illite along with minor kaolinite. Positive correlations are suggested between the relative percent of lithic matrix fragments in the 75- to 105-μm fraction and the weight percent of both the 0.1- to 2-μm fraction and the <0.1-μm fraction in the same sample. Fine-sand fractions containing more than 50 percent lithic matrix fragments give strong, low-angle X-ray reflections, in comparison with samples containing less than 10 percent matrix fragments; lithic-matrix-fragment alteration is thus suggested as one source of clay.

Fresh glass shards from the deepest (up to 1 m) midlake sediment samples show no corrosion and have compositions comparatively lower in magnesium but higher in aluminum, potassium, and calcium than lithic matrix fragments. No correlation was found between the relative abundance of glass shards and the percent (by weight) of clay.

MINERAL ALTERATION

Method for estimating ages of volcanic ash beds in late Cenozoic sedimentary deposits

A useful and rapid method for estimating the relative ages of volcanic ash beds in late Cenozoic sedimentary deposits was developed by V. C. Steen-McIntyre, who extended principles outlined by Friedman and Smith (1960) and Roedder and Smith (1965). Very young shards show thin rinds of hydrated glass, which are recognizable under the microscope by their higher refractive index. Shards from older ash beds show thicker rinds (greater depth of penetration of hydration), and those from still older ash beds show hydration throughout. In the oldest ash beds, liquid water collects slowly in the vesicles ("superhydration"); the amount of filling, again a function of the age of the ash bed, can be estimated visually under the microscope.

Removal of dolomite by ground-water alteration of the Edwards aquifer

R. G. Deike and F. J. Pearson, Jr., found that, in comparing altered and unaltered parts of the Edwards aquifer of Texas, bed for bed, 100-cm^3 samples altered by fresh ground water had an average of 133 g of dolomite altered to 67 g of calcite, and 66 g of dolomite was entirely removed. Late Tertiary to Holocene exposure and recharge of the Edwards Limestone with fresh ground water flushed out saline water and dissolved and removed dolomite along with sulfides, sulfates, organics, and a part of the original calcite. Downdip and downfaulted away from the freshwater aquifer, the unaltered Edwards today contains hydrogen-sulfide-bearing calcium sulfate water.

Use of X-rays in determining carbonate to noncarbonate ratios

A study by R. G. Deike and S. L. Rettig showed X-ray analysis to be a rapid and accurate reconnaissance tool for determining the ratios of carbonates to noncarbonates, particularly in carbonate-cemented sandstone aquifers. X-ray-diffraction peak-intensity measurements of the ratio of calcite and dolomite to quartz (ground sample and water smear on glass slide scanned at 1°, 2θ/min) were made on a Devonian carbonate-cemented quartz-rich sandstone. The ratios of cps (counts per second) carbonate d_{104} to cps quartz d_{101} are in excellent agreement with ratios of acid-dissolution carbonate weight loss to insoluble weight.

Isotopic composition of calcareous cement in sandstone related to Middle Devonian weathering

In an isotopic and mineralogic study of the Devonian Wildcat Valley Sandstone in southwestern Virginia, R. L. Miller, William Back, and R. G. Deike found that calcareous cement from the middle of the formation has retained the carbon- and oxygen-isotope composition typical of Devonian marine cements and that cement near the erosion surface has the isotopic characteristics of Devonian freshwater cement. This fact led to the hypothesis that alteration and weathering during Middle Devonian time could have produced porosity like that produced by weathering of present outcrops. In some geologic areas, this porosity may have been preserved and may have formed a gas reservoir.

GEOLOGIC CONTROLS ON WATER CHEMISTRY

Geopressure affects water quality in sediments

The salinity and concentration of chemicals dissolved in water squeezed from bentonite and recent muds decrease progressively as the compaction pressure increases, according to Y. K. Kharaka. These membrane-squeezing effects, which are similar to membrane-filtration effects (Y. K. Kharaka and W. C. Smalley, 1976), appear to explain the presence of relatively fresh water in geopressured reservoirs. W. W. Carothers (unpub. data, 1976), extending the work of L. M. Willey, Y. K. Kharaka, T. S. Presser, J. B. Rapp, and Ivan Barnes (1975), demonstrated that the alkalinity in many water samples from various California oilfields is largely due to dissolved aliphatic acid anions. Preliminary analyses of samples obtained from the Chocolate Bayou and the Halls Bayou oilfields in Texas show that the concentration of dissolved H_2S is low; the salinity (measured conductivity) of water from the geopressured zones is relatively high, and it is similar to that of water from the normally pressured zones.

Heterogeneities in southern Nevada aquifer

The assumption commonly used in the simulation of basinwide flow through fractured or solution-riddled aquifers—namely, that the aquifer is "homogeneous in its heterogeneity"—does not appear to be applicable to dense fractured Paleozoic carbonate rocks comprising the principal regional aquifer in southern Nevada. Studies by I. J. Winograd and F. J. Pearson, Jr., showed that heterogeneities in this aquifer appear to reinforce one another areally rather than to cancel one another

The carbon-14 content of water at the center of a 16-km-long fault-controlled spring line in south-central Nevada is five times greater than that of water from other major springs along the lineament. This difference in carbon-14 contents is in marked contrast to the near identity, in all these spring waters, of bicarbonate, pH, carbon-13, oxygen-18, deuterium, tritium, and other major- and trace-ion contents. Possible explanations of this major carbon-14 anomaly were evaluated by using all available chemical and isotopic data from basinwide wells tapping the regional carbonate aquifer that feeds the springs. The most plausible hypotheses require the presence of a major longitudinal heterogeneity in the distal part of the ground-water basin to explain the anomaly. Hydrodynamic channeling with an amplitude of at least 11 km is indicated.

Isotopic composition of precipitation and resulting ground water affected by climate

The stable hydrogen- and oxygen-isotope composition of precipitation varies with climate. In cold (high altitude or latitude) areas, precipitation is enriched in the heavy isotopes, deuterium or ^{18}O, relative to precipitation in warmer (low latitude, near sea level) regions. The isotopic composition of precipitation should also vary with climate; for example, precipitation falling on any location during a period of general glaciation should be more enriched in heavy isotopes than present-day precipitation. Many regional aquifers contain water recharged during the last glaciation, and studies are now underway on the isotopic composition of old water in several such aquifers. Studies by F. J. Pearson, Jr. (USGS), in collaboration with D. B. Smith and R. L. Otlet (Atomic Energy Research Establishment, Harwell, England) and R. A. Downing and R. A. Monkhouse (Central Water Planning Unit, Reading, England) (Smith and others, 1975), showed that water older than 12,000 years in the London Chalk and the Lincolnshire Limestone is enriched in ^{18}O by less than 0.8 permil. An assumption that the seasonal pattern of recharge has not changed could suggest that the temperature was less than 1°C cooler during the last glaciation than it is at present. However, a more reasonable interpretation is that recharge occurred only during mild climatic phases within the glaciation and only then during summer periods because frozen ground prevented recharge during late autumn and early spring, the seasons in which recharge now occurs.

MINERAL-EQUILIBRIUM STUDIES

T. M. L. Wigley (University of East Anglia, England) and L. N. Plummer (USGS) developed a computer program (WATMIX) for modeling closed- and open-system mixing of arbitrary end-member solutions. Test calculations isolated the following three processes leading to nonlinear behavior: (1) The algebraic effect, (2) the ΔP_{CO_2} effect, and (3) the ionic strength effect.

The WATMIX program was used by William Back and B. B. Hanshaw (USGS), T. E. Pyle (University of South Florida), and A. E. Weidie (University of New Orleans) (1976) to explain the geochemical behavior of an inlet on the eastern coast of the Yucatan Peninsula in Mexico. They concluded that the inlet was formed by the solution of limestone caused by the mixing of ocean water with discharging ground water.

Plummer and D. L. Parkhurst (USGS) and D. R. Kosiur (University of California, Los Angeles) extended the computer program (MIX2) to allow calculation of reaction paths in the closed system $CaO\text{-}MgO\text{-}Na_2O\text{-}K_2O\text{-}CO_2\text{-}H_2SO_4\text{-}HCl\text{-}H_2O$. Plummer used the program to calculate the solubility of calcite and dolomite in carbonate mixtures of ground water and seawater, simulate closed-system titration experiments, and model reaction paths in the Floridan aquifer. The MIX2 program was applied to studies of the Edwards Limestone aquifer of Texas by F. J. Pearson, Jr. (USGS), the Fox Hills Sandstone aquifer of North Dakota by D. C. Thorstenson (Southern Methodist University), and the Madison Limestone aquifer in the Black Hills of South Dakota by Back, Hanshaw, C. T. Rightmire, and Meyer Rubin (USGS) and Perry Rahn (South Dakota School of Mines and Technology).

TRACE ELEMENTS

Low concentrations of trace elements such as Ag, Cu, Cr, V, Mo, and As in surface and ground water may be controlled by reduction processes coupled to ferrous iron oxidation at ferric hydroxide surfaces or by coprecipitation of the anionic forms of some of these elements combined with ferrous or ferric cations. Dissolved concentrations of other trace elements—notably cobalt, nickel, and lead—may be greatly decreased by oxidation processes coupled to the disproportionation of Mn^{+3} oxides. Chemical thermodynamic calculations and graphs evaluating these effects were prepared by J. D. Hem (unpub. data, 1976).

C. J. Lind and J. D. Hem (1975) reported that, when small amounts of an organic complexing agent (quercetin) were present in a dilute solution of aluminum perchlorate, sodium, and silica near neutral pH, an amorphous 1:1 aluminosilicate solid was produced, which, after aging in solution at 25°C for 6 months or more, contained small well-crystallized kaolinite plates. These plates were identified by electron microscopy. The organic material seems to delay the polymerization of aluminum hydroxide toward development of gibbsite and provide sites for establishing the aluminum-oxygen-silicon bonds required in the kaolinite structure.

EXPERIMENTAL KINETICS

H. C. Claassen and A. F. White (USGS) reported that experimental reactions between tuffs and water equilibrated with various pressures of carbon dioxide have disclosed an initially parabolic reaction rate that changes to an approximately linear rate as the reaction proceeds. The parabolic reaction primarily represents solid-state diffusion. These results agree both qualitatively and quantitatively with the observations of others investigating artificial glasses and pure-mineral phases.

Increasing the partial pressure of carbon dioxide (P_{CO_2}) equilibrated with the aqueous reactant increases the resulting hydrogen-ion concentration and hence the overall reaction rate. The change in rates of appearance of different ions is not the same; that is, an increased selectivity is observed with decreased P_{CO_2}. Increasing the temperature of the reaction suppresses the parabolic rate because of pH changes associated with the temperature dependence of CO_2 solubility but increases the slope of the linear portion of the concentration-versus-time plot.

Experiments using P_{CO_2} pressures similar to pressures measured in water associated with tuffaceous-rock model systems have yielded results identical to values extrapolated from field data; initial dissolution results in ion ratios identical to those in the parent rock. Further dissolution reflects the processes of differential solubility and ion diffusion rate in the resultant solution composition.

L. N. Plummer and D. L. Parkhurst (USGS) and T. M. L. Wigley (University of East Anglia, England) studied the dissolution kinetics of calcite from 5° to 60°C and 0 to 1 atm P_{CO_2}. A surface-mechanism model was developed that accounts for observed linear forward-rate dependencies on (1) the bulk-fluid activity of the hydrogen ion, (2) the surface activity of dissolved carbon dioxide, and (3) a constant forward rate. The model also accounts for an observed linear back-rate dependence on the bulk-fluid product of calcium- and bicarbonate-ion activities. The results predict the rate of dissolution and crystal growth of calcite in the system CaO-CO_2-H_2O.

Plummer and D. C. Thorstenson (Southern Methodist University) evaluated the equilibrium criteria for two-component solids reacting with fixed composition in an aqueous phase. The kinetic-state, stoichiometric saturation was defined and differentiated from stable and metastable equilibrium. Thermodynamic relations were developed that allow calculation of the thermodynamic properties of binary solid solutions from nonequilibrium (stoichiometric saturation) experimental data. An analysis was made of the thermodynamic properties of magnesian calcites.

STATISTICAL GEOCHEMISTRY AND PETROLOGY

A. T. Miesch (1975) continued the application of an extended method of *Q*-mode factor analysis to problems in igneous petrology. He developed a series of interactive computer programs that prompt the user to give instructions for proceeding in the computations. The interactive programs use an input file produced by the CABFAC program developed by Klovan and Imbrie (1971) and modified by Klovan and Miesch (1975). The first major step is to determine the number of end members that are required to account for any given proportion of the variances in each of the oxide variables. The next step is to identify mathematically suitable end-member compositions and then to judge their petrologic plausibilities by computing and examining the required mixing proportions. The end-member compositions mixed in the indicated proportions yield estimates of the original oxide data rather than estimates of row-normalized data as produced by conventional factor analysis methods. Thus, petrologists may accept or reject the mathematical adequacy resulting from such models even without completely comprehending the methods by which the models were derived. Two of the most heavily used programs, EQEXAM and EQSCAN, are used to examine potential end-member compositions for their mathematical suitabilities in a given problem. Program EQEXAM is used to examine a specific composition, and program EQSCAN is used to examine compositions throughout such compositional series as fayalite-forsterite, wollastonite-enstatite-ferrosilite, or quartz-orthoclase-albite-anorthite. Compositions within such series that are identified as most compatible with the data in a given problem are generally the compositions of mineral phases that are present in the analyzed rock samples. The addition or subtraction of these phases may be inferred to have caused compositional variation among the samples.

Programs EQSPIN and EQSTER are used in situations where the factor models have been found to require three end members. Program EQSPIN is used to represent the compositional system in a stereogram and to rotate the stereogram in various ways to remove distortion and thereby facilitate the search for mathematically and petrologically suitable end-member compositions. Program EQSTER is used to determine the composition and the CIPW norm represented by any point that is or can be plotted on the stereogram.

Program EQMAIN is used to compute the required mixing proportions for a given set of selected end-member compositions, but it can also be used to search for end-member compositions. EQMAIN is the principal program used in interactive modeling procedures. The mixing proportions can be written on an output file for further computer processing. Program EQCHEK is used to recalculate an estimate of the oxide data and to derive final goodness-of-fit statistics and the model residuals.

Miesch and D. M. Morton used the extended *Q*-mode method in a study of chemical variability in the Lakeview Mountains pluton in the southern California batholith (Morton, 1969). Results indicated that the mafic inclusions in the pluton are genetically related to the hornblende-biotite quartz diorite that comprises most of the pluton. It is possible to account for 78 to 93 percent of the variance in each of seven major oxides, determined for 158 samples, by subtracting the composition of the inclusions from a parent magma that varies in composition between melanocratic and leucocratic schlieren. The compositional zoning found in the pluton is the opposite of that found in otherwise similar plutons in the southern California and Sierra Nevada batholiths in that the most mafic part is near the pluton's center rather than near its margins. This reversed zoning can be explained as a result of either a more extensive separation of the phases that comprise the inclusions from the marginal parts or the disintegration and reincorporation of inclusions into the central part of the magma. The disintegration may have been caused by the chemical action of volatiles as evidenced by the presence of pegmatites.

Miesch and B. L. Reed used the same method in a study of compositional variability in the Sierra Nevada and Alaska-Aleutian Range batholiths. Results showed that more than 90 percent of the variance in each of seven major oxides in the Alaska-Aleutian Range batholith can be accounted for by models having only three end members; four end members are required in models for the Sierra Nevada batholith. It is unlikely that this circumstance came about by chance; in fact, it was probably caused by three or four petrologic processes that were dominant over all others in the formation of the batholiths. One of the end members in the models derived for each batholith is a parent magma or magma-source material of andesitic composition. Two other end members in each of the models represent assemblages of plagioclase, hornblende, and magnetite. The model for the Sierra Nevada batholith includes a fourth end member that represents an assemblage of plagioclase and biotite. However, whether the derived models are approximately correct has no bearing on the fact that processes involving three and four end members can account for more than 90 percent of the compositional variability in two batholiths that are each comprised of numerous plutons formed over a duration of 130 million years.

ISOTOPE AND NUCLEAR GEOCHEMISTRY

ISOTOPE TRACER STUDIES

Application of lead isotopes to ore-prospect evaluation

Lead isotopes have been used in evaluating the ore prospects of Mesozoic and Cenozoic magmatothermal deposits in the rejuvenated cratons of the Western United States. B. R. Doe and R. E. Zartman found that deposits that have produced hundreds or thousands of millions of dollars worth of ore have characteristic lead isotope compositions ($^{206}Pb/^{204}Pb < 18.1$). Deposits in this isotopic range—including those in Bingham Canyon and Park City, Utah; Butte, Mont.; Bisbee, Ariz.; Santa Rita and Hanover, N. Mex.; and Leadville and Gilman, Colo., as well as many smaller and even noneconomic deposits —contain what are referred to as "main-spectrum" leads. Larger, more radiogenic lead isotope ratios ($^{206}Pb/^{204}Pb \sim 18.3$–$19.1$) are referred to as "normal" leads if their ratios are between 18.5 and 18.8 and as "radiogenic" leads if their ratios are greater than 18.8. Sizable deposits have been found in both of these isotopic groupings, but the largest individual deposits have produced from $100 to $200 million worth of ore (Tintic, Utah; Creede, Colo.; Sunnyside, Utah; and Idarado, Colo.), notably less than those in the main-spectrum category. Only one magmatothermal district has been found so far in which deposits have produced more than $1 million worth of ore and in which $^{206}Pb/^{204}Pb$ values are greater than 19.1 (actual ratios are between 20.2 and 20.4). This is the Wood River district of Idaho, adjacent to the Idaho batholith. The entire district has produced only $23 million worth of ore; individual mines have produced less than $10 million worth of ore. Lead isotopes appear to give some clues as to how large a production can be expected for individual mines formed by magmatothermal processes in rejuvenated cratons. Although these observations are of value in this grouping, they do not necessarily apply to other kinds of genetic origins. They particularly do not apply to deposits in the lateral secretion regime (for example, deposits in the Mississippi Valley). Care should therefore be taken in extrapolating the above observations to other kinds of ore deposits.

Lead isotope composition of basalts from the Reykjanes Ridge, Iceland

Lead isotope ratios of basalts erupted along the Reykjanes Ridge and the median neovolcanic zone of Iceland were obtained by Mitsunobu Tatsumoto (USGS), S. S. Sun (S.U.N.Y., Stony Brook), and J. G. Schilling (University of Rhode Island). Along the ridge axis, distinct gradients were observed in the ratios of isotopic and large-ion-lithophite (LIL) elements. Plots of lead isotope ratio against Pb/Pb, Th/U against La/Sm, and U/Th against distance are nearly linear; this linearity suggests that binary mixing has occurred between the LIL-depleted asthenosphere and a mantle plume. More subdued trends in major and single LIL elements appear to result from variations along the ridge in the degree of source melting and from crystal fractionation.

Strontium isotope composition of Yakima Basalt, southeastern Washington

The $^{87}Sr/^{86}Sr$ ratios of four intracanyon flows within the upper part of the Yakima Basalt of southeastern Washington were obtained by D. A. Swanson and T. L. Wright (USGS) and D. O. Nelson (Oregon State University). The flows, from oldest to youngest, give ratios of 0.7146 (Mesa flow) and 0.7078, 0.7079, and 0.7109 (lower Monumental flow). Uncertainty in a ratio is 0.0004 at the 95-percent confidence level. The ratio of 0.7146 sets a new upper limit on the range of known $^{87}Sr/^{86}Sr$ ratios for the Columbia River Basalt Group, the lowest value for which is 0.7033 (Picture Gorge Basalt). Preferred explanations for the large variation include isotopic inhomogeneity within the source region or involvement of the magma with "old" lithospheric mantle. The two intracanyon flows of intermediate age, interpreted as the Pomona and Elephant Mountain Basalt Members by Swanson and others (1975), have ratios that agree with those obtained by McDougall (1976) from the Pomona and the Elephant Mountain in central Washington.

Strontium isotopes as indicators of paleogeography

Initial $^{87}Sr/^{86}Sr$ ratios of Mesozoic granitic rocks in the vicinity of the Garlock fault zone of California were investigated by R. W. Kistler and Z. E. Peterman. The ratios show an offset pattern that is compatible with about 60 km of left-lateral movement along the central portion of the fault. A sharp boundary exists between granitic rocks with ratios greater than 0.7060 and those with ratios less than 0.7060. The boundary is interpreted as the edge of a Precambrian continental crust about 1,700 million years old and has a shape suggestive of a rift zone in that crust.

The configuration of the Precambrian continental crust is revealed by the isotopic pattern after lateral offsets are removed along the Garlock and San Andreas fault systems. This configuration, when it is viewed in relation to the loci of plutons of different ages in California, indicates that approximately 800 km of left-lateral early Mesozoic offset may have occurred along a Sonora-Mojave megashear (Silver and Anderson, 1974).

STABLE ISOTOPES

Equilibrium-disequilibrium relations in granite

J. R. O'Neil (USGS) and Martin Frey and J. C. Hunziker (University of Bern) distinguished Permian and Tertiary mineral assemblages in the Monte Rosa granite in the western Alps.

Disequilibrium between these assemblages is documented by the following facts:

- Muscovites show Permian ages and oxygen isotope temperatures of 520° to 560°C, and texturally distinguishable phengite shows Tertiary ages and oxygen isotope temperatures of 450° to 490°C.
- Comparison of radiogenic and stable isotope relations indicates that the radiogenic isotopes were mobilized during Alpine time without breaking aluminum-oxygen or silicon-oxygen bonds.
- Oxygen isotope "reversals" exist.

Equilibrium during Permian time is obscured by Alpine overprinting effects. However, for the rocks least affected tectonically, excellent concordancy exists between quartz-muscovite and quartz-biotite oxygen isotope temperatures, and these relations were undisturbed during Alpine metamorphism.

Arguments for equilibrium during middle Tertiary metamorphism are as follows: (1) middle Tertiary Rb-Sr mineral isochrons of up to six minerals exist, and (2) oxygen isotope temperatures of coexisting Alpine phengites and biotites are concordant. The major factor for the adjustment of the Permian assemblages to Alpine conditions was the degree of Alpine tectonic overprinting rather than the maximum temperatures reached during the middle Tertiary Alpine metamorphism. The lack of exchange with externally introduced fluid phases in the samples least affected by tectonism indicates that the Monte Rosa granite "stewed in its own juices." This seems to be the major cause for the persistence of Permian ages and corresponding temperatures.

Carlin, Nevada, gold deposits

R. O. Rye and A. S. Radtke concluded a stable isotope study of the Carlin, Nev., gold deposit. The gold is extremely finely disseminated in carbonate rocks in the upper part of the Silurian Roberts Mountains Formation and appears to be localized by high-angle normal faults. Oxidized ore grades into unoxidized ore at depth, and barite veins bottom out near the interface between oxidized and unoxidized ore.

The very low (~ -150 permil) δD values of water in fluid inclusions in late barite, quartz, and calcite indicate that the ore fluids were dominantly meteoric water. The $\delta^{18}O$ values of the same minerals suggest that hydrothermal fluids underwent extensive exchange with the carbonate host rock and widespread boiling during barite deposition in the oxidized zone.

The sulfur isotope data on coexisting sulfide barite pairs indicate that the circulating meteoric-water ore fluids reached temperatures of at least 350°C before they deposited ore at temperatures of 200°C or less. The $\delta^{34}S$ data further indicate that the sulfur was derived from the local Paleozoic rocks.

The data are consistent with the theory that the deposit was generated entirely by a circulating ground-water system related to a Tertiary intrusive that derived all of the significant components from the local country rocks.

Copper Canyon mine, Nevada

J. N. Batchelder studied the compositions of light stable isotopes and fluid inclusions in a porphyry copper-gold-silver deposit adjacent to an altered granodiorite laccolith at Copper Canyon mine near Battle Mountain in Nevada. The total volume of the granodiorite is smaller than estimates of the amount required to provide a source for the water in the ore-forming fluids. Fluid inclusion water in quartz yielded δD values from -102 to -76 permil. Calculated δD values for water in equilibrium with biotite range from -99 to -76 permil. The calculated $\delta^{18}O$ values of water in equilibrium with quartz range from $+2.7$ to $+9.2$, and water calculated to be in equilibrium with biotite ranges from $+5.8$ to $+10.4$ permil. These data suggest that the ore-forming fluids were most likely composed of magmatic water that had mixed with some meteoric water during metallization in a convective-type system.

ADVANCES IN GEOCHRONOMETRY

Uranium-lead isotope dating of Wyoming uranium ores

Work by K. R. Ludwig on uranium ores from the Shirley Basin of Wyoming, as well as data on ore samples from the Gas Hills and Crooks Gap districts of Wyoming, supports the concepts of uranium daughter migration. Pyrite associated with pitchblende or coffinite seems to incorporate consistently the radiogenic lead lost by these minerals.

None of the newly obtained uranium-lead isotope apparent ages of pitchblende and coffinite from these districts is younger than 27 million years; some samples place the minimum age of initial uranium concentration at more than 35 million years. Because most previously published estimates set the time of mineralization in these districts as Pliocene or younger, these much older apparent ages are of interest.

An interesting byproduct of these isotopic investigations is the finding of massive, easily separated amounts of coffinite in both Gas Hills and Crooks Gap ores. The coffinite seems to occur in two distinct, intimately intergrown types, both of which contain essential calcium.

Discordant $^{40}Ar/^{39}Ar$ age spectra of Mesozoic tholeiites, Antarctica

R. J. Fleck (USGS) and J. F. Sutter and D. H. Elliot (Ohio State University) completed conventional K-Ar and $^{40}Ar/^{39}Ar$ age-spectrum studies of tholeiitic basalt flows of the Ferrar Group in the central Transantarctic Mountains of Antarctica. The studies indicate an inhomogeneous distribution of radiogenic argon with respect to potassium. Argon-40/argon-39 release patterns distinctly different from those of thermally disturbed samples indicate redistribution of radiogenic argon within the basalt, with no net loss in some samples. The amounts of redistributed argon vary directly with devitrification and are reflected in progressive modification of the age spectra. Age spectra of samples having substantial amounts of redistributed argon but minor net loss display low-temperature heating increments containing excess ^{40}Ar and high-temperature steps indicating argon loss. Where devitrification involves most potassium sites within the rock, plateaus with no geologic significance may be formed.

Age of nephrite occurrences, Great Serpentine Belt, New South Wales, Australia

M. A. Lanphere (USGS) and J. J. Hockley (Fairfield, New South Wales, Australia) made K-Ar measurements on nephrite from two occurrences in the Great Serpentine Belt southeast of Tamworth, Australia, by using the $^{40}Ar/^{39}Ar$ total-fusion technique. The measurements yielded ages of 273 ± 5.8 and 280 ± 5.6 million years. The K-Ar ages indicate that tectonic emplacement, during which the nephrite was produced as a reaction product between ultramafic rock and country rock, occurred early in the Permian, about 275 to 280 million years ago. These results also demonstrate that the $^{40}Ar/^{39}Ar$ technique applied to nephrite can be used to date certain tectonic events that are undatable by conventional techniques because of the extremely low K_2O content of nephrite.

Age of Hawaiian-Emperor bend

G. B. Dalrymple and D. A. Clague gathered $^{40}Ar/^{39}Ar$ age data on alkalic and tholeiitic basalts from the Diakakuji and Kinmei seamounts in the vicinity of the Hawaiian-Emperor bend indicating that these volcanoes are about 41 and 39 million years old, respectively. Combined with previously published age data on the Yuryaku and Koko seamounts, the new data indicate that the best age for the bend is 42.0 ± 1.4 million years and that the average rate of relative motion between the Pacific plate and the Hawaiian hotspot during the last 42 million years was about 8.4 cm/yr.

An interesting aspect of the study is that $^{40}Ar/^{39}Ar$ total-fusion ages on altered whole-rock basalt samples from the seamounts are consistent with feldspar ages and with $^{40}Ar/^{39}Ar$ incremental heating data and appear to reflect the crystallization ages of the samples, even though conventional K-Ar ages are significantly younger. Electron microprobe examination of the basalts shows that this effect is probably caused by low-temperature loss of neutron-derived ^{39}Ar from nonretentive montmorillonite clays that have also lost radiogenic ^{40}Ar. The results suggest that reliable K-Ar ages can be obtained on altered and normally undatable submarine samples with the $^{40}Ar/^{39}Ar$ technique.

Old zircon from the Sierra Nevada

T. W. Stern determined a concordant Pb/U age of 259 million years for a zircon from the Sierra Nevada. The sample was collected by B. A. Morgan from a pyroxene diorite just east of Sonora, Calif. This date is older than any plutonic age yet determined in the central Sierra Nevada by about 50 million years. The implications of the 259-million-year date for the history of the central Sierra Nevada batholith are considerable; an understatement would be that this crust had a long and far more complex prebatholithic and early batholithic history than investigators had heretofore realized.

Fission-track dating in a deep drill hole

C. W. Naeser (USGS) and R. B. Forbes (University of Alaska) determined that fission-track ages of apatites from the Los Alamos Scientific Laboratory geothermal test holes in the Jemez Mountains of New Mexico are strongly affected by the elevated temperatures encountered in the holes. An age of 240 million years was obtained on apatite separated from Precambrian rocks exposed at the surface several kilometers from the drill site. Apatite separated from the core at a depth of 790 m (100°C) has an age of 69 million years. The apparent apatite age decreases with increasing depth to 1,880 m (135°C), where the apparent age is zero. Sphene fission-track ages average about 1,350 million years in the zone between 760 m (100°C) and 2,580 m (177°C). Sphene from a depth of 2,900 m (197°C) has an apparent age of 1,050 million years. The zero age for apatite is compatible with previous annealing studies done on apatite in the laboratory.

Status of uranium-series dating of bones

Fossil bones ranging from a few thousand to about 350,000 years old can be dated by the uranium-series method. This dating involves the assumptions that uranium is assimilated by the bones shortly after the death of an animal and that uranium and its daughter elements remain in the fossil. Little work had been done to examine the validity of these assumptions until B. J. Szabo dated 10 samples with known radiocarbon ages ranging from 10,000 to 30,000 years. The samples were taken from various localities in different depositional environments. Four of the samples yielded concordant uranium-series and radiocarbon ages; uranium-series dates were too low in three samples and too high in one sample; the analytical results for the remaining two samples showed evidence that uranium had migrated in and out of the samples. The average deviation between radiocarbon dates and uranium-series dates in the 10,000- to 30,000-year age range is ±4,200 years; the two samples that did not remain closed systems were excluded from the calculations.

Identification of excess ^{40}Ar in igneous rocks and minerals

M. A. Lanphere and G. B. Dalrymple completed $^{40}Ar/^{39}Ar$ age-spectrum studies of two pyroxenes, a plagioclase, and a biotite that were all known to contain excess ^{40}Ar. All the age spectra show a distinctive "saddle" shape having very high apparent ages at the low and high ends and minimum ages in the middle (intermediate amounts of ^{39}Ar released). The minimum ages in the spectra sometimes approach the crystallization ages of the minerals but are still too great. The data show a very large amount of scatter when they are plotted on a $^{40}Ar/^{36}Ar$ versus $^{39}Ar/^{36}Ar$ diagram; an isochron drawn through any combination of points would not reveal the correct crystallization age. These results are similar to those reported by Lanphere and Dalrymple (1971) and subsequently confirmed by several other investigators for igneous rocks. The saddle-shaped age spectra and the large scatter on the isochron diagram now appear to be diagnostic of excess ^{40}Ar in both igneous rocks and igneous minerals; thus, the technique is a valuable geochronologic tool.

GEOTHERMAL SYSTEMS

Mixing model geothermometry

A. H. Truesdell and R. O. Fournier continued to develop methods for estimating the underground temperatures of hot spring systems by using the chemical compositions of the hot spring waters that result from mixing hot- and cold-water components.

A new graphical method using a plot with dissolved silica and enthalpy as coordinates allows quick determination of the temperature of the hot-water component of a nonboiling thermal spring. The method is applicable to warm spring waters in which the hot-water component either has not lost heat before mixing or has lost heat by separation of steam before mixing.

A method to be used when boiling springs have different chemical compositions was also devised. The method uses a plot having chloride and enthalpy as coordinates. Enthalpy is estimated from the silica content of the boiling spring; saturation with respect to quartz is assumed. The method is used to test boiling and mixing relationships among the different hot spring waters and to predict aquifer temperatures at greater depths in the hydrothermal system than conventional chemical geothermometer techniques can. An equivalent analytical method was also devised.

Geochemical studies of geothermal waters

According to R. H. Mariner and L. M. Willey (1976), the chemical and isotope compositions of thermal springs and wells in Long Valley, Calif., indicate that the springs issue mixed waters. Some of the spring waters have also been altered by subsurface boiling. Reservoir temperatures of at least 220°C are reasonable for the thermal system in Long Valley.

The chemical compositions of several hot springs having low rates of flow in the San Emidio Desert of northwestern Nevada qualitatively indicate association with a high-temperature reservoir. The temperature of the thermal aquifer associated with these springs may be on the order of 200°C (Mariner, Presser, and Evans, 1976).

Electromagnetic modeling and inversion

W. L. Anderson developed numerical techniques and computer programs to model two-dimensional rectangular structures buried in a conductive half-space excited by a plane-wave source by means of an integral equation solution and to invert vertical magnetic-field sounding data obtained over a layered Earth model with a grounded, finite, horizontal electric-wire source by using a nonlinear least squares technique.

The first program has a variety of potential uses in geothermal investigations and other activities (for example, modeling hot magma dikes where very low frequency measurements have been made at the Earth's surface and studying the effects of depth of burial, different frequency sources, conductivity contrasts, body extent, body dip, and so on).

The second program provides a means of determining statistical estimates for unknown layer parameters of interest in geothermal investigations by using a controlled frequency domain, extremely low frequency source transmitter-receiver in the frequency range 1 to 10 kHz. The current implementation attempts to provide practical fits to observed field data through a variety of program options such as (1) inverting both frequency and distance soundings, (2) scaling parameters to constrain the least squares solution to positive conductivities and thicknesses, (3) scaling observations to control unusual round-off effects owing to widely ranging data, (4) weighing each observation in the least squares adjustment, (5) providing for mixed observations (both amplitude and phase data), (6) holding certain parameters fixed or constrained to a known value, (7) providing goodness-of-fit statistics, and (8) controlling accuracy during the solution by means of various numerical integration options.

Geothermal reservoir models verified

The theoretical models of J. W. Mercer, C. R. Faust, and G. F. Pinder, which described vapor- and liquid-dominated geothermal reservoirs (Mercer and Faust, 1975), were verified, and the resulting partial differential equations were solved in the areal plane by using finite-element and finite-difference techniques. The two approaches were tested by using analytical solutions and laboratory data. On the basis of these and additional numerical experiments, it appears that the finite-element model is better suited for single-phase (liquid-dominated) reservoirs and that the finite-difference model can better handle the strongly nonlinear problems associated with vapor-dominated geothermal reservoirs. Application of these models to field problems has been initiated.

Numerical modeling of liquid geothermal systems

M. L. Sorey (1975) reported that a computer program (SCHAFF) that solves the heat and fluid transport equations in porous media has been developed, tested, and applied to geothermal systems in California and Nevada. Natural (cellular) convection problems have been simulated in two and three dimensions with temperature-dependent viscosity, specific heat, and density.

M. L. Sorey and R. E. Lewis (1976) analyzed various models for heat transfer from hot spring systems and applied them to thermal discharge areas in Long Valley, Calif., and Grass Valley, Nev.

Velocity measurements in Franciscan rocks

R. M. Stewart and Louis Peselnick completed laboratory measurements of the compressional velocities (V_p) of 14 Franciscan rocks ranging from high-porosity sandstones of the coastal belt to jadeitized metagraywacke from the Diablo Range and including shale and mélange matrix samples. The measurements were made from 0 to 8 kbar and from 20° to 300°C. The highest velocities found (6.5 km/s at 4 kbar and 300°C) occur in a highly jadeitized rock. Since rocks with similar mineralogies and other high-velocity rocks such as basalts are localized in distribution and comprise a small volume fraction of the Franciscan terrane and since the compressional velocity identified from seismic refraction at a depth of some 12 km below the Diablo Range is 6.8 km/s, one can draw the conclusion that the Franciscan assemblage is less than 12 km thick in the central Diablo Range. For this region, samples with common lithologies and average densities display velocities in good agreement with field measurements of seismic velocities above 12 km.

The pressure-temperature-density data for the samples suggest a V_p inversion in the Franciscan. However, the critical thermal gradients for these rocks (13° to 21°C/km) were found to depend strongly on the gradient of the bulk density. Consequently, a small increase in bulk density with depth, owing to metamorphism, could easily prevent inversion. The strong dependence of V_p on bulk density illustrates the hazards of modeling a region by a single rock type without considering metamorphism.

Fractures in hot rock

Theoretical studies by D. D. Pollard of pressurized fractures in hot rock showed that stress gradients can have a profound effect on fracture form and propagation direction. Theory suggests that gradients can limit the possible height of a stable fracture. For example, a fracture greater than 0.1 km high requires that the gradient of least principal far-field stress be almost identical to the pressure gradient within the fracture, an unlikely condition. The design of a process to extract energy from hot, dry rock should take these effects into account, and the appropriate stress gradients in the geothermal reservoir should be determined. The theoretical mechanical interactions between vertical fractures and a nearby horizontal free surface also were determined. A fracture does not "feel" the effects of the surface at depths to fracture center greater than 10 times the half height. For more shallow fractures, the cross-sectional form is asymmetrical (wider near the surface) even for uniform stress conditions. The stress intensity is greater at the top of the fracture, so it should tend to propagate toward the surface rather than away from it. Determination of theoretical tilts and strains at the free surface provides a means for monitoring fracture height and form by measuring surface deformation during hydraulic fracturing operations. Reconnaissance fieldwork on sheet intrusions indicates that the theoretical models are not adequate to describe all of the common variations in form of the intrusions. By analogy, they probably are not an adequate description of hydraulic fractures. Several igneous dikes that were mapped in detail are not continuous, but individual segments are arranged en echelon. This form may be related to changes in the orientation of the stress field through which the hydraulic fractures or sheet intrusions propagate.

Hydrofracture of rock

Laboratory studies by J. D. Byerlee, D. A. Lockner, and J. D. Weeks (1975) of hydraulic fracture in sandstone at confining pressures to 1,000 bars and differential stresses to 4,000 bars showed that, at high fluid injection rates, classical hydraulic tension fractures were formed but that, at low injection rates, shear fractures were formed. The explanation for these phenomena is that, during slow injection, the fluid diffuses into the rock and lowers the effective confining pressure; if the differential stress on the rock is high enough, a shear fracture will form. At fast injection rates, appreciable fluid diffusion does not occur. The fluid pressure increases until the stresses around the injection hole exceed the tensile strength of the rock and tension fractures are formed.

Permeability changes in hot granite

Laboratory experiments by R. S. Summers, K. W. Winkler, and J. D. Byerlee (1975) showed that the permeability of hot granite under stress decreases very rapidly as water is flushed through. Samples of granite 3.8 cm long and 1.6 cm in diameter were studied at a confining pressure of 500 bars, temperatures to 400°C, and differential stresses to 3,500 bars. In all of the experiments, the initial permeability was high owing to thermal fracturing during heating of the sample and to the flow of water into the sample. In each of the experiments, the permeability decreased rapidly during the first 12 hours. The permeability changes showed little dependence on stress and temperature variations. The most likely explanation for the observed permeability decrease is that the pores and cracks in the rock became clogged with alteration minerals formed during the experiment.

Earthquake studies in geothermal areas

A. M. Pitt continued his study of the seismicity of the Yellowstone region. In 1975, seismic activity in the Hebgen Lake area of Montana was below normal, but the Yellowstone caldera was unusually active. On June 30, 1975, an earthquake of $M_b=6.1$ occurred; its epicenter was 7 km from the Norris Geyser Basin. Pitt and C. S. Weaver located the main shock and 100 associated aftershocks by using a new velocity model for the Yellowstone caldera. The activity defined two distinct northwest-trending zones that extend well into the Yellowstone caldera from the Norris area. Work to date suggests that the caldera boundary is not as important to the local tectonics as past seismic studies originally implied.

A. W. Walter, H. M. Iyer, and Weaver studied microearthquake activity and teleseismic delays in the Coso geothermal area near China Lake in California with a 16-element seismic array. Earthquake swarms have occurred in several sections of this region. During one swarm in December 1975, hundreds of events occurred within a 12-hour period. Background seismicity was widely scattered during the initial 3 months of monitoring, and few distinct trends developed. Preliminary teleseismic delay studies did not show any large delays such as those seen in Yellowstone or The Geysers in California.

Delineation of magma body under the Yellowstone caldera

H. M. Iyer and J. R. Evans found that there are large delays in the traveltimes of teleseismic *P* waves passing at various depths under the Yellowstone caldera inside the caldera and within a 200-km distance of the edge of the caldera (Iyer, 1975; Iyer and Evans, 1975). Using ray plotting and mathematical inversion techniques, they interpreted these delays as being due to the presence of a magma body in the crust and upper mantle under Yellowstone. A study of the attenuation of *P* and *S* waves from local earthquakes by A. M. Pitt and C. S. Weaver and other geophysical evidence indicated that the top of the magma body is 5 to 10 km beneath the surface under the caldera. Present data show that the body extends at least 200 km into the upper mantle. The compressional wave velocity is 15 percent lower than normal near the top of the body and decreases to about 5 percent lower than normal at depth. There is also evidence to show that the horizontal dimension of the body becomes much larger at depth than the surface dimensions of the caldera (40×80 km^2).

H. M. Iyer and Tim Hitchcock (1975) found similar teleseismic delays over a 500-km^2 area in The Geysers-Clear Lake region of California. These observations support available geothermal and geophysical data, which indicate the presence of a magmatic heat source under the region.

High seismic velocity zones under Kilauea

W. L. Ellsworth and R. Y. Koyanagi found significant lateral variations of seismic velocity to depths of 70 km in the crust and upper mantle under Kilauea Volcano in Hawaii. Inversion of teleseismic *P*-wave arrival times recorded in Hawaii shows that the crustal structure is dominated by a relatively high seismic velocity (an increase of about 4 percent) within the central summit complex and along the two radial rift zones, in comparison with seismic velocity along the nonrift flank of the volcano. A velocity increase of only about 1 percent was found in the mantle under the summit of Kilauea.

New geophysical instrumentation for geothermal surveys

A new portable telluric profiler that can be backpacked was developed by D. H. Rohret and others (1975). This new instrument enables continuous telluric profiles to be made in remote areas where roads are not available.

R. H. Lescelius and others (1976) developed a portable, digitally recording, three-component magnetometer system for use in making magnetometer array studies.

Helium surveys—a possible geothermal exploration tool

Field surveys of the concentration of helium in the soil gas around hot springs and Known Geothermal Resource Areas (KGRA) in the Western United States by A. A. Roberts and others (1975) indicated that a helium survey technique may be a quick and inexpensive exploration tool for geothermal reservoirs.

Initial work done around Indian Hot Springs at Idaho Springs, Colo., showed that the concentration of helium in the soil gas was equal to background (5.2 ppm) in many square kilometers surrounding the area but increased to a high of about 1,000 ppm within 10 m of the hot springs. High helium values also were found near hot springs in Yellowstone National Park in Wyoming, at Mount Princeton Hot Springs in Colorado, and at Roosevelt Hot Springs in Utah.

Further work was completed by Roberts and Mary Dalziel in a potential geothermal area in the East Tintic mining district of Utah. This area has no obvious surface manifestations of the anomalously hot water temperatures at depth. Helium readings in the surrounding cooler areas were all equal to background values; increasing helium values coincident with increasing water-table temperature readings (Lovering and Morris, 1965) reached a maximum near the water temperature high with 300 to 450 m of overburden.

Helium surveys were also completed by Roberts (1975) over three KGRA's in the Imperial Valley of California, an area where the geothermal reservoirs are 1,700 to 3,000 m underground. In each case, the observed helium highs correlated well with reported temperature gradients or heat-flow measurements.

These studies strongly support the usefulness of a helium survey technique in exploring for geothermal resource areas.

SEDIMENTOLOGY

Sedimentology, the study of sediment and sedimentary rock, encompasses investigations of principles and processes of sedimentation and includes development of new techniques and methods of study. Sedimentological studies in the USGS are directed toward (1) the solution of water-resource problems and (2) the determination of the genesis of sediment and the application of this knowledge to sedimentary rocks to gain a more precise interpretation of their depositional environments. Many USGS studies involving sedimentology have applications to other topics such as marine, economic, and engineering geology and to regional stratigraphic and structural studies; these studies are presented elsewhere in this volume under their appropriate headings.

Studies of fluvial sedimentation are directed toward the solution of water-resource problems involving water-sediment mixtures. Sediment is being considered more and more as a pollutant. Inorganic and organic sediment, transported by streams to sites where deposition takes place, carries major quantities of sorbed toxic metals, pesticides, herbicides, and other organic constituents that accelerate the eutrophication of lakes and reservoirs. A 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 transport to Lake Tahoe

A 4-year study of streamflow in five major streams in the 57-km^2 Incline Village area of Nevada along the northeastern shore of Lake Tahoe showed that about 73 hm^3 of runoff and 28,000 t of sediment were transported to the lake, according to P. A. Glancy. The composite sediment discharge, which averaged 383 g/m^3 (discharged weighted), consisted of about 76 percent sand and gravel, 15 percent silt, and 9 percent clay. About 90 percent of the sediment moved during snowmelt runoff, and 10 percent moved during the rainfall and low-flow runoff. The total annual sediment yield of the five streams ranged from 30 to 220 t/km^2. The total sediment discharge for the entire study period (water years 1970–74) was considerably less than the 45,000 t discharged by Second Creek, one of the smaller tributaries, during a brief flash flood in 1967.

The amount of sediment transported by Glenbrook Creek in Douglas County, Nevada, to Lake Tahoe ranged from 13 to 34 t annually between 1972 and 1974, according to Glancy. The annual sediment yields from the 10.6-km^2 drainage area ranged from 3.1 to 8.2 t/km^2 of drainage. The composition of sediment delivered to the lake was about 30 percent sand, 34 percent silt, and 36 percent clay. The sediment was transported by runoff that ranged annually from 1.1 to 1.5 hm^3. Between 60 and 65 percent of the sediment movement occurred during snowmelt runoff, and 35 to 40 percent occurred during rainfall and low-flow periods. Data indicate that nutrient movement generally increased when sediment transport increased.

Sediment yields determined for small basins in the oil-shale region of Colorado

V. W. Norman reported that sediment loads and yields for the 1975 water year were determined for 23 gaging stations in the Piceance Creek basin in Colorado. Using an approximate specific weight of 1,280 kg/m^3, Norman obtained preliminary figures indicating that the highest yields, about 33 m^3/km^2, were obtained from the perennial main stream, Piceance Creek; ephemeral streams that had no flow during the entire year yielded no sediment. Precipitation during the 1975 water year was about 108 percent of the mean annual precipitation of 330 mm at a long-term gaging station in the basin.

The measured sediment yields for the 1975 water year are less than those derived by the Pacific Southwest Inter-Agency Committee's method of estimating basin sediment yields; that method gave a sediment yield of 48 to 330 m^3/km^2 for Piceance Creek and its subbasins (D. G. Frickel, L. M. Shown, and P. C. Patton, 1975).

SEDIMENT TRANSPORT AND DEPOSITION

Bedload transport and channel armoring

Using the Helley-Smith bedload sampler to directly sample bedload transport in the Snake and Clearwater Rivers near Lewiston, Idaho, W. W. Emmett (1976) made the following determinations:

- When streamflow values are high and the rivers are competent to move almost all sizes of streambed particles, bedload transport rates are correlative with a predictable proportion of stream-power expenditure.
- As streamflow decreases and the rivers lose competence to transport the coarser bed particles, the channel bottoms become armored and limit the availability of the smaller sized material.
- As the channel becomes armored, the smaller material is transported much less efficiently than might be expected.

A unique system for measuring bedload transport

Using a conveyor-belt system contained within a bedload trap in the riverbed, L. B. Leopold and W. W. Emmett made direct quantitative measurements of the debris transport rate in the East Fork River of Wyoming at a point that drains from a 466-km^2 area. Data collected in three spring runoff seasons, during which the peak flow was 45 m^3/s, show that the transport rate is correlated with the power expenditure of the flowing water and that at high flows the transport rate becomes directly proportional to the power expenditure.

Revision of modified Einstein method

D. E. Burkham and D. R. Dawdy (1976) revised the modified Einstein procedure (H. A. Einstein, 1950) by applying corrections to four equations. The revision was needed because D_{65} was used directly in the modified Einstein procedure to replace the equivalent sand roughness, k_s, in Keulegan's (1938) velocity equation, whereas 5.5 D_{65} apparently should have been used. The revised procedure eliminated the need to arbitrarily divide the bedload transport intensity, $\Phi_*{}^1$, by 2, as was done in the modified Einstein procedure (B. R. Colby and C. H. Hembree, 1955). For the same data, the revised procedure gives shear velocities that are significantly larger and Einstein x values that are significantly smaller than the corresponding values computed by using the modified Einstein procedure. The revised modified Einstein procedure gives computed sediment discharges that apparently are slightly more accurate than the sediment discharges computed by using the modified Einstein procedure. Data for reaches of five rivers in Nebraska, Wyoming, and New Mexico were used to test the relative accuracies of the two methods.

Sediment transport in estuarine intertidal environments

As part of an effort to compare historical and modern sedimentation rates and patterns, cores were collected from 13 sites along the margins of the Tillamook Estuary in Oregon and from 2 sites along the adjacent ocean shoreline. According to J. L. Glenn, core samples from depths to 30 m below present mean sea level revealed some aspects of Pleistocene fluctuations in fluvial, estuarine, and marine sedimentation and provided considerable detail on Holocene sedimentation phenomena leading to the formation of modern sedimentary environments. A preliminary analysis indicated that sediment deposition in the estuarine embayment was unable to keep up with the rapid Holocene sea-level rise. As a result, the estuary margin was at least 11 km inland from the present margin. Since sea level stabilized at or near the present level, fluvial sediments have prograded over estuarine sediments, and the estuary has been filling rapidly, even prior to historical time.

Sediment transport and sediment dynamics in San Francisco Bay

According to D. M. Rubin and D. S. McCulloch, sediment transport directions in the central San Francisco Bay of California appear to be controlled by a jetlike stream that flows through the Golden Gate and by adjacent large-scale eddies. Areas of accumulation and erosion, inferred from observed sediment transport patterns, agree with recent recorded changes but differ significantly from older changes, the suggestion being that major changes in sediment transport directions have taken place within the recorded history of the bay. There appears to be a demonstrable relationship between median grain size, near-bottom current velocity, and bed configuration. The same relationship appears to hold for other field and flume or model systems.

SEDIMENTARY STRUCTURES

Comparison of subaqueous and aeolian cross-stratification

Modern water-formed and wind-formed cross-strata were found to differ consistently by R. E. Hunter; the differences offer the possibility of reliably distinguishing between ancient water-laid and wind-laid sandstones. The differences occur in cross-strata that were formed by the flowage of fine- to medium-grained sand down the slipfaces of dunes or in similar bed forms less than 2 m high. Water-formed sand-flow cross-strata are typically in contact with one another and extend to the top of the slipface, whereas wind-formed sand-flow cross-strata are commonly separated from one another by primary slipface deposits and wedge out upward. Also, water-formed sand-flow cross-strata tend to be wider than the slipface height and to have poorly defined lateral edges, whereas those that are wind formed tend to be narrower than the slipface height and to have well-defined lateral edges.

Sedimentary structure investigations

T. F. Tyler studied "small-scale" aqueous-ripple development on smooth, sloping sand beds and ripple development in the lee of barriers placed on smooth, leveled sand beds in a laboratory wave channel by means of tracings and still photography. These tracings and photographs were compared with Landsat imagery and with aerial photographs of "large-scale" dunes to determine similarities between aqueous and aeolian bed-form patterns. There is a remarkable similarity between the small-scale ripples and the large-scale dunes, considering that they developed under different environmental conditions.

Development of inverse grading in inertial grain flow

Several hypotheses have been proposed to explain how inverse size grading develops in flows having a high concentration of grains. Bagnold (1954) suggested that, because grains are supported in a high-concentration flow by dispersive pressures, the largest grains (those with the greatest dispersive pressure) should migrate to the top of the grain flow (a position of low shear stress and, therefore, of low pressure), whereas the smaller grains (low dispersive pressure) should go to the bottom of the grain flow (high shear stress and, therefore, high pressure). Middleton (1970) hypothesized that the finer grains simply fall through the interstices between the larger grains. According to Bagnold's hypothesis, a heavy grain of given density ρ_H and diameter D_H would be associated at any given level in the bed with a lighter grain of density ρ_L and diameter D_L as $(\rho_L/\rho_H)^{1/2}=D_H/D_L$. Since $\rho_L/\rho_H<1$, a heavy grain should be smaller than an associated light grain. Middleton's hypothesis suggests, however, that the diameter of a heavy grain should be equal to or larger than the diameter of an associated light grain. Experiments by A. H. Sallenger, Jr., using an inertial grain flow of particles of different densities and diameters in an avalanche flume that simulates the avalanche of granular solids at the angle of repose, show not only that the diameters of heavy grains are smaller than the diameters of associated light grains but also that the agreement with Bagnold's theory is good quantitatively. Size measurements of heavy and light grains of known densities within foreshore laminae (which are commonly inversely graded) also show quantitative agreement with Bagnold's hypothesis. These results introduce a new perspective on the concept of hydraulic equivalence in sands in that equivalences in deposits of inertial grain flows are governed by the derived expression of the form $\rho_L/\rho_H=D_H/D_L$ (as opposed to settling equivalence). Furthermore, the results strongly suggest that inverse grading in all beds deposited from inertial grain flows is controlled by vertical variations of grain dispersive pressures and shear stress.

Wave-formed ripples

J. R. Dingler reported that ripple parameters in sandy, wave-influenced areas are dependent on sand size, wave conditions, and tidal stage. Results of experiments using adjacent plots of sand having different grain sizes showed that, for the existing conditions, the ripples that formed (from flat beds) were of different sizes.

CHANNEL SCOUR

At two arroyos, Cañada de la Cueva and Pueblo Cañon, in an area of gently dissected bolson deposits southwest of Santa Fe, N. Mex., arroyo cutting since 1970 has been closely related to runoff from a summer rain. The arroyo cutting was measured by H. E. Malde, and the hydrographic data were collected by A. G. Scott. The study area included a tract of several thousand hectares that is being developed as a rural subdivision. Cutting was monitored by repeated surveys of channel floors, cross sections, and headcuts and by repeated large-format photographs taken as stereopairs. Rainfall and discharge were measured simultaneously at 5-minute intervals by dual digital recorders at a gaging station on Cañada de la Cueva (drainage area, 4.64 km^2). Discharge has been as much as 18.2 m^3/s from rainfall of 25.2 mm. The maximum 15-minute intensity for this storm was 64.0 mm/hr, and runoff was 7.9 mm. The flood peak arrived in 20 minutes, by which time 80 percent of the rain had fallen; the flow subsided to one-tenth of its maximum in less than 1 hour. The same storm at Pueblo Cañon (drainage area, 13.3 km^2) resulted in an estimated discharge of 140 m^3/s, and the duration of flow could have been as brief as 30 minutes. Observed increments of cutting at Cañada de la Cueva ranged from 0.28 m for 1.8 mm of runoff to 4.9 m for 12 mm of runoff. Aggregate cutting in 5 years has been as much as 13.7 m, and the erosion of 570 m^3 of alluvium has resulted. Increments of cutting measured near the mouth of Pueblo Cañon from 1971 to 1974 were 10.3, 14.6, and 20.7 m for an aggregate of 45.6 m. This cutting removed 1,780 m^3 of alluvium.

GLACIOLOGY

Glaciological research conducted by the USGS covers a broad spectrum of basic and applied water-resource topics ranging from the dynamics of water-flow in ice to the prediction of snowmelt runoff. Some of this research is concentrated at three mountain research stations (two in Alaska and one in Washington), where glaciers, seasonal snowcover, and meteorologic phenomena are observed. Although the studies are primarily directed toward snow and glacier hydrology, valuable information is also collected about climatic trends and potential glaciological hazards.

Climatic relationships observed from glacier studies

A model relating glacier balance and the climatic variables of precipitation and temperature for the period 1884–1974 was developed for two separate glacierized regions in the northern Cascade Range of Washington by W. V. Tangborn. Winter (October–April) precipitation, recorded at a lowland station, was used as a measure of glacier-snow accumulation, and the summer (May–September) maximum and minimum temperatures, recorded at the same valley station, were used to construct a simple ablation model. By using this model with the 1884–1974 precipitation and temperature data, it was possible to calculate the annual balances, and thus the long-term fluctuations, of the Thunder Creek glaciers and the South Cascade Glacier. The study showed that the drastic glacier-mass wastage, which began about 1920, ended in the mid-1940's and that, since then, the higher altitude Thunder Creek glaciers have shown distinct increases in mass and the South Cascade Glacier has shown a greatly reduced mass loss. A 0.5°C decrease in summer temperature or a 10-percent increase in winter precipitation from the 90-year mean can cause continued glacier growth in this region.

Continuously recorded air-temperature data were collected by L. R. Mayo and D. C. Trabant at altitudes of 1,480 m on Gulkana Glacier in the Alaska Range of southeastern Alaska and 1,000 m on Wolverine Glacier in the Kenai Mountains of coastal south-central Alaska. The mean annual air temperatures (MAAT) from these high-altitude stations showed a cooling trend of slightly more than 0.1°C/yr for the period of record (1968–75). Although this record is short, it agrees with NOAA's statewide MAAT trends reported by C. B. Fahl (University of Alaska, unpub. data, 1973). The cooling trend is most pronounced in February, March, and, to a lesser extent, June at both glacier stations.

Glacier-mass balance and activity

Important glaciological parameters can be calculated from data provided by the mapping of the two adjacent Klawatti Glaciers in the northern Cascade Range of Washington in 1947 and 1961, according to W. V. Tangborn. By assuming that the balance-altitude relationships for both glaciers can be approximated by a single parabola, it was possible to explain the divergent mass changes of these two glaciers from 1947 to 1961. In addition, the altitude distributions of thickness change, the emergence velocities, and the ice discharges were calculated for both glaciers. By shifting the calculated balance-altitude curve to form equilibrium profiles, the steady-state ice discharges for each glacier were determined. It was shown that a mathematical relationship exists between ice discharge and the activity index. The relationship between the equilibrium line altitude and the activity index, a means of equating the sensitivity of glacier activity to climate change, was also determined in this study.

Asynchronous advances and retreats of calving glaciers

Nineteen iceberg-calving glaciers in Alaska, South America, and Greenland that end in oceans or deep lakes were recently observed making drastic retreats or anomalous advances, while nearby glaciers that end on land experienced almost synchronous changes. Studies by A. S. Post indicated that asynchronous advances and retreats of calving glaciers are related to the water depth at each glacier's terminus. Stable and advancing calving glaciers end in quite shallow water (generally less than 80 m deep); rapidly retreating glaciers end in water more than 80 m deep (typically, 150 m or more). In this situation, the ice cliff is unstable, and physical collapse leads to greatly accelerated iceberg discharge. Post's studies suggest that glaciers advancing into deep channels build moraine bars against which they terminate and that even a small retreat from these shoals creates instabilities that lend to drastic retreats.

New glacier-survey adjustment program

A three-dimensional geodetic survey adjustment computer program, developed by W. G. Sikonia for a survey of Washington's Columbia Glacier, was used to determine control nets on the Variegated and Black Rapids Glaciers in Alaska and the South Cascade Glacier in Washington. The same program was also used to determine stake locations on the Black Rapids Glacier from a 1975 survey that used theodolite sightings from the glacier surface to the control net. The program adjusts the coordinates of survey stations to those that best fit the data in the least squares sense; a wide variety of measurements can be used as input data, including horizontal directions, azimuths, distances, zenith distances, and astronomical observations.

PALEONTOLOGY

Research by USGS paleontologists involves biostratigraphic, paleoecologic, taxonomic, and phylogenetic studies on a wide variety of plant and animal groups. The results of this research are applied to solving specific geologic problems related to the USGS geologic mapping and resource investigation programs and to providing a biostratigraphic framework for synthesizing the geologic history of North America and the surrounding oceans. Some of the significant results of paleontological research conducted during the past year are summarized in this section by major geologic age and area. Many additional paleontologic studies carried out by USGS paleontologists in cooperation with their colleagues are reported in other sections of this publication.

MESOZOIC AND CENOZOIC STUDIES

Limnologic changes caused by human settlement

J. P. Bradbury's studies of the stratigraphic distribution of diatom assemblages in several Minnesota lakes revealed that marked changes have occurred that correlate with changes in European-American settlements in the drainage basins of the lakes. An ecologic comparison of modern diatom floras with fossil diatoms indicates that the lakes have become more productive. The correlation of these changes with settlement changes suggests that lake enrichment resulted from an increase in the amount of nutrients released by soil erosion following land clearance and later from an influx of nutrients supplied by municipal and private waste disposal.

Biostratigraphic study of several lacustrine environments in Minnesota and South Dakota suggests that the reaction of diatom floras to cultural disturbance varies according to the lake's limnology and the amount and timing of influxes of different nutrients. Thus, generalizations about the specific changes that have taken or are taking place are unlikely to be of great value in assessing pollution problems in other lakes. Only by studying the transition of a lake from a natural condition to a disturbed condition is it possible to understand or appreciate the impact of human settlement on lakes.

Middle Miocene diatoms from South Carolina and Georgia

G. W. Andrews (USGS) and W. H. Abbott (South Carolina State Development Board) identified fossil marine diatoms in clay deposits of the Hawthorn Formation within the southeastern Georgia Embayment near the South Carolina-Georgia border. These diatom assemblages, which contain many distinctive middle Miocene taxa, suggest that the clay deposits are correlative with a part of the Calvert Formation of Maryland and Virginia. The associated foraminifers in these Hawthorn deposits suggest equivalency to planktic foraminifer zones N.12 or basal N.13. Extant diatom species in these assemblages suggest that deposition was in a littoral to shallow neritic marine environment.

Unconformities in a South Carolina core

The distribution of six fossil groups (calcareous nannofossils, dinoflagellates, foraminifers, mollusks, ostracodes, and sporomorphs) was determined in a 792-m core from a test hole in Dorchester County, South Carolina, 41 km west-northwest of Charleston. Sediments of Oligocene through Late Cretaceous age were penetrated. These determinations reveal that there are unconformities of considerable time significance in the core. The Oligocene is Chattian (Chickasawhayan and upper Vicksburgian in provincial stage terms) and rests on upper Eocene (Bartonian; Jacksonian). Therefore, equivalents of the Lattorfian and Rupelian Stages of Europe (lower Vicksburgian) are missing. This unconformity is at 55 m in the core and also has been observed in outcrops in the area. It is probably present elsewhere in the Atlantic Coastal Plain, but, in the eastern Gulf Coastal Plain, lower Oligocene marine beds are present. In South Carolina, the unconformity is in the Cooper Formation as currently used in the area.

Another unconformity is recognized in the core at the contact between the Santee Limestone and the Black Mingo Formation at 125 m. This unconformity is within the Eocene and between sediments assigned to the provincial Clairbornian and Sabinian Stages. This contact may also represent the Lutetian-Ypresian boundary. Much of the lower Claibornian and also the upper Sabinian, present in the Gulf Coastal Plain, are apparently missing.

The Upper Cretaceous is penetrated at 244 m. Here Danian (lower Midwayan) sediments are in contact with sediments that are assigned to the Peedee Formation and that are of middle Maestrichtian (middle Navarroan) Age. The upper Maestrichtian is missing and seems to be missing throughout the Coastal Plain.

A fourth unconformity is present in the 567- to 587-m segment of the core. Beds above this unfossiliferous interval are in the Black Creek Formation and are Santonian or lower Campanian (upper Austinian) ; beds below the interval are in the Middendorf Formation and are Cenomanian (lower Eaglefordian). There is no evidence of the Turonian (middle and upper Eaglefordian) or Coniacian (lower Austinian). The unfossiliferous interval is tentatively assigned to the Black Creek Formation. The absence of Turonian and Coniacian beds is consistent with stratigraphic relationships elsewhere in eastern Gulf and Atlantic parts of the Coastal Plain. This interval is, however, present in outcrop in Texas.

Laurel Bybell, R. A. Christopher, N. O. Frederiksen, J. E. Hazel, F. E. May, D. W. McLean, R. Z. Poore, C. C. Smith, N. F. Sohl, and P. C. Valentine analyzed the faunal and floral assemblages from the core.

Correlation of the Monmouth Group, Washington, D.C., area

Studies of ostracodes, calcareous nannofossils, and dinoflagellates from the Monmouth Group in Prince Georges County, Maryland, by C. C. Smith, F. E. May, and J. E. Hazel (USGS) and Elisabeth Forester (University of Illinois) led to a correlation of the Monmouth with beds in the type area of the Maestrichtian in Europe and with other Coastal Plain units. The dinoflagellates (May) indicate that the Monmouth correlates with beds assigned to the *Belemnitella occidentalis* zone in the type area. The calcareous nannofossils (Smith) indicate correlation of the Monmouth with the *Globotruncana gansseri* planktic foraminifer zone, which corroborates the dinoflagellate correlation to the type area. The ostracodes (Forester and Hazel) suggest placement of the Monmouth in the middle Navarroan Provincial Stage and correlation with the upper part of the Peedee Formation in North and South Carolina, the upper part of the Ripley Formation and (or) the Prairie Bluff Chalk in the Alabama-Mississippi area, and the Arkadelphia Marl in Arkansas.

Coral reef in the Caloosahatchee Formation

Spoil banks from a canal in Collier County, Florida, have yielded abundant coral. The locality was discovered by S. E. Hoerle and R. C. Hoerle of West Palm Beach, Fla. Druid Wilson (USGS) and John Meeder (University of Florida) were able to trace a coral reef of Caloosahatchee age (late Pliocene and early Pleistocene) with a north-northwest-south-southeast strike for about 11 km. Meeder identified some 20 species of coral, including the common reef-building coral genera *Montastrea, Siderastrea, Acropora,* and *Diploria.* Forereef and backreef areas were recognized. The associated molluscan fauna corroborated Wilson's (1964) report of a different Caloosahatchee biofacies occurring west of the so-called Buckingham arch. The oilfields of southern Florida (Klopp, 1975) almost exactly delineated the trend of this arch. The bivalve genera *Agnocardia* and *Hawaiarca* and large species of the gastropod genus *Strombus* characterized the molluscan part of the fauna. None of these occurred in the typical Caloosahatchee east of the arch. The north-south extent of this fauna was about 105 km, from Shell Creek in Charlotte County to Collier County.

Southwestern Atlantic Ocean Cretaceous foraminifers

Cretaceous foraminifers from Deep Sea Drilling Project Leg 36 sites on the eastern Falkland Plateau range in age from Albian to Maestrichtian. These faunas, examined by W. V. Sliter, are Austral in character and indicate water depths of 100 to 400 m in Campanian and Maestrichtian time. Santonian assemblages indicate water depths in excess of 2,500 m and are related to a complex middle Cretaceous history of tectonism and altered hydrogeographic conditions.

Comparison of Leg 36 assemblages with those from other Southern Hemisphere localities reveals that: (1) Aptian and Albian faunas are Austral in character; (2) the middle Cretaceous hiatus found at Site 327A is interregional in extent; and (3) three major provincial provinces—Tethyan, Transitional, and Austral—are recognized for Campanian and Maestrichtian foraminifers.

The provincial character of the faunas and their subsidence history suggest that the eastern Falkland Plateau may have occupied a pre-Tertiary paleogeographic position adjacent to the Magallanes Basin of South America and the Antarctic Peninsula.

Pollen stratigraphy, Mesaverde Group, New Mexico

According to R. H. Tschudy, successive evolutionary changes in the pollen flora through the Mesaverde Group of northwestern New Mexico are of sufficient magnitude that these continental coal-bearing rocks can be palynologically characterized. Triporate pollen first appears in the Dilco Coal Member of the Crevasse Canyon Formation; Normapolles pollen first appears in the overlying Gibson Coal Member; *Plicapollis* and *Pseudoplicapollis* pollen of the Normapolles group first appear in the upper part of the Gibson Coal Member of the Crevasse Canyon Formation. Pollen of the genus *Proteacidites* first appears in the basal part of the Menefee Formation. Tschudy indicated that the pollen sequence can be correlated with certain marine fossil zones in the upper part of the Carlile Shale and the Niobrara Formation of the Western Interior.

Seeds of extinct gymnosperms, Morrison Formation

R. A. Scott reported that numerous silicified seeds and reproductive organs from the Morrison Formation (Upper Jurassic) of Utah furnish evidence of a flora of extinct gymnospermous plants with cycadophytic and pteridospermous affinities. Structural features typical of these unusual forms include the following:

- The naked seeds have simple, orthotropous structure.
- The two integuments of the seed split into longitudinal valves through a conspicuous circular micropyle at the distal end.
- The seeds are borne sessile on the placenta.
- The micropylar canal is occupied by a pointed nucellus that may appear as a "plug;" this plug resembles the germination plug present in some angiosperm families.

Despite suggestive resemblances of some of the seeds to seeds of certain angiosperm families (for example, *Cyperaceae*), all the Morrison fossils are gymnospermous. Some resemblances exist to such extinct genera of gymnosperms as *Beania*, *Carnoconites*, and *Calathospermum*. The Morrison seed assemblage, except for *Araucaria*, represents a previously unknown group of naked-seeded plants that are in part possibly intermediate between pteridosperms and cycadophytes.

Fauna of Miocene age from the Topsy Formation, Alaska

The first well-preserved collection of fossils from the Topsy Formation in the Lituya district on the eastern Gulf of Alaska was identified by L. N. Marincovich. This identification allows the age and depositional environment of these strata to be assessed. The fossils, collected by Marincovich, George Plafker, and T. L. Hudson, consist of 22 taxa of mollusks and 1 fish vertebra and suggest an early Miocene ("Temblor") age for the Topsy beds. The Topsy Formation strata are therefore correlative with the lowermost beds of the Yakataga Formation, the principal marine upper Tertiary unit in this region. Most of the collection from the Topsy Formation is comprised of bivalves that suggest deposition in depths of 20 to 90 m within the inner part of the Continental Shelf. This fauna provides new information on the easternmost Gulf of Alaska Tertiary province, the paleontology of which is still poorly known.

PALEOZOIC STUDIES

Permian guide fossil, southwestern Alaska

Atomodesma, an uncommon but geographically widespread bivalve, has long been recognized as a valuable Permian guide fossil in New Zealand, Australia, Russia, and elsewhere in the world. It has been identified only recently at localities in North America (Kauffman and Runnegar, 1975). J. M. Hoare and W. L. Coonrad (USGS) collected *Atomodesma* at 25 new localities in the Goodnews, Hagemeister Island, and Bethel 1:250,000-scale quadrangles in southwestern Alaska and obtained specimens collected by William Polski (Shell Oil Company) from a locality in the Taylor Mountains quadrangle, also in southwestern Alaska.

E. G. Kauffman (U.S. National Museum) confirmed the generic identification of the fossil material and suggested that at least four species representing two subgenera (*Intomodesma* Popov and *Aphanaia* de Koninck) are present in the fauna. Unfortunately, poor preservation in all cases prohibits definite species identification and limits precise biostratigraphic correlations. Most of the material is highly fragmented, the pieces ranging in size from a few millimeters to 15 cm across. The unique prismatic shell structure of *Atomodesma,* however, permits generic identification to be made from such fragments with a hand lens. Only two relatively complete internal molds of adult valves were found; both represent a new species closely related to the Late Permian species group of *Atomodesma* (*Intomodesma*) *costata* Popov-*A.* (*I.*?) *inoceramiformis* (Licharew) from Russia. *A.* (*I.*?) sp. 1 of Kauffman and Runnegar (1975, pl. 1, figs. 2 and 7) from the Permian of Nevada is more distantly related. In addition, half-valves of two species of *Atomodesma* (*Aphanaia*) are present in the collections; one is very closely related to *A.* (*A.*) *erectum* Kauffman and Runnegar from the Nevada Permian, and the other is a larger and more coarsely ribbed form that probably represents a new species. The preponderance of fragments in the Alaskan collections belong to a large species of *A.* (*I.*?), the proportions of which are closely comparable to those of *A.* (*I.*?) sp. 1 Kauffman and Runnegar (1975, pl. 1, fig. 7) of the Nevada Permian. A Late Permian age is suggested for at least part of the Gemuk Group on the basis of these identifications.

From the standpoint of geologic mapping, these occurrences of *Atomodesma* are valuable because they extend the known stratigraphic and geologic range of Permian strata in southwestern Alaska and because they provide criteria for subdividing the Gemuk Group into smaller stratigraphic units.

Most of the fossils were found in fetid limestones that ranged in thickness from a few meters to 300 m. They were also found in argillite, calcareous graywacke, and pebble-cobble conglomerate. At several localities, *Atomodesma* were associated with other fossils (brachiopods, bryozoans, corals, and crinoid columnals) that were also of Permian age. But, at most localities, other fossil taxa were rare, absent, or too fragmentary to be identified, and *Atomodesma* predominated. This predominance is typical of other occurrences of the genus elsewhere in the world.

Fossiliferous rocks of Permian age in southwestern Alaska have a relatively small aggregate thickness, but they indicate the geologic age of a much thicker sequence of nonfossiliferous strata. They are interbedded with several thousand meters of largely volcanogenic rocks consisting of pillow basalts, tuffs, siliceous argillite, chert, graywacke, and conglomerate. Some of these rocks are similar to younger rocks of Mesozoic age with which they are isoclinally folded. The widespread occurrence of *Atomodesma* has been helpful in understanding some Permian structure and stratigraphy in Alaska.

Late Paleozoic Eurasian bryozoans, Western United States

Collections from unnamed lithic units of late Paleozoic age were submitted to O. L. Karklins for identification of bryozoans that have been reported rarely or that have not been known to occur in the United States. Samples were gathered in Utah by V. R. Todd, in Idaho by B. A. Skipp, S. S. Oriel, and J. F. Smith, and in Nevada by K. B. Ketner and F. J. Kleinhampl. The genus *Rhombotrypella,* which occurs in the collections, was reported only once before in the United States by Condra and Elias (1944) in the Pennsylvanian of Utah. The genera *Timanodictya* and *Streblascopora,* which are distributed widely in the U.S.S.R. and the Far East, are also present. *Streblascopora* had not been reported in the United States until this study. *Rhombotrypella* and *Streblascopora* occur in Permian and Carboniferous strata, but *Timanodictya* apparently is found only in Permian strata. The forms found in the United States possess morphologies closely comparable to those of forms found in the U.S.S.R. and the Far East and therefore may be of considerable value in determining the biostratigraphic positions and paleographic significance of the unnamed rock units.

Middle Ordovician ostracodes, western Utah

A study by J. M. Berdan (USGS) of ostracodes collected by L. F. Hintze (Brigham Young University) from the Pogonip Group (Middle Ordovician part) in the Ibex area of Millard County, Utah, indicated that distinctive genera and species can be used for correlation in western Utah and eastern Nevada as far west as the Egan Range. Ostracodes occur as low in the section as the Wah Wah and Juab Limestones but form a significant part of the fauna in the Kanosh Shale and the overlying Lehman Formation; some beds of the Kanosh are a coquina of small ostracodes. Three ostracode zones can be recognized in the Kanosh. The oldest, in the lower part of Zone M of Hintze, is sharply separated faunally from the middle zone, although it belongs to the same lithologic facies. The middle and youngest zones intergrade to some extent and appear to be facies controlled. The youngest zone continues up into the Lehman Formation.

Dating of British Ordovician

A sample of bentonite from the Acton Scott beds of the type section of the Caradocian Series in Shropshire, England, was dated by C. W. Naeser (USGS) at minimum ages of 459±27 and 443±27 million years on the basis of fission tracks. R. J. Ross, Jr. (USGS), collected the sample along the Onny River in company with W. T. Dean (Geological Survey of Canada). No mineral suite satisfactory for radiometric dating seemed to be present. However, G. A. Izett, L. A. Wilson, and Ross (USGS) succeeded in separating apatite crystals, which were then dated by Naeser.

The results are of particular interest because:

- They are the first radiometric dating of the British type Caradocian and are a minimum age.
- Conodonts, fragments of which were in the bentonite, indicated that the ash had not been above 80°C since deposition, according to the scheme of A. G. Epstein (USGS) (Epstein and others, 1976). This point is critical inasmuch as apatites are "reset" at 80° to 100°C.
- Although fission-track dating is usually performed on zircons that can be reset at 200° to 300°C, Epstein's "conodont thermometer" permits a check on the reliability of apatite ages; it may prove to be similarly useful in dealing with zircons.

Corals with coiled coralla

Planispirally coiled protocoralla were found by W. J. Sando in specimens of *Cyathaxonia tantilla* (Miller) from the Lodgepole Limestone (Lower Mississippian) of Utah and Montana, the first record of this phenomenon in corals. Coiling is interpreted as a mode of attachment of young coralla to planktic algae. The postulated pseudoplanktic growth habit may be a significant factor in the widespread distribution of this species and other species of *Cyathaxonia*, which are generally found in rocks that record a bottom environment considered unfavorable to optimum coral growth.

Factors controlling faunal provincialism

The distance from continental platforms is only one of a number of factors that govern the development of the unique association of brachiopod genera found in rocks surrounding islands in the Early Ordovician proto-Atlantic Ocean, the Celtic province (Williams, 1973). In North America, Celtic province brachiopods are found in volcaniclastic rocks in Maine, New Brunswick, and Newfoundland; these, together with the extrusive rocks with which they are associated, lie east (offshore) of Continental Rise deposits, probably originally at considerable distances. In the British Isles, Celtic province brachiopods under investigation by R. B. Neuman and D. E. B. Bates (University College of Wales, Aberystwyth) occur in coarse-grained sandstone and conglomerate on the flanks of the Irish Sea uplift; such rocks in Anglesey in northwestern Wales were originally no more than 160 km west of the Welsh borderlands, where coeval rocks have altogether different brachiopods of the Anglo-French province. Here the explanation of the faunal contrast must be sought in local conditions such as substrate and water-circulation patterns rather than in wide geographic separation.

Pennsylvanian fusulinids, eastern Kentucky

Fusulinids of Middle Pennsylvanian age were recognized by R. C. Douglass in samples from Bell, Breathitt, and Leslie Counties in southeastern Kentucky. Previous reported occurrences of fusulinids in Kentucky were limited to the margins of the Illinois Basin in western Kentucky and to Upper Pennsylvanian rocks along the Ohio border. The occurrence of these fusulinids as far south as Bell County opens the possibility for finding more throughout the southern Appalachian Basin and using them for correlation of the marine beds associated with coal. Fusulinids of Late Pennsylvanian age are now known from the Brush Creek and Ames Limestone Members of the Glenshaw Formation of the Conemaugh Group in northeastern Kentucky and should be looked for in equivalent beds to the south.

Palynological analyses

Twenty-one samples of the Cumberland Gap coal and associated strata from the Lee Formation (Lower Pennsylvanian part) of Kentucky were prepared and examined in detail by R. M. Kosanke for spore-pollen content. The coal at this locality in Cumberland Gap National Historical Park is 233 cm thick. Twenty-one genera of spores and pollen grains were identified, and this assemblage was found to be dominated by *Densosporites* and *Lycospora*. The presence of *Densosporites irregularis* is considered significant because previous studies in Kentucky have shown this taxon to be restricted in occurrence. *D. irregularis* is not known to occur in coals younger than the Stearns 1½ coal in Kentucky.

GROUND-WATER HYDROLOGY

USGS ground-water hydrology research covers a broad range of subjects with the common objectives of (1) better understanding ground-water systems and (2) developing and applying new technical methods of study to improve management of ground water as an important national resource.

Model simulation of aquifer systems received much attention during the year; documentation was prepared and performance was improved for both two- and three-dimensional digital models. A model that computes recharge to a water table from areal climatic data was developed. Work continued on a hybrid computational system to solve multiaquifer problems. In addition, a transient three-dimensional subsurface waste-disposal model was developed to provide a methodology for designing and testing waste-disposal systems.

Shortages of ground water in many parts of the United States led to experiments on the artificial recharge of ground water through both pits and wells as a means of augmenting the ground-water supply. Experiments were carried out in Alaska, Florida, New York, and Texas. Research on some of the fundamental problems of recharge was done in the USGS facility in Lubbock, Tex. Studies during the year included laboratory and field tests on the alteration of the anion ratio in water being recharged and the gathering of data to test a new model of porous media clogging.

Deep-well waste disposal continued to be an important area of research, particularly in Florida, where limestone aquifers containing saline water are being used for injection.

In other studies, it was determined (1) that the calcium-magnesium ratio can be used as an indicator of ground-water mixing between a shallow limestone aquifer and a deep dolomite aquifer, (2) that ancient submarine canyons in the Capitan aquifer of Texas and New Mexico restrict ground-water flow, and (3) that faults are sources of thermal springs in the Appalachian Mountains. A significant discovery was the presence of "fossil" freshwater believed to have been trapped beneath Nantucket Island, Mass., during Pleistocene time when the sea level rose again after the continental shelves had been exposed to freshwater infiltration.

AQUIFER-MODEL STUDIES

Modification of parameter β in the strongly implicit procedure

The finite-difference model for the simulation of two-dimensional ground-water flow was improved by P. C. Trescott, G. F. Pinder, and S. P. Larson (1976). Larson reported that numerical difficulties associated with the solution of equation systems for water-table or highly anisotropic ground-water flow problems were greatly reduced by a simple modification of the parameter β in the strongly implicit procedure (SIP).

Most iterative solution methods applied to problems having complex geometry or nonlinear coefficients yielded poor convergence rates or incorrect deletion of nodes from the solution when head values dropped below the base of the aquifer during the iteration process. Stone (1968) used an additional iteration parameter, β, in the SIP algorithm but concluded that it was not useful for his problems. In the standard application of SIP, $\beta=1$, but using other β values for some ground-water flow problems was advantageous. In water-table simulations in which nodes were deleted, using $\beta=0.5$ restricted deletions to those that were reasonable for the solution. For a cross-section problem characterized by strong anisotropy and layers having contrasting hydraulic conductivity, using $\beta=1.5$ significantly improved the convergence rate. Effective values of β were generally in the range $0<\beta<2$ and were easily determined by trial and error.

Simulation of three-dimensional ground-water flow

Trescott (1975) reported that documentation for a finite-difference model simulating three-dimensional ground-water flow was completed. The new model, in comparison with the quasi-three-dimensional model developed by J. D. Bredehoeft and G. F. Pinder (1970), reduced the computation time required for a solution by a factor of 5.

Predicting recharge from climatic data

SUPERMOCK, a ground-water and rainfall runoff model developed for a digital computer by J. E. Reed and M. S. Bedinger, was used to predict the response of the alluvial aquifer along the Red River in Louisiana to a waterway project involving the construction of locks and dams. The model is unique because it uses climatic data to compute recharge to a water table. The model simulates three layers, the topmost of which is the soil zone, whose moisture content is computed from daily precipitation records and whose potential evapotranspiration is determined by the Thornthwaite method. Infiltration from the soil zone recharges a middle layer of fine-grained alluvium whose water table is computed as a function of recharge from the soil zone and fluctuations in the potentiometric surface in the aquifer below. The bottom layer, a confined aquifer whose water is under a different potentiometric head than water in the fine-grained layer above, is modeled as a two-dimensional flow system.

Simulation of the hydrology of the primary basalt aquifer of the Pullman, Washington-Moscow, Idaho, basin

A digital model was developed to simulate the hydrology of the primary basalt aquifer system in the Pullman, Wash.-Moscow, Idaho, basin. An historic water-level decline in the system of about 24 m was due to limited recharge and increased pumpage, which from 1971 to 1975 averaged 8.1 hm^3/yr. According to R. A. Barker, model simulation indicated that (1) vertical leakage from upper aquifers (simulated as about 6 hm^3 in 1975) has always been the most important source of recharge; (2) the amount of ground water moving laterally into the basin had increased from zero under prepumping conditions to about 1.78 hm^3/yr by 1975; and (3) the subsurface discharge, which under prepumping conditions had been about 3.5 hm^3/yr, was reduced to about 1.54 hm^3/yr by 1975. Simulation to the year 2000, which assumed a doubling of present-day pumpage, indicated that water levels in the Pullman-Moscow area would decline between 9.0 and 10.6 m below 1975 levels. If, however, pumpage were to stabilize at 8.1 hm^3/yr, the decline at Pullman would be only about 3 m below 1975 levels, and the annual rate of decline would be reduced to about 0.06 m/yr by the year 2000.

Calibration of ground-water models

According to T. J. Durbin, the Gauss optimization technique can be used to determine the parameters of a model of a ground-water system if parameter values are computed from a least squares fit between the response of the aquifer and the response of the model. Unavoidable uncertainty in the true stress on the aquifer and in the true response of the aquifer to that stress will introduce errors into values of the model parameters, and these errors subsequently will be transferred to the predicted hydrologic values.

The scale of parameter discretization used modifies the effect that data errors have on the estimated model parameters, but it has little effect on the predicted hydrologic values. Decreasing the scale of parameter discretization will improve the fit of the model to the data used to determine the parameters, but it will not improve the predictions made.

Modeling waste-disposal systems

According to D. B. Grove, a transient three-dimensional subsurface waste-disposal model was developed by the Intercomp Corporation to provide a methodology for designing and testing waste-disposal systems. The model is a finite-difference solution to the pressure, energy, and mass-transport equations. Equation parameters such as viscosity and density are allowed to be functions of the equations' dependent variables. Multiple user options allow the choice of x, y, and z Cartesian or r and z radial coordinates, various finite-difference methods, iterative and direct matrix solution techniques, restart options, and various provisions for output display.

The addition of well-bore, heat, and pressure-loss calculations to the model makes available to the ground-water hydrologist the most recent advances from the oil- and gas-reservoir engineering field.

ARTIFICIAL RECHARGE

ALASKA

The rapid urbanization of the Anchorage area of Alaska has placed increasing demands on developed water-supply sources. In an effort to increase the availability of ground water, experiments on the feasibility of naturally recharging the ground-water supply were carried out.

In 1975, for the third summer, artificial-recharge operations were conducted at a 4.1-ha pit near Ship Creek in the Anchorage area. G. S. Anderson and N. A. Matson, Jr., reported an infiltration rate ranging from 0.3 to 0.45 m/d and a total-recharge rate of approximately 15,000 m^3/d in the pit, values similar to those obtained in the two previous summers' operations. Late in the summer of 1975, a 2.8-ha pit adjacent to the larger pit was also made available for recharge experiments. The smaller pit was flooded for about 1 month by a 0.28- to 0.62-m^3/s overflow from the larger pit. Although the smaller pit was not completely filled during the short period that water flowed into it, stage measurements made after inflow to the pit stopped indicated an infiltration rate approximately four times as great as that of the larger pit. The unconfined ground-water table in the vicinity of the pits, which had increased by 4.6 m as a result of recharge to the first pit on May 20 and August 14, rose an additional 4.6 m.

FLORIDA

Predicted water shortages in southern Florida led to an investigation by F. W. Meyer and J. E. Hull of the feasibility of injecting seasonal surpluses of freshwater runoff into a saline artesian aquifer for storage, conservation, and ultimate recovery and reuse. As a part of this program, a 335-m-deep injection well and a monitor well were successfully drilled at a site adjacent to the Miami-Dade Water and Sewer Authority's Hialeah Water Treatment Plant. The monitor well is 90 m from the injection well and is capable of yielding quality-of-water data from seven depth zones. The chloride concentration of native water in the injection zone is about 1,000 mg/l.

About 160,000 m^3 of water with a chloride concentration of 60 mg/l was injected into the artesian zone during July and August 1975. About 60,000 m^3 of water was recovered by backpumping before the chloride concentration exceeded 250 mg/l, the USPHS recommended limit for a public water supply.

NEW YORK

D. A. Aronson made a survey of more than 200 storm-water basins in Nassau County on Long Island, N.Y., to determine which basins would be best suited for recharging ground water with reclaimed sewage from tertiary treatment plants. The 50 largest basins were further analyzed to evaluate their suitability as potential recharge sites. Basins were selected on the basis of several criteria, including basin size, basin location with respect to a ground-water divide and to proposed transmission mains, tendency of the basin to retain water after a rainfall event, underlying lithology, and depth to water table. Fourteen of the 50 largest basins met all criteria and were tentatively selected for additional study. Preliminary evaluation, by means of mathematical and electric-analog models, of the amount of reclaimed water that can be safely applied indicated that the development of water-table mounds at some of the potential recharge sites will restrict rates of recharge to less than the amounts computed on the basis of basin size and expected infiltration rates.

Ponding tests in which tertiary-treated sewage effluent was infiltrated through outwash sands and gravels demonstrated the feasibility of artificially recharging ground water by spreading processed sewage, according to R. C. Prill and E. T. Oaksford. In a test where a high-quality effluent was applied over a 10-day period, a steady infiltration rate of 1.3 m/h was measured. Saturated conditions prevailed from the land surface to a depth of 1.5 m, an indication that infiltration rates were at their highest. In subsequent tests, lower infiltration rates resulted when the effluent applied was of poor quality because of plant malfunction. In these tests, saturated conditions extended for only a few centimeters below land surface, an indication that surface clogging had occurred. Rates were readily restored by removing the upper 5 cm of sand. Specially designed gravity samplers installed through a manhole 2.4 m in diameter were used to collect water samples from the unsaturated zone. The samplers collected water over a 0.45-m^2 area, and their outflow was proportional to the infiltration rate. Measured outflows from a sampler at a depth of 2.3 m were 18.0 and 7.8 l/h at infiltration rates of 1.0 and 0.25 m/h, respectively.

TEXAS

An important aspect of research on artificial recharge is the determination of functional relationships among the physical, chemical, and biological characteristics of water and of the aquifers being recharged.

Laboratory studies by D. C. Signor showed that a suspension of 500 mg/l montmorillonite clay flowing into porous media columns resulted in sediment concentrations in the outflow that were related to the reciprocal of the inflow volume by an exponential function. The functional relationship was found to be applicable to columns of sand from the Ogallala Formation, "Ottawa sand" (from Illinois), and glass beads. Analyses of the relationship of inflow volume and outflow concentration gave correlation coefficients ranging from 0.96 to 0.99.

Clay retention of 0.3 to 0.4 percent of the total weight of the column material caused fairly uniform reductions in intrinsic permeability of up to 90 percent in 75-cm column lengths. Inflow of the 500-mg/l montmorillonite suspension into columns 12.5 cm in diameter was at a constant rate of 25 mm/s under variable pressures up to 3.5 kg/cm^2.

Alteration of the anion ratio in water being artificially recharged was investigated by W. W. Wood and M. E. Crawley, who found that sulfate ($SO_4^{=}$) ions are sorbed on the iron hydroxide coatings of the sand grains forming the skeletal framework of the Ogallala aquifer. This sorption follows a Freundlich isotherm in which the slope depends on the surface area of the sorbing sediment. The amount of sorption is also pH dependent—maximum sorption occurs at pH less than 7, and none occurs at pH greater than 10. Sulfate is completely desorbed by equal concentrations of phosphate ($PO_4^{=}$) but not by other common anions. The results of laboratory findings were confirmed by field tests.

The anion-exchange capacity of fluoride (F^-) ions and hydroxyl (OH^-) ions approached one-fourth of the cation-exchange capacity of sediments in the Ogallala aquifer. By using an empirically derived anion-selectivity coefficient, it was possible to model the distribution of fluoride ions in the unsaturated zone of an artificial-recharge site.

MISCELLANEOUS STUDIES

Ground-water movement and natural recharge

New Mexico and Texas.—The Capitan aquifer is an important source of ground water for both municipal and industrial purposes in southeastern New Mexico and western Texas. This aquifer has been mapped in the subsurface as a reef deposit that extends for more than 300 km as a continuous arcuate unit, unbroken by faulting, parallel to the northern and eastern margins of the Delaware Basin from the Guadalupe Mountains southwest of Carlsbad, N. Mex., to the Glass Mountains southwest of Fort Stockton, Tex.

According to W. L. Hiss (1974, 1975b), submarine canyons of the same and (or) slightly younger age that are filled with complexly interbedded sandstone, siltstone, and limestone of relatively low hydraulic conductivity are incised in the Capitan aquifer. The thickness and transmissivity of the Capitan aquifer have been significantly reduced where these canyons are present, the result being a much smaller amount of water moving eastward from the Pecos River into the extensively developed Capitan aquifer of southeastern New Mexico and western Texas.

Tennessee.—The clay overlying the Memphis Sand in the Memphis area of Tennessee was believed to be an almost perfect confining bed and may well be nearly impermeable. However, according to J. H. Criner, Jr., the long-term water-level record of an observation well and the potentiometric surface maps for 1970 and 1975 indicated that recharge may be occurring in downtown Memphis near the Mississippi River where the confining clay is thickest. Water levels in the vicinity of the observation well have declined more than 30 m since 1886, when they were near ground level. This decline reversed the hydraulic gradient between the artesian aquifer and the overlying water-table aquifers and nearby streams. The water-level fluctuations in the observation well are similar to those of other wells in the area, except that the water level of the observation well has not declined significantly since 1954. Annual pumpage was reduced slightly in the vicinity of this well from 1955 to 1970 but was increased significantly from 1971 to 1975. The increases in pumping had only a slight effect on the annual low-water level in the observation well, but annual high-water levels appeared to correlate well with reduced annual pumping rates. If recharge has begun, the source of water could be the streams in the vicinity, the overlying aquifers, a storm sewer, or a combination of these. The recharge path could be through sandy parts of the confining clay, sand-filled crevices, abandoned wells, or a combination of these.

Underground waste disposal

Research investigations conducted in Florida to evaluate the effects of injecting liquid waste through wells into carbonate aquifers containing saline water revealed that an accurate measurement of the vertical conductivity of the confining layer is the most important parameter, according to G. L. Faulkner. Conventional pumping can measure this parameter, but drilling deep observation wells and disposing of the saline water pumped from test wells are very expensive procedures. Although injection tests have drawbacks, they avoid the problem of disposing of saline water during a pumping test.

C. A. Pascale (1975) reported that wellhead pressure at an injection well near Milton, Fla., averaged 6.7 kg/cm^2, 5.8 kg/cm^2 above the preinjection potentiometric surface. The pressure at three deep monitor wells in the injection zone 2.5 km northeast, 0.31 km southwest, and 0.47 km south of the injection well averaged 1.2, 2.4, and 3.0 kg/cm^2, respectively. At the injection site, the water level in a shallow monitor well immediately above the aquifer's confining layer was not affected by the injections and stood at about 19.2 m below land surface. Monthly analyses of water samples from all monitor wells showed some variations but no significant changes in chemical constituents.

W. A. J. Pitt, Jr., and F. W. Meyer (1976) reported that a suitable zone for storing large amounts of treated waste water was found between depths of 980 and 1,040 m in a test well 1,090 m deep at West Palm Beach, Fla. The test well was drilled by the city of West Palm Beach, with financial aid from the Environmental Protection Agency, to determine the feasibility of using a deep-well injection system for a new secondary sewage-treatment plant. Data collected by Meyer and Pitt indicated that saltwater spills during drilling operations were minimal and that cleanup operations effectively restored the potability of water in the shallow aquifer. Three injection wells, each 61 cm in diameter and each having a daily capacity of 37,850 m^3, will be drilled at the site.

Ground-water mixing

Water-level measurements made in wells in the Springfield area of Missouri show a difference in head that favors downward movement of water from the shallow limestone aquifer to the deep dolomite aquifer. L. F. Emmett found that evidence for this movement is further supported by the calcium-magnesium ratios (in equivalents per million) of water from the two aquifers. The ratio of calcium to magnesium in water from the shallow limestone aquifer is more than 5:1. In areas of Missouri where the dolomite aquifer is not overlain by limestone, the ratio of calcium to magnesium is about 1:1. In Springfield-area wells, where the shallow limestone aquifer has been cased off and the casing has been grouted, the ratios of calcium to magnesium in ground water range from 1.5:1 to 2:1. Higher ratios are found in water from wells open to both the limestone and the dolomite aquifers. In this hydrogeologic environment, the calcium-to-magnesium ratios can be used as indicators of ground-water mixing.

Hydrogen sulfide gas in ground water

Results of a study by R. E. Krause indicated that objectionable amounts of hydrogen sulfide gas are found in water from the principal artesian aquifer in the Valdosta area of southern Georgia. The aquifer, a limestone and dolomitic limestone, is about 75 to 100 m thick and between 40 and 75 m below land surface. In an area southeast of Valdosta, water from the aquifer has hydrogen sulfide concentrations as high as 3.0 mg/l. In much of the urban area, including an industrial park where new water supplies are needed, hydrogen sulfide concentrations are greater than 2.0 mg/l.

The hydrogen sulfide gas in the ground water is related to the reduction of the sulfate ion in the aquifer. Sulfate concentrations in the aquifer are also high; well-water samples for both hydrogen sulfide and sulfate indicate a direct correlation between the two constituents. Hydrogen sulfide and sulfate concentrations also increase with depth in the Valdosta area. For example, sulfate concentration in a test well drilled in 1974 increased from 23 mg/l in the depth interval of 120 to 140 m, to 230 mg/l in the depth interval of 150 to 170 m, and to 2,400 mg/l below the 170-m depth.

Thermal springs

W. A. Hobba, Jr., conducted a reconnaisance study of 10 thermal springs in the Appalachian Mountains of Georgia, North Carolina, Virginia, West Virginia, Pennsylvania, and New York. Many of the springs discharge along faults or at the intersections of two or more faults, many of which are readily apparent on Landsat or SLAR imagery. The faults visibly extend for as much as 113 km, and some give rise to both warm and cold springs. One northwest-southeast-trending fault gives rise to several warm springs in the Valley and Ridge province and to at least one large, salty (4,000 mg/l chloride) cold spring in the Appalachian Plateau province. The locations of some of these faults have been checked and verified in the field. Complete chemical analyses of 35 water samples collected from the warm and the cold springs and from nearby wells may provide additional clues to the source of heat and the depth of circulation of the water.

Effect of surface coal mining on shallow aquifers

Ground-water studies conducted by F. N. Visher in northwestern Colorado showed that subbituminous coal beds in the Mesaverde Group commonly yield to wells adequate water of suitable quality for rural-domestic and livestock use. Despite the apparent moderate permeability of these beds, however, they often do not drain readily to mine pits or outcrop areas where coal is exposed considerably below the water levels in nearby wells. This local phenomenon is tentatively attributed to directional permeability in the coal aquifers controlled by the natural fracture system of the coal beds.

Resistivity measurements of alluvium

Resistivity measurements of alluvium were used by W. J. Head and K. T. Kilty in evaluating the hydrology of alluvial aquifers in the Bighorn Basin of Wyoming. Schlumberger-type soundings were made across valleys to form geoelectric profiles of the alluvium and the depth to bedrock. The study was concentrated on the western slope of the Bighorn Mountains, the Greybull River drainage, and the Owl Creek drainage. The alluvium in Tensleep Creek, which is typical of creeks on the western side of the mountains, varied from high-resistivity sand and gravel in the active channel to low-resistivity sand and silt in the terraces. The maximum depth to bedrock interpreted from the resistivity measurements at Tensleep Creek was 24 m. Measurements on Nowood River in the foothills indicated that sand and silt were present. In the Greybull River alluvium, low-resistivity clay, silt, and sand were the dominant sediments. Some zones along the river had large, high-resistivity gravel deposits, and terraces could be defined. The average geoelectric depth was approximately 10 m.

Dye tracer used to study ground-water velocity

As part of a study to determine the amount, direction, and velocity of effluent percolating from sewage-disposal ponds in Grand Teton and Yellowstone National Parks in Wyoming, E. R. Cox used Rhodamine-WT dye as a tracer to determine the ground-water velocity. A test was made between two wells 18.1 m apart that penetrated beds of gravel, sand, and silt near Yellowstone Lake in Yellowstone National Park. The ground-water velocity was 0.3 m/d under a hydraulic gradient of 0.18 m/m.

Fresh ground water deep beneath Nantucket Island

F. A. Kohout, E. H. Walker, M. H. Bothner, and J. C. Hathaway reported that a deep water-resource and stratigraphic test well drilled near the center of Nantucket Island, Mass., about 48 km off the New England coast, encountered freshwater at greater depths than the Ghyben-Herzberg principle had predicted. An uppermost lens of freshwater, which occupies relatively permeable glacial-outwash sand and gravel to a depth of 158 m, is believed to be in hydrodynamic equilibrium with the adjacent body of saltwater. However, two zones of freshwater between depths of 222 and 249 m and 274 to 283 m are anomalously deep. The most likely explanation is that the entire surface of the Continental Shelf was exposed to recharge by precipitation during long periods of low sea level in Pleistocene time. After the last retreat of glacial ice, about 8,000 years ago, seawater rapidly drowned the shelf around Nantucket Island. Since then, the deep freshwater zones that underlie dense clay layers have not had time to adjust to a new equilibrium. Under similar circumstances, freshwater may remain trapped under extensive areas of the Continental Shelf wherever clay confining beds have not permitted saltwater to intrude rapidly to new positions of hydrodynamic equilibrium. The implications are far reaching because all continental shelves were exposed to similar hydrologic influences during Pleistocene time.

SURFACE-WATER HYDROLOGY

The objectives of research in surface-water hydrology are (1) to define the magnitude and variation of streamflow in time and space, under both natural and manmade conditions, (2) to understand the flow process in stream channels and estuaries, and (3) to define the rates of movement and dissipation of pollutants in streams.

Flow routing

T. N. Keefer compared linear and quasi-linear flow-routing models to finite-difference models on the basis of each model's ability to reproduce discharge hydrographs at the downstream ends of prismatic channels of various shapes. Both types of model predict peak flows with an accuracy comparable to that of the finite-difference model. The quasi-linear model is more accurate when time is considered. The linear model is one-tenth as costly as a finite-difference model, and the quasi-linear model is one-half as costly as a finite-difference model.

On the basis of the regulation schedule for Raystown Lake in Pennsylvania, J. T. Armbruster (1976a) developed a digital model that was used to generate outflows from the lake. These outflows were routed to several downstream sites by means of the unit-response method (V. B. Sauer, 1973). Frequency analyses of the routed flows indicated that the regulation schedule of the lake will raise the low-flow regime at downstream sites relative to the regime for natural flows.

R. K. Livingston developed a digital model that routes reservoir releases along natural river channels by accounting for changes in channel storage, bank storage, and evaporation. The primary variables in the model include the amount, duration, and date of the reservoir release and the antecedent flow condition. The model computes channel storage, bank storage, and evaporation changes in the reach for each time interval and generates a hydrograph at the downstream end of the reach. Predicted downstream hydrographs on several reaches of the Arkansas River in Colorado were in good agreement with hydrographs recorded at gaging stations. The model can be used to determine the transit loss incurred when water is conveyed in a natural channel and to select the optimum times, amounts, and durations of releases to minimize transit loss. In case of accidental pollution, the model can provide information on traveltime, recession characteristics, and possible ground-water contamination. If observed hydrographs are available at both ends of a reach, the unknown river-channel properties can be estimated.

Open-channel hydraulics

Nobuhiro Yotsukura completed the derivation of turbulent mixing equations by using a natural coordinate system that follows the geometry of a natural stream. The derivation provides a satisfactory description of three-, two-, and one-dimensional convection diffusion processes in natural streams by using the depth- and width-averaging procedure and the distance-correcting metric coefficients.

Some results of numerical simulations using the mathematical models of one- and two-dimensional unsteady open-channel flows were reported by Chintu Lai. Simulated loop-rating curves for flood flow or pulsating flow are seldom the idealized simple hysteresis loops shown in textbooks. Lai found that they usually appear highly deformed, being superposed by numerous tiny secondary loops and kinks. Quite often, the main loop does not close. This is not surprising if one recalls that, in actual field reaches, both the flood hydrographs and the channel geometry are seldom regular and simple.

Lai also modified a one-dimensional unsteady-flow model by using a variable resistance coefficient that is a function of temperature (viscosity), depth, discharge, Reynolds number, and other factors. This innovation has greatly improved unsteady-flow model predictions; for example, it has brought the computed discharges within a few percent of the observed discharges throughout a wide range of discharge for a prolonged period of time.

Low flows

J. T. Armbruster (1976b) derived equations for estimating low-flow frequency characteristics in the Susquehanna River basin in Pennsylvania from basin characteristics and an infiltration index. Inclusion of the latter, which is based on hydrologic soil groupings maps produced by the U.S. Soil Conservation Service, reduced the standard error of estimate of the 7-day 10-year low flow from 63 to 37 percent.

Both the daily duration curve and the low-flow frequency curve are used to characterize low flows of streams. K. L. Lindskov found a close relationship between the 7-day 10-year low flow and the daily discharge exceeded 90 percent of the time. A least squares fit to the logarithms of the data at 74 sites gave a correlation coefficient of 0.98 and the equation

$$ {}_7Q_{10} = 0.263\ Q^{1.13}{}_{90}, $$

where ${}_7Q_{10}$ is the 7-day 10-year annual low-flow discharge and Q_{90} is the discharge at 90 percent on the duration curve (in English units).

Channel geometry

G. P. Williams developed empirical relations for estimating the rates at which mean velocity, mean depth, and water-surface width change with discharge at a cross section on an alluvial channel. The relations apply to water discharges ranging from 0.0003 to 2,000 m^3/s, channel widths ranging from 0.3 to 600 m, mean depths ranging from 0.3 to 11 m, and median bed-material sizes ranging from 0.06 to 100 mm.

Using standardized measurements of width on high-gradient stream channels, W. R. Osterkamp and E. R. Hedman found a power-function relation, indicative of static allometric growth, between width and average discharge in a downstream direction. Mountain streams were selected because variables affecting the width-discharge relations of these channels have smaller ranges than those in other climatic-geologic-topographic environments. Regression results based on data from streams having similar sediment characteristics suggest that a constant exponent of discharge of 2.0 exists for the power-function relation with width. This exponent agrees with results obtained by L. B. Leopold and Thomas Maddock, Jr. (1953), and thus confirms their b exponent.

Time of travel

S. E. Eikenberry developed equations for estimating traveltimes on Indiana streams from stream slope and average discharge; the equations apply to discharges ranging from 20 to 200 percent of average. They are based on traveltimes measured on 2,600 km of stream reaches and have standard errors ranging from 11 to 15 percent for streams draining more than 3,200 km^2 and from 16 to 18 percent for streams draining areas between 200 and 3,200 km^2.

Results of fluorescent-dye velocity measurements made in contrasting reaches of the Fox River in northeastern Illinois showed that average velocities in natural channels are approximately four times greater than those in modified reaches of the river, according to C. R. Sieber. The 80-km segment of the Fox River below McHenry Dam traverses an urban industrial area and contains a series of dams and pools. Average velocities of about 0.11 m/s were measured at a discharge of about 50 percent on the duration curve. Conversely, the 75-km segment from Aurora to Ottawa, which flows through a rural area in a predominantly natural channel, had average velocities of about 0.41 m/s at a discharge of about 40 percent on the duration curve.

A. O. Westfall used fluorescent-dye tracers to measure traveltimes of water in five Ohio streams. The purpose of the measurements was to determine the dispersion characteristics of the rivers and to provide a basis for estimating DO recovery rates and traveltimes of accidental pollutant spills. Discharges of the streams ranged from 32 to 80 percent on the duration curve, and velocities ranged from 0.03 to

0.32 m/s. Velocities of the leading edges were slightly higher than those of the peak concentrations of dye.

A. J. Calandro reported the injection of a water tracer into the Mississippi River at three locations in July 1975 to determine the traveltime, maximum concentration, dispersion characteristics, and duration of the tracer cloud in the reach from the Arkansas-Louisiana State line to Plaquemine, La., a distance of about 480 km. The flow in the river was about 11,300 m^3/s during the study period. Measured traveltimes were 112 hours for the leading edge, 128 hours for the peak, and 159 hours for the trailing edge. These data were used to calibrate a mathematical model developed by R. S. McQuivey. This calibrated model was then used to generate traveltimes for discharges ranging from 6,000 to 40,000 m^3/s.

Computer programs for surface-water processes

D. P. Bauer concluded preliminary documentation of computer programs for unsteady-state DO analyses in streams and for nutrient additions to an existing steady-state DO model. Both programs were being field tested.

M. E. Jennings documented a computer program for BOD parameter determination for standard BOD tests and, with D. W. Stephens, documented a computer program for determining community metabolism parameters by means of oxygen-curve methods.

J. O. Shearman refined computer programs for river-basin simulation of flow quantity and made test applications in Wisconsin, Oregon, North Carolina, and Pennsylvania.

Jennings also developed an urban stormflow-quality model that incorporates data-specific algorithms for flow and pollutograph routing in urban storm drains. Data from basins in Florida, Wisconsin, Colorado, and Mississippi were used to test the model.

Streamflow prediction

W. V. Tangborn and W. G. Sikonia developed an operational model (OPSEA) that uses only standard runoff and precipitation observations to predict seasonal runoff. This model is a descendant of the hydrometeorological method developed by Tangborn and R. A. Rasmussen. OPSEA significantly improves prediction accuracy; the results of testing on drainages in Washington, California, and Norway were encouraging.

Streamflow transmission losses

Much of the storm runoff that enters stream channels in western Kansas is absorbed into the alluvial material of the streambed and flood plain. Using data taken from pairs of gaging stations on the same stream, P. R. Jordan found that the losses in a channel reach are proportional to the stormflow volume at the upper end of the reach. In each kilometer of valley length, the loss is about 1.2 percent of the flow volume that enters.

Basin characteristics from satellite imagery

E. F. Hollyday (1976), E. J. Pluhowski, and Doyle Smith (USGS) and W. E. Evans (Stanford Research Institute) used imagery from Landsat–1 to discriminate physical features of drainage basins in an effort to improve equations used to estimate streamflow characteristics at ungaged sites. Records of 20 gaged basins in the Delmarva Peninsula of Maryland and Delaware were analyzed for 40 statistical streamflow characteristics. Equations relating these characteristics to the physical features of the basins were obtained by multiple regression. A control group of equations used physical features of the basins derived from topographic maps. Another group of experimental equations used physical features derived both from maps and from imagery. For 12 of the 40 flow characteristics, the equations in the experimental group had standard errors of estimate 10 percent lower than those in the control group. The investigators concluded that the use of data from Landsat imagery can improve the accuracy of estimates of some streamflow characteristics in the Delmarva Peninsula.

Canal evaporation determined by thermal modeling

H. E. Jobson (1975) studied the thermal balance of the 26-km San Diego Aqueduct in southern California to determine the manner in which the surface exchange varies with meteorological factors. Meteorological and hydraulic variables, as well as the temperature at each end of the canal, were continuously monitored. A finite-difference model was constructed that allowed the data to be analyzed in the Lagrangian framework and that also allowed construction of a graph of Dalton wind function versus windspeed. Within the range 0.5 to 4 m/s, the wind function appeared to vary linearly with windspeed. The mass-transfer coefficient developed for lakes provided a reasonable approximation of the wind function, provided that the short effective fetch of a canal was properly accounted for.

Streamflows preferred by steelhead trout

C. H. Swift III (1975) related the stream discharges preferred by steelhead trout for spawning and rearing in 18 western Washington streams to four drainage-basin parameters and, optionally, to one stream-channel parameter. The basin parameters were drainage area, site altitude, mean basin altitude, and channel slope. The channel parameter was channel width at a toe-of-bank water level. The preferred discharges for spawning were those that produced the greatest streambed area having the water depths and velocities preferred (according to fish biologists) for spawning, as measured at 54 study reaches (3 reaches on each of the 18 streams). The preferred discharges for rearing were those that wet the entire streambed, as determined from wetted-perimeter curves for the same 54 study reaches. Regression equations that related the preferred discharges to the basin parameters had standard errors of estimate ranging from 45 to 68 percent for spawning and 52 to 57 percent for rearing. Regression equations relating preferred discharges to the toe-of-bank width had standard errors of estimate ranging from 28 to 46 percent for spawning and 56 percent for rearing.

CHEMICAL, PHYSICAL, AND BIOLOGICAL CHARACTERISTICS OF WATER

Extension of water-quality data by use of geophysical logs

W. L. Hiss (1975c) developed empirical and mathematical relationships between physical and chemical water-quality characteristics by using geophysical records and approximately 8,000 chemical analyses of water in geologic formations of several different ages in southeastern New Mexico and western Texas. Expressions were obtained for (1) the relationship of dissolved solids to electrical resistivity (as recorded in geophysical logs), computed resistivity, chloride-ion concentration, and density of water and (2) the relationship of chloride-ion concentration to the density and electrical resistivity of water.

Using a method developed by the oil industry, Hiss determined electrical resistivities of water on the basis of concentrations of the six most common constituents dissolved in natural water. The calculated resistivities compared favorably with the measured resistivities of ground water in the area. An extension of data for the relationships between water-quality characteristics and computed resistivities was used to produce spatial distribution maps.

Organic analyses of waters affected by oil-shale retorting

J. A. Leenheer reported that 30 surface- and ground-water samples from the oil-shale areas of the Piceance Creek basin in Colorado and the Uinta River basin in Utah were analyzed for their organic-compound class composition to determine the baseline water quality of organic constituents prior to development of the oil-shale industry. The major source of organic residuals presently entering these waters was found to be related to agricultural activity.

An oil-shale retort waste-water sample was analyzed to determine the types and amounts of organic compounds that are likely to be released into the environment as a result of the retorting process. The sample contained 5,000 mg/l of dissolved organic carbon, approximately 65 percent of which can be classified as being present in hydrophobic constituents that are likely to become strongly attached to the spent shale, soil, and sediment in the disposal site; 35 percent can be classified as being present in hydrophilic constituents that probably will reach the water table or become runoff.

Trace metals in ground water of the Fort Union coal region, Montana and North Dakota

According to G. L. Feder, preliminary results of a random sampling of ground water associated with the Tertiary coal measures in the Fort Union coal region of North Dakota and Montana indicated that the trace-element content of the water is highly variable. Geometric deviations of more than 2 were found for all trace metals detected; zinc, with an observed range in concentration of <1 to 2,500 μg/l, had the highest geometric deviation, 12.6.

The presence of hydrogen sulfide and reduced nitrogen species (organic nitrogen and ammonia) indicated a reducing environment in most aquifers associated with the coal. Apparently, in this environment, both precipitation of trace metals by hydrogen sulfide and complexation of trace metals by organic ligands may occur. Adsorption and exchange reactions with the coal may also be important in reducing the trace-metal content of ground water in the region.

Water quality in Boulder County, Colorado

In an assessment of rapidly urbanizing Boulder County, Colorado, D. C. Hall and E. C. Linden found that the surface water is predominantly a calcium bicarbonate type and that sodium, magnesium, and sulfate locally occur as dominant ions. The dissolved-solids content ranges from about 20 mg/l in high mountain streams to 1,500 mg/l where the streams leave the county. There is a severalfold seasonal variation in the dissolved-solids content at many sites. Dissolved gross-alpha radioactivity ranges from less than 0.5 to 73 μg/l as uranium, and dissolved gross-beta radioactivity ranges from 1.6 to 23 pCi/l as cesium-137. Most samples contain fecal streptococcal and fecal coliform bacteria.

The ground water also is primarily a calcium bicarbonate type. Its dissolved-solids content, which is generally lower in the mountains and higher in the plains, ranges from 30 to 34,000 mg/l. Dissolved gross-alpha radioactivity ranges from 1.2 to 120 μg/l as uranium, and dissolved gross-beta radioactivity ranges from 1 to 30 pCi/l as cesium-137. Radium ranges from 0.1 to 4.6 pCi/l in eight samples, and uranium ranges from 12 to 35 μg/l in three samples. Selenium concentrations were above the levels recommended by the Environmental Protection Agency for drinking water in two samples, and fluoride exceeded recommended levels in one sample. All 4 of the springs sampled were frequently contaminated with coliform bacteria, but none of the 30 wells completed in crystalline or sedimentary bedrock was contaminated.

Geochemistry of shallow water in the Fort Union Formation of southeastern Montana

R. S. Roberts and R. W. Lee found that the geochemistry of water at shallow depths in the Fort Union Formation of southeastern Montana is determined primarily by the following three major chemical phenomena:

- Dissolution of sulfates (evaporites) in aquifers comprising sandstone, siltstone, shale, and conglomerate.
- Cation exchange by interspersed clay minerals in the same aquifers, which increases the sodium-ion concentration and removes calcium and magnesium ions from the water.
- Sulfate reduction in some coal aquifers, which lowers sulfate concentration and enriches the bicarbonate content of the water.

Dissolution of sulfates and sodium-ion enrichment by cation exchange occur throughout the lateral extent of the aquifers. Sulfate reduction occurs only locally. All three phenomena are related to the movement of water from recharge areas to discharge areas within a particular aquifer zone.

Dissolved-solids concentrations in water from the Fort Union Formation range from as low as 300 mg/l in shallow wells and springs, which may have any combination of sodium, calcium, magnesium, sulfate, and bicarbonate ions, to 8,000 mg/l in sodium-magnesium-sulfate water from other wells. The average water well (45 m deep in sandstone) produces water containing 2,000 to 3,000 mg/l dissolved solids; the water is a sodium-magnesium-sulfate type having about 300 to 500 mg/l bicarbonate ion and a calcium-ion concentration that is generally less than that of the magnesium ion.

Although coal aquifers may contain water similar in quality to water in aquifers composed of sandstone, siltstone, shale, and conglomerate, water in reducing zones in the coal generally contains dissolved-solids concentrations of 1,000 to 2,000 mg/l; the water is a sodium bicarbonate type having very low concentrations of calcium, magnesium, and sulfate ions. Water from coal aquifers is occasionally colored yellow to brown by soluble organic compounds (probably fulvic acids), and hydrogen sulfide gas produced in the reducing zones may affect the potability of the water.

Distribution of major and minor ionic species in ground water in the Green River Formation, Colorado

S. G. Robson and G. J. Saulnier, Jr., reported that chemical analyses of water from selected wells in the Piceance Creek basin of Colorado are being used to identify the sources and distribution of major and minor ionic species in ground water in the Green River Formation. Of particular concern are (1) the sources of fluoride, boron, lithium, and barium, which have average concentrations of 95, 320, 42, and 13 mg/l, respectively, and (2) the effect of dissolution of nahcolite ($NaHCO_3$), which occurs in the aquifer.

The oil shale and the overlying beds of the Green River Formation form a dual aquifer system separated by a leaky confining layer (the Mahogany zone). The lower aquifer is the source of most of the trace constituents and produces water containing high concentrations of sodium and bicarbonate. Saline water with a dissolved-solids content greater than 30,000 mg/l has moved from the lower aquifer into the upper aquifer and onto the land surface in the north-central part of the basin.

A solution to the lateral-dispersion equation, coupled with a two-dimensional finite-difference flow model, was used in an attempt to predict the distribution of saline water at the top of the lower aquifer (the leakage source) and at the bottom of the upper aquifer; results to date have been inconclusive. Future analyses will include the use of chemical reactions in the model, as well as profile modeling.

Water quality of Upper Cretaceous aquifers in the northern Great Plains

D. W. Fisher and M. G. Croft reported that water-quality analyses of samples from 39 wells tapping

Cretaceous aquifers of the northern Great Plains indicated a pattern of increasing dissolved-helium concentrations with increasing distances from recharge areas for both the Fox Hills and the upper Hell Creek aquifers. Levels of dissolved helium range from less than 0.001 to more than 0.03 mg/l. Dissolved hydrogen gas was found in some of the samples that had high helium contents; the highest concentration of hydrogen found was 0.01 mg/l.

D. C. Thorstenson, who conducted a study of water from several wells in the Fox Hills aquifer of North and South Dakota, found only traces of DO, iron, and nitrite (<0.02, <0.002, and <0.01 mg/l, respectively) in any part of the aquifer (including a shallow well within a few kilometers of the recharge area). Despite high variability in sulfate, bicarbonate, and chloride concentrations, pH ranged between 8.9 and 8.6 throughout the aquifer.

An abrupt change in water quality downgradient in the aquifer was observed. Recharge water to the west and south of a north-northwest-trending line passing near the town of Fairfield, N. Dak., had high and variable sulfate concentrations (>100 mg/l), nearly uniform pH (8.8) and bicarbonate concentration (700 mg/l), and low methane levels (<1 mg/l). East of the line, the sulfate was uniformly low (<20 mg/l), bicarbonate concentrations were greater than 1,200 mg/l, and methane levels were as much as 50 mg/l.

Chloride increased from 5 to almost 300 mg/l along the flow path of water in the Fox Hills aquifer. Increasing bromide-to-chloride and iodide-to-chloride ratios along this path indicated mixing of the original recharge water with a more saline water.

Water-quality modeling

D. B. Grove developed a numerical-simulation water-quality program that predicts temporal and spatial concentrations of reacting solute species in the saturated subsurface environment. The computer program used the Galerkin finite-element technique to solve the partial differential equations that define mass transport. Both chapeau (linear) and hermite cubic-basis functions were successfully used as approximating functions for the finite-element method. Field data for releases of chloride, tritium, and strontium from the National Reactor Testing Station in Idaho and the simulated data were in general agreement. The finite-element technique was less susceptible to numerical oscillation than finite-difference methods and more rigorous in terms of mathematics than the method of characteristics.

Influence of iron bacteria on pyrite oxidation in soils

G. G. Ehrlich and E. M. Godsy found that the rate of oxidation of pyrite was temporarily accelerated when columns containing sand-pyrite mixtures were inoculated with iron bacteria, *Thiobacillus ferrooxidans,* but oxidation soon returned to its original rate. The concentration of iron in the effluent increased more than tenfold shortly after inoculation of the effluent with fresh cultures of *T. ferrooxidans.* Iron levels subsequently declined to values observed before inoculation, even though iron bacterial cell counts remained high. This effect was noted with various culture media being used as column elutants and even with deionized water. The results of these experiments suggested that the effect of iron bacteria on the oxidation of pyrite in the unsaturated zone is minor.

Trace elements in northern California streams

The trace-element content of clean streams is of interest because it provides a standard against which to compare streams that have been contaminated by man. In the spring of 1975, V. C. Kennedy and M. J. Sebetich sampled five apparently uncontaminated northern California coastal streams. Suspended solids were removed by passing the water through 0.4-μm polycarbonate membrane filters without a surfactant coating. The filtered samples were immediately acidified or frozen for preservation, and the samples were analyzed by the method of standard additions. The results of the analyses of these samples are shown in the following table:

Sample location[1]	Concentrations (μg/l)								
	Ag	Cd	Cr	Cu	Mn	Pb	Zn	NO_3-N	PO_4-P
Little Lost Man Creek near Orick	<0.05	0.02	0.7	0.8	1.3	0.1	0.6	6	13
Mattole River near Petrolia	<0.05	0.03	0.7	1.0	3.1	0.1	0.6	29	25
Eel River near McCann	<0.05	0.02	1.0	1.0	5.1	0.1	0.4	8	14
Klamath River near Klamath	0.05	0.03	1.5	1.3	3.5	<0.1	0.5	14	15
Pieta Creek near Hopland	<0.05	0.01	0.8	1.0	0.9	0.1	0.2	7	14

[1] All locations in northern California.

These results can be compared with concentrations reported by W. H. Durum, J. D. Hem, and S. G. Heidel (1971) for surface waters of the United States. In 54 percent of the approximately 720 samples that they collected, cadmium content was less than their detection limit of 1 μg/l; chromium content was 5 μg/l or less in 98.5 percent of their samples; lead content was below 1 μg/l in only about 35 percent of their samples; zinc content was below 10 μg/l in only 26 percent of their samples. Data were not available for comparison with other constituents measured by Kennedy and Sebetich. The comparison of available data suggested that a high percentage of the Nation's streams are contaminated by zinc, lead, and cadmium, whereas chromium concentrations are generally low.

Naturally occurring organic-nitrogen compounds in ground water

A study by G. L. Feder, J. A. Leenheer, and E. R. Whipple of naturally occurring organic-nitrogen compounds in ground water from the Fort Union coal region of North Dakota indicated that about 85 percent of the organic-nitrogen compounds occur in the hydrophobic acid fraction. Specific compounds were not identified, but the hydrophilic acid fraction probably can be characterized as fulvic acid, which is a naturally occurring organic polyelectrolyte originating in the coal beds or in associated dark shales.

A ground-water sample collected from a shallow well in a coal seam near Dunn Center in Dunn County, North Dakota, was analyzed to determine dissolved organic carbon (DOC) and nitrogen species content. The DOC in the sample was 83 mg/l, and ammonia and organic nitrogen (both as N) were 2.3 and 1.3 mg/l, respectively. Ground-water samples collected from other areas in the Fort Union coal region of North Dakota showed a DOC range of from 5 to 83 mg/l, which may indicate widespread occurrence of fulvic acids in the ground water. Fulvic acid is quite resistant to microbial degradation and assimilation, and its most important role in the region's ground-water geochemistry is as an organic-ligand complexation agent for certain trace metals.

RELATION BETWEEN SURFACE WATER AND GROUND WATER

Interaction of lakes and ground water

T. C. Winter (1976) used digital-model simulations of vertical ground-water flow near lakes in a wide variety of hydrogeologic settings to demonstrate that the existence, position, and head value at the stagnation point of the ground-water flow field, relative to the head represented by lake level, are the keys to understanding the interaction of lakes and ground water. The stagnation point is the point of least head along the ground-water divide between flow systems of different magnitudes adjacent to a lake. Therefore, if a stagnation point exists, the divide is continuous, the lake cannot leak, and the lake is the discharge point of ground-water flow systems. If there is no stagnation point, the ground-water divide is not continuous, and a lake can leak through part or all of its bed.

Factors that strongly influence the interaction of lakes and ground water are (1) the height of the water table on the downslope side of the lake relative to lake level, (2) the position and hydraulic conductivity of aquifers within the ground-water reservoir, (3) the ratio of horizontal to vertical hydraulic conductivity of the ground-water system, and (4) the lake depth.

R. C. Reichenbaugh reported that the terrain around Keystone Lake in Florida is dotted with sinks that allow leakage from the surficial aquifers to the underlying Floridan aquifer. Variations in the lake-stage hydrograph and in the potentiometric surface of the Floridan aquifer correspond closely to seasonal rainfall. Deficient rainfall in the last 14 years has resulted in decreasing levels in the lake and the aquifer.

Calculation of maximum induced infiltration from a model determination of riverbed leakage

E. J. Weiss obtained a value of riverbed leakage (ratio of streambed hydraulic conductivity to streambed thickness) for a 1.6-km reach of the Scioto River south of Columbus, Ohio, by varying values of leakage and aquifer transmissivity within a computer program to simulate two potentiometric surfaces of the surrounding aquifer. One surface was the steady-state surface existing from May 19 to 21, 1975, and the other surface was one created by a 73-hour aquifer test. The aquifer test yielded a transmissivity of 3,400 m^2/d. This value was used in the steady-state simulation of the potentiometric surface, and a riverbed leakage of 2.5×10^{-6} s^{-1} was found by trial and error. Two computer simulations were used; one was based on a finite-difference numerical technique, and the other was based on a finite-element method. The results of both simulations were in final agreement. If an average river depth of 1.5 m and a width of 49 m are assumed, a maximum induced-infiltration rate of 0.18 m^3/s per river kilometer can be calculated for this reach.

Saline ground-water discharge to the Smoky Hill River, Kansas

Natural pollution of the Smoky Hill River by saline ground-water discharge occurs between New

Cambria and Sand Spring in central Kansas. The major area of discharge is in the reach that extends about 3 km upstream from the mouth of the Solomon River. J. B. Gillespie (USGS) and G. D. Hargadine (Kansas Water Resources Board) found that chloride discharge in the Smoky Hill River on August 7–8, 1975, increased from 113 t/d at New Cambria to about 517 t/d at Sand Spring.

Subsurface mapping defines eastern extent of Hutchinson Salt Member of Wellington Formation

A. J. Gogel constructed geologic-structure and isopach maps of the Hutchinson Salt Member of the Wellington Formation (Permian) in central Kansas to determine the hydrologic relationships between saline water in the Permian rocks and freshwater in the major stream-aquifer systems. The maps delineate the eastern edge of the salt front and an associated solution-collapse zone, which trend southerly from Saline to Sumner Counties. The maps also indicate that the location of the McPherson Channel, formed during the Pleistocene Epoch, coincides with the location of the solution-collapse zone in McPherson, Harvey, and Sedgwick Counties.

Vegetation as a hydrologic indicator in Ozarks basins

John Skelton and E. J. Harvey reported that one of the purposes of a current study of the Osage Fork, Grand Glaize, and Niangua basins in Missouri is to use various methods of determining the depth to the water table in valleys and adjacent uplands and to evaluate their usefulness in relating streamflow patterns to the position of the water table.

In late summer and early fall, many tributaries of the major streams are dry, but it is uncertain whether they are dry because of evapotranspiration or because of water loss to a deep water table. Vegetation is useful in determining whether an Ozarks valley has a shallow or a deep water table. A shallow water table is often indicated when phreatophytes are present, even though no flow can be observed in the stream channel. The most common indicators are the willows, but there are other trees, shrubs, vines, and herbaceous growths that can be useful indicators throughout the year.

Reduced canal infiltration in the Miami Springs-Hialeah area

According to W. L. Miller, sediments in the Miami Canal system have reduced infiltration to the major well fields in the Miami Springs-Hialeah area of Florida, particularly near the center of the cone of depression. Water-table profiles indicate that the quality of water in the well fields would be little affected by removing the canal sediments to increase infiltration. Sufficient material exists between the canals and the pumping zone to replace the filter effects of the sediments.

Flow in Silver Creek, Idaho

A multiagency study of the water resources of the Silver Creek area of Blaine County, Idaho, is being made to evaluate the possible effects of various land- and water-use alternatives. The USGS role in the study is to define the relations between ground water and surface water. J. A. Moreland reported that pumpage from the aquifer totaled 20.9 hm^3, and flows from artesian wells totaled 14.8 hm^3 in 1975. Nineteen shallow observation wells were installed to determine vertical-head differences in the aquifers. These wells and 75 others were measured monthly to define ground-water fluctuations. Reach gains and losses in Silver Creek and the Big Wood River were determined through a series of discharge measurements made in June, July, and October of 1975. Preliminary analyses of data indicated that Silver Creek is effectively separated from the deep artesian aquifer by a thick sequence of fine-grained sediments.

EVAPORATION AND TRANSPIRATION

Evapotranspiration, the conversion by plants of water to vapor that is mixed with the atmosphere, accounts for the expenditure of approximately 70 percent of the 760-mm average annual precipitation in the conterminous United States. Because a large part of our water resource is being lost to evaporation and transpiration, measurements of the losses are very important for planning purposes.

Most of the significant results of evaporation studies obtained during the year were from studies of stream channels and reservoirs, but a unique evaporation-control study was also done in the Carlsbad Caverns of New Mexico.

Evapotranspiration losses from streamflow

T. W. Anderson reported that maximum potential evapotranspiration losses (both present and future) from flood-plain areas have been estimated for all or parts of 29 streams in Arizona; the 2,032 km of stream channels covers nearly 16,000 ha of riparian vegetation and bare soil. The streams for which large increases in evapotranspiration are possible if additional streamflow is made available are mainly in the arid to semiarid west-central part of the State. The maximum possible increase in evapotranspiration losses will probably occur along the 79.3-km reach of the Santa Maria River in west-central Arizona, where present and possible future losses are estimated to be 13.6 and 19.7 hm^3/yr, respectively.

Evaporation from Denver water-supply reservoirs

According to D. B. Adams, evaporation studies at seven Colorado water-supply reservoirs owned by the Denver Board of Water Commissioners were begun in 1967. Energy-budget studies were made at Elevenmile Canyon Reservoir (1967–70), Dillon Reservoir (1967–71), and Gross Reservoir (1972–73). Mass-transfer studies were made at Elevenmile Canyon Reservoir (1967–75), Dillon Reservoir (1969–75), Gross Reservoir (1972–75), Antero Reservoir (1967–71), Cheesman Reservoir (1967–75), Williams Fork Reservoir (1969–75), and Ralston Reservoir (1972–75). Pan evaporation studies were made at Elevenmile Canyon Reservoir (1967–75), Dillon Reservoir (1969–75), Gross Reservoir (1972–75), Antero Reservoir (1967–71), Cheesman Reservoir (1967–75), Williams Fork Reservoir (1969–75), and Ralston Reservoir (1972–75).

Seasonal energy-budget evaporation rates ranged from a low of 3.5 mm/d at Gross Reservoir in 1973 to a high of 5.5 mm/d at Elevenmile Canyon Reservoir in 1970. Seasonal mass-transfer evaporation ranged from a low of 2.0 mm/d at Ralston Reservoir in 1972 to a high of 5.0 mm/d at Elevenmile Canyon Reservoir in 1968.

Thermal loading of Hyco Lake, North Carolina

Meteorological data taken over a 10-year period for 1,760-ha Hyco Lake in North Carolina were analyzed by G. L. Giese to determine the effect of thermal loading from a powerplant on evaporation from the lake. Results showed that about half of the heat added to the lake is used in increasing evaporation. This conclusion verified Harbeck's (1964) relation for estimating the increase in reservoir evaporation resulting from the addition of heat by a powerplant.

Maximum thermal loading for the lake occurred from July 1973 through December 1974 and averaged 4.1×10^{15} J/mo. During the same period, natural evaporation from the lake averaged 520 l/s, whereas evaporation caused by thermal loading averaged 280 l/s. In addition, an average of 100 l/s was evaporated from a canal heat-distribution system before it reached the lake.

Evaporation in Carlsbad Caverns, New Mexico

During the winter, the microclimate in the principal cave of the Carlsbad Caverns of New Mexico is primarily controlled by cold airflow into the natural entrance; the cold air displaces warmer air in the cave. J. S. McLean (1971, 1976) reported that uncontrolled airflow up the elevator shaft removed an estimated 833,000 l/yr of water from the cave before August 1972, when revolving doors were installed at the base of the elevator shaft. Net evaporation was reduced 10 percent—there was a 34-percent decrease near the elevator shaft and a 23-percent increase at most stations distant from the elevator shaft. Increased evaporation at remote locations in the cave is believed to be caused by the increased heat generated by more prolonged use of the cave's lighting system.

LIMNOLOGY AND POTAMOLOGY

The sciences of limnology and potamology comprise the scientific study of inland waters and the interactions between the environment and the organisms within those waters. Limnology is often defined as the study of standing waters, and potamology is defined as the study of running waters. Usage varies, however, and the term "limnology" frequently includes all inland waters. Research during the past year was directed toward both streams and lakes. Many lakes exhibited summer thermal stratification. Such lakes are separated into three horizontal strata as a consequence of solar heating and wind mixing. The uppermost warm and well-mixed layer, the epilimnion, overlies an intermediate layer, the metalimnion, wherein temperature decreases sharply with depth. Below these layers, at the lake bottom, lies a cold, dense, stagnant layer, the hypolimnion. The well-lighted epilimnion is characterized by the occurrence of photosynthesis, whereas, in the hypolimnion, decomposition of sedimented organic material dominates.

Lake reconnaissance

Lake-reconnaissance surveys provide baseline information, identify problems for more intensive investigation, and form a basis for regional classification of lakes.

An initial set of 17 lakes in Ohio, selected statewide, were sampled for overall water-quality conditions in 1975 by R. L. Tobin (USGS) and John Youger (Ohio Environmental Protection Agency). The cooperative program calls for a spring and a late-summer reconnaissance of each lake, which includes profile measurements, water-sample collections for various chemical and biological analyses, and water-quality evaluations of major inflows. A different set of lakes will be studied each year.

Thermal stratification was observed in lakes having depths greater than 5 m. Exceptions were those reservoirs controlled by multilevel release valves. The highest oxygen concentrations (20–21 mg/l) were observed in the epilimnion of the recently filled Paint Creek Reservoir. Oxygen depletion occurred in all stabilized hypolimnia. These lower zones were commonly characterized by the presence of hydrogen sulfide and high concentrations of ammonia.

Lake pH values ranged statewide from 4.2 to 9.8 and frequently varied from 1 to 2 pH units within a given lake. A similar pattern was observed for specific-conductance values, which ranged from 128 to 510 μmho. Light penetration, measured by Secchi-disk observations, ranged from 0.1 to 2.8 m; 11 lakes had values of less than 1.2 m.

Nutrient availability, uptake, and recycling were apparent in many of the lakes. Total plankton densities upward of 2,800,000 cells/ml were noted. Blue-green algae (Cyanophyta) dominated in 8 lakes in the spring and 16 lakes in the summer. Pesticides and toxic metals were not detected in significant amounts.

A reconnaissance study of about 760 Washington lakes was undertaken by G. C. Bortleson during 1973 and 1974 to provide preliminary lake information that will be useful for land-use planning, lake preservation, and lake restoration. Natural and cultural effects on lakes were evaluated by comparing 24 variables grouped into two categories related to (1) factors affecting increased nutrient enrichment from both natural and culturally related causes and (2) indicators of eutrophication and water quality, based on chemical, physical, and biological aspects of water quality. The potential for increased nutrient enrichment from natural sources was evaluated on the basis of (1) mean depth, (2) volume, (3) bottom slope, (4) shoreline configuration, (5) ratio of drainage area to volume, (6) altitude, and (7) water-renewal time. The potential for increased nutrient enrichment from cultural sources was evaluated on the basis of (1) total phosphorus loading from both point and nonpoint sources, (2) volume of water per nearshore home, and (3) percentage of shoreline developed. Total phosphorus loading of the lakes was calculated by using criteria based on phosphorus exports from various nonpoint sources in the lake basin. Indicators of eutrophication and water quality were evaluated from (1) phosphorus and nitrogen concentrations, (2) specific conductance, (3) DO concentration in the hypolimnion, (4) Secchi-disk visibility, (5) fecal coliform bacteria, and (6) the abundance of rooted aquatic plants. These evaluations serve as a basis against which future observations can be compared and as a source of data for incorporation into other theoretical and practical investigations. The data are used to assist the Washington State Department of Ecology in complying with the Federal Water Pollution Control Act of 1972, which requires that, to be eligible for Federal lake-restoration funds, each State must classify, according to "eutrophic condition," all publicly owned lakes.

Most lakes in Clackamas County, Oregon, are less than 8.1 ha in area. The largest lake in the county, Timothy Lake, has a surface area of 570 ha at normal pool level. According to M. V. Shulters, DO was undetectable in the hypolimnia of 9 of the 55 lakes sampled during the 3-month summer sampling period; all of these lakes were artificial irrigation reservoirs in the low-lying Willamette Valley. In contrast, most of the lakes in the Cascade Range had DO values near saturation in the hypolimnia. Eighty percent of all lakes had dissolved-solids values of 60 mg/l or less. The lowest observed pH, 4.9, was in Kinzel Lake in the Cascade Range. The highest observed pH, 9.4, was in one of the irrigation reservoirs.

Variations in specific conductance of a southeastern Oregon lake

D. A. Curtiss reported that the specific conductance of Malheur Lake in Oregon varied widely both areally and with time. The lake, one of the largest freshwater marshes in the United States, is the main unit of the Malheur National Wildlife Refuge. In 1975, samples were taken on 8 different occasions at 40 sites on the lake. In May, specific conductance ranged from 130 to 6,290 μmho at 25°C. The specific conductance of inflow streams ranged from 130 to 360 μmho, and, at the point of lake outflow, specific conductance was 580 μmho. Specific conductance was considerably higher on the eastern side of the lake than on the western side; the two sides are partly separated by a dike. From May to October, specific-conductance values ranged from 1,640 to 6,290 μmho at the sampling site where conductance was highest. In contrast, at the site of lowest conductivity, values ranged from 130 to 390 μmho, and, at the outlet, they ranged from 480 to 680 μmho.

Dissolved oxygen in Raystown Lake, Pennsylvania

D. R. Williams, J. L. Barker, and M. S. Johnson observed that, throughout the summer months, a distinct DO minimum occurred between the 7- and 10-m depths at four sampling sites in Raystown Lake in Huntingdon County, Pennsylvania; on many occasions, the DO concentration was zero. Below the 10-m depth, the DO concentration increased considerably, and, in most instances, the increased concentration persisted to the lake bottom. On each occasion, the depth of the minimum DO concentration corresponded to a distinct decrease in temperature. It is postulated that dead algal cells remain between the surface and the 7-m depth of the lake, above the colder, denser water, and that the oxygen demand resulting from the decomposing organic matter produces the noticeable drop in DO concentration.

Trace metals in Lake Michigan

H. V. Leland reported that distributions of solute Cr, Cu, Fe, Pb, Mn, and Zn were studied in Lake Michigan, a large oligotrophic lake. Distributions were examined during lake stratification and were related to time of sampling, concentrations of major dissolved constituents, and phytoplankton densities. Other important factors limiting the amounts of trace metals in solution are their coprecipitation with $CaCO_3$, adsorption on suspended particulates such as clays and hydrous metal oxides, and association with organic species such as humic material. Concentrations of solute trace metals in Lake Michigan are not significantly related to chlorophyll *a*, the predominant phytoplankton pigment. Uptake by plankton does not significantly limit solute metal concentrations, except in some nearshore areas of high productivity.

Mathematical modeling of lake circulation

With the aid of hydrodynamic numerical models, R. T. Cheng (1975, 1976) conducted studies of large-scale wind-driven circulation in large lakes and reservoirs. Parameters included were wind stress, river discharge, Earth rotation, basin topography, and turbulence. Turbulent mixing was introduced in terms of eddy-mixing coefficients, and the three-dimensional resolution of the velocity field was calculated. Knowledge of the velocity field will enable future extension of the modeling efforts to study solute transport. Both steady-state and transient wind-driven circulation were considered. Numerical solutions of the models were obtained by combining finite-element and finite-difference methods. The model was tested in the San Luis Reservoir of California by Cheng and R. F. Middelburg, Jr. Under the assumptions that the water was incompressible and homogeneous and that the Rossby number and the ratio of depth to lateral dimension were small, an Ekman-type model for simulating the steady-state wind-driven circulation was developed. The speed and the direction of currents in San Luis Reservoir were measured by inclinometers for up to 12 days at three depths. Considering the uncertainties involved in the model and in the field observations, very good correlation between the numerically simulated velocity distribution and the measurements was obtained when the lake was homogeneous.

Limnology of selected lakes and streams in the Fallen Leaf Lake basin, California

A comprehensive study of the physical, chemical, and biological characteristics of Fallen Leaf Lake in El Dorado County, California, was completed by R. H. Fuller (1975b). Included in the study were bathymetric mapping of the lake, sampling of the lake over a 12-month period, and sampling of major influent and effluent streams. Fallen Leaf Lake is typical of Sierra Nevada subalpine lakes. It was formed by glacial-moraine damming of the major streams of a glacially scoured valley. The bottom of the lake is an extension of the valley sides and reaches a depth of 115 m. At the bottom, temperature remained at 4°C throughout the year, an indication that the lake may not be completely mixed annually, and there was only slight evidence of oxygen depletion. At the lake's edges, ice formed in the winter, but the lake surface has not frozen completely since 1942. The strong thermocline that had developed by August disappeared in early autumn. The water was chemically pure, soft, and unbuffered, and specific-conductivity values rarely exceeded 40 μmho. Algal nutrient concentrations and coliform counts also were extremely low, except locally where septic-tank seepage was suspected. The lake can be classified as oligotrophic or ultraoligotrophic. The steeply sloped watershed extends from the lake at elevations of 1,950 m to more than 2,740 m at its highest point. The watershed contains several lakes that are limnologically similar to Fallen Leaf Lake, although they are smaller and covered with ice for up to 6 months of the year. The chemical quality of streams in the Fallen Leaf Lake basin was extremely good. Total dissolved-solids content was generally less than 20 mg/l, and specific conductance ranged from less than 5 μmho in the upper basin to near 25 μmho in the lower basin. Bacteriological studies indicated that there was no significant fecal pollution of these streams. There were many species of benthic invertebrates in the streams; the dominant ones included 17 species of mayflies (order Ephemeroptera), 14 species of stoneflies (order Plecoptera), 27 species of caddisflies (order Trichoptera), and 27 species of midges (order Diptera, family Chironomidae).

Limnology of Laguna Tortuguero, Puerto Rico

A comprehensive study of Laguna Tortuguero, P.R., was conducted from July 1974 to June 1975 by Ferdinand Quiñones-Márquez. Water and nutrient budgets, lagoon morphometry, and seasonal fluctuations in chemical, physical, and biological parameters were investigated. Seawater flowing into the lagoon accounted for most of the ions, other than calcium and nutrients, and maximum seawater concentration was about 5 percent. Ions were generally more concentrated in the western part of the lagoon as a result of poor drainage and less evaporation there. The bottom sediments occupied a volume of about 4.6 hm^3, or about 1.7 times the normal water volume. The sediments, mostly calcium carbonate precipitated from ground water supersaturated with calcium, were about 6.8 percent organic C, 0.8 percent total N, and less than 0.01 percent total P. Sixty-five species of periphyton, 44 genera of phytoplankton, and 16 genera of zooplankton were identified. Pennate diatoms dominated the periphyton, and *Anacystis* sp. dominated the phytoplankton. Rotifers were the principal zooplankters. High diversity among all the communities was observed.

Stream-water quality and aquatic insects along the trans-Alaska pipeline corridor

Studies of selected streams along the trans-Alaska pipeline corridor have been conducted since 1970. The pipeline route traverses the arctic, continental, and maritime climatic zones. The water quality of streams crossed by the corridor varies seasonally, but it is generally excellent; the dissolved-solids and nutrient concentrations are low, and pollutants are rarely detected. Sediment concentrations are low during low flow, which occurs under winter ice cover. Suspended-sediment loads are generally less than 500 mg/l in nonglacial streams except during spring breakup or summer floods. Stream water is cold owing to prolonged ice cover, presence of permafrost, or its glacial origin. Artificial substrate samplers were used by J. W. Nauman and D. R. Kernodle to collect aquatic insects in streams crossed by the pipeline route. Samples representing 2 years of sampling during open-water and ice-cover periods were pooled for each site to provide an estimate of aquatic-insect abundance and diversity. Aquatic insects are more abundant and diverse in nonglacial streams than in glacial streams, and midges (order Diptera, family Chironomidae) comprise from 50 to 90 percent of the total number of individuals in both stream types. Midge abundance and diversity data indicate that the streams studied are unpolluted but environmentally stressed, probably by the cold climate. The effects of construction activity along the pipeline route can be monitored by periodically comparing water quality with preconstruction conditions. In a similar manner, aquatic insects can be used to monitor water quality.

Reconnaissance study of summer benthic invertebrates along the proposed Alaska Arctic Gas Pipeline Company route

J. W. Nauman made reconnaissance collections of benthic invertebrates during the summer along the proposed Alaska Arctic Gas Pipeline Company route. Sampling consisted of drift collections made by using a 216-μm drift net during a 1-hour period at each of 13 sites. The dominant organisms in the collections were midges (order Diptera, family Chironomidae), stoneflies (order Plecoptera), and mayflies (order Ephemeroptera). A total of 27,459 organisms was collected. Drift ranged from 357 to 10,620 individuals/h for the Canning River and the Red Hill Spring, respectively. These two sites are not considered typical; only a small fraction of flow in the Canning River was sampled, and the Red Hill Spring is a hot sulfur spring. An average of approximately 1,300 individuals/h was collected in the summer drift samples.

Similarities of benthic invertebrates in two arctic mountain streams

K. V. Slack and J. W. Nauman noted many similarities in the benthic invertebrates found in reconnaissance samples taken in August 1971 from the Dietrich and Atigun Rivers in Alaska. Both the southward-flowing Dietrich and the northward-flowing Atigun Rivers are fifth-order streams on the Continental Divide in the Brooks Range. Detailed taxonomic analyses of the invertebrates collected by L. J. Tilley and S. S. Hahn showed that Chironomidae (order Diptera) dominated at all sites on both rivers. At the headwaters of both streams, where the rivers are principally snowmelt and glacial-melt waters, the chironomid subfamily, Diamesinae, predominated. At the upper Dietrich River station, Diamesinae made up 82 percent of the collection, and, at the upper three Atigun River stations, Diamesinae made up 87, 89, and 73 percent of the collections. At all other sites on both streams, the chironomid subfamily, Orthocladiinae, predominated. Stoneflies (order Plecoptera) were the second most abundant group at all stations on both rivers, except at the lowermost station in Atigun Gorge, where mayflies (order Ephemeroptera) were more abundant. Preliminary indications were that the first- and second-order streams in the Atigun drainage were located in the same regimen as the first-order stream in the Dietrich drainage basin. The benthic faunas of the fifth-order streams for both rivers had the greatest species diversity and evenness, and they were the most dissimilar taxonomically in comparison with the benthic faunas of other stations within the drainage basins.

Lead in the Vermilion River, Illinois

H. V. Leland completed a field study of the distribution, transport, and biological accumulation of lead in a small-river ecosystem, the Saline Branch of the Vermilion River in Illinois. He found that soluble-lead concentrations did not vary in a regular pattern with either discharge or primary production. Soluble-lead concentrations were primarily regulated by the interactions of metal species with particulate matter. The concentrations of lead sorbed by periphyton correlated well with the particulate lead concentrations in the stream water. Although high lead concentrations were found in periphyton and some aquatic plants in areas of the Saline Branch receiving urban runoff and discharge from a municipal waste-water treatment plant, the concentrations were apparently not great enough to affect the ecosystem.

Evaluation of samplers for collection of benthic invertebrates

R. F. Ferreira, K. V. Slack, R. C. Averett, and B. W. Lium compared four types of artificial substrate samplers (Bull Basket, Bar-b-que Basket, Beak Tray, and standard multiple plate) and a Ponar Grab sampler, all of which had the capability to avoid loss of organisms during sampling. The artificial-substrate samplers were placed in the Sacramento River near Freeport, Calif., for 33 days. The Bar-b-que Basket collected the highest mean number of individuals and total number of taxa; the Bull Basket collected the highest mean number of taxa and mean species diversities. The multiple-plate sampler ranked second in mean species-diversity collections. The Beak Tray consistently provided samples containing fewer taxa and individuals than the other three artificial substrates, but the samples were much larger and more diverse than the samples collected by the Ponar Grab. These results showed that artificial-substrate samplers are better than other types of samplers for collecting benthic invertebrates in water-quality investigations of large rivers.

Information theory and diversity index in water quality

In many biological studies of water quality, a diversity index is calculated in "bits per individual" by using Shannon's approximation to Brillouin's formula. The difficulties associated with such use of Shannon's formula and its associated parameters were investigated by S. M. Zand. Zand concluded that the usefulness of the diversity indices can be improved if (1) the diversity index is measured in "sits per individual" rather than the presently used unit of "bits per individual" and (2) the equation:

$$e = (H - H_{\min}) / (H_{\max} - H_{\min})$$

is used to evaluate the uniformity of distribution of individuals among species in a sample, where e equals relative evenness and H represents diversity.

PLANT ECOLOGY

Natural vegetation and water in the environment are interrelated, and an understanding of the interrelationships aids in predicting the effects of land use on the environment. A few examples of this action-reaction sequence follow. In desert-shrub communities in Colorado, plants in moist stream channels convert far more soil moisture to growth than upland species on dry sites. After artificial recharge ended in a short-grass prairie in Texas, the vegetation that became established consisted of fewer species than were found there before recharge began. In Wisconsin, the expansion and contraction of peat with the rise and fall of the water surface permit the growth of trees commonly found on dry land. Natural emissions of sulfur from hot springs in California apparently prevent the growth of a lichen species that is abundant in areas where there is no geothermal activity.

Evapotranspiration by northern desert-shrub communities

Plants occupying dry habitats make less efficient use of water than plants in moist habitats. A study of moisture relationships in 12 northern desert-shrub communities by F. A. Branson, R. F. Miller, and I. S. McQueen confirmed this hypothesis. Rabbitbrush growing in moist stream channels near Grand Junction, Colo., was found to be nearly four times more efficient in converting soil moisture to growth than nuttall saltbush, a species occupying dry upland sites. A partial explanation of this phenomenon may be that greater amounts of bare soil on uplands allow more water to be evaporated and thus unavailable for plant use.

Highly significant inverse relationships were found between evapotranspiration and moisture-removal forces (internal plant stress) in plants. Maximum internal plant stresses ranged from more than 10 MPa for plants in dry habitats to only 4 MPa for plants occupying relatively moist habitats. Differences in forces exerted by various species seemed to determine the kinds of plants found in the various habitats.

Results of a study of 14 plant communities in the Ruby Valley of Nevada showed that the amounts of live plant cover are directly related to the amounts of water evapotranspired by the different plant communities; the regression line for the relationship can be used to estimate evapotranspiration for similar communities. The correlation coefficient of +0.92 for the relationship is highly significant. The pressure required for plants to extract 1 cm of water from soils ranged from less than 1 bar for moist habitats to about 9 bars for the driest habitats.

Artificial recharge lowers vegetation diversity

In studying changes that took place in vegetation near Lubbock, Tex., T. E. A. van Hylckama found that artificial recharge reduced the number of species in the recharge basins. The original short-grass prairie vegetation consisted mainly of buffalograss (*Buchloe dactyloides*) and bluegrama (*Bouteloua gracilis*), interspersed with pricklypear (*Opuntia polyacantha*), mesquite (*Prosopis glandulosa*), Spanish-dagger (*Yucca angustifolia*), and about 25 less common species. Six weeks after 14 months of ponding, a very dense vegetation consisting of only eight species, dominated by two kinds of tumbleweed (*Salsola kali* and *Kochia scoparia*), Johnson grass (*Sorghum halepense*), and horse-nettle (*Solanum elaeagnifolium*), was established in the treated basin.

A strikingly similar change in vegetation characteristics took place in the dunes in the Netherlands where, during a 6-year period, a species-rich vegetation was replaced by nearly pure stands of large nettle (*Urtica dioica*). This change was attributable to chemical changes in soil moisture due to changes in water quality. Whether similar changes will further simplify the vegetation composition in the Lubbock recharge area is being investigated.

Water levels may control forestation in Wisconsin bogs

According to R. P. Novitzki, a study of wetlands throughout Wisconsin showed that bogs are unique among the State's wetlands. Forests normally occur only in those wetlands where soils are dry at least for short periods of time. Although bogs seem to be among the wettest of wetlands, they commonly support thriving forests of tamarack, spruce, and other trees that generally exist on dry land.

Conditions dry enough to support tree growth apparently result because the peat in the bog expands and deflates with changing water conditions; the surface is thus kept at a fairly stable position relative to the water level, and an environment suitable for forestation is maintained. This stability can be upset by several factors. Raising the water level above a point that can be accommodated by sediment expansion causes surface flooding and destruction of the peat by oxidation (or fire) down to the new water level, and wetter conditions less suitable for tree growth are again created. With the inception of wetter conditions and the destruction of the forest cover, the wetland changes to a sedge and grass community, and the process of bog formation begins anew.

Vegetation cover in Colorado oil-shale region

D. G. Frickel measured vegetation cover, hillslope gradients, and orientation at 112 sites in 2 vegetation zones of the oil-shale region of Colorado. Hillslope gradients ranged from 1 to 70 percent. A preliminary analysis indicated that vegetative cover in the desert-shrub zone (altitudes below 2,134 m) averaged 25 percent and ranged from 17 percent on slopes facing south-southeast to 33 percent on slopes facing west-northwest. Vegetative cover in the mountain-shrub zone (altitudes above 2,134 m) ranged from 16 to 73 percent and averaged 53 percent. There were not enough sites in the mountain-shrub zone to compute averages by orientation sectors. Steep hillslope gradients may be a factor in the higher percentage of cover in this zone.

Lichens do not grow on trees near hot springs

Observations made by R. S. Sigafoos in Lassen Volcanic National Park in California indicated that the staghorn lichen (*Letharia vulpina*) does not grow on trees in basins where hot springs are abundant. The yellow, many-branched lichen is common in the park and in coniferous forests elsewhere. Field tests showed that concentrations of sulfur in hot spring gases had a wide range of values. Although the odor of H_2S is strong in the basins, concentrations of H_2S were not detected by instruments, except in two small vents where they were less than 500 mg/l. Concentrations of SO_2 ranged from 1 to 12 mg/l, and concentrations of CO_2 ranged from 300 (the concentration in ambient air) to more than 10,000 mg/l. The assumption that there is an absence of lichens where there is a high sulfur content in the air has been verified by others who have conducted investigations in large metropolitan areas or near certain kinds of smelters.

NEW HYDROLOGIC INSTRUMENTS AND TECHNIQUES

Equipment for measurement of quality and quantity of water

G. F. Smoot and R. H. Billings reported the development of an urban hydrology monitor. The monitor is an integrated system including precipitation gages, a sewer-flow measuring device, an automatic water sampler, a clock, and a recorder. The system is being used to monitor storm runoff in city sewers. System logic inhibits data recordings during dry-weather no-flow conditions. When flow is detected above a preset level in the sewer, recordings are continuous on a 1-minute cycle. Between these two extremes, single recordings are initiated when the precipitation gage registers an increment of rainfall. Sampling is also initiated when flow exceeds a preset level; 2-l samples are collected and refrigerated at a programmable repetition rate of from 1 to 15 minutes until 24 samples have been collected.

A new water-surface follower was developed, and 15 are in field operation for evaluation, according to S. E. Rickley. These devices provide an analog shaft-position output for driving a recorder. They operate in wells having diameters as small as 5 cm.

Rickley also reported the development of a rechargeable power supply, which uses sealed-type lead acid batteries. The power source for maintaining the batteries can be either a solar panel or a 115-V a.c. powerline.

Equipment for sampling and analyzing suspended sediment

In order to meet the demand for large sample volumes, USGS personnel revised all suspended-sediment samplers. The new samplers hold liter containers, double the capacity of the older models. S. M. Hindall assisted in designing a new unit to facilitate sampling ice-covered streams. J. V. Skinner designed an auxiliary compression chamber for the P–63 sampler. In addition to pressurizing the P–63, the chamber supports a current meter and an acoustic depth transducer. The unit will operate in high-velocity flows and at depths as great as 80 m. A light-weight capacitive-discharge power supply was designed to operate point samplers. J. P. Beverage and Skinner conducted a series of tests to establish the relationship between hydraulic efficiency and expansion ratio for the Helley-Smith bedload sampler (W. W. Emmett, L. A. Druffel, V. R. Schneider, and J. V. Skinner, 1976).

Skinner and Beverage evaluated a commercial liquid-density cell for possible use as a field instrument for monitoring sediment concentrations. The cell proved to be rugged and dependable, but its resolution is limited to a concentration of ±100 mg/l. Sample pretreatment is being investigated as a means of improving overall sensitivity. Required instrument sensitivity in field applications was established by analyzing nationwide requirements (Skinner and Beverage, 1976).

Equipment for borehole geophysical studies

W. S. Keys reported that a new high-temperature acoustic televiewer probe was successfully operated in geothermal well GT–2 near Los Alamos, N. Mex. Although the probe will require further modification, logs of excellent quality were made to a depth of 2,851.4 m. A temperature log showed the bottom-hole temperature to be 196°C. Caliper, natural gamma, neutron, and single-point resistance logs were successfully made in this hot well. This temperature is undoubtedly the highest at which a televiewer log has been made. Perforations in a liner near the bottom of the hole were clearly shown, and well-defined fractures in the rock were logged at a depth of 2,606 m.

L. M. MacCary ran performance tests on a density system and a resistivity system. The density system records simultaneously the bulk density of the formations, the hole size, the natural gamma log, the average porosity, and a self-potential log. The resistivity system records simultaneously the short normal, the long normal, the long lateral, and the self-potential log.

Joe Sena developed a new recording technique for use on logging trucks. The high-speed system digitizes the acoustic waveforms from two receivers in a sequence of 1,024 8-bit binary words. Each digitized record is held in the digitizer memory until a footage command transfers the data to magnetic tape by means of a digital coupler system. The magnetic-tape transport is a 9-track 800-bpi unit and acquires data fast enough to allow continuous logging speeds of 18 m/min. The magnetic tape is directly compatible with the USGS DEC–10 computer system for ease of data playback and analysis.

A. E. Hess developed a system to interface the Canberra pulse-height analyzer with the digital magnetic recording system on a logging truck. This system allows a gamma spectrum, which has been stored in the analyzer memory, to be recalled and recorded on magnetic tape. The tapes can then be used with the USGS computer to perform complex operations such as removing background noise (spectral stripping). The system was field tested and is now in regular use on a logging truck.

Data transmission via satellite

A portable radio frequency (RF) monitor for use with the GOES-Landsat convertible data-collection platforms was designed by E. H. Cordes. The monitor has a broadband RF detector coupled to a sample-and-hold meter circuit. An alert is sounded by the monitor whenever the RF input exceeds a certain threshold. When the alert sounds, the user can read the peak field strength on the meter. This instrument is particularly useful in monitoring intermittent or random pulses.

Data-handling techniques

R. E. Booker developed a technique to reduce the amount of computer memory required by digital models of nonrectangular study areas. Instead of the variables' being stored in two-dimensional arrays, they are stored in linear arrays. The technique was used in stream-aquifer modeling for the Platte River Level-B Study. This technique reduced computer memory requirements by 50 percent for some of the areas modeled.

J. K. Sullivan developed a program for minicomputers to accommodate data with statistical variation in both axes—for example, crossplotting one log versus another or a log versus laboratory core analysis. The equation for the line of best fit is produced.

SEA-ICE STUDIES

Remote sensing of floating ice

W. J. Campbell (1975) used active microwave imagery to study polar ice fields, and W. J. Campbell, R. O. Ramseier, W. F. Weeks, and Per Gloersen (1975, 1976) completed an overview of the application of rapidly evolving remote-sensing platforms and sensors to floating-ice studies. The remote-sensing requirements for floating-ice studies were defined, as well as the capabilities of existing and future sensors and sensor combinations. An ideal operational ice satellite system was defined as a satellite in a polar orbit equipped with both a multifrequency passive sensor and a multifrequency active sensor to give high-resolution imagery and all-time all-weather capability.

Landsat–1 (formerly ERTS–1) imagery was used by Campbell (1976a, b, c, d, e) in five separate studies to determine the morphology of Beaufort Sea ice, to observe the seasonal metamorphosis of sea ice, to track ice flows, and to determine the dynamics of leads and polynyas and the ice shear zone off the coast of Alaska and Canada.

Skylab infrared, photographic, and passive microwave data were used, along with surface and aircraft-collected data, to study the dynamics and morphology of ice in the Gulf of St. Lawrence and Lake Ontario in Canada by Campbell, Ramseier, Weeks, and R. J. Weaver. Particularly interesting were the results of the passive microwave imagery collected by aircraft, the first time that dual polarization images of ice were obtained. It was found that:

- The higher brightness temperature was invariably obtained in the vertical mode.
- As the age increased, the brightness temperature increased in both modes.
- Associated with the age change, the difference in temperature as observed by the different polarizations decreased.
- In general, the horizontally polarized data were the most sensitive to variations in ice type, both for freshwater ice and sea ice.

The experiment also showed that a great deal of information on roughness and deformation could be obtained from X-band SLAR observations. This conclusion reinforced the investigators' opinion that the best all-time all-weather floating-ice data can be obtained by combining both active and passive microwave systems.

AIDJEX experiment

During the Arctic Ice Dynamics Joint Experiment (AIDJEX) 1972 Pilot Experiment, passive microwave and infrared data were obtained by NASA's Convair–990 remote-sensing aircraft over the Beaufort Sea. Per Gloersen, W. J. Campbell, R. O. Ramseier, W. J. Webster, and T. T. Wilheit (1975) compared these data with microwave data obtained on the surface at the AIDJEX test area on the pack ice. From these data, the ice in the area could be divided into five distinct zones. Three of the zones also were clearly distinguishable in passive microwave images obtained from the Nimbus–5 satellite. The aircraft data, surface data, and satellite imagery will be applied to numerical models of Arctic pack-ice dynamics.

Antisymmetric stress

C. H. Ling and W. J. Campbell studied the stress-strain relationship of sea ice and found that an antisymmetric stress tensor must be included to satisfy the angular momentum equation of sea ice, which is treated as a large-scale continuum. This antisymmetric stress is shown to be a very significant term for the basic equations of motion.

ANALYTICAL METHODS

ANALYTICAL CHEMISTRY

Determination of tellurium in silicate rocks

A rapid method was devised by L. P. Greenland for determining the nanogram per gram concentrations of tellurium in silicate rocks. A 0.25-g sample was dissolved in a hydrofluoric, nitric, perchloric acid mixture, the solution was evaporated, and the residue was dissolved in 6 molar hydrochloric acid. Nitrogen gas was passed over the solution in a flask; sodium borohydride was added, and the hydrogen telluride gas generated was passed through a heated cell mounted in an atomic absorption spectrophotometer. The peak height of the transient tellurium signal was measured on a recorder. A detection limit of about 5 ng/g Te was achieved. The method was not applicable to mineralized samples containing heavy metals or to the analysis of organic-rich samples such as coals or soils. Copper at 0.2 percent reduced the tellurium signal 10 percent; 0.5 percent Cu reduced it by about 90 percent.

Determination of arsenic, antimony, and selenium in coal

Philip Aruscavage developed a method for determining submicrogram quantities of arsenic, antimony, and selenium in coal by using a graphite furnace-atomic absorption technique. A 0.1-g sample of powdered coal is decomposed with a mixture of nitric, sulfuric, and perchloric acid. Ascorbic acid and sodium iodide are added to the acid solution, which is then extracted with toluene. The constituents are determined in the toluene layer by using an electrically heated graphite atomizer placed in an atomic absorption spectrophotometer. Routine determinations are made down to 0.1 μg/g for each of these three constituents.

X-RAY FLUORESCENCE

H. N. Elsheimer, B. P. Fabbi, and L. F. Espos (1975) developed an automated X-ray spectrograph controlled by a dedicated computer. In addition to controlling the operations of the X-ray spectrograph, the computer performs complex mathematical corrections for matrix effects and calculates the percent concentration of the constituents. Major constituents determined include SiO_2, Al_2O_3, Fe_2O_3, CaO, Na_2O, K_2O, TiO_2, P_2O_5, and MnO. Minor and trace elements determined include S, Cl, K, Zn, As, Rb, Sr, Y, Zr, Sb, and Ba.

EMISSION SPECTROSCOPY

Lithium, cesium, and rubidium in silicate rocks

A quantitative emission spectrographic technique for determining lithium, cesium, and rubidium was developed by R. E. Mays and J. L. Seeley. The method was designed to cover all concentrations down to 1 μg/g by using intensity values rather than line-width measurements. Application of the technique was successful in analyzing biotite separates having a high lithium content (0.1–0.5 percent) as well as materials having a lower lithium content, such as synthetic quartz samples and the USGS rock standards AGV–1, BCR–1, G–2, and GSP–1.

Determination of selenium in stibnite

The need for a rapid, sensitive, and inexpensive technique for determining low concentrations of selenium in sulfide materials such as stibnite encouraged Chris Heropoulos and J. L. Seeley to develop an emission spectrographic analytical procedure sensitive down to 1 μg/g in a stibnite matrix. The methodology included use of a short-wavelength radiation-sensitive emulsion; sample preparation was limited to dilution with graphite. Optimum excitation conditions, exposure time, and sample charge were established. The technique was applied to a suite of stibnites that contained selenium concentrations ranging from 3 to more than 2,000 μg/g.

Spectrographic thermometry and manometry

In a continuing investigation of spectral lines for thermometry and manometry, D. W. Golightly, Anthony Dorrzapf, and C. P. Thomas developed a minimal list of six iron lines for thermometry and six titanium lines for manometry. These lines have tested characteristics that rigorously conform to theoretical and experimental criteria that enable investigators to make precise measurements of temperature and electron pressure in d.c. arcs of geological materials. Such measurements have led to an elucidation of the dynamic processes of transport and excitation in d.c. arcs currently used for routine computerized emission spectrography. This information is needed to develop analytical methods with improved accuracy, especially for sample matrices greatly dissimilar to those of the calibration standard.

A microcomputer-based data-acquisition system

C. P. Thomas designed procedures and programmed a minicomputer to perform all chemical data handling from plate reading to report writing. The minicomputer acquires transmittance readings from an automatic plate-reading unit set up by A. W. Helz (1973) at a 1.4-kHz rate. Transmittances are sampled every 0.025 A in the wavelength region between 2,332 and 4,664 A across each spectrum. The data are stored on a disk until semiquantitative determinations, using internally stored coefficients from 6-step synthetic standards for 64 elements, are performed. The programs use adaptions of programs used on a large computer (Walthall, 1974; Thomas, 1975). Preliminary information such as plate-emulsion coefficients, transmittances of the peaks and backgrounds of 214 iron calibration lines and 450 analytical lines, intensities, interference corrections, and preliminary concentrations from all the analytical lines are temporarily stored on a magnetic tape. The tape facilitates production of a 269-frame microfiche to accompany each 10-sample report form. Report forms are printed automatically on the line printer. The magnetic tape also facilitates storage of sample analyses on the Rock Analysis Storage System. A plate containing 26 spectra can be recorded in 1 hour, and data analysis and storage can be completed in another 45 minutes.

Data reduction from one plate can occur simultaneously with data acquisition from another plate. Combining the data acquisition and analysis systems results in one-third the throughput time for analyses and one-tenth the computer charges that result when calculations are performed on an outside computer.

Determination of trace elements in galena

A semiquantitative spectrochemical method for determining trace elements in galena was developed by E. L. Mosier, J. C. Antweiler, and J. M. Nishi (1975). Results on 40 elements are reported as 6 logarithmically spaced intervals per order of magnitude and obtained by visual comparison with standards prepared in spectrographically pure lead sulfide. For most elements, detection limits are generally between 1 and 20 $\mu g/g$; for cerium, sodium, strontium, tantalum, and zinc, however, the limits are 50 to 100 $\mu g/g$.

Analysis of native gold for trace elements and silver

A spectrographic method for the semiquantitative determination of trace elements and silver in gold was developed by E. L. Mosier (1975). By analyzing the gold in its native states, the method avoids the need for complicated sample preparation. The method uses 5-mg samples in an aluminum oxide-graphite mixture placed in the anode of a d.c. arc. Results are obtained by visual comparison with standard films prepared by arcing mixtures of spectrographically pure powders in a graphite base, pure gold, and aluminum oxide. Trace elements are reported in micrograms per gram. Silver, a major constituent in gold, is reported to the nearest percent.

ANALYSIS OF WATER

Stable isotopes

T. B. Coplen II and P. A. Emery successfully demonstrated that imported and native ground water can be differentiated in the northern Santa Clara Valley ground-water system of California by using stable hydrogen-isotope or stable oxygen-isotope analyses of water samples.

Dissolved gases

A gas chromatograph with a flame ionization detector was used by D. J. Shultz, D. W. Stephens, and R. E. Rathbun to measure microgram-per-liter quantities of low-molecular-weight hydrocarbon gases in water samples. The gases were stripped from the water and concentrated in a cold trap before they were flushed into the chromatograph. A set of 20 samples with mean ethylene and propane concentrations of 0.145 and 0.258 $\mu g/l$, respectively, had coefficients of variation of 2.3 and 2.1 percent, respectively.

Neutron-activation analysis

The application of a neutron-activation analysis procedure developed by L. L. Thatcher showed good reproducibility for all elements except selenium and tungsten. Selenium present as selenite ion was quantitatively recovered by the thioacetamide precipitation procedure used to separate and concentrate the desired elements; the recovery of selenium from selenate varied, however, because of incomplete reduction. This problem was eliminated by heating the samples in the presence of stannous chloride. This procedure also resulted in quantitative recovery of tungstate, and sodium contamination of the sulfide precipitate was reduced.

Thatcher also found that the sensitivities of the determinations of Al, Br, Cl, Cu, I, Mg, Mn, Na, Sr, and V by rapid instrumental neutron-activation analysis could be significantly improved by sequentially irradiating several 5-ml parts of a sample. Counts obtained for each 5-ml part were totaled in each significant spectral region. Four sequential irradiations improved the detection sensitivity by a factor of approximately 2. The determination of aluminum by this technique is particularly reliable and reproducible.

Thatcher applied neutron-activation analysis to the investigation of thorium concentrations in surface and ground water of the Front Range area of Colorado and of an area in northeastern Wyoming. Analytical methods for determining thorium in water have been generally unsatisfactory because of their inadequate sensitivity and their failure to determine thorium adsorbed on the containers; acidification of a sample does not prevent the adsorption loss of thorium. Thatcher used a thin polyethylene bag of the same low trace-element content (content determined by nondestructive neutron-activation analysis) as the sample container. Thorium adsorbed on the sample container was determined directly by activation analysis, and that result was added to the quantity of thorium determined to be in the water. Amounts of thorium exceeding 1 $\mu g/l$ were found in water from several wells near Golden, Colo., and thorium content of 3 $\mu g/l$ was found in a Wyoming ground-water sample.

GEOLOGY AND HYDROLOGY APPLIED TO HAZARD ASSESSMENT AND ENVIRONMENT

EARTHQUAKE STUDIES

SEISMICITY AND EARTH STRUCTURE

A revolutionary seismic data acquisition system, called the Seismic Research Observatory (SRO), was developed at the Albuquerque Seismological Laboratory in Albuquerque, N. Mex. J. R. Peterson, H. M. Butler, G. L. Holcomb, and C. R. Hutt reported that the SRO system is capable of magnifications of 100,000 in the long-period band. The SRO sensor is operated in a borehole, at a depth of 100 m. The surface digital recorder has a dynamic range of over six orders of magnitude. The data acquired from SRO systems are having a significant impact on seismological research. SRO systems are now operational at Albuquerque, N. Mex.; Guam, Mariana Islands; Wellington, New Zealand; and Mashad, Iran. Plans are complete for the installation of SRO systems in nine other foreign countries.

A network of telemetered short-period seismograph stations was established in 1975 by the National Earthquake Information Service. Digital data are telemetered to Golden, Colo., from Menlo Park, Calif.; Salt Lake City, Utah; Newport, Wash.; Albuquerque, N. Mex.; and St. Louis, Mo. This network, coupled with the 29 domestic World-Wide Standard Seismograph Network stations (supported by the USGS) permits the rapid location of significant earthquakes in the United States.

B. R. Julian developed a new technique for calculating seismic wave paths in seismically complex three-dimensional media. The new technique is about 20 times faster and about 20 times less expensive than the old techniques and is expected to bring such calculations into much wider use in the future.

The February 4, 1976, Guatemalan earthquake ($M_S=7.5$) occurred on the Motagua fault (Espinosa, 1976). J. W. Dewey and Julian used a focal mechanism solution for this earthquake to show that seismic slip occurred in the same sense as the direction of relative motion between the North American and Caribbean plates. Dewey, W. J. Person, and W. J. Spence, using the spatial distribution of large aftershocks, suggested that the rupture length of this earthquake was approximately 250 km. Spence and Person showed that the rupture of the Guatemalan earthquake progressed into the triple junction zone between the Caribbean, Cocos, and North American plates.

Dewey studied the seismicity of the North Anatolian fault in Turkey, a major strike-slip fault similar to the San Andreas fault. Dewey felt that the seismic characteristics of the North Anatolian fault could be applied to the San Andreas fault. If so, the next great San Andreas earthquake will begin in a region of frequent, small to moderate earthquakes and then rupture into portions of the fault that have been relatively aseismic.

The 1965 earthquake that occurred on Rat Island in the Aleutian chain was related to the main underthrust event ($M_S=8.1$) by a simple model of strain diffusion (Spence, 1975). The corresponding effective mantle viscosity is 6×10^{19} P. Spence proposed a working hypothesis that relates island-arc volcanism and interarc basins to episodically subducting oceanic lithosphere. Research by Spence and others (1975) on the Peruvian earthquake of October 3, 1974 ($M_S=7.6$), showed that this earthquake and its aftershocks filled a previously identified seismic gap off the coast of Peru (Kelleher, 1972).

R. N. Hunter (1975) demonstrated that a sidereal period component in the times of earthquake occurrences, which Sadeh and Meidav (1973) postulated to be caused by unknown extraterrestrial forces, is due instead to the biasing of the total earthquake record by two extensive aftershock sequences.

EARTHQUAKE MECHANICS AND PREDICTION STUDIES

SEISMICITY

Automatic location of local earthquakes

S. W. Stewart developed a real-time, computer-based earthquake detection and location system that is now operational. The system monitors 91 seismic stations from the central California seismic network and 16 stations from the Oroville, Calif., seismic array. Earthquakes originating within either seismic array are detected immediately as they occur, and locations and magnitudes are printed out a few minutes later. The system performs especially well for the relatively dense Oroville network. During the month of October 1975, 118 events were timed by hand, and the locations thus determined were compared with those calculated by the on-line system. One hundred and seven of the Oroville events (91 percent) were picked and located by the on-line system, 8 events (7 percent) were picked but had insufficient data for location, and the remaining 3 events (2 percent) were not picked at all. Approximately 80 percent of the 107 hypocentral locations computed on line were within ± 0.5 min of latitude and longitude as determined by hand-timing methods. The automated computer system proved the feasibility of on-line, real-time detection and location of local earthquakes. The high performance of the system for the Oroville network enabled more extensive studies of seismicity to be made with a limited staff. Performance of the automatic system was not as good for the 91 stations of the central California seismic network, partly because the seismic network was relatively less dense than the one at Oroville and also because the geographic area being monitored was much larger. A second-generation automatic detection system will need to be developed to significantly increase the usefulness and reliability of automated methods.

Analysis of microearthquake data

During the past year, W. H. K. Lee (USGS) and Keiiti Aki (Massachusetts Institute of Technology) developed techniques for the inversion of *P* arrival times, as E. R. Engdahl (Cooperative Institute for Research in the Environmental Sciences) and Lee did for seismic ray tracing. These techniques yielded detailed information concerning the seismic velocity over time that may be present before an earthquake of moderate size. If such velocity variations are found, they may provide a basis for predicting such earthquakes. In addition to this theoretical work, much effort was directed toward collecting and processing seismic data in a manner that allows for more efficient analysis.

History of earthquake occurrence, San Francisco, California

R. D. Nason's compilation of earthquake history data showed that, in the greater San Francisco Bay area of California, damaging earthquakes were much more frequent (6–8 per decade) in the 20 years before 1906 than they have been in the many years since 1906 (1–2 per decade). Nason suggested that a highly stressed condition may have existed before 1906; the comparatively low level of earthquake activity at the present time may indicate that a highly stressed condition such as that existing before 1906 is not occurring in the 1906 earthquake area at this time.

Oroville, California, earthquakes

On August 1, 1975, an earthquake of magnitude $M_L = 5.7$ occurred in the Sierra Nevada foothills southeast of Oroville, Calif. The earthquake was felt strongly in Sacramento and was noticeable in Menlo Park, at a distance of 225 km. The epicenter was near the town of Palermo, 7 km south of Oroville and 11 km from the 235-m-high Oroville Dam. The maximum Modified Mercali intensity was VII. Because of the proximity of the earthquake to the dam and the possibility that the seismicity was induced by the 4.3-billion-cubic-meter reservoir, the USGS began deployment of a network of high-gain telemetered seismographs in the area. Data from these stations were augmented by data from a tripartite array of local stations telemetered to Menlo Park through a data-exchange agreement with the California Department of Water Resources.

C. G. Bufe, F. W. Lester, K. M. Lahr, J. C. Lahr, L. C. Seekins, and T. C. Hanks showed that early aftershocks of the earthquake defined a 12×12-km fault plane striking north-south and dipping 60° to the west to a depth of 10 km. Focal mechanisms from *P*-wave first motions indicated normal faulting, the western (Great Valley) side being downdropped relative to the Sierra Nevada block. The northward projection of the fault plane passed beneath Oroville Dam and cropped out under the reservoir. Lester, Bufe, Lahr, and S. W. Stewart showed that progressive growth of the aftershock zone and the position of foreshocks and the main shock suggested that rupture began at depth near the western margin of the aftershock zone and propagated upward to the east along the fault plane. Later aftershocks indicated further extension of the rupture surface to the north and south; several small shocks occurred near Oroville Dam in early October. The ratio of smaller events to larger events was unusually low ($b = 0.6$) in relation to the ratios reported for other earthquake sequences near reservoirs. C. B. Raleigh and M. S. Simirenko estimated that the crustal stress orientation obtained from first-motion studies of aftershocks showed large spatial variations and little evidence for premonitory temporal patterns of the type reported for earthquakes in the Garm region of the U.S.S.R.

The distribution of aftershocks led M. M. Clark, R. V. Sharp, R. O. Castle, and P. W. Harsh to discover a 3.8-km-long north- to north-northwest-trending zone of new fractures near Lake Oroville. In position, orientation, and sense of slip, the surface faulting agreed with the fault zone defined by mapped aftershocks and focal mechanisms and was compatible with the deformation shown by comparisons between leveling surveys conducted before and after the earthquake. The block to the east of the fault moved upward relative to the block on the west, as was shown by at least 55 mm of slip across the surface ruptures and 180 mm of vertical movement of benchmarks near the rupture zone. The faulting followed a zone of earlier displacement that may have been active in Quaternary time.

Seismic waves generated by aftershocks of the August 1, 1975, Oroville earthquake were recorded on portable seismic stations by D. P. Hill, J. M. Coakley, and J. P. Eaton along a profile extending 300 km south-southeast of Oroville along the metamorphic belt in the Sierra Nevada foothills. Preliminary plots of first-arrival P-wave traveltimes along this profile showed (1) relatively high apparent velocities (6.7–6.8 km/s) at distances between 20 and 100 km, (2) a $\frac{3}{4}$-second delay between 110 and 130 km, followed by somewhat lower apparent velocities (6.0–6.3 km/s) from about 140 to 200 km, and (3) P_n apparent velocities of 7.7 to 7.9 km/s beyond 200 km. These data suggested a relatively shallow depth (about 10 km) to intermediate P-wave velocities (6.8 km/s) in the metamorphic belt. The question of whether the delay beyond 100 km is due to a widespread low-velocity zone beneath the 6.8-km/s material or to lateral variations in velocity structure must await further analysis.

Anderson Reservoir, California

C. G. Bufe suggested that a persistent 10-km gap in seismicity along the Calaveras fault appears to be related to the presence of the Leroy Anderson Reservoir in the Calaveras-Silver Creek fault zones southeast of San Jose, Calif. A magnitude 4.7 earthquake occurred at a depth of 5 km in the center of the gap on October 3, 1973. The sequence of immediate aftershocks usually accompanying shallow earthquakes of this magnitude in central California did not occur. The b slope in the relationship between magnitude and frequency of occurrence was 30 percent lower in the vicinity of the gap than it was along adjacent sections of the Calaveras fault. A bridge crossing the reservoir near its southeastern end underwent severe deformation, apparently as the result of tectonic creep on the Calaveras fault. The occurrence of creep and the absence of small earthquakes along the Calaveras in the vicinity of the reservoir suggested a transition from stick-slip to stable sliding, possibly brought about by increased pore pressure.

Imperial Valley, California

Since its installation in April 1973, the Imperial Valley seismic network has recorded two series of earthquakes near Brawley, Calif., and one along the Imperial fault. A diffuse pattern of earthquakes was observed along other faults in the Imperial Valley. The two series of earthquakes near Brawley occurred as major swarms. Both sets of earthquakes occurred on the inferred location of the Brawley fault. D. P. Hill, P. K. Mowinckel, and K. M. Lahr (USGS) reported that most of the activity in the first series of earthquakes occurred between June 20 and July 17, 1973.

The second major swarm occurred in January 1975. Six portable three-component seismic stations were installed at the beginning of the swarm. C. E. Johnson and D. M. Hadley (California Institute of Technology), in cooperation with the USGS, made an intensive study of this swarm. The swarm began on the Brawley fault, which is located about 8 km southeast of Brawley. Focal mechanisms from this swarm and the previous fault indicated that the fault is a nearly right-lateral fault striking N. 8° W. Seismicity migrated bilaterally north and south and terminated to the north on a steeply dipping N. 50° E.-striking fault. To the south, a similar trend in seismicity (that is, transverse to the Brawley fault) was observed. The focal mechanisms of the earthquakes lying on the transverse faults indicated a thrust-type mechanism, whereas those on the Brawley fault were predominantly strike slip. The fault structures detailed in this study may have important consequences for understanding geothermal resources in Imperial Valley. Since the intersection of the northernmost transverse fault and the Brawley fault appears to be an area of high heat flow, this structure is a likely candidate for the vertical transport of the hot brines feeding the Brawley geothermal area.

Earthquake sounds

A swarm of earthquakes that occurred between January 23 and February 12, 1975, near Brawley, Calif., in the Imperial Valley produced numerous reports of low rumbling sounds accompanying many of the earthquakes. In an effort to document the relationship between the audible sounds and the seismic waves generated by the earthquakes on magnetic tape, D. P. Hill, F. G. Fischer, K. M. Lahr, and J. M. Coakley set up a portable stereo cassette tape deck to record an audio signal, a seismic signal, and a WWVB time code. On the morning of February 9, three earthquakes having epicenters about 3 km west of the recording site and focal depths of 7 to 8 km were first heard and then felt by Coakley, who was tending the recorder. (The magnitudes of these earthquakes were between 2.0 and 2.8.) Subsequent playback of the cassette tape showed that an acoustic signal having frequencies between 50 and 70 Hz began within 0.02 second of the *P*-wave first arrival and gradually died out by the time of the *S*-wave arrival about 2 seconds later. This result indicated that the audible sounds are generated by seismic *P* waves coupling directly into the atmosphere in the immediate vicinity of the recording site. It also explained the frequent reports that the sound preceded the shaking by several seconds, since perceptible shaking apparently begins with the *S* wave for local earthquakes of magnitude less than about 3.

Eastern Mojave Desert and San Bernardino, California

No earthquakes occurred during 1975 in the easternmost Mojave Desert of California (east of long 115° 30′ W.). Seismicity was concentrated on numerous faults in the vicinity of the San Andreas and San Jacinto faults in the San Bernardino Mountains and in the region north and east of the San Bernardino Mountains. Several large events that were studied in detail are the Lavic Lake earthquakes (M_L=4.4 and 4.3, July 30, 1974), the Galway Lake earthquake (M_L=5.2, June 1, 1975), the Anza earthquake (M_L=4.7, August 2, 1975), and the Goat Mountain earthquakes (M_L=4.7, November 14, 1975; M_L=4.7, December 1975). Analyses of the Mojave and San Bernardino earthquakes were carried out by G. S. Fuis and B. B. Mavko.

Island of Hawaii

A detailed study by J. D. Unger of the locations of events in an earthquake swarm that accompanied an eruption near the junction of the east rift zone and the Koae fault zone on Hawaii's Kilauea Volcano showed clear spatial and temporal relations between the intrusion of magma, the locus of earthquake hypocenters, and ground-surface deformation as measured by continuously recording tiltmeters. However, the nodal planes of individual earthquakes in the swarm gave no clear indication of the mechanism of the subsurface deformation.

Guatemalan earthquakes

A study of Fuego Volcano in Guatemala for the period from March to December 1975 showed a strong correlation between minor eruptive activity and observed changes in seismic and ground tilt phenomena. These results provide new data on the mechanics of eruptive activity at andesitic volcanoes and therefore bear directly on the capability of forecasting volcanic eruptions at these volcanoes. Seventy-five shallow, local earthquakes were located near Pacaya and Fuego Volcanoes and Guatemala City. The most intense seismic activity concentrated very locally around Fuego Volcano. Other epicenters indicated that the Jalpataqua fault (15 km south of Guatemala City), the Mixco fault (10 km west of Guatemala City), and the Motagua fault (25 km north of Guatemala City) were seismically active. In addition, a few epicenters were located 5 to 15 km northeast and east of Guatemala City. These results suggest that many faults are seismically active in this area and that the local tectonics are very complex.

THEORETICAL AND LABORATORY STUDIES OF EARTHQUAKE MECHANICS

Premonitory fault slip and earthquake precursors

J. H. Dieterich developed a model for earthquake precursors based on laboratory and field observations. The model is distinct from both the well-known dilatancy-diffusion model and the various "dry" models that have been proposed in the United States and the U.S.S.R. Premonitory fault creep is specifically identified as the underlying process that controls observations on earthquake precursors. Detailed laboratory observations and limited observations of earthquakes support the assertion that fault creep precedes earthquakes. In laboratory stick-slip experiments, fault creep invariably precedes unstable slip. Two phases of premonitory creep are observed. The first is a creep event that begins at a point on the fault and slowly propagates over a significant portion of the slip surface. The second phase is an accelerating and rapidly propagating creep event that begins when the initial creep event reaches the edge of the sample. The second phase culminates in the stick-slip event. For the earthquake model, it is assumed by analogy that both creep phases are necessary to prepare the fault for unstable slip and that the length of the creeping fault segment is proportional to the source length of the subsequent earthquake. The observed relationship between precursor time and earthquake magnitude is closely satisfied if the rates of creep propagation are similar for all earthquakes. Computations of seismic traveltime variations suggest maximum traveltime variations of about 1 percent for dry rocks and 6 to 7 percent for saturated rocks.

Properties of fault gouge material

In laboratory studies, J. D. Byerlee (USGS) found that (1) attenuation changes are very much greater than the velocity changes in rocks during formation; (2) a fault gouge dilates before microscopic failure; (3) the permeability of granular material becomes anisotropic during deformation at high pressure; and (4) the structural changes in a fault gorge during deformation depend on whether the mode of deformation is stable or unstable.

Louis Peselnick and J. H. Dieterich (USGS) and V. I. Mjachkin and G. A. Sobolev (Institute of Physics of the Earth, U.S.S.R.) investigated *P*-velocity changes in a simulated fault gouge subjected to normal and shear stress. Such investigations are considered to be a closer approximation to the physical conditions at active earthquake faults than investigations on intact rocks. Two types of fault gouge were used: fine-grained, well-compacted, unsorted granite powder and coarse-grained, loosely compacted, sorted sand. A distinctive velocity dependence on stress and time was observed for each gouge type. The powdered granite exhibited continuous and reversible velocity changes with shear stress, the *P* velocity decreasing to about 9 percent up to the point of stable sliding. Gouge lineations were developed at 45° to the normal stress. These data indicated that the velocity changes in the granite gouge are a result of the elastic opening and closing of small cracks with shear stress. The results for the sand gouge showed a large acoustic emission with increasing stress, a sudden and smaller (2 percent) decrease in the velocity prior to sliding, a large irreversibility of the velocity with increasing and decreasing stress, and a strong time dependence for equilibrium of the velocity with decreasing shear stress. These data indicated that, for the sand gouge, velocity changes result from fracturing of the grains (dilatancy) and readjustments of the grains to a new (denser) state of compaction. These experiments demonstrated that, in addition to rock dilatancy, other physical mechanisms occurring in a simulated fault gouge result in substantial velocity changes with general stress.

Multiple failure model for earthquakes

E. C. Robertson noted that the pore pressure-dilatancy model of earthquakes is based on erroneous interpretations of experimental results. Velocities V_p and V_S were measured on rock samples under confining pressures $P_c \leq 0.5$ kbar, under stress difference $\sigma_D = 0$ kbar, and under pore pressures $P_p = 1$ atm, whereas even shallow earthquake conditions are $P_c \geq 1$ kbar, $\sigma_D \geq 2$ kbar, and low P_p. When a σ_D is applied to a sample under $P_c \geq 1$ kbar, the decrease in V_p does not begin at half the strength (start of dilatancy) but begins just before failure, at extreme dilatation. Accepting this fact and experimental rock strengths ($\sigma_D = 2$–10 kbar), Robertson proposed that σ_D builds up over a small area of a fault (<5 km across for a magnitude 4 earthquake) until failure, which is caused by stable sliding if P_c and friction are low and by stick slip if they are high. According to this model, the two stages of the dilatancy model would be (1) a sliding failure with dilatation and a decrease in V_p, followed by (2) a rise in V_p with increasing σ_D to a second failure by stick slip. Multiple failure sequences in any combination can explain the appearance or nonappearance of a decrease in V_p or other premonitory phenomena.

Dynamics of sea-floor spreading

A. H. Lachenbruch developed a model for the upwelling of asthenospheric material at oceanic spreading centers in which the elevation of the sea floor is related to the spreading velocity and to the accretion process by which new lithosphere is created. The model reconciles the small gravity disturbance observed at spreading centers with the likelihood that dynamic forces there could be substantial and is also consistent with the observation of axial valleys in slow-spreading areas and axial ridges in fast-spreading areas. As Lachenbruch noted, the model suggests that the Earth's lithosphere is well organized into large plates because slowly spreading small plates are more difficult to separate and their coalescence is an energy-saving process.

CRUSTAL STRAIN STUDIES

Strain accumulation in southern California

Geodetic surveys carried out in southern California since 1929 have provided new clues to the mechanism of strain accumulation and release for major earthquakes in this region. Aseismic post-earthquake effects due to slip beneath the seismic zone, previously shown to have followed the 1906 San Francisco earthquake, were demonstrated by

W. R. Thatcher to have followed both the 1952 Kern County ($M=7.7$) and the 1940 El Centro ($M=7.1$) earthquakes. Geodetic traverses across the San Andreas fault north of Los Angeles showed that this segment of the fault is locked to considerable depth beneath the seismic zone. Other data indicated strain accumulation on the San Jacinto fault near Riverside that has persisted since at least 1929.

Precise distance measurements of a 10×25-km 15-station trilateration network that spans the San Andreas fault west of Palmdale, Calif., have been repeated annually since 1971. The network appears to be deforming under a simple uniform shear of about 0.5 μstrain/yr (engineering shear), the direction of maximum right-lateral shear being parallel to the local strike of the San Andreas fault. A comparison of trilateration and triangulation surveys of the same network shows that the rate of strain accumulation has been constant over the past 40 years. The strain accumulation can be explained by conventional dislocation models (that is, slip at depth beneath a locked section) of the San Andreas fault with 30- to 50-mm/yr slip.

Deformation associated with the 1974 Hollister earthquakes

A magnitude 5.2 earthquake in Hollister, Calif., on November 28, 1974, occurred near the center of an 81-line trilateration network. Five lines near the epicenter were surveyed 2 days before the earthquake, and the entire net had been measured 5 months before the earthquake. After the earthquake, the entire net was measured again. Examination of these data by J. C. Savage, M. A. Spieth, and W. H. Prescott indicated that no observable deformation preceded or accompanied the earthquake. Precision in the observations was such that any deformation greater than 1 ppm would have been observable.

Rate of fault creep

Review of creepmeter records from 1968 to 1975 for the segment of the San Andreas fault from San Juan Bautista to Bear Valley, Calif., demonstrated that most sites along that section recorded anomalously low fault-creep rates for a period of months before local earthquakes of magnitude 4 to 5. R. O. Burford suggested that the postearthquake accelerated creep (afterslip) reported previously at these sites represents the attenuated surface "catchup" resulting in part from the preearthquake surface-slip lag as well as from the sudden slip input to the system from the stuck or retarded patch acting at the earthquake source area. Burford further noted that, combined with other information for the particular fault segment under study, the results of analysis and interpretation of creep-rate anomalies may play a critical role in the effort to anticipate and prepare for (in terms of development of field experiments) future $M=4$ to 5 shocks along the central San Andreas fault.

Measurement of tidal gravity at the Yellowstone caldera

Immediately following the $M=6$ Yellowstone earthquake of June 30, 1975, a tidal recording gravity meter was deployed 5 km northwest of the epicenter at a site (Norris) where it was subsequently determined that the greatest elevation change in a first-order level line had occurred. Anomalous gravity changes were recorded for the principal aftershocks ($M>2.5$) that quite roughly followed a cubic power law in distance to the event. By mid-August, the severity of aftershocks subsided enough for a 38-day record to be secured at a site (Lake) away from the epicentral area but still on the caldera. A tidal analysis of these results by M. D. Wood indicated that an order-of-magnitude excess of nontidal energy was present that was not observed in similar studies made with the same instrument in nonvolcanic areas. Because the relative gravimetric factor (O_1/M_2) differed insignificantly (0.5 percent) from other worldwide values, as it should have, the excessive electrical energy was tentatively considered as being due to a latent response of the region to the June 30 earthquake and not to an instrumental problem. The phase lag of the M_2 wave was also significantly greater (31 percent) than that of comparative but nonvolcanic worldwide values. It appears that a tidal lag profile would be able to define the bulk anelastic properties of the caldera as compared with those of the host rock.

Relation of temperature, rainfall, and earthquakes to Earth tilt

Least squares shaping and prediction error-filtering theory were applied by M. D. Wood to the study of the relationships between temperature, rainfall, earthquakes, and Earth tilt in shallow soil environments. Although there does seem to be a significant relationship between a subclass of local earthquakes (that is, all events less than 30 km from the Libby-N tilt site), the fit of local weather (rainfall and temperature) was found to be more significant. The most unusual tilt anomaly observed in 2 years of data was not found to be premonitory to an earthquake but was more likely the convolved effect of weather—especially heavy rainfall—on the local soil environment. For larger earthquakes with longer anomalous lead times that approach the rise time of the soil to weather and seasonal changes, the identification and separation of meteorological and tectonic effects are imperative.

EARTHQUAKE PREDICTION STUDIES

Observations of tilt, strain, and magnetic events and earthquake prediction

Arrays of relatively inexpensive tilt, strain, and magnetic instruments, installed along active faults in the Western United States, are used to provide details about both seismic and aseismic (creep) fault failure. Of particular interest is the detailed fault mechanics sequence that results in earthquakes. C. E. Mortensen and M. J. S. Johnston's preliminary results indicated that the precursive slip seen most clearly for an $M>4$ earthquake occurs before and dominates the earthquake process (an earthquake prediction scheme has therefore been designed around automatic detection of this slip) and that surface expression of aseismic slip (creep) does not appear to be associated with large-scale strain field changes. Johnston noted that change in crustal stress fields, as inferred from magnetic measurements, can apparently have a scale exceeding several tens of kilometers.

Search for seismic velocity anomalies

A magnitude $M_L=5.2$ earthquake occurred on June 1 (May 31, Pacific Daylight Time), 1975, near Galway Lake about 60 km southeast of Barstow, Calif. The first-motion data, the distribution of aftershocks, and the surface rupture associated with this earthquake indicated right-lateral strike slip on a fault striking N. 20° W. and dipping approximately 90°. The epicenter was close to two of the quarries that have been monitored by the California Institute of Technology (Caltech) since June 1973 in an effort to observe seismic velocity changes prior to earthquakes. Precise velocity data were obtained at about 10 stations of the Caltech-USGS southern California network that were located near the epicentral area of the Galway Lake earthquake. Although these data precluded the precursory velocity change that the prevalent dilatancy model would predict before this earthquake, detailed inspection of the data revealed a small but significant (about 1 percent) increase in average velocity during at least a 1-year period before the earthquake. This increase before the earthquake may represent tectonic stress loading.

A series of active seismic experiments was carried out to determine the velocity structure along the San Andreas fault zone and to search for temporal changes in seismic velocity. J. H. Healy reported that a pronounced vertical low-velocity zone parallels the San Andreas fault in the region studied between the Pinnacles National Monument and Hollister, Calif. No convincing temporal velocity anomalies have been detected in this region to date, but the existence of an extremely complex structure confuses the data, and substantial velocity anomalies could be present in this region.

Search for seismic waveform anomalies

W. H. Bakun, C. G. Bufe, and R. M. Stewart studied spectra of earthquakes ($0.9\leqq M\leqq 4.1$) in the January 15, 1973, earthquake sequence on the San Andreas fault near Bear Valley, Calif. Noting that the *PZ* and *SH* spectra of five of the aftershocks ($M=2.8$–2.9) were nearly identical, Bakun, Bufe, and Stewart then showed that, in contrast, the spectra of five "foreshocks" ($M=2.8$–3.0) that occurred 3 to 4 weeks earlier showed considerable scatter, even for events only 4 minutes apart. Routine USGS hypocenter locations for the 10 events lie on the fault surface within about 2.5 km of the hypocenter of the $M=4.1$ main event. These data imply that, during the several hours following the main event, the aftershocks occurred within a relatively homogeneous volume and also that the parameters at the foci controlling source spectra were relatively uniform. The variability in the spectra for the earlier events probably reflects spatial and temporal variations in source parameters rather than variations in path effects such as attenuation.

Fluctuations of radon concentration

Radon concentration in soil gas was monitored by C.-Y. King, who used the track etch method at 20 sites along two active segments of the San Andreas and Calaveras faults between Hollister and San Benito in central California. The measured radon emanation on the faults displayed some characteristic changes beginning weeks before several larger local earthquakes of magnitude 3.0 to 3.2: an increase of approximately 50 percent followed by a decrease in the emanation followed by the earthquake.

GEOLOGIC STUDIES

Earthquake occurrence from sedimentary structures

J. D. Sims and M. J. Rymer reported that preliminary field investigations in Alaska yielded cores from a number of lakes within the area that was shaken intensely by the 1964 Alaska earthquake. The lakes examined were Big Lake (near Palmer), Eklutna Lake, Summit Lake (near Moose Pass), Upper Trail Lake, Kenai Lake, and Skilak Lake. Five cores up to 1 m in length were recovered from Skilak Lake on the Kenai Peninsula, 75 km south of Anchorage, Alaska. X-ray radiographic examination of the cores showed that varved sediments within the lake contained both volcanic ashes and probable earthquake-induced structures. Five zones of deformational structures 1 to 4 cm thick have been preserved; these have been interpreted to represent the effects of major earthquakes that occurred in the 1780's, the 1870's, 1899 or 1901, 1911 or 1912, and 1964. Uncertainty about the dates of the older structures may be due to errors in counting varves. Uncertainties about the precise dates of formation of the third and fourth deformed zones are due to closely spaced earthquakes, the effects of which cannot be separated. Possible explanations are either that, in each case, only one earthquake affected the sediments enough to deform them or that each zone represents the cumulative effects of more than one shock. Six ash beds preserved in the cores are approximately dated, by the varve-counting method, as occurring in 1816, 1845, 1870, 1875, 1935, and 1963. The 1963 and 1935 ashes are from the Augustine Volcano, less than 175 km southwest of Skilak Lake. Assigning the earlier ashes to their sources is more difficult. However, they probably originated predominantly from the Augustine Volcano and possibly from the Iliamna Volcano nearby. On the assumption that the ages of the ashes are correct, the date for the oldest sediments recovered in the cores is 1785.

Northwestern migration of range-front faulting in Idaho

On the basis of a preliminary photogeomorphic study of faulted fans, M. H. Hait, Jr. (USGS), suggested that range-front fault movements seem to have migrated from southeast to northwest along the southern reaches of the Lemhi, Beaverhead, and Lost River Ranges north of the Snake River Plain in Idaho. The southeastern 60 km of the 100-km-long Lemhi Range fault is divisible into three segments, each of which contains older and younger fans. In each segment, only the oldest fans are offset by scarps. The apparent age of the offset fans decreases from the southeastern segment through the central segment to the northwestern segment. Fault movement did not recur within each segment because the younger fans are not offset. The same kind of fault-fan relationship seems to be true for the western sides of the southern Beaverhead Range to the northeast and the southern Lost River Range to the southwest. The southernmost Beaverhead Range has no scarp cutting the fans, but G. F. Embree and R. D. Hoggan (USGS) and E. J. Williams (Ricks College) found stratigraphic evidence for range-front movement in a series of basalt flows having steeper dips in the older flows and gentle dips in the youngest flows. Northwestward about 20 km, scarps cut the fans.

Along the southern Lost River Range, the fans are cut by scarps that have been dissected and smoothed, and, about 20 km to the northwest, young steep fans are cut by scarps having essentially no smoothing.

California offshore Hosgri fault

Geologic mapping offshore of the Diablo Canyon nuclear reactor site, reported by H. C. Wagner (1974), was extended from Point Sal southward to Point Arguello, Calif. W. H. Gawthrop (1975) relocated the epicenter of the 1927 Lompoc earthquake ($M=7.5$), and C. A. Hall, Jr. (1975), determined the relationship between the onshore San Simeon fault and the offshore Hosgri fault and correlated ophiolite sequences associated with these faults but now separated by a distance of 80 km. From acoustic-reflection profiles made between Point Sal and Point Arguello, Wagner determined that nearshore structures can be correlated from profile to profile for only a short distance offshore; conversely, offshore structures can be correlated shoreward only a short distance. Faulting within the zone between the nearshore structures and the offshore structures is believed to represent an extension of the Hosgri fault southward at least as far as Point Arguello. The 1927 Lompoc earthquake may indeed have occurred on the Hosgri fault, and late Cenozoic motion on the fault may be very large.

EARTHQUAKE HAZARD STUDIES

Fault activity and earthquake hazards

Field studies conducted by George Plafker along the Fairweather fault in southeastern Alaska, the site of the July 1958 magnitude 7.9 earthquake, showed that streams near Crillon Lake and a lateral moraine of the Finger Glacier have systematic dextral offsets of 50 to 60 m. Radiocarbon dating of wood from moraines indicated that the offset stream drainages are probably not older than 940 years B.P. and that the lateral moraine is about 1,300 years old. These data indicate that the minimum displacement rate along this part of the Fairweather fault for the last 1,000 years has been at least 5 cm/yr, a figure approximately equal to the full relative displacement rate of 5.3 cm/yr between the Pacific and North American plates as deduced from deep-sea magnetic patterns. The new offset data imply that the Fairweather fault is presently a transform boundary along which most, if not all, of the relative motion between the Pacific and North American plates is currently taking place.

The relationship between the damage done by the 1935 earthquake at Helena, Mont., and the underlying geology was investigated by R. G. Schmidt. He found that the damage was apparently greatest along a contact between underlying lakebeds and bedrock.

A deposit containing obsidian was deformed by the 1959 Hebgen Lake earthquake in Montana. The deposit was dated as about 30,000 years old by K. L. Pierce, J. D. Obradovich, and Irving Friedman by means of obsidian hydration dating. The fact that the deposit had apparently experienced no more than two similar deformations before 1959 suggested a recurrence interval of perhaps 10,000 years for the Hebgen Lake earthquake.

R. C. Bucknam examined the region of the damaging 1934 Hansel Valley, Utah, earthquake—in which there was fault displacement of up to 50 cm—and found evidence of older fault scarps. The fault scarps offset terraces of Lake Bonneville by up to 3 m, an indication of significant Holocene activity prior to the 1934 earthquake.

Bucknam also mapped fault scarps along the eastern foot of the Wassuk Range north of Hawthorne, Nev. The most youthful scarps predate a 1,100-year-old air-fall ash but are younger than 10,000-year-old (or younger) Lake Lahontan shorelines.

A study by R. E. Wallace of the fault scarps formed in past earthquakes showed that large earthquakes may be unevenly distributed in both time and space in the Basin and Range province. Only seven or eight sets of fault scarps comparable to those formed in the magnitude 7+ earthquakes of 1915 and 1954 were found in an area of 17,000 km^2. The indicated earthquake occurrence rate is thus approximately one per 25,000 years per 1,000 km^2, which is much less than the estimates of from one per 500 years to one per 3,300 years per 1,000 km^2, which is based on historic seismicity. In addition, the density of the scarps suggests that large earthquakes occurred more frequently within the central Nevada seismic belt than they did elsewhere in the Basin and Range province in the past few hundred thousand years.

Geologic and geophysical studies by P. D. Snavely, Jr., H. D. Gower, and J. C. Yount along the western margin of the Puget Sound lowland suggested a major tectonic boundary extending along Hood Canal. This structure may be a southern extension of the Leach River fault on Vancouver Island and may have been active during Quaternary time.

R. V. Sharp investigated a swarm of earthquakes that occurred in January and February 1975 and found surface displacements along the newly discovered Brawley fault, which branches northward from the Imperial fault northeast of El Centro, Calif. Vertical movements of up to 0.2 m occurred along 10.4 km of the fault. Movement apparently occurred also in the 1940 Imperial Valley earthquake and at other times between 1940 and 1975.

Sharp's detailed studies showed many complexities in the fault pattern in different parts of the Imperial Valley. A region southwest of the Superstition Mountain fault shows active crustal extension. A zone of normal faulting west of the Salton Sea offsets middle Pleistocene sediments and forms prominent scarps on an alluvial surface of probable late Pleistocene age. The faults do not displace the 300-year-old shoreline of Lake Coahilla, however.

A south-facing topographic scarp up to 12 m high and more than 10 km long along the hill front north and east of Ventura, Calif., was studied in detail by A. M. Sarna-Wojcicki, K. M. Williams, and R. F. Yerkes. The scarp is attributed to movement on a north-dipping reverse-left oblique fault and is alined with the Pitas Point fault, which vertically displaces a late Pleistocene erosional surface by about 25 m, up on the north. Total offset may be as much as 275 m. In trench exposures, surficial deposits over and north of the scarp are deformed by arching and small faults, and dips of the sedimentary materials north of the scarp steepen progressively downward, an indication of recurrent movement. The offsets of soils on this part of the east-west fault system in the Transverse Ranges of southern California show that this fault is active.

Studies of the faults in the San Francisco Bay region conducted by E. J. Helley, D. G. Herd, B. F. Atwater, C. W. Hedel, and M. G. Bonilla found several active faults that were previously unrecognized and showed that the fault pattern in the region is more complex than original mapping indicated. Geologic evidence for at least two pre-1906 earthquake events on the San Andreas fault in Marin County was discovered, and trenching showed recent faulting on the Healdsburg-Rodgers Creek fault in Sonoma County.

Active crustal movements

A synthesis of geodetic data in southern California by R. O. Castle documented episodic and apparently aseismic uplift that began about 1960. The uplift centers in the Palmdale area and extends from the intersection of the Garlock and San Andreas faults eastward to Cajon Pass and Barstow. The uplift above the 0.15-m contour occupies at least 12,000 km^2.

Marine terrace deformation near San Diego

Detailed studies by K. R. Lajoie indicated that the Linda Vista terrace near San Diego, Calif., is a composite erosional feature cut during successive sea-level high stands in early and late Pleistocene time. Each beach ridge merges with a distinct marine terrace cut into bedrock to the north and represents a separate high stand of sea level. Older terrace deposits are more uplifted and are tilted southwestward more steeply than younger terrace deposits. The continuing uplifting and tilting are probably related to the active Newport-Inglewood fault, which is on the southwestern side of the terrace offshore of the coast.

Techniques for mapping faults

D. L. Hoover found that isotangent (percent slope) maps can be used to detect faults on low slopes. In an area of about 78 km^2, this technique disclosed 12 linear features that were not visible on the surface or on aerial photographs. Detailed gravity data confirmed these linear features as faults. Fault lengths range from 1.3 to 6.4 km.

Alaskan seismicity

The seismic network installed in the eastern Gulf of Alaska area has shown the patterns of current earthquake activity. J. C. Lahr, R. A. Page, and Lorel Kay reviewed the data and found a tight cluster of events 50 km south-southwest of Yakutat and a concentration of earthquakes in the Icy Bay area. Scattered activity also occurred along the Chugach Mountains between Cordova and Yakutat Bay.

South Carolina seismicity

A seismograph network operated in South Carolina has shown that current earthquake activity is concentrated in the same area as the damaging 1886 Charleston earthquake, at a depth of 10 to 12 km, according to A. C. Tarr. Geophysical explorations by D. L. Campbell and H. D. Ackermann found a buried north-trending structure in the area that is probably a sedimentary basin. The buried structure probably influenced the seismic shaking in the 1886 earthquake.

Hawaiian volcanic chain

Studies of the time and space history of the Hawaiian volcanic chain by E. D. Jackson, H. R. Shaw, and K. E. Barger showed a linear age-distance relationship. The spatial patterns were also used for determining the orientation of stresses with time. It appears that the Pacific plate has been subjected to oscillatory, but principally clockwise, rotations of horizontal stress components during the last 40 million years.

Numerical modeling of ground motion

In numerical studies of the mechanics of the earthquake source, D. J. Andrews found that the concepts of theoretical fracture mechanics apply to rupture propagation in an inelastic medium, if inelastic energy loss is included in the "effective fracture surface energy." Peak particle velocity at the rupture front is limited by material strength. A realistic rupture criterion should require that energy be absorbed at the rupture front as stress drops and also that there be an upper limit on shear stress. With such a model, a plane-strain shear crack may propagate faster than the shear wave velocity.

Wave propagation in anelastic materials

The theoretical characteristics of plane waves in anelastic materials are substantially different from their characteristics in perfectly elastic materials, as was shown by the recent work of R. D. Borcherdt on the classic problem of a plane wave incident on a plane boundary. For boundaries between materials having different intrinsic attenuations, such as a bedrock-soil interface or a crust-mantle interface, the reflected and transmitted P and S waves in the general case are inhomogeneous, have elliptical particle motions, have velocities and maximum attenuations that depend on the angle of incidence, have directions of phase propagation, and cause energy to flow and dissipate owing to interaction of the waves. Elasticity fails to predict any of these characteristics. Preliminary calculations completed by L. R. Silva (oral commun., 1975) showed that the velocity of the transmitted waves varies by as much as 4 percent, depending on the angle of incidence, for a bedrock-soil interface and by as much as 50 percent for a boundary between materials having similar velocities but highly different intrinsic attenuations. These preliminary calculations suggest that some of the unique physical characteristics predicted for plane waves in anelastic media may be measurable in the field.

Studies in the San Francisco Bay region

R. M. Hazlewood completed fieldwork on a program to determine the depth to bedrock beneath the bay mud and alluvial deposits in the southern San Francisco Bay region of California. The data from 85 reversed seismic-refraction profiles ranging in length from 800 to 2,400 m were recorded. The profiles covered the area from Redwood Shores on the western side of San Francisco Bay to Alviso on the southern end of the bay to the Oakland Airport on the eastern side of the bay. The data from the first 35 profiles were reported earlier (Hazlewood and Joyner, 1973; Hazlewood, 1974). The data from the remaining 50 profiles have been interpreted, and a contour map showing the depth of bedrock is being prepared. The refraction data showed that the depths are significantly different than gravity data had previously implied. Profiles were recorded across the inferred Palo Alto fault and the inferred northern extension of the Silver Creek fault. Within the resolution of the data, no vertical offset was detected in either case.

J. F. Gibbs, R. D. Borcherdt, and T. E. Fumal were engaged in a program to measure seismic velocities in the San Francisco Bay region at an estimated 150 sites. At each site, seismic traveltimes were measured at 2.5-m intervals in drill holes to a depth of 30 m by means of techniques developed by R. E. Warrick. Geologic logs were determined from drill-hole cuttings, undisturbed samples, and penetrometer samples. The data provided a detailed comparison of geologic and seismic characteristics on a regional scale for purposes of seismic zonation. The data also provided parameters for estimating strong earthquake ground motions quantitatively at each site and a base for the development of techniques that will permit some of the results of seismic zonation studies in the bay region to be extrapolated to other areas.

At present, measurements of seismic traveltimes and preliminary geologic logs have been completed for 35 holes. The data from the first 12 holes were analyzed in detail and published (Gibbs, Fumal, and Borcherdt, 1975). The data collected to date have established that reliable velocities for both shear waves and compressional waves can be determined for all near-surface geologic units in the San Francisco Bay area. Poor results were obtained at only one site, which was underlain by so-called "Montara Granite." Since repeated measurements at the site did not improve the results, it was suggested that the poor results were probably due to inadequate coupling of the casing to the sidewalls of the borehole.

Preliminary comparisons of the data from the first 12 holes showed that the measured seismic velocities correlate strongly with the type of geologic unit, as well as with amplifications measured from nuclear explosions and the 1906 earthquake intensities. These correlations and the quality of the data collected to date suggest that extending the measurements to a much larger number of sites would provide a significant new data set from which ground-motion predictions could be made on a regional scale for purposes of seismic zonation.

Data collected by E. L. Harp and D. K. Keefer from the monitoring of selected landslides in the San Francisco Bay region indicated that rainfall and the degree of saturation of landslide materials played key roles in reactivating the movement of those materials. Instruments that will register a continuous record of landslide movement with time have been developed and installed to detect possible earthquake-induced movement.

Reconnaissance of slope failures from three moderate-sized earthquakes in California also tended to show a general correlation between the occurrence of slope failure and existing ground-water conditions. Although no quantitative comparisons can be made between soil or rock failure and ground-water conditions, the most significant slope failures were those triggered by the magnitude 5.5 earthquake of June 7, 1975, near Fortuna, Calif., which occurred during a period of relatively high subsurface water level just after spring rains. The magnitude 5.3 earthquake of November 28, 1974, near Hollister, Calif., and the magnitude 5.7 earthquake of August 1, 1975, near Oroville, Calif., occurred during relatively dry periods and triggered only the loosest, most unstable materials from steep, nonvegetated slopes. Although cohesive soils are extremely weak when they are saturated, they appear to be a key factor as a stabilizing influence when they are dry. In all three regions affected by the earthquakes, slides containing cohesive soils showed little, if any, detectable movement from shaking. It appears that, where cohesive soils are present, seismic slope stability in the San Francisco Bay region is closely tied to the natural water content or to the degree of saturation of slope-forming materials because of the marked effect of these parameters upon in-place shear strength.

Aftershocks of the Oroville earthquake

Within 48 hours of the Oroville, Calif., earthquake of August 1, 1975, 10 strong-motion accelerographs, each with the capability of writing the WWVB time code on the recording film, were installed in the epicentral region by the California Division of Mines and Geology (CDMG), the California Institute of Technology (Caltech), and the USGS. Although the array changed configuration several times owing to the redeployment and addition of CDMG instruments, at least 10 accelerographs were operational in the epicentral region from August 3 to November 7, when the Caltech instruments were removed.

Through the end of October, T. C. Hanks reported that 316 accelerograms were recorded from 86 different aftershocks, whose M_L's ranged from 1.8 to 5.2. Throughout that magnitude range, acceleration amplitudes at distances (R) in the neighborhood of 10 km were as great as, and commonly greater than, those known before this earthquake sequence. The following values were the largest recorded at Oroville for the magnitudes given in parentheses: 0.70 g (M_L=4.7, R=13 km); 0.58 g (M_L=4.6, R=13 km); 0.42 g (M_L=4.3, R=5 km); 0.24 g (M_L=4.0, R=12 km); 0.19 g (M_L=3.3, R=8 km); 0.19 g (M_L=3.2, R=9 km); 0.10 g (M_L=2.5, R=6 km); and 0.05 g (M_L=1.8, R unknown). Peak accelerations of 0.10 g or greater were a common occurrence for all well-recorded $M_L \geqq 3$ aftershocks.

A preliminary inspection of these data yielded several important insights. Hanks and D. A. Johnson suggested that, in the absence of the effects of faulting duration, anelastic attenuation, and instrumental response, peak accelerations at R=10 km would be independent of magnitude. Observations available at that time for approximately 35 earthquakes ($3.2 \leqq M \leqq 7.1$) recorded at $R \cong 10$ km formed the basis of this interpretation; simple theoretical arguments suggested that a maximum acceleration of 0.75 g at R=10 km would correspond to a maximum shear stress difference of 2 kbar likely to be sustained by active crustal fault zones at a depth of 10 km. The accelerograms taken at Oroville provided substantial support for this observational interpretation and simple theoretical model.

Two further observations are (1) that peak accelerations for the same shock at comparable distances are generally lower—often by a considerable margin—at sites located on substantial thicknesses of alluvium than they are at hard-rock sites and (2) that, for aftershocks of comparable magnitudes, peak accelerations generally decrease more rapidly with R for the shallower events. The latter observation suggests that the upper 3 to 5 km of the Earth's crust, in which lies the entire transmission path for the shallow events, is considerably more effective in attenuating and (or) scattering high-frequency seismic radiation than the crustal material at greater depth. The first observation implies that unconsolidated alluvium is considerably more effective in this regard than near-surface crystalline rock. Both observations are in accord with present seismological knowledge, although the lack of sufficiently dense measurements, together with the notoriously erratic behavior of high-frequency amplitudes, has made them difficult to document.

Aftershocks of the San Fernando earthquake

W. W. Hays, K. W. King, and S. T. Harding analyzed the set of aftershock data recorded on a 20-station array deployed in the Sylmar-San Fernando area after the San Fernando, Calif., earthquake of February 9, 1971. The aftershock data complement the two strong-motion accelerograms recorded in the area and provide a basis for estimating ground-motion characteristics and correlating those estimates with damage. The velocity-response-spectral values and the ground acceleration levels estimated within the area correspond fairly well to the damage distribution. In particular, zones of high ground acceleration and high short-period ($<$0.2 second) response values correspond to zones of damage located along the base of the San Gabriel Mountains where thin valley alluvium is in contact with crystalline rock.

Ground response in Long Beach, California

Ground motion was recorded at eight alluvial sites in Long Beach, Calif., from two nuclear events that occurred at the Nevada Test site, 430 km away. Four alluvial sites were instrumented to record each event, and one hard-rock site in Pasadena was instrumented to record both events. A. M. Rogers reported that ratios of peak particle velocity as large as 6 were observed between the alluvial sites and the hard-rock site on the horizontal components. In the period range of the recorded signal (0.2 to greater than 6 seconds), ratios of pseudo-relative velocity (PSRV) spectra as high as 11 were observed between the alluvial sites and the hard-rock site at some periods. Station-to-station variability was as great as a factor of four. The PSRV ratios between the alluvium sites and the hard-rock site were greater than 1 over the entire period range 0.2 to 6 seconds. The stations were situated in areas that sustained different amounts of damage during the 1933 Long Beach earthquake, as Martel (1965) reported. A correlation between the magnitude of the PSRV ratios for different period ranges and the reported damage has not been found.

Seismic risk studies

Methods for estimating earthquake losses, developed in 1969 for the Department of Housing and Urban Development, were revised and simplified as described by W. A. Rinehart, S. T. Algermissen, and M. A. Gibbons. Sensitivity analysis was done on the controlling parameters, and observational data from the 1971 San Fernando, Calif., earthquake were used. The new methodology accurately estimates the loss to single-family dwellings in the San Fernando earthquake and thereby establishes its validity. It is general enough to be transferable to other parts of the country, provided that damage ratios and damage factors are available or derivable from local damage and construction cost statistics. According to the new methods, the loss to single-family dwellings in a maximum credible earthquake on the San Andreas fault in the San Francisco Bay area would be about $2.2 billion, and the loss to single-family dwellings in a maximum credible earthquake on the Newport-Inglewood fault in the Los Angeles Basin would be about $4 billion. The earthquake history for a 100-year period was used to estimate the total loss over that period to single-family dwellings in the State of California. The total loss was calculated by using the following assumptions:

- Throughout the 100-year time period, the U.S. Bureau of the Census 1970 housing inventory was used. Of the nearly 7 million total housing units reported in 1970, about 5.2 million are designated in this model as single-family dwellings or their equivalents.
- The dollar value is constant throughout time. The total replacement cost of these 5 million plus units is about $93 billion in constant 1970 dollars.
- The damaged structures are repaired immediately, to be damaged anew in the next earthquake.
- The intensity distribution follows a geometrical spreading law away from the causative fault; modifications are made to account for the effects of varying surficial geology.

The model loss for a 100-year period was estimated to be $11.2 billion. Over this time period, about 29 million dwellings would sustain some form of damage. The average dwelling loss for those dwellings damaged in any earthquake in the 100-year earthquake history would be about $385. This loss is consistent with the losses predicted by the 1969 computational methods. The methodology permits the estimation of loss in cents per $100 of valuation.

Research by R. K. McGuire (1976) indicated that ample seismic history exists for determining activity rates (but not maximum intensities) for seismic source areas in the Eastern United States for the purpose of seismic risk analysis. Hence, a risk analysis having a probability distribution based on maximum intensity is a logical and simple method of deriving design intensities. Such design intensities are not sensitive to the manner in which observed seismicity has been assigned to source areas for the eastern coast. Modified Mercalli intensities associated with annual risks of 10^{-4} are VIII and IX for the majority of sites on the eastern coast of the United States.

Algermissen and D. M. Perkins completed a preliminary seismic risk map for the contiguous United States. The map shows peak horizontal ground accelerations having a 10-percent probability of being exceeded in 50 years—equivalent to the peak acceleration for a return period of 475 years. Areas that have seen strong damage in the past appear on this map within the following contours:

New England	0.10 g
Charleston, S.C	.10 g
Southeastern Missouri	.20 g
Wasatch Front, Utah	.20 g
Puget Sound, Wash	.20 g

In California, the map shows accelerations ranging from near 0.10 g in the Great Valley to 0.40 g in southern California and 0.60 g or greater along the San Andreas and Owens Valley faults.

ENGINEERING GEOLOGY

SLOPE STABILITY

More than 30 examples of large-scale gravitational spreading along rock fractures were recognized in the mountains of the Western United States by Dorothy Radbruch-Hall, D. J. Varnes, and R. B. Colton. The spreading movements are characterized by horizontal linear fissures, trenches, and uphill-facing scarps on the tops and sides of mountain ridges.

In some places, valleyward squeezing-out of weak shales overlain by rigid rocks causes tensional fracturing and outward movement of the rigid layers. This kind of spreading is exemplified by a ridge extending northward from Mount Dolores in southwestern Colorado, although movement in this case may have taken place along preexisting fractures. Here a trench a maximum of 60 m deep and more than 1 km long cuts granogabbro of a Tertiary laccolith that intruded Mancos Shale. Other trenches on the eastern side of the ridge are defined by uphill-facing scarps. The trenches probably originated after the laterally confining glacial ice melted from the sides of the ridge. Outward movement of soft Mancos Shale under the granogabbro placed the granogabbro under tension.

In more homogeneous rocks, tensional spreading parallel to the long axis of a ridge may take place by means of slow movement along a series of disconnected planes. This type of movement occurred along existing joint systems in granitic rock and formed a ridge north of Mount Massive in Colorado. A survey course approximately 2.4 km long was placed across the fractured ridge by Varnes and Radbruch-Hall. It will be monitored to determine whether movement is continuing and, if so, at what rate.

Recognition and understanding of these large gravitational features are pertinent to the process of selecting sites for future structures in high mountains. At the present time, major highway and water-diversion tunnels pass through mountain ridges whose tops and sides are marked by large gravitational trenches. Other structures have been built or are planned in valleys below spreading ridges or on their slopes. Bulges on valley walls caused by gravitational spreading cause rockfalls and landslides from the valley sides. If fractures extend to considerable depth and if movement along them continues, tunnels through the ridges could be damaged.

Radbruch-Hall, Colton, Varnes, W. E. Davies, Ivo Lucchitta, and B. A. Skipp prepared a map showing areas of abundant landslides and areas susceptible to landsliding, at a scale of 1:7,500,000 for the conterminous United States. The map indicates that certain regions of the United States are far more prone to slides than others; examples are the Coast Ranges of California, the Colorado Plateau, the Rocky Mountains and northern Great Plains, and the Appalachian Mountains.

This study revealed certain pronounced differences among the areas of high landslide incidence in various parts of the United States. In the Coast Ranges of the Pacific coastal area, landslides occur mainly in tectonic mélanges and in poorly consolidated Tertiary sediments. They include both (1) small but damaging debris flows that form at times of intense rainfall and (2) slumps and flows of great depth and areal extent; some are more than 60 m deep and cover many square kilometers. On the Colorado Plateau, large landslides occur primarily where shales or other relatively soft rocks are interbedded with or overlain by more resistant rocks such as basalt, sandstone, or limestone. Slumps and block glides are the dominant forms of landslides. In the Appalachian Mountains of the Eastern United States, many slide-prone areas underlain by weathered rock or colluvium are characterized by shallow landslides of large areal extent.

In addition, this nationwide study showed that certain types of rocks and certain geologic conditions favor landsliding wherever they occur on slopes. Fine-grained clastic rocks—those consisting predominantly of silt- and clay-sized particles—are most prone to landsliding. They are particularly susceptible if they are poorly indurated and (or) are interbedded with or overlain by more resistant rocks such as limestone, sandstone, or basalt. Highly sheared rocks, particularly tectonic mélanges, slide extensively. Nationwide, loose slope accumulations of fine-grained surface debris are subject to landsliding, particularly during times of heavy precipitation.

In addition, Colton compiled data for areas underlain by landslide deposits in 13 $1° \times 2°$ quadrangles in Colorado and Utah by interpreting small-scale aerial photographs and using all available geologic maps. Deposits mapped included landslides, avalanches, block glides, debris slides or flows, earthflows, mudflows, rockslides, rockfalls, rotational slides, slab or flake slides, slumps, talus accumulations, and translational slides. In addition, rock-glacier deposits, colluvium, and solifluction deposits were included in some areas. Preliminary evaluation by Colton and Edward Reyes of the areas inferred to be underlain by landslide deposits indicated that at least 15,600 km^2 of Colorado is underlain by these deposits.

R. W. Fleming studied the relationship between geology and landslides occurring in a colluvial soil developed on the Kope Formation of Late Ordovician age in the Cincinnati area of Ohio and made field measurements of soil creep in California. In the

Cincinnati study, he found that the mode of failure depends on the thickness of the colluvium. Colluvium less than 2.5 m thick tends to develop into earthflows, whereas thicker colluvial cover generally fails as a large rotational slump. The presence of excessive amounts of ground water along the colluvium-bedrock boundary contributes to the instability. Field measurements conducted in the California study covered a period of 5 years. During that interval, a 1.5-m-thick soil on a slope of about 8° moved at an average rate of about 1 cm/yr at the ground surface. Creep occurs during the onset of the rainy season, and the creep rate appears to diminish with time.

A study of landslides in the Santa Clara River valley area of southern California by D. M. Morton indicated two distinct types of landsliding: deep-seated slides and shallow surficial slides. Deep-seated landslides, mainly prehistoric and involving more than 24 percent of the upland area, have substantially lowered the slope angle of these areas. Surficial landsliding appears to be an important process in the formation and retention of steep hillslide slopes. In 1969, more than 36,000 such slides, mainly soil slips, were triggered by storms in the area. Only 21 percent of the soil slips occurred within the areas bounded by the older deep-seated landslides. More than 70 percent of the soil slips originated on, and left scars on, slopes of $\geqq 34°$. By 1975, only traces of the 1969 slips remained. Morton suggested that any attempt to predict the locations of future landslides should take into consideration the differences between the two distinct landslide processes and should recognize that evaluating the risk of shallow landslides is more relevant to site selection.

Landslides in the Santa Monica Mountains of southern California include many diverse types (though not all possible types), and the hazards posed by landslides of different classes differ in severity, distribution, and recurrence interval, according to R. H. Campbell. A preliminary analysis of the distributions of different classes of landslides in the Santa Monica Mountains indicated that a rapid classification based on the type of parent materials, the geometry of the surface along which movement takes place, and the dominant type of mechanism aids in correlating variations in the potential for hazard with specific factors of slope angle and bedrock strength.

The occurrence of natural landslides in stiff plastic Cretaceous clays in Fairfax County, Virginia, appears to be a direct function of slope angle, according to S. F. Obermeier. Previously, local engineers and planners estimating the stability of cut slopes discounted standard geologic information as being unreliable; most of their concern centered around ground-water pressures in the stiff clays that were unpredictable from place to place. Now, information that can be obtained from geologic maps, combined with measurements of the natural slope angles of these materials, can provide a basis for adequately planning and routinely designing highway cuts.

Unstable slopes in an area of approximately 780 km^2 southeast, south, and southwest of Sheridan, Wyo., constitute a major geologic problem in planning for future urban and industrial expansion. Slope failures have already caused economic losses in and around Sheridan in the form of highway damage, broken utility lines, foundation failures, and minor flooding. A study by T. C. Nichols, Jr., A. F. Chleborad, and W. F. Ebaugh indicated that most of the slope failures occur in poorly consolidated, plastic, fine-grained sediments of the Wasatch and Fort Union Formations. More than 80 percent of the mapped landslides in the area are on slopes having an easterly component of direction, and more than 60 percent of those are on slopes having a northeasterly exposure. Melt from heavy spring snowstorms and infiltration of irrigation water provided the saturation and consequent instability that resulted in much of the recent landsliding; thus, the likelihood of major fluctuations in the moisture content of geologic materials should be evaluated in future land-development projects.

The stability of highwalls in open-pit mines becomes more of a problem as open-pit coal mines in the Western States deepen during extraction of thick seams of low-grade coal. As part of the investigations being conducted in the Powder River area of Wyoming, F. T. Lee, W. K. Smith, and W. Z. Savage developed a stability model based on overconsolidation of the weak, clay-rich rocks. Rock deformations, including fracturing, are induced by mining. The stability model is combined with finite-element analyses to predict deformation. Values of safety factors in terms of slope stability can then be calculated for the rock mass. The accuracy of the predictions will be refined during the course of the studies by monitoring slope deformations and by analyzing data obtained during field measurements of the rock-mass properties.

GEOLOGIC HAZARDS IN URBAN AREAS

Detailed engineering geologic mapping of the Buffalo 7½-min quadrangle of Wyoming by Ernest Dobrovolny provided assurance that geologic hazards to urban expansion in this area are minor. Foundation conditions are generally good, existing underground coal-mine workings that frequently result in surface collapse are of limited extent, and underground mining operations are currently inactive. In addition, because the coal beds thin toward the southwestern part of the quadrangle and cease to be a source of extractable coal, it is unlikely that geologic land-use conditions will deteriorate.

Reports on geology and water resources provided by the USGS were used by the Planning Department of the Greater Anchorage Area Borough of Alaska for a variety of projects, ranging from subdivision review and analysis to the preparation of a comprehensive plan for the development of the entire borough. A subdivision ordinance on hillside development requires in-depth review of the effects of topography, geology, hydrology, and engineering where the terrain has slopes in excess of 25 percent. On more gently sloping ground, subdivision development is modified to conform to geologic and hydrologic constraints. The comprehensive plan (Schmoll and Dobrovolny, 1972a, b, 1974; Zenone and others, 1974), used as a guideline for certain long-range projections of community needs, included development of additional water-supply facilities, such as damsite locations, and reservation of land for artificial ground-water recharge; location of sites for waste disposal; and selection of open-space areas.

Consolidation-swell test data for bedrock and fine-grained surficial deposits in the Englewood quadrangle of Colorado and the surounding area, gathered by R. R. Shroba as part of Front Range urban corridor studies, indicated that swelling and compressible soils and soft bedrock that cause foundation problems are serious geologic hazards in much of southeastern Denver. The wide range in volume-change potential displayed by these materals stresses the importance of adequate on-site soil and subsurface investigations prior to construction and urban development.

According to E. L. Madsen, tunneling in the Minneapolis-St. Paul metropolitan area of Minnesota is greatly facilitated by the local Ordovician lithology. The competent, flat-lying Platteville Limestone acts as a near-land-surface cap on the underlying St. Peter Sandstone. The sandstone is homogeneous and easily excavated by hydraulic methods—commonly hand-held, high-pressure water hoses. Where it is dry, the sandstone is free standing; as a result, some of the 265 km of tunnels in the area and many of the storage and natural caves have been open and unlined for more than 50 years. The main problems encountered in tunneling have been discontinuities in the bedrock and excessive inflows of water. Unexpected, drift-filled, buried bedrock valleys that cut out the Platteville Limestone and the St. Peter Sandstone require more expensive tunneling techniques and can cause collapse where they have not been provided for. Although it is dry in some places, the St. Peter aquifer may have tens of meters of artesian pressure. Recent experiments by researchers at the University of Minnesota provided an efficient grouting system that may eliminate the need to use a temporary lining before the permanent concrete lining necessary in wet areas or in sewer tunnels is poured.

SOIL ENGINEERING

Liquefaction-induced ground failures generated during the 1906 earthquake and during other earthquakes in northern California were identified and investigated by T. L. Youd and S. N. Hoose. They concluded that the most common and most damaging ground failures caused by liquefaction were laterally spreading landslides and that those sites that have had additional failures subsequent to lateral spreading will probably be vulnerable to renewed ground displacement during future earthquakes.

ROCK MECHANICS

Measurements made in the Sunnyside No. 1 coal mine in east-central Utah by F. T. Lee revealed that changes in the principal stress orientations in the coal and siltstone roof rock appear to be controlled by regional joints and faults. Stress-magnitude changes are caused by the advancing longwall face in this single-entry operation and by seismic activity generated tectonically or by mining.

Stress instruments were installed in Sunnyside No. 1 by Lee and R. A. Farrow in September 1974 to augment mine-deformation studies being conducted by the U.S. Bureau of Mines Spokane Mining Research Center. Seismic and geologic information was obtained by F. W. Osterwald and Jerome Hernandez for the Coal Mine Bumps Project. Large decompressive stress changes of as much as 306 bars occurred in December 1974 and January 1975 when the longwall face of the mine advanced to within 90 to 180 m of the emplaced stress instruments. Significant and abrupt changes in the number and magnitude of seismic events corresponded to this early episode of stress change, which may have been due to the effects of other mining activity, to tectonic stress changes, or to a combination of both. Severe floor deformations in this part of the mine made it difficult to mine and haul the coal. A later onset of reduced stress, influenced by the advancing longwall face, was detected by the stress probes at a horizontal distance of about 55 m.

Studies of selected underground coal mines in Utah, Colorado, and Wyoming showed that differential settling and associated cracking are common above the boundaries of mined-out areas and around large coal pillars left within mined-out areas. Cracks as wide as 0.5 m were mapped in Utah about 300 m above a barrier pillar between two mines. Mine air was detected at the surface in these cracks. In western Colorado, mine gases from a crack 20 cm wide and about 215 m above a mine-panel barrier pillar were detected by chemical analysis. According to Osterwald and C. R. Dunrud, these coal-mine subsidence studies revealed a potential condition under which "controlled" in-place coal gasification operations could suddenly burn out of control. The crux of the problem is the differential settlement of overburden. As long as there is no differential settlement of overburden, there is little or no chance that a fire front in a controlled gasification experiment will burn out of control. The chances are good, however, that a fire will burn out of control when differential settlement occurs, because the fracturing and fissuring that commonly accompany settlement give air access to the fire.

Dunrud also reported that a comparison of the results of field physical properties tests on drill core with results from geophysical tests in the same drill holes indicates that more than half the time and money commonly spent on a coal-resource appraisal and geotechnical program involving core drilling might be saved if modern down-hole geophysical logging technology were integrated into the study. This conclusion is based on studies made as part of the coal-mine deformation investigations conducted in Somerset, Colo. Only selected holes would be core drilled; perhaps only one of every five or six holes would be cored for direct physical measurement and analysis. The remaining holes would be plug drilled and immediately logged by means of a complete suite of geophysical techniques that would include natural gamma ray, induced gamma ray, neutron, electric-Sp, and three-dimensional sonic.

The physical properties and strengths of coal beds and bedrock can be established by analyzing the various geophysical logs. Engineering properties such as compressive and shear modulus, bulk modulus, Poisson's ratio, and unit weight can be determined by cross correlating the sonic log and other geophysical logs.

Comparisons of physical properties tests and geophysical studies of the same core hole to date show good correlation. In fact, testing by geophysical methods is advantageous technically as well as economically because the in-place properties of the coal and rock can be determined.

Preliminary data obtained from in-place stress measurements made on a 25×10×5-m block of Barre Granite in the Wetmore and Morse quarry near Barre, Vt., prior to removal of the block, demonstrated the existence of near-surface strain energy large enough to cause measurable surface deformations when the block is quarried. Moreover, concentrations of near-surface strain energy have created elastic and time-dependent deformations large enough to cause visible rock failures and floor heaving in the quarry. Continuing measurements indicated that there are time-dependent deformations that cannot be explained by thermal strains. In addition, good comparison is shown by data obtained from in-place stress measurements made with the U.S. Bureau of Mines borehole deformation gage, the USGS three-dimensional borehole probe, and hydrofracturing techniques.

The field experiment to measure in-place stress in the quarry was conducted by a team made up of T. C. Nichols, Jr., F. T. Lee, W. Z. Savage, P. S. Powers, G. C. Brethauer, J. R. Ege, W. L. Ellis, G. M. Fairer, D. R. Miller, J. D. Kibler, G. R. Terry, and J. E. Magner (USGS) and H. S. Swolfs (Terra Tek, Inc.).

SUBSIDENCE-ASSOCIATED GROUND FRACTURES

Literature research and fieldwork in parts of the Western United States affected by land subsidence caused by ground-water withdrawal led T. L. Holzer to conclude that many of the subsidence-associated fractures in these areas are controlled by faults that existed prior to the subsidence. Holzer divided the fractures into two types: fissuring and faulting. In the case of fissuring, displacement is perpendicular to the plane of failure (that is, an open crack develops at the surface); in the case of faulting, the displacement of opposite sides of the plane of failure is parallel to the plane.

In addition, Holzer discovered the first example of fault movement that possibly was triggered by ground-water extraction in the San Joaquin Valley of California. Although recent fault movement along the Pond-Posco fault within the Tulare-Wasco subsidence bowl has been attributed to tectonic forces, the hydrogeologic setting of the fault makes the extraction of ground water an equally plausible cause of the movement.

ENVIRONMENTAL GEOLOGY

Coal in alluvial valleys

The impact of surface mining on alluvial valley floors has been a problem in current efforts to draft strip-mine legislation. In Western States, such valleys provide hay needed by livestock and are the basis for sustaining cattle production from a hinterland of sparsely vegetated rangeland. Maps showing the extent of alluvial valley floors significant for farming and ranching have not been generally available. To correct this deficiency, R. F. Hadley and H. E. Malde agreed that alluvial valley floors could be objectively mapped on the basis of well-defined geologic and hydrologic relations. They undertook the mapping of alluvial valley floors in representative regions of strippable coal in Wyoming and Montana. At the same time, R. F. Madole evaluated the extent of alluvial valley floors with respect to strippable coal in the Yampa coal field of northwestern Colorado. The first maps to result from this work, 42 7½-min quadrangles in Big Horn, Rosebud, and Powder River Counties in southeastern Montana, were compiled by Malde and J. M. Boyles. According to the Montana Bureau of Mines and Geology, 27.6 percent of this area (1,590 km^2) is underlain by strippable coal. Of this amount, 2.67 percent (42.3 km^2) coincides with alluvial valley floors. In the Yampa coal field, alluvial valley floors overlap 0.7 percent of the strippable coal (2.6 km^2 in 366 km^2). In addition, beyond the limits of strippable coal, a considerably larger area of alluvial valley floor is potentially vulnerable to nearby surface mining, even though the severity of possible impacts might be mitigated by taking suitable preventive action to control erosion. Such impacts might take place both upstream and downstream from the mine and could be caused, for example, by a lowering of the water table, by an increased frequency of destructive floods, or by an increased yield of sediment. The nature of the probable impacts, and the feasibility of methods designed to reduce or eliminate their severity, can be predicted from detailed studies of particular sites. The maps of alluvial valley floors show where such studies might be required for assessment of mining plans.

Premining plans needed for land reclamation

A reconstruction of the landscape that will result from surface mining, based on detailed studies of coal and overburden thicknesses and structure, was prepared by F. R. Shawe for a 30-km-long tract overlying the thick Wyodak-Anderson coal bed in central Campbell County, Wyoming. The resulting maps (1:24,000 scale), which assume certain mining and reclamation practices, show the potential extent of land disturbance and surface drainage disruption that will occur if the entire coal deposit is removed down to the 61-m overburden line. The data indicate that, because the coal is thick in comparison with the overburden, a broad-scale lowering of the land surface will occur to the extent that surface-mined tracts will become areas dotted with large to small topographic depressions and characterized by internal drainage systems. Special attention must be given in the premining planning stages to minimize what could potentially become a long-term serious problem relative to surface drainage and erosional patterns throughout the region.

Slope failures in northwestern Colorado

Nearly one-quarter of the western half of the Craig $1° \times 2°$ quadrangle of Colorado is underlain by landslide deposits determined by R. F. Madole during mapping of the surficial geology. These 2,000 km^2 of landslides are nearly 9 times more than what has been shown on previous maps of the region. The majority of landslides are concentrated in two areas, the Elkhead Mountains and the flanks of the White River Plateau. The geologic units most likely to fail, in decreasing order of importance, are the Browns Park Formation (Miocene), the Mancos Shale (Upper Cretaceous), the Lewis Shale (Upper Cretaceous), the Wasatch Formation (Eocene), and rocks of the Mesa Verde Group (Upper Cretaceous). Ongoing and planned energy development and related civil engineering works in the region are adversely affected by slope failures and must consider them in construction designs.

Erosion rate measured by tree roots

Sixty sections of exposed tree roots were collected by P. E. Carrara from three study areas in the Piceance Creek area of Colorado in an attempt to determine erosion rates over the last several centuries. Data were gathered on slope angle and orientation, height of exposed root above present ground surface, and percentage of vegetation cover. Tree species sampled were pinyon, pine, and juniper. Junipers provided more accurate ages because their tree-ring records generally were better defined.

Thusfar, only minimum erosion rates have been calculated (height of root above ground divided by age of root). The rates, however, are fairly high, ranging from 0.42 to 0.65 mm/yr. Empirical evidence suggests that these minimum rates may be low by a factor of 2. Observations and preliminary analyses also suggest that erosion rates are considerably higher on south-facing slopes and that a threefold increase in the erosion rate has occurred on southwest-facing slopes during the last 500 years. The implication is that southwest-facing slopes in the Piceance Creek area are particularly environmentally sensitive.

Map of active faults in the United States

An overview map (1:7,500,000 scale) of active and possibly active faults in the United States, on the continental shelves, and in Puerto Rico shows that active faults may be more widespread than generally appreciated. For example, several active and suspected active faults are known onshore and offshore along the eastern seaboard. The western third of the country is riddled by young faults but contains some relatively stable regions such as the Sonoran region (western Mojave and eastern Arizona) and the Sierra-Great Valley-Cascades belt in which active faults are rare. Sharp boundaries in Utah, Wyoming, and Colorado separate regions of active north-trending normal faults in the intermountain belt from regions to the east having east-trending faults. Some fault regions such as those in eastern Utah or on the gulf coast are the sites of considerable aseismic fault activity owing to low-stress failure of salt or of geopressured clastic rocks. The map was being prepared by K. A. Howard, E. A. Brabb, M. R. Brock, H. D. Gower, D. J. Milton, W. R. Muehlberger, George Plafker, D. C. Prowell, R. E. Wallace, and I. J. Witkind.

Computer mapping system for land-use planners

According to J. N. Van Driel, a computer-based environmental information system was tested as a tool for communicating geologic information to land-use planners. The Montgomery County Environmental Information System (MCEIS), which consists of digitized geologic information and a computer mapping program that permits planners to combine different types of environmental information for use in land-use decisionmaking, was used to produce maps of a portion of Montgomery County, Maryland, showing optimum areas for various types of urban development on the basis of the presence of shallow bedrock, alluvium, steep slopes, surface water, and mature trees. These computer maps were used by the planning staff in rewriting the sector plan for the Shady Grove area of the county. The information system was also used by environmental planners to make recommendations for siting a sanitary landfill. A computer composite map showing depth to bedrock, occurrence of surface water, and drainage characteristics of the unconsolidated overburden was produced by the MCEIS mapping program. On the basis of this map and other planning staff recommendations, a proposed landfill site that had been selected originally without regard for geologic conditions was rejected.

Risk-slip faulting, central California

Detailed geologic mapping in western San Luis Obispo County, California, by C. A. Hall, Jr., provided new evidence for defining the age and nature of movement along the San Simeon-Hosgri fault system. In the vicinity of San Simeon, a sequence of rocks consisting of (1) Jurassic ophiolite, chert, and shale, (2) Franciscan rocks, (3) Oligocene conglomerate and tuff, (4) Miocene rocks (including a unique cherty shale), and (5) a fault block of probable upper Pliocene fossiliferous sandstone lies west of a prominent zone of northwest-trending faults, some of which cut marine terraces. The lithologies, stratigraphic relationships, and structural style of this sequence bear a striking resemblance to a similar sequence exposed near Point Sal, some 100 km southeast, on the eastern side of the Hosgri fault zone. The rocks in the sequence at San Simeon are unlike those within a 100-km radius to the east; thus, it appears that they have been offset along the San Simeon-Hosgri fault system from the similar sequence at Point Sal. The age of the faulting, which began between the late Miocene and the late Pliocene, must be Pleistocene or younger, and the record of seismicity in this region suggests that the system is still active. Offshore geologic and geophysical studies indicate that the fault system extends at least as far south as Purisima Point. To the north, the fault system appears to extend as far as Monterey and possibly may tie into the San Gregorio fault and related faults north of Santa Cruz. The recency of movement of faults in this system poses serious questions relative to the safety of public and private facilities in existence, under construction, or being planned along the coast from San Simeon to the vicinity of Purisima Point. The type of offset occurring along this system also is significant because it permits speculation on a possible offset extension of the oil-producing Santa Maria basin.

Slope stability in Franciscan terrane

Preliminary evidence from detailed field mapping in the Franciscan terrane of Marin County, California, by S. D. Ellen, J. M. Coyle, D. M. Peterson, G. O. Reid, M. E. Savina, and C. H. Trautmann suggested that both the abundance and the types of landslides that have occurred in the area correlate well with general topographic types previously mapped from small-scale (1:80,000) aerial photographs by C. M. Wentworth, Jr., and Ellen. Work on the hillside materials of the San Francisco Bay region demonstrated the correlation of bedrock condition with topographic type. The present work will relate slope processes to topographic types and provide a technique for rapid regional appraisal of slope stability in Franciscan terrane.

Loess landscapes need soil conservation

Studies of the surficial geology of the eastern Snake River Plain by W. E. Scott indicated that the highly productive agricultural areas of southeastern Idaho are intimately tied to upper Quaternary deposits in the region. The Snake River and Henrys Fork valleys are filled with alluvial sand and cobble-pebble gravel to depths as great as 250 m. The upper part of the fill is broadly late Wisconsinan in age and has been locally terraced. Only a very small area of pre-upper Wisconsinan alluvium is exposed in the region. The valley was a source for the loess and minor eolian sand that is found throughout the eastern plain. On the coarse-grained gravels of the valley, a thin (in most places <0.5 m) loess cover supports irrigated agriculture. Without the loess cover, the permeability and stoniness of the alluvial sand-gravel would decrease productivity. On surrounding uplands and benchlands, loess thicknesses are greater, and slopes having up to five levels are in cultivation. In some areas, over welded tuff or basalt bedrock, loess from multiple episodes of deposition may exceed several tens of meters in thickness. In other areas, however, such as Rexburg Bench, where several hundred square kilometers are cultivated, the loess is thinner. Here loess thicknesses of 0.5 to 2 m are most common. A complex K horizon underlies the loess, which usually lies on thin loess or bedrock. Apparently, during breaks in loess deposition (interglacials?), soils with calcareous subsoils were forming and concurrently being stripped down to the hardpan formed by the carbonate horizon. These K horizons thus represent the deposition and stripping of multiple, thin loess blankets during the Quaternary. It is thus suggested that, during the present interglacial, a stripping phase that may be accelerated by cultivation is in progress in these areas. Clearly, conservation measures should be used with an understanding of the past history of these landscapes.

Land-use maps, Centennial Mountains, Montana and Idaho

I. J. Witkind completed two environmental geology products for the Centennial Mountains of Montana and Idaho. The first is a geologic map of a strip along the active Centennial fault. The fault, along the northern flank of the Centennial Mountains, is a major structure in southwestern Montana, and the zone is considered to be a potential geologic hazard. The second product—another geologic map containing land-use information—shows the central part of the Centennial Mountains, including the Upper Red Rock Lake quadrangle of Montana and Idaho. A summary accompanying this map gives the physical properties (dry bulk density, grain density, porosity, saturated bulk density, and Shore hardness), elastic constants (Young's modulus, bulk modulus, and Poisson's ratio), and wave propagation characteristics (velocity of both longitudinal and shear waves) of most of the bedrock units exposed in the Centennial Mountains.

Land-use maps, Jefferson County, Colorado

K. L. Pierce's reconnaissance mapping of mountain soils was almost complete for Jefferson County, Colorado, one block of the Front Range urban corridor study. The area mapped is a complex association of Precambrian crystalline bedrock overlain by a discontinuous covering of regolith. Since conventional geologic mapping procedures do not satisfy needed land-use planning criteria, the goal of this project was to map the area and present the information in a manner that could be understood by and would be useful to nongeologists. Five simple map units were used to relate regolith more than 2 m deep to hard bedrock. The text accompanying each map, which was written to be easily understood by nongeologists, gives relative rankings of the map units in relation to their salient environmental properties.

Landslides

Landslide studies conducted by W. E. Davies, R. J. Hackman, A. B. Olson, and G. C. Ohlmacher led to the recognition of a new topographic form in the Appalachian Plateau: striking, U-shaped, steep-headed secondary tributary valleys formed on the plateau from Butler County, north of Pittsburgh, Pa., south to Charleston, W. Va. Although a few such valleys, called "landslide cirques," had been noted previously, their extent was not recognized. The U-shaped valleys are from 92 to 610 m wide and are as much as 460 m long. The valleys closely resemble glacial cirques in shape. The headwalls have smooth slopes as steep as 60°, but downstream the slopes of the valley walls and floors gradually decrease. Valley profiles and sections are uniformly concave. The valley floors are clay slabs, commonly 1.2 to 2.4 m thick, that are underlain by weathered shale about 1 m thick. Generally, these valleys do not have surface drainage, and stream channels are lacking. At the bases of the clay slabs, zones of moving water up to 30 cm thick are confined by the clay and are under hydrostatic heads of 1.8 to 2.4 m. Farmers use these water sources by placing concrete pipes vertically in the clay to intercept the water. The water emerges near the bases of the concave slopes in the valleys as small seeps that unite in perennial streams. The resurgent areas are generally covered by a grove of trees or are the upper limits of dense woods. The clay slabs appear to be in equilibrium, although they are slowly moving downslope. Seeps remove clay at the toes; clay is replenished at a balanced rate by the rapid weathering of the shales in the upper parts of the valleys. Clay slabs are very sensitive to overloading, and slides develop when fills are placed on them. Hummocks and lobes from old earthflows are present at the lower ends of many valleys. Soil slips are common, especially in the middle parts of the valleys. The prevalence of U-shaped valleys indicates that mass wasting from slow but progressive clay-slab slides plays a dominant role in shaping the topography of much of the Appalachian Plateau in southwestern Pennsylvania, West Virginia, and southeastern Ohio.

Slope stability in southwestern Pennsylvania

J. S. Pomeroy's preliminary findings in a three-county area of southwestern Pennsylvania emphasized the importance of rock lithology in landslide susceptibility. In Butler County, slope stability problems exist in three distinct geologic environments: the red mudstones below the Ames Limestone Member of the Glenshaw Formation in the southern part of the county, the largely reclaimed land in the Freeport coal interval to the north, and the homogeneous clayey till in the extreme northwestern (glaciated) part of the county. In the northern, northwestern, and western parts of Allegheny County (Pittsburgh area), landslide incidence increases significantly, in part because of the greater amount of man-modified land and steeper slopes but mostly because of the presence of red mudstones (Conemaugh Group). In Washington County, however, the landsliding problem increases to the south and southwest away from Allegheny County and is related to the unstable clay shales and limestones of the Dunkard Group. Fortunately, the most highly susceptible Washington County landslide areas are in sparsely populated rural areas. Many landslides have been shown on geologic quadrangle maps of Washington County, and it is significant to note the areas in which landslides have occurred since the mapping began over a decade ago. It can be demonstrated that most active landslides emanate from large, old (mostly prehistoric) slide areas. However, man's modification of slopes is also an important factor. For example, in eastern Washington County, the largest earthflows occur along a regarded slope where the Waynesburg coal was being stripped at the time of the geologic mapping in 1964.

Saprolite thickness in Maryland

Recent studies by J. B. Roen of water-well records and selected field exposures in Howard County, Maryland, indicated that the saprolite thickness is a function of the original rock type and that the configuration of the saprolite-bedrock interface closely parallels the topography. Areas of the county underlain by phyllite, quartzite, and mafic and ultramafic rocks typically have little or no saprolite cover. Where saprolite is present, the thickness is generally 1 to 2 m or less. A thicker cover, generally greater than 6 m and sometimes as much as 15 m, overlies the schists and granitoid rocks. A contour map of the saprolite-bedrock interface shows that this surface reflects the hills and valleys in the county and defines the drainage divide separating the Patuxent and Patapsco Rivers. The map also shows local closed basins and domes that are superimposed on the regional topographic gradient. The basins are of particular importance, as they may be possible sources of ground water.

RELATION OF RADIOACTIVE WASTE TO THE HYDROLOGIC ENVIRONMENT

As the need to expand the development of nuclear energy as a viable source of power for the Nation increases, finding solutions to the problems of isolating radioactive-waste materials from the hydrologic environment becomes more urgent. USGS research is directed toward studying disposal methods and toward understanding the geohydrological processes and principles involved in moving waste from storage and disposal sites. USGS research sponsored by ERDA and NRA has been directed toward understanding specific waste-disposal areas.

Hydrogeologic investigation of the Maxey Flats radioactive-waste storage site

Radioactive wastes, termed "other than high level," have been buried continuously since 1963 at the Maxey Flats storage facility in Kentucky. An estimated 1,200,000 Ci of byproduct material, 208,000 g of special nuclear material, and 39,000 kg of source material were buried from 1963 through 1972. All burial of waste takes place in weathered and unweathered shale near the ground surface. The wastes are buried in rectangular trenches, most of which are about 110 m long, 21 m wide, and 6 m deep. The trenches cover an area of about 77,000 m^2 and are located atop an erosional remnant in a dissected plateau 110 m above the surrounding valleys. Water accumulated to various depths in the trenches during the first 9 years of operation.

Although the geology of the Maxey Flats site is well defined, little is known about the local hydrologic system. Investigations by H. H. Zehner indicated that several perched water tables may exist in the series of aquitards underlying the site. These aquitards are extensively fractured shales and sandstones. The inhomogeneous character of the fractured media complicates quantitative evaluation of the local hydrologic system.

Chemical analyses and electrical conductivity measurements of water from wells, springs, and streams near the site indicated that most base flow is from colluvium and soil on hillsides, plus alluvium in valley bottoms. Bedrock, however, makes some contribution to the streamflow. Thirteen existing wells used for monitoring ground-water quality at the Maxey Flats site proved to be of marginal value in analyzing the positions of saturated zones and the direction of ground-water movement. Future drilling is planned to determine this information.

Elevated levels of radioisotopes in the area around the burial site were observed during the past 3 years by the State agency responsible for regulating and monitoring the site. Because the pathways of water collected for analysis have not been defined, it is not known whether the isotopes are transported from the site by runoff of surface spills, flow in shallow weathered material, or flow at depth through fractured bedrock. USGS geophysical logging equipment was used to identify cesium and cobalt isotopes at a depth interval of 6 to 14 m in one well located on the Maxey Flats site.

Evaluation of radioactive-waste burial in coastal sediments

A study of radioactive-waste burial in coastal sediments was conducted by J. M. Cahill in Barnwell County, South Carolina. Preliminary monitoring of shallow wells (less than 30 m deep) in the study area indicated that none of the waste material has entered the saturated zone. A piezometric map of the Miocene sediments indicated that ground water drains from the burial site toward a spring located about 1 km south of the burial grounds. Efforts are now being directed toward monitoring the unsaturated sediments in the vicinity of the burial pits.

Radioactive-waste landfill in New York

Surficial geologic mapping near Springville in western New York by R. G. LaFleur revealed the nature and extent of an unusual till of Woodfordian age. The till, rich in silt and moderately poor in stones, is notable for its tendency to fail by landsliding where relief greater than 2 m is produced by stream incision or artificial means. The till is a valley facies, widely distributed in the Cattaraugus Creek basin below the level of saddles in the drainage divide to the south, and must have been deposited by an ice sheet partially suspended in ponded water.

Test drilling and excavations near low-level radioactive-waste burial trenches in the till revealed that severely deformed, discontinuous beds of silt to very fine sand and, rarely, coarser sand are about 7 percent of the till mass. Oxidized fractures occur to a depth of about 3 m.

Water saturates at least the bottom meter of refuse in each burial trench. A preliminary analysis of measurements made in nearby piezometers by D. E. Prudic suggested that, as of early 1976, hydraulic gradients were generally downward and outward from the trenches, except in the uppermost part where inward gradients are commonly observed. Water levels have risen for several years in some trenches; in early 1975, when water levels were higher than the natural land surface in the mound of reworked till covering the trenches, some water was pumped out and treated.

Radioactive contaminants identified near radioactive-waste burial grounds

W. S. Keys and T. A. Taylor identified radioactive contaminants in test holes drilled near the trenches in radioactive-waste burial grounds in West Valley, N.Y., and Oak Ridge, Tenn. In West Valley, inhole gamma spectrometry was used to locate the contaminated intervals and to identify cobalt-60 and cesium-137. Most of the contaminants occurred in the depth interval from 1.52 to 1.82 m; no artificial radioisotopes were detected at depths greater than 3 m. Most of the holes were cased with 5.08-cm pipe, and so it was necessary to use a 4.76-cm spectral probe containing a 3.18×5.08-cm sodium iodide crystal. Because of larger casing in several holes, it was possible to use a new 10.16-cm probe containing a 7.62-×30.48-cm sodium iodide crystal. This probe significantly reduced counting time and improved detection limits. It also permitted continuous spectral logging to record the relative amounts of naturally occurring uranium, thorium, and potassium, as well as of artificial radioisotopes. At Oak Ridge, cesium-137 was identified in several wells near burial grounds at depths up to 46 m. Acoustic televiewer logs showed fractures in the Conasauga Shale that may be transmitting the contaminated ground water. Significant concentrations of cesium-137 and cobalt-60 were identified in a well near disposal pits that have not been used since 1961.

Stripping techniques for borehole gamma spectrometry

A. E. Hess designed and assembled a borehole gamma spectral system and D. E. Eggers developed computer programs to facilitate onsite identification and determination of the concentration levels of contaminants emitting gamma rays. These techniques are being used on gamma spectra obtained in boreholes in the vicinity of nuclear-waste disposal sites at Maxey Flats, Ky., West Valley, N.Y., and Oak Ridge, Tenn. The primary problem with this interpretation technique is separating the contribution of the contaminant from the contributions of the natural gamma emitters, such as an isotope of potassium, and members of the thorium and uranium decay series. Models have been constructed and model results have been compared with laboratory radiometric analyses to determine the characteristic spectra of individual isotopes and the calibration of the system.

Evaluation of single-well tracer method of aquifer evaluation

The transmissivity of an aquifer can be determined during a pumping test from a single well. The local hydraulic gradient can be estimated by the point-dilution technique through a single-well test. The effective porosity and the local natural ground-water flow velocity can be determined by means of the single-well pulse technique, which takes the natural ground-water flow into consideration. The porosity and velocity data are necessary to predict the migration of wastes by the movement of the ground water.

R. J. Sun (1976) successfully applied the single-well tracer test method when he interpreted the injection data observed at West St. Paul, Minn., during an investigation of artificial recharge through a well in fissured carbonate rock. However, before the single-well tracer method can be used extensively for preliminary site evaluation, the results obtained from both single-well and multiwell tests at a given test site must be compared to determine whether they will give the same or similar results.

A field experiment was being conducted in the Amargosa Desert in Nye County, Nevada, an area southwest of the Nevada Test Site, to evaluate the single-well tracer method. Six wells were constructed at the site, and well-tracer tests were underway. The test results will be used to evaluate the reliability of the single-well tracer method.

Disposal of radioactive waste by grout injection after hydraulic fracturing of shales

ERDA selected a site in the Melton Valley of Tennessee, near the Oak Ridge National Laboratory, to dispose of intermediate-level liquid radioactive wastes by grout injection and hydraulic fracturing of shale. The site was evaluated by means of a grout injection in 1974 and a water injection in 1975. The fluids used in both injections were tagged with gamma-energy tracers. Formation of bedding-plane fractures during the injection tests was interpreted from injection pressure by R. J. Sun (1975) and confirmed by gamma-ray logs made in observation wells before and after the injections. Pressure decay-time data during the water injection in 1975 indicated that no interconnected fractures and joints of wells existed at the proposed site and that, at the injection depth, the shale permeability was very low. The shut-in wellhead pressure of the water injection was about 162 kg/cm^2; 18 days after termination of the injection, 41 kg/cm^2 of pressure was still recorded at the well head. If there had been interconnected joints and fractures of wells in the shale, no wellhead pressure would have been observed after 18 days. On the basis of this information, Sun concluded that the proposed site is probably suitable for disposal of radioactive wastes in shale by grout injection and hydraulic fracturing.

Influence of radioactive- and chemical-waste disposal on the Snake River Plain aquifer in southeastern Idaho

The chemical quality of the ground water in the Snake River Plain aquifer was analyzed to determine the effects of more than 20 years of waste disposal in southeastern Idaho. The studies were made at an ERDA facility, the Idaho National Engineering Laboratory.

According to J. T. Barraclough and R. G. Jensen (1976), several chemical- and radioactive-waste products were traced in the Snake River Plain aquifer, and the waste plumes were mapped. The principal wastes discharged include tritium (H–3), strontium-90, cesium-137, sodium, chloride, chromates, and warm water. The wastes are subject to hydraulic dispersion, sorption, and radioactive decay, which spread, dilute, and retard their migration. Waste plumes cover about 40 km^2 in the aquifer and have migrated about 9 km downgradient from discharge points.

Computer simulation of subsurface waste migration

J. B. Robertson (1976) developed a digital computer model to analyze migration rates and to predict possible future concentrations of radionuclides in a valuable freshwater aquifer beneath the waste ponds at the Idaho National Engineering Laboratory in Idaho. The model indicated that relatively small quantities of nonradioactive chloride and tritium (a weakly radioactive form of hydrogen) will continue to enter the Snake River Plain aquifer as long as present disposal rates continue. Model simulations showed that other major radioactive solutes in the waste, such as strontium-90, cesium-137, and cobalt-60, probably will not migrate to the aquifer in detectable concentrations if present disposal conditions continue; radioactive-waste migration is delayed by absorption reactions with minerals, which, in turn, allow the isotopes to decay radioactively.

FLOODS

The three major phases of USGS flood studies are (1) measurement of stage and discharge, (2) definition of the relation between the magnitude of floods and their frequency of occurrence, and (3) delineation of the extent of inundation of flood plains by specific floods or by floods having specific recurrence intervals.

OUTSTANDING FLOODS

Flood of April 1975 in Lansing, Michigan

On April 18, 1975, intense rainfall caused extensive flooding in Michigan's Red Cedar River basin and in the headwaters of the Shiawassee River. As much as 131 mm of rainfall was reported during a 7-hour period. Damage estimates for the Lansing metropolitan area were as high as $20 million.

Recurrence intervals of flood discharges in the headwaters of the Red Cedar River and many small tributaries there were about 100 years. In the lower reaches of the Red Cedar River, recurrence intervals did not exceed 50 years.

Aerial photographs taken at the time of the peak stage of the flood and assembled as a mosaic delineated inundated areas. Reports for four Lansing area communities were prepared (R. L. Knutilla and L. A. Swallow, 1975a, b, c; J. B. Miller and L. A. Swallow, 1975).

Flooding in the Shiawassee River basin was not as severe as that in the Red Cedar River basin, and damage was not great, although three dams on streams in the basin were washed out.

Hydrologic appraisal of flash flood in the Las Vegas Valley of Nevada

Thunderstorm precipitation on July 3, 1975, in the area between metropolitan Las Vegas, Nev., and mountains to the south, west, and north caused flash flooding in and adjacent to the city. T. L. Katzer, P. A. Glancy, and Lynn Harmsen (1976) reported that total storm precipitation exceeded 80 mm in some areas, and runoff was probably between 25 and 30 hm^3. Peak flows of Las Vegas Creek and the Las Vegas, Tropicana, and Flamingo Washes were the highest ever measured. Flooding caused the loss of two lives, and property damage was estimated at about $4.5 million. Sediment movement was dominated by sand, silt, and clay. Generally, there were no gravels and boulders available for transport in major channels, but sediment transported during the flood was deposited in Lake Mead near the mouth of Las Vegas Wash. Lateral erosion appeared more prominent than vertical erosion along most major channels, except on Las Vegas Wash at Northshore Road, where downcutting threatened the loss of the highway.

Flood of July 21, 1975, in Mercer County, New Jersey

S. J. Stankowski, R. D. Schopp, and A. J. Velnich (1975) reported that intense frontal rainfall caused flooding in highly urbanized Mercer County, New Jersey, on July 21, 1975. Rainfall totaling more than 178 mm fell on parts of Mercer County in a 10-hour period. Indirect discharge measurements showed that runoff from small basins within the storm area reached a maximum of 15.2 $m^3\ s^{-1}\ km^{-2}$. Flooding was devastating in the vicinity of Trenton, the capital of New Jersey, where industrial, commercial, and residential development along the Assunpink

Creek is extensive. The peak discharge of the Assunpink Creek at Trenton was 40 percent greater than the previous maximum in 51 years of record and 10 percent greater than that of the 100-year flood. No lives were lost, but damages to highways and bridges, to industrial, business, and residential buildings, to farmlands and crops, and to water-supply systems were severe.

FLOOD-FREQUENCY STUDIES

Flood hydrology of four physiographic regions in Colorado

J. F. McCain and R. D. Jarrett (1976) developed regression equations for 10-, 50-, 100-, and 500-year floods on nonregulated streams in four physiographic regions (plains, mountain, northern plateau, and southern plateau) of Colorado. The equations relate both flood discharges and flood depths to measurable basin and climatic parameters.

Many streams in Colorado originate in high mountain areas and flow to much flatter plain or plateau areas. At higher elevations, floods on these streams are caused by snowmelt runoff, but, at lower elevations, floods can result from snowmelt, rainfall, or a combination of rain on snow. Reaches of streams that receive annual maximum floods from both phenomena are referred to as "foothill streams." In a statistical analysis, the part of a drainage basin affected by both rainfall and snowmelt floods is called a "mixed-population flood area." An interim procedure was developed to define flood characteristics in mixed-population flood areas.

Flood investigations in Idaho

Flood data collected by W. A. Harenberg for the Idaho Department of Highways and the U.S. Forest Service will be used to estimate the magnitude of peak flows from ungaged watersheds in Idaho. The oldest continuing part of the project is the collection of annual peak-flow data at 56 crest-stage gaging sites. The second part involves a study of the feasibility of using channel geometry measurements to transfer peak-flow data to ungaged sites. During the year, channel geometry data were collected at 30 sites. Analyses of these data and those collected during the preceding year are continuing. Data have been collected for approximately 60 percent of the State.

Flood-frequency model

W. D. Mitchell (1962) developed a method for manually determining T (basin lag time between rainfall and runoff) and k (linear reservoir recession characteristic) for a number of rainfall-runoff recording stations in Illinois. G. W. Curtis reported that the T and k characteristics described by Mitchell are the same as the T and KSW parameters used in the routing phase of the USGS rainfall-runoff model for studying floodflows on rural drainage areas of less than 26 km^2.

A generalized parameter describing volume characteristics developed from model calibrations of 31 gaging stations was used with available T and k values for 25 additional stations to calculate Q_{50} (peak discharge of 50-year flood). The regression variance for observed Q_{50} for the 25 additional stations was not significantly different from that for the observed Q_{50} versus the synthesized Q_{50} for the 31 calibrated stations. The values of Q_{50} for the uncalibrated stations appear reasonable enough to be used to increase the network to 56 stations.

Flood-frequency relations for rural streams in Massachusetts

The USGS rainfall-runoff model described by C. W. Boning (1974) was used by S. W. Wandle, Jr., to extend short-term flood records at 10 sites in Massachusetts draining less than 26 km^2 in an effort to improve the accuracy of the flood-estimating relations defined by C. G. Johnson and G. D. Tasker (1974). The standard error of estimate of these equations ranged from 45 percent (2-year peak) to 73 percent (100-year peak). The most significant basin parameters were drainage area, main-channel slope, and mean annual precipitation.

Relationship of flood height to drainage area for streams in Massachusetts

The relationship of the height of the 100-year flood above the height of median flow (H_{100}) to the drainage area (A) for streams in Massachusetts was defined by S. W. Wandle, Jr. Stepwise regression of the data from 45 gaging stations ranging in size from 1.27 to 1,287 km^2 resulted in the following equation:

$$H_{100}=2.34\,A^{0.31}.$$

The average standard error of estimate was 40 percent. This relationship proved useful in delineating flood-prone areas on topographic quadrangle maps of the Connecticut River basin.

Flood-frequency evaluation in Minnesota

L. C. Guetzkow reported that multiple-regression analyses of flood-frequency relations at 220 gaging stations in Minnesota and adjacent areas indicate that there are larger-than-desirable standard errors of estimate throughout the range of frequencies tested. Defined regional relations indicate a trend toward more accurate flow estimates. This trend is expected to result in more realistic flow-frequency estimates, and the evaluation of flow-frequency relations is continuing. Preliminary results indicate that significant basin characteristics, such as drainage area and storage, cannot be adequately defined from topographic maps in glaciated terrane. Undetected basin depressions account for substantial storage, the effects of which vary with the magnitude of the flood event.

Flood magnitude and frequency of Rhode Island streams

C. G. Johnson developed a technique for estimating the magnitude and frequency of floods on rural streams in Rhode Island having drainage areas of between 1.27 and 764 km^2. Multiple-regression methods were used to define the relationships between 2-, 5-, 10-, 25-, 50-, and 100-year peak discharges and selected basin characteristics. Results based on station data obtained through 1974 showed that flood peaks can be estimated from drainage-area size, mean basin elevation, and area of forest cover. Standard errors of estimate ranged from 43 percent (2-year peak) to 67 percent (100-year peak).

FLOOD MAPPING

Channel flood surveys in Alaska

J. M. Childers and J. P. Meckel made channel surveys along 14 streams located between the Colville River and the Canadian border on Alaska's North Slope to obtain flood-hazard information. Indirect measurements of the maximum evident flood (MEF) were made, and bankfull discharges were computed by slope-conveyance methods. The results indicated that flood hazards on the eastern Arctic Coastal Plain of Alaska were significantly greater than estimates based on drainage-basin, physiographic, and climatic parameters might suggest. On 12 of the 14 streams, the MEF exceeded the 50-year flood estimated by multiple-regression equations for Alaska. At some sites, flooding and flood evidence may have been affected by ice conditions. Where flood-discharge records did not exist, the channel flood-survey data provided valuable planning and design information for the development of Alaska's arctic resources.

Flood maps of Avra Valley, Arizona

R. H. Roeske and B. N. Aldridge delineated flood boundaries on maps and computed water-surface profiles for 100-year floods on the Brawley and Blanco Washes in the Avra Valley of Arizona. Step-backwater analyses, photointerpretation, and data from previous floods were used to determine flood profiles and inundated areas. In the 5.5-km-long Avra Valley, about 233 km^2 will be inundated by the 100-year flood.

Flood-hazard maps of Casa Grande, Arizona

Flood-boundary maps were prepared by R. P. Wilson and B. N. Aldridge for Casa Grande, Ariz., by using step-backwater and photointerpretation techniques. Flood-prone areas and water-surface profiles for the 100-year flood were shown for the reach of the North Branch of the Santa Cruz Wash within the city limits. In addition, profiles of the 10-, 25-, 50-, and 500-year floods were determined.

Shallow sheet runoff, the primary source of flooding, occurs in much of the city. A subdivision east of Trekell Road along Bisnaga Street is located in the low area near the center of the natural flood channel, and a trailer park on the western side of Trekell Road is situated in the flood-prone area.

North of the North Branch of the Santa Cruz Wash, an alluvial fan is dissected by a network of small channels. The areas between channels are subject to sheetflow at depths of less than 0.3 m. Minor floods do not reach the North Branch because they are dissipated on the fan. During major floods, however, large amounts of water flow down the fan.

The main floor of the valley is located in the area south of the North Branch. Flooding in this area is caused mainly by pondage behind dikes and embankments or by concentrations of runoff in small drainage ditches.

Overland flow to the North Branch from the south has an average velocity of about 0.3 m/s and a mean depth of 0.3 m. The velocity of overland flow from the north is about twice that from the south.

Flood-prone-area maps of Huachuca City, Arizona

R. H. Roeske used step-backwater and photointerpretation techniques to prepare flood-boundary maps for Huachuca City, Ariz. Water-surface profiles and areas inundated by the 100-year flood were shown for the reach of the Babocomari River located within the city limits. Also, flood profiles for the 10-, 25-, 50-, and 500-year floods were determined.

The major source of potential flooding is the Babocomari River. On the basis of 1973 channel conditions, about 20 percent of the area within the corporate limits of Huachuca City is subject to inundation by the 100-year flood.

Flow from the Huachuca Canyon area could cause as much as 0.6 m of sheetflow in the northwestern corner of the city. Much of the southern part of the city is subject to flooding from sheetflow less than 0.3 m deep.

Flood-hazard maps of Kingman, Arizona

Otto Moosburner used step-backwater and photo-interpretation techniques to prepare flood-boundary maps for Kingman, Ariz. Inundated areas and profiles of the 100-year flood were shown for most stream channels within the city limits. In addition, profiles of the 10-, 25-, 50-, and 500-year floods were determined.

About 25 percent of the city is subject to sheetflow, the primary source of flooding in Kingman. In the business district and in the adjacent older residential area, intense runoff from rainfall in the mountains and the urban area cascades down the streets at depths ranging from 0.3 to 0.6 m. Water spills over the curbs and into buildings. Damage to the downtown area can be expected on an average of at least three times in 10 years.

In the hilltop area, sheetflow several centimeters deep may move directly downslope into yards and homes during severe floods, but the probability of any one place sustaining damage more than once in 10 years is small.

The main streams flowing through Kingman are contained in well-defined channels between steep rocky banks. The flood-prone areas along the streams are designated as floodway because no significant amount of bank encroachment can be justified. The average width of the floodway on these streams is about 90 m.

Flood maps in Paradise Valley, Arizona

B. N. Aldridge used step-backwater and photo-interpretation techniques to delineate flood boundaries on maps of Paradise Valley, Ariz. Water-surface profiles and areas inundated by the 100-year flood were shown for the reaches of Indian Bend Wash and Echo Canyon within the city limits. Also determined were flood profiles of the 10-, 25-, 50-, and 500-year floods.

Indian Bend Wash flows through the northeastern corner of Paradise Valley and constitutes the primary flood hazard. A small amount of flooding occurs along Echo Canyon in the southwestern corner of Paradise Valley and along the Arizona Canal. Sheetflow inundates an area north of Indian Bend Wash.

Flood-hazard studies in Colorado

R. C. Christensen and H. E. Petsch, Jr., conducted flood studies on 571 km of streams located in the unincorporated area of Jefferson County and at Palmer Lake in El Paso County, Colorado. Water-surface profiles were computed for the 10-, 50-, 100-, and 500-year floods along 249 km of streams and for the 100-year flood on the remaining 322 km. Flood-hazard areas were identified in the communities of Buffalo Creek, Evergreen, Idledale, Indian Hills, Kittredge, and Pine and in other developing areas in Jefferson County and at Palmer Lake. The information will be used by local governmental units to develop flood-plain-management measures that meet the requirements of HUD's Flood Insurance Program.

Flood mapping in Lindsborg, Kansas

C. O. Peek determined that about 9 percent of the land area in Lindsborg, Kans., would be inundated by a 100-year flood, whereas only 10 percent of the area would be covered by a 500-year flood.

Historically, Cow Creek has been a major source of flooding at Lindsborg. Peek's study determined that the 100-year water-surface elevation is about 1.8 m above the streambed and that the floodwater depth varies from 0.3 to 0.9 m on some city streets. The width of the 100-year flood plain along Cow Creek varies from about 60 to 300 m.

The 100-year flood on the Smoky Hill River will be contained within the main stream channel within the city limits. This condition is attributed to the flood-control storage in Kanopolis Lake located 60 km upstream from Lindsborg.

Flood-insurance studies in Minnesota

L. C. Guetzkow reported that investigations were being conducted to identify special flood-hazard areas and to provide other technical data required by HUD for the implementation of a flood-insurance program in Minnesota. Studies were set up to define flood-frequency profiles, delineate on maps the areas inundated by floods of selected frequencies, determine floodway configurations, and describe hydrologic and hydraulic analyses. Information obtained from these studies will be used by a local governmental unit as a technical basis for adopting land-use controls. These data will also make it possible for affected governing bodies to carry out the comprehensive flood-plain-management programs required by HUD's flood-insurance program and thereby significantly decrease potential flood losses.

Flood-prone-area mapping in Minnesota

Studies were being conducted along designated reaches of Minnesota streams to provide the information required by State regulations for the implementation of comprehensive flood-plain-management programs in affected areas. L. C. Guetzkow reported that priorities for the selection of study areas were based on the degree of flood-damage potential and on development pressures. The almost-completed initial thrust to develop data for all mainstem river corridors in the seven-county Twin Cities metropolitan area resulted in reports containing flood-frequency analyses, water-surface profiles, flood-inundation maps, and floodway evaluations.

The flow-frequency relationships determined in all flood-plain studies undertaken in Minnesota are coordinated between State and Federal agencies. Flow-frequency estimates have been coordinated at 32 sites thusfar.

Maps of flood-prone areas

Areas inundated by the 100-year flood are outlined on topographic maps as part of the National Program for Managing Flood Losses. The objective of this program is to rapidly inform cities and towns of the general extent of their potential flood problems. More than 12,000 such maps have been completed for all the States, the District of Columbia, and Puerto Rico.

The maps identify the flood-prone areas of most of the developed and developing parts of the Nation. Flood-hazard maps are used extensively to meet local planning needs and to meet the objectives of the National Flood Insurance Act of 1968 and the National Disaster Protection Act of 1973.

Inundation maps of urban areas

Maps showing areas inundated by major floods, flood profiles, discharge-frequency relationships, and stage-frequency relationships were published during the current year as Hydrologic Investigation Atlases for Lock Haven, Pa. (H. N. Flippo, Jr., 1975), and the Carolina-Río Grande (W. J. Haire, 1975a), Fajardo-Luquillo (W. J. Haire, 1975b), and lower Río Loco basin (K. G. Johnson, 1974) areas of Puerto Rico.

WATER QUALITY AND CONTAMINATION

Sedimentary heavy metals and PCB apparently mobilized in the Hudson River

Past accumulations of lead, copper, and PCB are apparently mobilized by the resuspension of bottom materials in New York's Hudson River, according to J. T. Turk. Preliminary data indicated that, even in the absence of continued massive dumping of these pollutants, problems may remain for municipal and recreational users of the Hudson River because high discharges rework older sediments that were contaminated before the development of modern abatement programs. Present research is directed toward assessing the magnitude of the problem and the effectiveness of traditional water-treatment processes in coping with the problem.

Chemical quality of precipitation assessed

Although rain and snow are commonly thought to be the purest kinds of water, in the industrialized Northeast they are often contaminated by lead and acid in concentrations that are potentially harmful to man and his environment, according to J. T. Turk. Data from a monitoring network operated by the USGS in cooperation with the New York State Department of Environmental Conservation showed that precipitation is normally more contaminated with lead than the rivers that receive industrial wastes. Lead concentrations in precipitation sometimes exceed the USPHS recommended maximum for drinking water. In areas where pH values of precipitation are low (the minimum value obtained was 3.4) and where rock weathering is not rapid enough to neutralize acid rain, fish production has decreased and plumbing systems have corroded. Further problems may result if drinking-water systems contain copper pipes with lead solder; the increased corrosion introduces large amounts of lead and copper into water standing in the plumbing.

Some hydrologic impacts of trans-Alaska pipeline construction

Trenching of streambeds and backfilling to bury the pipe for the trans-Alaska pipeline system in stream channels resulted in increased suspended-sediment loads and turbidity downstream from a crossing site. The Little Tonsina River, a salmon-spawning stream in the Copper River basin of Alaska, was crossed by the pipeline in April 1975. The rate of streamflow was about 0.2 m^3/s under an ice and snow cover. According to C. E. Sloan, turbidity in the stream upstream from the crossing site was 5 JTU. A maximum turbidity of 1,500 JTU occurred immediately downstream from the crossing site during backfilling operations. The sediment plume attenuated rapidly downstream, and a maximum turbidity of 120 JTU was measured about 1.6 km below the crossing site.

Observations by D. R. Kernodle indicated a local absence of benthic invertebrates in the highly turbid reach downstream from the crossing site during construction. Sampling of the same area in July 1975 indicated that the substrate had been repopulated by an apparently healthy community of caddisflies, stoneflies, mayflies, blackflies, and midges.

Relation of highway deicing chemicals to surface-water quality

L. R. Frost, Jr., reported that both annual maximum daily and annual mean chloride concentrations in several streams were found to be closely related to the logarithm of the ratio of applied highway deicing salt (as chloride) to annual mean streamflow.

Specific conductance-chloride concentration relationships used in the computation of chloride discharge were found to be of doubtful value when the rate of salt application was less than 3.5 t/km of roadway.

Comparisons between the amount of chloride applied (in the form of sodium and calcium chlorides) and the amount of chloride discharged indicated that, unless salt applications were similar for several prior years, annual comparisons were not very meaningful. The lag due to the slow transport of chloride through the ground-water system at one site, combined with a reduction in salt application of approximately 40 percent between 1972 and 1973, resulted in ratios of chloride discharge to chloride application that varied from 0.65 to 1.03 to 0.67 in 1972, 1973, and 1974, respectively.

Influence of recreation on surface-water quality in the Missouri Ozarks

According to J. H. Barks, the results of several short-term nutrient and bacteria studies conducted on streams of the Ozark National Scenic Riverways in Missouri indicated that horseback riding was the only recreational activity that significantly affected water quality. A cross-country trail ride in which about 1,300 people and 500 horses participated was held August 11–17, 1974, on the Jacks Fork. Nitrogen concentrations increased only slightly because of the trail-ride activities, but fecal coliform and fecal streptococci densities increased sharply. Immediately upstream from the activities, fecal coliforms ranged from 1 to 16 colonies/100 ml, and fecal streptococci ranged from 26 to 56 colonies/100 ml. Immediately downstream, fecal coliforms ranged from 290 to 2,000 colonies/100 ml, and fecal streptococci ranged from 260 to 2,100 colonies/100 ml. About 8 km downstream, fecal coliforms ranged from 40 to 130 colonies/100 ml, and fecal streptococci ranged from 120 to 280 colonies/100 ml.

Private waste-water treatment systems and ground-water quality in Jefferson County, Colorado

The typical aquifer in the mountains of Jefferson County, Colorado, is fractured crystalline rock. The soil layer above the crystalline rock is thin. Private waste-treatment systems are common in the area, and the potential for contamination of the ground water is high. D. C. Hall reported that the quality of the ground water is generally good, and specific conductance is usually between 100 and 500 μmho/cm at 25°C. Some contamination exists, however. If USPHS recommended drinking-water standards are used as the criteria, about 3 percent of the ground-water samples taken from the area are contaminated by total coliform bacteria, 1 percent by fecal coliform bacteria, 1 percent by detergent (methylene-blue active substance), and 3 percent by nitrate. The medium-density housing area contains most of the contaminated ground water; 67 percent of the samples are contaminated by detergent and nitrate.

There is a variation in the quality of water in septic tanks, aeration tanks, and leach fields; additional data are needed before these systems can be evaluated.

Ground-water contamination resulting from sludge spraying in eastern Pinellas County, Florida

In eastern Pinellas County, Florida, a sludge-spraying site and the area surrounding it were monitored for possible ground-water contamination. Mario Fernandez, Jr., reported that, after 1 year of sludge spraying, analyses of ground-water samples from the shallow sand aquifer indicated a large increase in conductivity, nitrates, ammonia, and chlorides within the spray site. A shallow well located downgradient of the spray site also showed an increase in contaminants, an indication that the contaminants have moved laterally.

Quality of urban runoff in the Bloomington-Normal area of Illinois

Samples of urban runoff in the Bloomington-Normal area of Illinois tended to have different discharge-concentration relationships for physical or inorganic parameters and for organic parameters, according to B. J. Prugh, Jr. Temperature, pH, specific conductance, and chloride concentration decreased with increasing discharges, whereas ammonia, BOD, and bacterial densities increased with discharge to a peak value and then decreased as the discharge continued to increase. A second increase in the organic constituents in streams may have occurred at even higher discharges when effluent from combined sewer overflows first reached the streams. One site, downstream from the sewage treatment plant, showed smaller changes in temperature and concentration of organic parameters because of the influence of effluent from the plant.

Water-quality assessments of Indiana streams

M. A. Ayers reported that studies were made of 11 Indiana watersheds ranging from 52 to 945 km^2 in area. Water-quality problems in particular streams were largely associated with land-use and cultural practices in the drainage basin. Streams draining heavily farmed (corn and soybeans) areas in central Indiana had the highest dissolved-nitrate concentrations (>10 mg/l as N), and streams in largely forested drainages in southern Indiana had the lowest dissolved-nitrate concentrations (usually <1 mg/l as N). Nitrate concentrations also followed definite seasonal trends—high concentrations during winter and spring high flows and low concentrations during summer and fall low flows. In general, aldrin, dieldrin, and DDT concentrations in stream-bottom materials increased (from low to moderate) with increasing agricultural land use. In addition to insecticides, stream-bottom materials downstream of municipalities usually contained moderate to high concentrations of chlordane and PCB. High manganese concentrations were found in streams in the southern half of the State; many concentrations were greater than 0.1 mg/l, and some were as high as 7.3 mg/l. Water was usually a calcium and magnesium bicarbonate type; increased relative sulfate was present in southern Indiana streams. Central Indiana streams were usually more mineralized than southern streams, except in southwestern Indiana, where coal-mine drainage affected several streams. Benthic invertebrate genus diversities ranged from 0.1 to 3.4, and most streams had well-balanced communities of 2.4 or more. Phytoplankton populations were usually less than 1,000 cells/ml, and diatoms were usually dominant.

S. E. Eikenberry reported that the primary pollution sources in the Busseron Creek watershed (drainage area, 614 km^2) in Vigo, Clay, Greene, and Sullivan Counties were acid mine drainage and organic loading from sewage-treatment plants. The primary pollutant in the Feather Creek watershed (drainage area, 21.5 km^2) in Vermillion County was bacteria from both human and nonhuman sources. No significant pollution was observed in four sampling efforts in the Bailey-Cox-Newton Ditch system (drainage area, 47.4 km^2) in Starke County.

Chemical and biological effects of sanitary landfill leaching in northeastern New York

Chemical and microbiological samples were collected upstream and downstream from four landfills in northeastern New York. Each landfill studied was selected because it was located near a small stream. According to T. A. Ehlke, chemical analyses indicated increased concentrations of some metallic constitutents, such as iron and manganese, downstream from the landfills. Phenol was detected in some stream reaches downstream from landfill operations. The bacterial types, fecal coliforms, sulfate reducers, *Nitrosomonas*, *Nitrobacter*, and denitrifiers were enumerated in stream-water and sediment samples collected upstream and downstream from each landfill. Except for fecal coliforms, the bacterial types were most numerous in sediments downstream from landfill operations. In most cases, the bacterial numbers were proportional to the concentration of the chemical substrates (SO_4, NH_4, NO_2, NO_3) altered during growth.

Effects of mining activities on water quality

C. G. Angelo and C. L. Terbeek made a general reconnaissance study of 150 sites in the coal-bearing region of Ohio in an attempt to relate water quality to mining activity. The sites, representing a variety of drainage-area sizes and land uses, were sampled twice; the samples were then tested for pH, acidity, heavy metals, phenols, organic carbon, sulfate, and chloride. An attempt was made to correlate test results with observed land-use conditions upstream from the sample sites. The following land-use categories were used: (1) Abandoned underground mine, (2) abandoned strip mine, (3) working underground mine, (4) working strip mine, (5) reclaimed strip mine, and (6) no evident mining. Samples taken from the first three types of land-use areas were characterized by low pH values (usually below 4.5), high specific conductances (over 1,000 μmho), and high sulfate and iron contents (over 500 and 10 mg/l, respectively). Working and reclaimed strip mines produced samples having high sulfate contents and high specific conductances but normal pH values (7.0 and above) and relatively low iron concentrations (below 3 mg/l). Samples from nonmining areas had normal pH values and low specific conductances (often below 100 μmho), low sulfate contents (below 100 mg/l), and low iron contents (below 0.1 mg/l).

Water-quality and streamflow data collected in the Tioga River basin in Pennsylvania indicated that the basin is severely affected by acid mine drainage entering the river near its headwaters. J. R. Ward reported that contributions from alkaline tributaries downstream provide some relief from the effects of mine drainage. The Tioga River recovers sufficiently to support aquatic life before it crosses the Pennsylvania-New York State line. Values for pH range from 3.2 at the source of mine drainage to 7.8 at the downstream limit of the study area. Both the acidic and the alkaline streams in the study area are fairly well buffered. High nutrient concentrations are frequently observed; however, algal growth is limited because of the high acidity of the water.

Data collected at 50 reconnaissance sites sampled twice in 1975 showed that sulfate is probably the most sensitive indicator of the effects of mine drainage on Illinois streams, according to L. G. Toler. At these sites, sulfate concentrations greater than 100 mg/l and dissolved-solids concentrations greater than about 450 mg/l during base flow appear to be attributable to mining activities. Increases in dissolved-solids concentrations above 450 mg/l are largely attributable to increases in the concentration of sulfate. The highest concentrations of sulfate (2,000–4,000 mg/l) occur in small tributaries and are associated with acid conditions (pH 3.0–5.0) and with high concentrations of some minor chemical constituents, including Zn (5.9 mg/l), sulfide (1.4 mg/l), Al (220 mg/l), As (0.52 mg/l), Cr (0.64 mg/l), Hg (2.2 μg/l), and phenol compounds (0.027 mg/l).

Anaerobic activity by *Desulfovibrio* and associated bacteria in the bottom of an acid mine lake will, in time, reduce the acidity if an energy source in the form of organic matter is available. The time required for neutralization may be between 50 and 70 days, depending on the pH and the SO_4^{2-} concentration. The reaction rate can be accelerated by bleeding off through an external circuit the charge on the S^{2-} ion produced during the anaerobic reduction of SO_4^{2-}. F. E. Senftle and F. D. Sisler accomplished this in a laboratory test cell by short circuiting an iron electrode in the anaerobic mud at the bottom of the cell with a carbon electrode suspended in the water. Under the short-circuit conditions, neutralization of simulated acid lake water was achieved in about 12 days. When larger surface-area electrodes and a more favorable ratio of water to anaerobic mud were used, neutralization time was reduced to about 5 days. The practical application to static holding ponds and to water flowing through several holding tanks or ponds at a mine site can be projected from laboratory results.

R. H. Fuller studied the extent and magnitude of acid mine-effluent pollution in California's Upper Sacramento River and Shasta Lake in order to evaluate possible methods of treatment and to propose a water-quality monitoring program that will assess the effects of those methods. In addition to a high concentration of acid, the drainage water also contains high concentrations of iron and copper that roughly increase with increasing acidity. The metals are apparently leached from low-grade sulfide ores left behind in the mined-out formation and from tailings dumped outside the mine entrance. The major sources of the acid water have been located, and, because the mine topographies and the processes that produce the acid water differ, several different treatment schemes will probably be required to curtail the pollution.

ENVIRONMENTAL GEOCHEMISTRY

Geochemical survey of the Western coal regions

The 1975 geochemical survey of the Western coal regions included an examination of the scales of geochemical variability for selected elements in soils, stream sediments, and spoil-bank materials in the northern Great Plains of western North Dakota, eastern Montana, and northeastern Wyoming.

R. R. Tidball and R. C. Severson noted that detectable chemical differences occur in selected elements from soils on either side of the limit of glaciation in the northern Great Plains (U.S. Geological Survey, 1975d, p. 42–49). The A horizon of soils in the glaciated area contains slightly lower amounts of potassium, thorium, and uranium and slightly higher amounts of silicon than similar soils in the nonglaciated area. The C horizon of soils in the glaciated area contains slightly less potassium and slightly more calcium than similar soils in the nonglaciated area. Iron and titanium showed no regional patterns in either horizon.

J. M. McNeal and R. J. Ebens found that the variation in selected chemical properties of stream sediments in the northern Great Plains does not appear to be related to stream order. The amounts of Mg, Na, Li, Zn, Rb, and C in the $<$100-mesh fraction are independent of whether the sample was taken from a first-, second-, or third-order stream (as defined at a scale of 1:1,000,000). Further, geographic variations in these properties are found largely at the smallest ($<$10 km) or largest scales ($>$100 km); virtually no differences are seen among areas separated on the average by 10 to 100 km.

Ebens and J. A. Erdman found a marked geochemical variation in both sweetclover and associated spoil material from eight coal strip mines scattered through the northern Great Plains (U.S. Geological Survey, 1975d, p. 29–35). The variation in spoil material from mine to mine contrasts with the much weaker regional variation found in the native soil and indicates that the geochemical baselines in the overburden may have to be approached on a site-by-site basis. Further, statistical significant correlations for concentrations of Ca, Na, S, and Li between spoil material and sweetclover suggest the presence of an overburden "control" on plant chemistry in disturbed areas.

Point-source chemical pollution

Field studies conducted during 1975 continued to demonstrate the efficacy of soil and plant tissue as natural monitors of secular geochemical change around point sources of chemical emissions.

The potential health hazard from soils contaminated with plutonium derived from the Rocky Flats Nuclear Weapons Plant northwest of Denver in Jefferson County, Colorado, was evaluated by R. R. Tidball and R. C. Severson (USGS) and C. J. Johnson (Jefferson County Health Department). Respirable dust, which is defined as particulates ≤ 5 μm in diameter on the ground surface, was collected in areas that have been proposed for housing developments only 2 to 5 km downwind from the plant. The samples contained levels of plutonium that ranged from 2 to 280 times background levels. The interim State tolerance standard is 25 times background. Plutonium particles are susceptible to suspension by the wind and are, therefore, considered to be a health hazard because of the increased risk of inhalation.

Severson and L. P. Gough showed that emissions from phosphate processing factories in Pocatello, Idaho, contribute to the trace-element content of surrounding vegetation and soils. Concentrations of Cd, Cr, F, Ni, Se, U, V, and Zn in big sagebrush (*Artemisia tridentata*) and cheatgrass (*Bromus tectorum*) showed significant negative correlations with distance from the phosphate processing site. Plant tissues within 3 km of the site contained unusually high amounts of all these elements except selenium. Significant inverse relations between distance and the concentrations of Be, Cu, F, Hg, K, Li, Mn, Ni, Pb, Rb, Th, Ti, U, V, and Zn in A horizon soils were also found. Amounts of 12 elements being contributed to the upper 5 cm of the soil by phosphate processing were estimated; fluorine showed the greatest increase (at least 350 kg/ha out to a distance of 4 km).

A similar study at Soda Springs Idaho, showed negative correlations between distance and the concentrations of Cd, Cr, F, Li, Se, U, V, and Zn in big sagebrush and an unidentified perennial bunchgrass. Again, the concentrations of many of these elements in plant tissue near the site (<4 km) were unusually high. The large natural geochemcial variability of soils in the Soda Springs area made it difficult to measure the trace-element contribution to the soil from the emission sources.

Work done by J. J. Connor, J. R. Keith, and B. M. Anderson east (downwind) of the Dave Johnston coal-fired generating plant at the southern edge of the Powder River Basin in Wyoming showed that certain trace metals in either surface soil or sagebrush tissue increased in a statistically significant fashion toward the powerplant. The elements were Se, U, V, and Sr in sagebrush and Sb and As in soil. The systematic increase in concentration toward the powerplant suggested that the powerplant was introducing these elements into the local landscape.

A similar study was undertaken around the Jim Bridger powerplant near Rock Springs, Wyo., by Anderson and Keith. The sampling was completed prior to the plant's going "on line," but, nevertheless, systematic decreases in the concentrations of selected elements in sagebrush going northward away from the plant were found. The elements involved in these trends included silicon, aluminum, and titanium, and they indicated that the plant site may have been a source of windblown soil during construction.

Element transfer during weathering of basalt

R. W. White found that progressive weathering of fine-grained basaltic rocks under humid conditions in Washington, Oregon, and northern California produced a distinctive sequence of weathered materials grading from fresh rock in core-stones to typical halloysite-rich basaltic saprolite. A comparison of the element content of the weathered materials with that of the fresh rock permitted the following generalizations about relative chemical changes during weathering:

- Elements strongly depleted: Ca > (Sr, Na, K) > (Mg, Fe^{+2}) > (Y, La, Si).
- Elements strongly accumulated: (Fe^{3+}, H) > (Cu, Al, Ti, Cr, Ga).
- Elements showing strong but inconsistent variation: (V, Zr, Mn, Co, P) > (Ba, Sc, Yb).
- Elements showing little variation: Be, Nb, Pb, Ni.

Landscape geochemistry

J. J. Connor and H. T. Shacklette (1975) compiled summaries of 48 elements in rocks, unconsolidated geologic deposits, soils, and plants from 147 landscape units. These summaries were based on a large amount of original fieldwork done by many investigators, mostly in Georgia, Kentucky, Missouri, and Wisconsin. The summary clearly demonstrated the wide diversity to be expected in the chemical properties of the natural materials studied and emphasized the caution that is necessary in establishing "typical" abundances, or ranges in abundance, of elements in the natural environment.

In related work, Shacklette, J. A. Erdman, T. F. Harms, and C. S. E. Papp compiled additional data on the elemental composition of plants (with emphasis on food and feed plants) and noted that 63 trace elements and 8 major elements have been found in plant tissues. It seems probable that all of the remaining naturally occurring elements of the periodic table are also present in plants but in concentrations below the limits of determination of the analytical methods that have been used. If so, it is unrealistic to establish zero tolerance levels for any toxic or other element in foods and feeds of plant origin.

Goldschmidt's rules—a model for plants?

R. W. White reported that the concentrations of some elements in plant ash are relative to the amounts of those elements present in the unmineralized igneous bedrock underlying the residual soils in which the plants are rooted. This relation appears to hold according to the element's essentiality, availability, and ease of substitution for essential elements. All of the essential elements determined except Fe (B, Ca, Cu, K, Mg, Mn, Mo, P, S, Zn) are more abundant in plant ash than they are in supporting bedrock. Volatile elements (As, Hg, I, Se), presumably supplied by the atmosphere, also are concentrated in plants. The concentration of a few nonessential elements may represent substitution for essential elements of similar ionic radius and charge (Sr for Ca, Ba for K, Pb for Ca or K, Cd for Zn or Ca). The volatile elements concentrated in plants also have this characteristic (As for P, Hg for Ca, I for Cl, Se for S), and elements whose abundances are roughly equal in plant ash and supporting bedrock may also reflect substitution for essential elements (Ni for Mg). Other elements are less abundant in plant ash than they are in bedrock because they are not essential (except Fe), are not provided by the atmosphere (except F), and are not of appropriate size and charge so as to readily substitute for an essential element (F, Ti, Be, Cr, V, Zr, Al, Ga, U).

Exceptions to this model among the elements analyzed to date include Fe, Na, Co, and Li. Iron is essential to plants but nevertheless is not concentrated in plant ash relative to supporting bedrock. This probably means that almost any residual soil on granitic or basaltic bedrock contains more than enough iron to satisfy the needs of plants, provided that the iron does not become unavailable in the solum. Sodium might substitute for K or Ca, Co for Fe, Mg, or Cu, or Li for Mg in plants, but none is concentrated relative to bedrock in the samples studied.

The relations outlined above show differences in degree of concentration relative to bedrock and point to the substitution of nonessential elements for essential elements. The relations differ from species to species and between basalt and granite. Differences from tissue to tissue within individual species are also expected. The comparison was made with bedrock because elements in plants were found to have more significant correlations with elements in fresh bedrock than with elements in either decomposed rock or surficial soil and because bedrock constitutes the starting material for soil formation in these residual profiles. The set of data from which this pattern emerged includes analyses of stems from 21 deep-rooted woody species, each of which was an important component of native vegetation growing on residual soil at the site; 65 specimens were collected from 36 sites in 11 States. Mixing species in this way tends to minimize the effect of differences between species and, if these differences are not contradictory, should provide a usable model.

LAND SUBSIDENCE

After 40 years of ground-water overdraft, subsidence rates have slowed significantly in the principal subsidence areas of California. Problems of widespread land subsidence caused by intensive pumping of ground water continue in Texas, Louisiana, Arizona, Nevada, and locally in various other States. Continuing subsidence in the Houston-Galveston area of Texas is not only the most widespread and rapid of any in the Nation, but it is also the most costly. The probability of subsidence occurring in areas of geothermal fluid extraction is currently being investigated. Networks of precise vertical and horizontal control are being monitored in eight selected geothermal areas to detect possible ground movement caused either by natural processes or by geothermal developments.

Subsidence in the Houston area of Texas

Considerable advisory assistance has been given by the USGS to the recently formed Harris-Galveston Coastal Subsidence District, according to R. K. Gabrysch. This agency was created by the Texas Legislature in 1975 and given the responsibility of stopping subsidence by regulating ground-water withdrawals. Surface-water imports from Lake Livingston, on the Trinity River 100 km north of Houston, into the area of maximum subsidence became available in June 1976, and a slowing of subsidence rates was anticipated as the artesian head rose. At Seabrook, between Houston and Galveston, an estimated 2.5 cm of subsidence occurs for each meter of continued water-level decline.

Three additional recording extensometers installed in the Houston-Galveston area brought to 10 the number of extensometers measuring the stress-strain parameters of the ground-water reservoir. Several months of record from these new extensometer units will monitor the effects of decreased pumping as surface-water use increases. Three of the 10 extensometers extend to the estimated base of the compacting interval and thus should be a direct measure of total subsidence at these sites. A releveling of a line of bench marks through the center of the subsidence area was carried out in May 1976.

Subsidence slows in San Joaquin Valley, California

B. E. Lofgren reported that significantly slower subsidence rates in most of the San Joaquin Valley of California were indicated by a recent releveling of bench marks along the California Aqueduct and by precise measurements made at a dozen extensometer sites. After 40 years of ground-water pumping overdraft, canal imports have generally reversed declining water-level trends. Subsidence rates have decreased from an earlier maximum of 0.5 m/yr to nearly zero in much of the valley. Increasing irrigation demands, however, particularly during years of deficient precipitation, pose the threat of increased pumping and another cycle of widespread land subsidence.

Estimating parameters of compacting aquitards near Pixley, California

A digital model that allows parameters for nonrecoverable compaction to be functions of transient effective stress was developed by D. C. Helm (1976) for simulating land subsidence. Lumped parameters for the ground-water system near Pixley, Calif., were estimated by a trial-and-error matching of field measurements. The simulation postulated (1) that, for any single material, the product of hydraulic conductivity and an incremental effective stress is a constant and (2) that the product of nonrecoverable specific storage and past maximum effective stress (transient preconsolidation pressure) is a constant. The second postulate is a standard simplification of laboratory stress-strain data, which are observed to be nonlinear for a freely draining saturated clay sample. The first postulate improves severalfold the simulation of observed compaction and expansion at the Pixley site. Maximum deviation between simulated and observed compaction from January 1, 1959, to February 4, 1971, occurred in mid-1962 and equaled 2.9 percent of observed compaction.

Introducing a double transformation of applied stress to linearize the nonlinear partial differential equation, Helm estimated that hydraulic conductivity decreased by more than an order of magnitude during 12 years of record from 2.8×10^{-6} m/d near the midplane of an idealized aquitard to 2.5×10^{-7} m/d near the drainage faces of the idealized aquitard. Average nonrecoverable specific storage was evaluated to decrease from 7.6×10^{-4} to 6.2×10^{-4} m^{-1}. The average recoverable specific storage was evaluated as 1.5×10^{-5} m^{-1}.

Rate of subsidence increasing in Savannah, Georgia

Releveling of bench marks in the Savannah area of Georgia by the National Geodetic Survey in late 1974 and early 1975 indicated that the rate of subsidence had increased from a maximum of 2.3 mm/yr between 1935 and 1955 to 3 mm/yr between 1955 and 1975, according to G. H. Davis and H. B. Counts. The area affected by more than 20 mm of subsidence increased from about 130 km^2 in 1955 to about 450 km^2 in 1975. The maximum subsidence between 1918 and 1975 was about 150 mm. Paradoxically, the rate of subsidence accelerated over the period 1955–75, while the decline in artesian head in the principal limestone aquifer system, believed to be the cause of subsidence, decreased. This fact supports the theory that compaction is due to slow drainage of fine-grained sediments, such as interbedded clay and marl of the overlying Hawthorn Formation, rather than to compaction of the Tertiary limestone.

Results of extensometer measurements at Anchorage, Alaska

No permanent compaction has been measured by the Merrill Field extensometer during its 3½ years of operation, according to R. F. Brown. This extensometer, which is located on the margin of the water-supply well field for Anchorage, Alaska, was installed to a depth of 93 m in September 1972 to detect possible land-surface changes caused by groundwater pumping. During the intervening years, the local artesian head has remained above the pre-September 1972 levels except from April through June 1975.

The maximum elastic compaction and rebound measured for the upper 91 m of sediments was 4.0 mm during a corresponding maximum head change of 16.1 m; this fact indicates that the gross-storage coefficient for the upper 91 m of sediments is at least 2×10^{-4}.

Earth cracking, land subsidence, and water-level decline in central Arizona

An updated map showing locations of earth cracks in central Arizona was prepared by the U.S. Bureau of Reclamation in cooperation with the USGS, the Arizona Resources Information System, and the Arizona Water Commission, according to R. L. Laney. Many new earth cracks were mapped in the Eloy-Coolidge-Casa Grande area, where the amount of water-level decline in the basin sediments has been as much as 24 m (between 1964 and 1972). In addition to numerous new earth cracks, known earth cracks have lengthened and become more complex since 1970, the year in which previous USGS mapping was done.

A preliminary interpretation of water-level changes in the eastern part of the Salt River Valley from 1972 to 1976 indicated that continuing water-level declines ranged from 0.6 to 3.0 m/yr. An increased rate of decline of as much as 4.6 m/yr occurred near the Santan Mountains in the southern part of the Salt River Valley, where several new earth cracks were mapped recently.

Leveling data for 1971 and 1975 gathered by the Bureau of Reclamation in eastern Maricopa and northern Pinal Counties indicated that land subsidence ranged between 0.03 and 0.21 m. A new earth crack developed near Apache Junction, where the greatest measured amount of subsidence occurred.

Monitoring ground movement in geothermal areas

Significant ground movement frequently accompanies the extraction of large quantities of fluids from the subsurface. Both vertical and horizontal components of any deformation that may occur are caused either directly or indirectly by geothermal developments or by unrelated natural processes.

Networks of vertical and horizontal control in eight selected areas of geothermal development are currently being monitored to detect possible ground movement, according to B. E. Lofgren. Sites include The Geysers and the Long Valley and Coso areas of California; the Heber, Brawley, Salton Sea, and East Mesa areas in the Imperial Valley of California; and the Raft River Valley in Idaho. The investigators, using first-order leveling and precise electronic distance-measuring equipment, periodically resurvey these networks to measure changes as they occur. Most of the changes measured to date in these areas have been due to natural tectonic processes that occurred before geothermal extractions began.

ASTROGEOLOGY

PLANETARY STUDIES

COMPARATIVE PLANETARY GEOLOGY

Flux histories of impact objects

L. A. Soderblom showed that the flux histories of objects impacting on the Moon, Mars, and Mercury have been very similar. Until recently, crater-frequency measurements for the Moon and Mars were available only for scattered localities. The relative ages of individual localities on a particular planet were known, but the relative percentages of planetary surfaces in different age intervals were not. Recent techniques developed by Soderblom and J. M. Boyce construct continuous crater-density maps for each planet. Histograms of crater frequencies derived from these data are very similar for the three planetary bodies. They show that each body experienced a similar flux history—an early torrential impact phase followed later by a much less intense period of bombardment that persisted throughout most of each planet's history to the present time.

Age of Martian volcanoes

The relatively young volcanoes of Mars achieve elevations that are extreme by terrestrial standards. In contrast, the old volcanoes show almost no relief. M. H. Carr explored the implications of this apparent inverse relation between height and age. He concluded that the younger volcanoes have been accumulating for a large fraction of the planet's history and that the thickness of the lithosphere has increased with time. Older volcanoes had a shallow magma source and have undergone some isostatic compensation.

Degradation index as indicator of Martian channel age

Harold Masursky's degradation index for Martian channels serves as a coarse measure of the age of a channel. The index, together with stratigraphic relations and numbers of superposed craters, suggests that channel formation has taken place throughout the history of Mars, although individual episodes of channel formation may have been short. The present temperature-pressure conditions on Mars are such that water cannot exist on the surface in liquid form. If the channels on Mars were formed by running water and if channel formation has taken place episodically on Mars, then the Martian atmosphere also must have varied drastically throughout the planet's history.

Early history of Mercury

Continued studies of the Mariner 10 photographs of Mercury confirm the importance of intercrater plains in deciphering the early history of Mercury. Studies of crater morphology by N. J. Trask and A. V. Lassman indicated that these plains have not been cratered to equilibrium; all craters larger than 3 km have been preserved. The population index of the crater distribution is relatively low. The index for impacting objects derived by mutual collisions in a swarm of bodies would be higher, the suggestion being that the craters were not formed from such a population. Similar low-population indices on the lunar highlands and on heavily cratered parts of Mars and the Moon indicate that the same population of objects bombarded all the inner planets.

Viking landing site assessment

Harold Masursky and G. G. Schaber examined radar traces from potential Viking landing sites on Mars in an attempt to assess the safety of the sites. Recent radar studies of Mars showed that the surface is highly variegated in its reflection characteristics. Schaber demonstrated, on the basis of SLAR observations of the Cottonball Basin in California's Death Valley, that reflection characteristics at a 3-cm wavelength depend almost entirely on surface roughness at 1- to 70-cm scale lengths. Signal penetration or anomalous dielectric effects were found to be minor. These results were applied to Viking landing sites as part of an extensive site certification.

Mariner missions to Jupiter and Saturn

Substantial revision of the baseline plan for the Mariner missions to Jupiter and Saturn (1977–81) resulted in a significant increase in the scientific potential of the mission, according to L. A. Soderblom. Aside from the major planets and rings, the satellites that are now targets for the mission are the Jovian satellites Io, Europa, Ganymede, Callisto, and J5 and the Saturnian satellites Titan, Tethys, Rhea, Dione, Mimas, Iapetus, and Hyperion. It is interesting to note that the sum total of the areas of all the satellites that will be studied by photogeologic techniques is roughly equivalent to the total areas of Mercury, Mars, and the Moon and those areas of the Earth above the hydrosphere.

TOPOGRAPHIC MAPPING OF MARS AND MERCURY

The first six 1:5,000,000-scale shaded relief maps of Mars have been published as part of a series of 30 maps that will cover the entire planet. Each map is to be produced in two versions. The first shows shaded relief only; the second shows shaded relief, contours, and albedo. The albedo maps are made by a combination of airbrush and image-processing techniques. Determination of absolute brightness is extremely complex and is not attempted. Effects of Sun-elevation variations, atmospheric effects, and camera artifacts are removed from the Mariner 9 photographs by digital image-processing techniques. The contrast is then enhanced to occupy the full dynamic range of available photographic materials. Final portrayal is done on a shaded relief base map by an airbrush illustrator, who uses absolute albedo values determined telescopically to preserve the appropriate contrast.

Work has begun on a series of 1:5,000,000-scale shaded relief maps of Mercury. Part of this task involves building digital data bases from the spacecraft imaging data. All images within one quadrangle are corrected for camera artifacts and mosaicked in the computer. This data set can then be treated as one frame and is amenable to a wide range of computer processing according to specific geologic and cartographic needs.

LUNAR INVESTIGATIONS

During 1975, cratering studies focused on events and relationships associated with large basins and young craters. Studies of small craters mostly served to define stratigraphic units on mare surfaces, and special attention was given to units that appeared to be of relatively young age. Volcanic investigations centered on possible pyroclastic deposits. Structural studies included analyses on both global and detailed scales.

BASINS AND CRATERS

Orbital gravity data and geologic interpretations indicate that Mare Serenitatis is underlain by two basins (Scott, 1974). V. S. Reed and E. W. Wolfe (1975) showed that the ring structures associated with the southern Serenitatis basin are consistently greater than the corresponding ones associated with the Orientale basin. Following other investigators, they suggested that the outer Rook ring represents Orientale ejecta emplaced near the rim of the transient cavity. Extrapolating these conclusions to the southern Serenitatis basin, they inferred that up to 15 km of ejecta was emplaced in the vicinity of the Apollo 17 landing site during the formation of a transient cavity that may have reached depths as great as 100 km. Supporting evidence that some of the materials were derived from great depths is provided by some of the massif samples. Crystallization depths of 5 km and 10 to 30 km are estimated for samples of coarse-grained plagioclase orthopyroxene and plagioclase-olivene cumulates, respectively. Large dunite clasts and spinel cataclasites may have been excavated from below the 65-km seismic discontinuity.

Secondary impact craters of multiringed basins played a major role in shaping the lunar terra of the central near side of the Moon. This interpretation is based on the patterns that emerged in photogeologic mapping done by D. E. Wilhelms (1976) on the well-exposed secondary craters of the Orientale basin and on laboratory experiments. A great variety of features is produced in a secondary crater chain or cluster by the interaction of many projectiles impacting close together (Oberbeck and Morrison, 1974) and by burial by nearly contemporaneous deposits. One result is that nearly contemporaneous secondary craters may look very different; adjacent secondaries of the same basin have commonly been interpreted as primary impact craters of widely different ages. The new studies augmented the already large numbers of craters and related features on the south-central near side interpreted as being secondary to the Imbrium basin. Moreover, in "windows" that lack strong Imbrian effects, numerous secondary craters of pre-Imbrian basins were identified. Only one part of the central near side—its south-central "backbone"—survived the barrage from basins well enough to display many pre-Nectarian primary craters. Identification of craters as basin secondaries correspondingly reduced the number of craters smaller than about 25 km in diameter that are identified as being of primary impact origin. As a result, at least for the time from late pre-Nectarian through pre-mare Imbrian, the size-frequency curves for primary impacts are skewed more strongly toward large objects than is commonly believed. This discovery requires reassessment of impact flux rates and of the methods of dating stratigraphic units by superposed craters.

D. H. Scott and J. F. McCauley mapped the Orientale basin. They established the Orientale group, an assemblage of all material cogenetic with the Orientale basin. The location of Orientale secondary craters on the Imbrium ejecta blanket directly confirms for the first time that the Imbrium basin is older. Also, the Hertzprung basin is now believed to be younger than the Humorum basin. Plains material appears to be both older and younger than the Orientale basin. Scott and McCauley found an ancient structural pattern around the basin, upon which the radial basin sculpture is superposed, and the symmetry of the basin ring structure proved to be much less than investigators had previously thought. The maximum possible diameter of the original crater is estimated to be about 450 km. The floor of the basin was raised isostatically prior to mare intrusion; in fact, the mascon of the Orientale basin was probably due to uplift of the mantle and a plug of basalt extending down to the mantle. During impact, the velocity of the ground surge was probably less than 1 m/s outward to 600 km from the basin center.

Secondary craters from young, fresh impact craters were also important in reshaping parts of the lunar surface. B. K. Lucchitta (1975a) investigated the numerous small craters on the floor of the Apollo 17 landing site to verify their suspected origin as secondary craters from Tycho (Scott and others, 1972). The morphology of well-known Tycho secondary craters and their ejecta deposits were studied by means of full-Moon, Lunar Orbiter, and Apollo panoramic photographs. These data were compared with similar data for the secondary craters and light mantle of the Apollo 17 landing site. The results indicated that the central crater cluster and the light mantle of the Apollo 17 site can be attributed to Tycho; that the dominant mechanism for emplacement of the light mantle was secondary crater impacts that threw material across the valley floor; that essentially level sheets of material can be emplaced by secondary impact; and that analysis of returned samples confirms that secondary impacts rework mostly local material.

VOLCANIC UNITS

The ages of mare surfaces and the superposition and extent of flows are significant to lunar investigators because they furnish a framework for petrologic and geochemical analyses. Consequently, several investigations focused on establishing ages for mare units.

L. A. Soderblom (USGS) used the method of Soderblom and Lebofsky (1972), combined with color investigations, to arrive at the following results: (1) The period of major mare volcanism continued until about 2.8 billion years ago; (2) Apollo 11 and 12 samples represent units of old and moderate age, respectively; and (3) certain small localized volcanic episodes may be less than 2 billion years old. Several stages of mare volcanic evolution are recognized. These are thought to be geochemically and geophysically distinct. Relative age data and low-resolution lunar color data indicate that the first and third stages involved high-titanium basalts emplaced between 3.8 and 3.5 and between 3.2 and 2.8 billion years ago, respectively. These titaniferous ("blue") basalts are not correlated with large gravity anomalies, as are the basalts of the middle stage (low titanium, 3.5–3.3 billion years).

J. M. Boyce and A. L. Dial, Jr. (USGS) (1975; Boyce, 1975a), indicated that their new crater morphology age technique yields results that are consistent with the results of previous relative age techniques for dating mare surfaces and with Apollo results. The new technique is more applicable to lower resolution photographs than previous techniques and thereby extends relative age measurements throughout much greater areas. Boyce and Dial applied the technique to Lunar Orbiter IV pictures of Mare Imbrium and Sinus Iridum and concluded that the age-color (geochemical) relationships are more complicated than Soderblom and Lebofsky (1972) thought and that older units are found generally around the edge of the basin, similar to the pattern indicated by the previously limited relative age data (Boyce and others, 1974). Boyce (1975b) mapped the relative age of volcanic flows in the western maria and showed that older flow units are generally located around the edge of basins. He suggested that this pattern may be due to premare topography or sagging during mare emplacement. Several flows trending northeast-southwest, in alinement with Rima Sirsalis, suggest a structure that may have extended for nearly 3,000 km and that may have been active into the time of mare emplacement.

Young flows found in Oceanus Procellarum are elongate in a northwest-southeast direction coincident with systems of mare ridges and gravity anomalies. These features may be part of the latest stages of igneous activity in the area. Boyce later added the distribution of flows for the eastern maria to his map. He showed that there are six major mare age units; the two youngest were not sampled by either Apollo or Russian Luna projects. G. G. Schaber, J. M. Boyce, and H. J. Moore II (USGS) (1976) indicated that identifiable flow lobes and scarps are restricted to young mare areas and that, in general, the identifiable flows are less than 10 m thick (except for the thicker Imbrium flows). Soderblom and Boyce (1976) discussed global age-color (geochemical) correlation and indicated that the earlier model of Soderblom and Lebofsky (1972) was indeed an oversimplification and that there are different color units that have similar ages. This conclusion supports the work of Boyce and Dial (1975).

High temperatures measured from Earth during an eclipse were found in Oceanus Procellarum by R. W. Shorthill (University of Utah). Moore showed, through crater morphology studies, that such areas also have vast expanses of young volcanic flows covered by thin regoliths. The combined evidence indicates that extrusion of lava on the Moon continued for millions of years beyond the date indicated by the samples returned by the Apollo missions (Boyce and others, 1974; Shorthill, 1973).

Moore and Schaber developed a theory to explain lunar lava flows. They found five variables that affect the distance to which a flow may travel: (1) Supply of lava from the source, (2) slope of the surface, (3) lava yield strength, (4) lava viscosity, and (5) lava thickness. This concept can be applied to terrestrial lava flows to assess environmental hazards (Moore and Schaber, 1975).

A volcanic origin for dark mantle deposits on the Moon has been contested (Roedder and Weiblen, 1973), but a pyroclastic origin associated with certain phases of lava emplacement still remains the most likely hypothesis. Lucchitta (1975b) synthesized current ideas on the characteristics and origin of dark mantle deposits. These deposits cover both mare and highland surfaces. The fact that many are located on basin margins or in a concentric band around Imbrium may have genetic implications. They tend to be associated with deep rimless rilles or calderalike depressions. A link with old, dark, titanium-rich maria can be demonstrated or inferred in places. The composition of some dark mantle deposits can be deduced from circumstantial evidence: Orange and black spheres from the dark rim of Shorty Crater at the Apollo 17 site are composed of titanium-rich glass having a high reflectivity in the blue-ultraviolet and near infrared (relative to a Mare Serenitatis standard). The similar reflectivities of the surrounding area and of other dark mantle areas, as well as field and photogeologic evidence, suggest that orange and black glass spheres are concentrated in deposits of the dark mantle, which forms stratigraphic units at the base of the regolith. "Reddish" dark mantle areas such as the Aristarchus Plateau and the dark crater halos in the craters of Alphonsus may be similar to the "bluish" areas but with a higher proportion of orange glass.

Most dark mantles are old. The smoothness of the deposit reflects rapid crater degradation in unconsolidated material rather than a young age (Lucchitta and Sanchez, 1975). Interruption of rays across dark spots, which leads investigators to assume a young age, results from a lack of contrast between secondary crater ejecta and the background. Associated deeply incised depressions and rilles that look fresh are probably as old as the dark mantle deposits but retain their crispness because mass wasting on steep slopes causes sharp angles to remain intact.

Most dark halo craters are of impact origin and thus excavated dark underlying material. Only a few are volcanic, such as the craters of Alphonsus and other craters that occur along rilles. The deep depressions associated with dark mantle deposits probably are vents; additional vents may have extruded fire fountains, which deposited shallow cones that were easily erased as the regolith developed.

STRUCTURE

Structural investigations on a global scale were conducted by D. H. Scott, J. M. Diaz, and J. A. Watkins (1975). They reported that a direct correlation exists between the major ridge and rille systems on the Moon. Structural style changes between mare and highland regions; ridges, lobate scarps, and volcanic constructs are representative mostly of the maria, whereas extensive linear-rille systems, troughs, and lineaments characterize the terra. Both ridges and rilles probably formed by crustal extension. Within a given area, rilles generally predate ridges and occur at higher elevations. A change in regional trends occurs between the western linear ridge systems within Oceanus Procellarum and the large rilles in the east-central part of the near side.

Major ridge systems are associated with positive gravity anomalies, but neither the linear ridge system nor the rille system shows any correspondence with deep moonquakes; volcanic centers are roughly in alinement with the east-west belt of deep seismic events.

A detailed study of structures was made by B. K. Lucchitta, who singled out two prominent scarps that transgress from mare into highlands at the edge of the Serenitatis basin. They are faults offsetting mare and highland surfaces, and, on the mare, they are topped by wrinkle ridges. Both scarps follow older structural trends, including massif-bounding faults. Observations of the fault trace showed that the fault planes are irregular in strike as well as in dip, and measurements along the fault trace suggested both normal and reverse faulting, which, in turn, suggests tensional as well as compressional stress regimes. These observations, although contradictory for regional stress systems, are compatible with local systems resulting from vertical tectonic movement. A model fitting the observations proposed that ridges and scarps formed as a result of vertical structural adjustment caused by gravitational settling and following older structural trends.

TECHNICAL RESULTS

H. J. Moore II reported that continued studies of lunar surface roughness as determined by photogrammetric techniques applied to Apollo mission photographs and the Apollo Orbital Bistatic-Radar Experiment show marked parallelism. Of particular importance is the fact that slope probability distributions measured by both methods are very similar (Moore and others, 1975; Moore and Tyler, 1973). S. S. C. Wu (1975) concluded that the optimum Sun angles for good lunar photography are between 10° and 30°. These results are based on investigations into the effect of illumination on the precision of photogrammetric measurements using Apollo metric photographs. The precision of photogrammetric measurements decreases when Sun-elevation angles increase beyond 30°. On the other hand, when Sun-elevation angles are less than 10°, large areas are covered by shadow. In contrast, optimum Sun-elevation angles for Earth are near 45°, and all high-Sun-angle photography is assumed to be superior.

TERRESTRIAL ANALOG AND EXPERIMENTAL STUDIES

TERRESTRIAL IMPACT CRATERS

Lonar Crater, India

Deposition of ejecta around the small (1,830 m in diameter) Lonar Crater in India shows many of the features postulated for large lunar basins. The extent to which surface material has been incorporated into crater and basin ejecta and the interior limit of secondary cratering are controversial topics in lunar geology. Mapping and observations of Lonar Crater may serve as a test of rival hypotheses. D. J. Milton (USGS) and A. Dube (Geological Survey of India) found continuous ejecta extending to about 1½ crater radii from the rim to be composed of debris throughout the bedrock stratigraphy in juxtaposed slices and clumps rather than in an inverted sequence. One slice, near the rim, comes from a lower unit several hectares in area. It overlies debris from the topmost unit but is itself right side up and somewhat broken.

The bedrock beneath the ejecta is locally strongly deformed. Soil is incorporated in the ejecta as small clasts and as larger pods and sheets.

A secondary impact crater (the first secondary impact crater discovered on Earth), 70 m in diameter and at least 3 m deep, lies 3 km from the rim of Lonar Crater, well beyond the general limit of Lonar ejecta. The bedrock in the rim of the secondary crater has been upturned to tangential strikes and steep or vertical dips. The deformation of the bedrock indicates that the impacting mass was probably mixed debris composed of small, rather soft clasts.

Ries Crater, Germany

Significant new evidence and specimens collected at the Ries Crater in Germany by E. C. T. Chao (USGS) revealed that much of the sedimentary ejecta was transported by the roll-glide, nonballistic (nonairborne) mode along the ground surface under high confining pressure.

Chao's study of a 1,206-m drill core, in cooperation with A. El Goresy (Max-Planck-Institut für Kernphysik, Heidelberg, West Germany), revealed that the more strongly shocked, higher temperature fallback suevite overlies the less strongly shocked, low-temperature suevite ejecta. A clearly defined compressed zone is present, but no melt layer was found anywhere in the drill core. The evidence cited is inconsistent with any model characterized by a melt-lined crater cavity or with base surge caused by gaseous expansion or fluidization.

Chao and El Gorsey also discovered the mineral armalcolite in impactite glasses at the Ries Crater, the first reported occurrence of this mineral in terrestrial glasses and the second reported terrestrial occurrence.

On the basis of data now available, it is postulated that the Ries Crater is an impact crater with a diameter of 25 km, a depth of 750 m, a depth-diameter ratio of 1:33, and, possibly, two inner rings 12 and 4 km in diameter. The crater volume is 184 km^3; the ejecta consists of 90 percent (by volume) varicolored sedimentary ejecta and 10 percent glass-bearing crystalline and nonglass-bearing crystalline ejecta.

VOLCANIC FEATURES

C. A. Hodges studied circular structures outlined by dikes that are localized in an exceptionally thick (70–100 m) section of the Roza Member of the Yakima Basalt near Odessa, Wash. The structures are 75 to 500 m in diameter and typically are characterized by a series of two to five concentric dike segments. Some describe nearly complete rings surrounding either a craterlike depression or a central mound. Glass selvages and inclined columns define the narrow (1–3 m) dikes. Dike remnants form arcuate, outward-dipping walls or are incorporated in conspicuous ridges of country rock commonly separated by deep moats. Two nearly linear dikes exposed in cross section appear to emanate from the lower part of the entablature, and an autointrusive origin is thought to be likely for all.

The occurrence of palagonite in the central mounds of a few structures suggests an origin involving interaction of ground water and lava. The ring structures must have formed, however, after 30 m or more of columnar crust formed on the ponded basalt flow. Tentatively, Hodges proposed that, after partial cooling, the molten interior of this thick basalt section may have been intersected by a rising water table, the result being a doming of the crust by rapidly accumulating volatiles and an associated autointrusion of ring dikes and possible venting. Cores of palagonite breccia could explain the negative gravity anomalies identified with some of these features (Parks and Banami, 1971). Differential erosion by the Spokane floods etched the dikes in relief and removed most of the near-surface fragile palagonite, but its remnants suggest that some sort of phreatic activity must have been involved. Although more analysis is required, this explanation may offer a viable alternative to the sag flowout hypothesis of McKee and Stradling (1970) for the origin of these enigmatic structures. Whatever the initial cause of the ring dikes, the mechanism of their intrusion as a concentric array in a solidified crust may be applicable to the interpretation of circular structures in lunar maria.

PHOTOGRAMMETRIC TECHNIQUES

R. M. Batson determined that image-processing techniques originally developed for exploring the planets can be applied to any data set in which "brightness" values can be arranged in a television-like raster of rows and columns. Data sets may consist of actual television pictures like those taken by Landsat, matrices of terrain elevation, or parameters of land use or natural phenomena. Color, stereoscopic parallax, and "relief" shading can be used to show each data set in a distinctive way within a single composite map.

S. S. C. Wu, F. J. Schafer, and Raymond Jordan's photogrammetric evaluation of Skylab imagery showed that the image quality of multispectral and Earth terrain camera photography is adequate. Photographic maps, thematic maps, and line maps can be directly compiled from Earth Resources Experimental Package data. Both the ground resolution and the photographic scale of the Earth terrain camera imagery have adequate definition for the compilation of 1:100,000- and possibly 1:50,000-scale maps.

LUNAR SAMPLE INVESTIGATIONS

PETROLOGY OF LUNAR BRECCIAS

The Apollo 17 astronauts collected a number of samples of highland breccias of unique significance. These rocks are extremely complex aggregates of fragments broken and recombined by lunar impacts, and there is evidence that the Serenitatis basin-forming impact may have played a role in their origin. In recognition of the complexity of these rocks and their special importance, NASA established interdisciplinary consortia of investigators to perform coordinated research on them. E. C. T. Chao and O. B. James (USGS) were selected to lead two of the six consortia established.

The Chao consortium was set up to study a group of four samples taken from a large boulder at Station 7: (1) 77215, a coarse-grained noritic breccia;

(2) 77075, a fragment-laden melt rock forming dikes within the noritic breccia; (3) 77115, a fragment-laden melt rock enclosing the noritic breccia; and (4) 77135, a feldspathic pigeonite basalt enclosing all other rock types. Petrologic studies by Chao, J. A. Minkin, and C. L. Thompson (USGS) concentrated on samples 77115 and 77215. The results suggest that sample 77115 formed as a fragment-laden feldspathic pigeonite basalt melt, which crystallized rapidly at or near the lunar surface (Chao and others, 1975). The population of xenocrysts and xenoliths that it contained came from at least two separate sources. Textures suggest that the melt may have cooled at two different rates, the initial rate being slower than the final rate. If two cooling rates can be demonstrated, it is likely that the melt was the result of endogenous processes rather than impact. Studies of sample 77215 (Chao and others, 1976) established that this rock is a low-temperature, low-shock impact breccia and did not form as a regolith breccia. It is made up largely of fragments of coarse-grained norite, which apparently originally crystallized and cooled slowly in a lunar plutonic environment. Cratering processes fragmented and excavated this norite and mixed it with noritic impact glasses and fragments of olivine-rich breccia.

The James consortium was established to study two rocks collected from regolith at Station 3. Studies thus far have been confined to sample 73215 and have been reported by James (1975, 1976) and James and others (1975a, b). The bulk of this breccia consists of an aphanitic rock, termed "matrix." Studies by James showed that this matrix consists of lithic and mineral clasts set in a very fine grained groundmass that crystallized from a melt. Bulk groundmass (analyzed by broad-beam microprobe methods in collaboration with Klaus Keil (University of New Mexico)) has lower Al_2O_3 and CaO contents and higher FeO, MgO, SiO_2, and TiO_2 contents than bulk matrix chips (analyzed by neutron activation and atomic absorption by D. P. Blanchard and L. A. Haskin (NASA Johnson Space Center)); thus, groundmass melt was not derived simply by melting of the included clasts, for it is more noritic. James' studies of the fragment assemblage suggested that the clasts were derived from a fairly homogeneous, possibly deep-seated source area and that this material had no significant history of near-surface reworking and regolith evolution before it was incorporated in the breccia. Studies by other consortium members supported this inference. Charged-particle track studies by I. D. Hutcheon and Donald Braddy (University of California at Berkeley) and analyses of rare gases by Kurt Mari (University of California at La Jolla) and Till Kirsten (Max-Planck-Institut für Kernphysik, Heidelberg, Germany), of hydrocarbon compounds by C. T. Pillinger and L. R. Gardiner (University of Bristol, England), and of carbon and nitrogen by J. F. Kerridge and I. R. Kaplan (University of California at Los Angeles) showed no evidence of near-surface irradiation of the clasts or of the presence of solar-wind components.

On the basis of petrologic studies, James hypothesized that sample 73215 formed as an aggregate of mineral and lithic debris plus melt produced during a very large impact event. According to this hypothesis, the clasts were derived from rocks crushed beneath and within the growing crater cavity and subsequently ejected in a debris cloud. The groundmass represents impact melt generated in the same event; during ejection of the crushed debris, this melt penetrated the debris cloud and cemented the fragments together. The impact that mixed melt and clasts was probably one of the basin-forming events. Since the preliminary age data (fission-track dating of clasts by Hutcheon and Braddy, Pb-U-Th analyses of bulk matrix by L. T. Silver (California Institute of Technology), and K-Ar analyses by Kirsten) suggest that the rock aggregated at about the same time as other Apollo 17 breccias, the consortium favors the hypothesis that sample 73215 represents consolidated ejecta from the event that formed the southern Serenitatis basin.

PETROLOGY AND MINERALOGY OF LUNAR METAMORPHIC ROCKS

D. B. Stewart (1975) investigated the genesis of lunar deep-seated metamorphic rocks. He found that deep-seated rocks display two distinctive kinds of textures. One kind has the characteristics of crystallization from magma—interlocking coarse crystals having shapes known to form by growth in melt. The second kind has characteristics produced by solid-state recrystallization—polygonal and granular crystals having smoothly curved grain boundaries and abundant triple junctions. Rocks having both textures displayed evidence of extensive compositional equilibration on both intracrystalline and intercrystalline scales, an indication of prolonged annealing at subsolidus temperatures. In order to explain why these two types of rocks have different textures despite their similar subsolidus thermal histories, Stewart proposed that they have had different deformational histories. Textural recrystallization is a strain-activated process. Stewart suggested that the probable cause of the polygonal texture was recrystallization in hot lunar crust to relieve inelastic strains introduced by impacts. These rocks show no evidence of preferred dimensional or crystallographic orientations of grains; therefore, the recrystallization was probably static. Stewart proposed the term "Apollonian" to designate such polygonal texture, in view of its unique origin and in honor of the Apollo program that led to its recognition.

A classical example of a lunar Apollonian metamorphic rock is troctolite 76535. G. L. Nord, Jr., Malcolm Ross, and J. S. Huebner are currently investigating the sample in detail by means of X-ray diffraction and transmission electron microscopy (TEM). The rock is thought to have originated deep (10–30 km) within the lunar crust and to have experienced a long (10–500 million years) cooling period to temperatures below 300°C before excavation. These conclusions are based on textural maturity, compositional homogeneity, and "ordered" structural states of the mineral phases. Some of the major results of the studies of individual minerals are summarized below:

- *Orthopyroxene.* TEM examination showed the presence of augite lamellae that are commonly only 2 to 8 unit cells thick, are continuous for several micrometers, and terminate at dislocations. Growth of the lamellae seems to have proceeded by a ledge mechanism. In addition, the grains contain small (<0.25 μm), homogeneously distributed patches that appear to be calcium-rich orthopyroxene. These patches are comparable to Guinier-Preston zones.
- *Olivine.* This mineral contains 10 nm-sized pores and micrometer-sized inclusions of symplectic intergrowths of orthopyroxene, augite, and chromite occurring in association with dislocation arrays. The observed dislocation types most resemble dislocations produced experimentally in samples deformed at 800° to 1,000°C and at strain rates of 10^{-4} to 10^{-5} per second.
- *Plagioclase.* This mineral contains antiphase domains (APD). Since the sizes of such domains vary with cooling rates through the interval 450° to 623°C, they can be used to make some rough deductions on cooling history. Comparisons with other lunar rocks suggested that the cooling rate was as rapid as that for feldspathic basalt 68415 and much more rapid than that for plutonic anorthosite 15415.

In summary, the results of these studies were consistent with a long cooling history. The presence of zones of calcium-rich orthopyroxene in orthopyroxene reflects either a slow cooling rate to low temperature or a long, low-temperature isothermal annealing episode. The nature of the dislocations in olivine suggested that the rock cooled slowly through the 800° to 1,000°C temperature range. The sizes of the APD in plagioclase, however, suggested rapid cooling through the low-temperature range 400° to 623°C; this observation can be explained if the rock was excavated at a temperature above 600°C and if the APD formed during cooling after excavation.

OTHER MINERALOGICAL–CHEMICAL STUDIES

Edwin Roedder (USGS) and P. W. Weiblen (University of Minnesota) investigated the origin of lunar microsymplectites. These structures, which consist of minutely intergrown spinel, high-calcium pyroxene, and low-calcium pyroxene, have been found in olivine in Apollo samples of several different types and from several different missions. The genesis and significance of these structures have aroused considerable controversy, and several very different interpretations have been proposed (Gooley and others, 1974; Albee and others, 1974, 1975). Roedder and Weiblen (Bell and others, 1975) clarified the controversy by showing that there are six distinct types of symplectite in lunar samples, some of which were formed by entirely different and unrelated processes. They felt that the symplectites studied by Gooley and others (1974) were, indeed, formed by solid-state reaction between olivine and plagioclase, as these investigators proposed, and that the symplectites studied by Albee and others (1974, 1975) were, in fact, formed by crystallization of trapped late-stage melts, as these investigators proposed. They suggested that the other four types were all produced by the diffusion of minor elements out of the olivine structure in response to changes in the pressure-temperature environment. These studies demonstrated the importance of symplectites as possible indicators of the pressure-temperature histories of the rocks in which they are found.

Motoaki Sato (USGS) measured the oxygen fugacity values of Apollo 16 highland rocks 60025, 60315, 60335, 65015, and 68415, Apollo 17 high-titanium mare basalts 70017 and 74275, Apollo 17 orange soil 74220, and Apollo 17 soil breccia 70019. The solid-electrolyte double-cell method was used to make the measurements. The f_{O_2} values of high-titanium basalts at 1,200°C are similar to those of low-titanium Apollo 12 and 15 basalts; at lower temperatures, however, the high-titanium basalts show increasingly higher f_{O_2} values. The very similar f_{O_2} values of the Apollo 17 high-titanium mare basalts and the Apollo 17 orange soil suggest a close genetic relationship. The Apollo 16 highland rocks generally show f_{O_2} values much lower than those of the mare basalts. The lowest values ever measured in lunar rocks are found in anorthositic breccia 60025 and poikilitic rock 65015. Rock 60025 has a low FeO content (0.67 percent by weight), which is compatible with its low f_{O_2} value. Rock 65015, however, has a much higher FeO content, on the order of 8 percent by weight, and its measured f_{O_2} values are difficult to interpret. During first heating, at temperatures below 1,050°C, rock 65015 shows f_{O_2} values comparable to those of mare basalts. In the temperature range 1,050° to 1,180°C, the sample shows signs of self-reduction, and the f_{O_2}-$(1/T)$ trace is shifted downward by as much as 1.5 log f_{O_2} units on subsequent heatings. Similar, but less pronounced, evidence of self-reduction is observed during f_{O_2} measurements on rock 60335, soil breccia 70019, and orange soil 74220.

P. R. Brett (USGS) investigated the role of sulfur in the reduction of mare basalt magmas. Metallic iron content and sulfur abundance are inversely correlated in mare basalts, an indication that either volatization of sulfur from the parent magmas resulted in reduction of ferrous iron to metallic iron or that high sulfur content decreased the activity of metallic iron. Brett showed that theoretical considerations favor the former interpretation. He further proposed that the Apollo 11 and 17 mare basalt magmas were saturated with sulfur at the time of eruption, whereas the Apollo 12 and 15 basalts probably were not.

CHEMISTRY OF LUNAR SAMPLES

Twenty-five rock and soil samples collected during the Apollo 15, 16, and 17 missions were analyzed by H. J. Rose, Jr., P. A. Baedecker, Sol Berman, R. P. Christian, E. J. Dwornik, R. B. Finkelman, and M. M. Schnepfe (Christian and others, 1976). The following conclusions can be drawn from their results:

- A strong inverse correlation exists between anorthosite content and KREEP content in the Apollo 16 soils.
- An apparent general relationship exists between soil maturity and anorthosite content.
- All Apollo 16 soils can be viewed as mature soils diluted with varying amounts of fresh ejecta composed of anorthosite-rich subregolith materials.
- The Apollo 17 mare basalts are richer in TiO_2, Cu, and Ga and poorer in SiO_2 than any of the other mare basalts returned by the Apollo missions.

A study of the trace-element content of size fractions from Apollo 16 soils was made by Finkelman, Baedecker, Christian, Berman, Schnepfe, and Rose (Christian and others, 1976; Finkelman, 1976). They made the following observations:

- Most Apollo 16 soils show slight enrichment in trace elements in the <30-μm size fractions relative to the >30-μm size fractions; the small variations observed suggest that the soils are locally derived.
- Because the excess reducing capacity and the agglutinate content of lunar soils show a strong positive correlation, it may be possible to use excess reducing capacity as a measure of soil maturity.
- Most soils in the North Ray Crater area form a distinctive trace-element-poor suite.
- Soil 67941 is a sample of immature subregolith material excavated by the event that formed the North Ray Crater and derived from a lens or horizon of material genetically related to the soils in the vicinity of the South Ray Crater.

ISOTOPIC SYSTEMATICS

The U-Th-Pb contents and the lead isotope ratios in lunar anorthositic gabbros 78155 and 77017 were determined by P. D. Nunes, Mitsunobu Tatsumoto, and D. M. Unruh (1975). Most lunar U-Pb data, when they are plotted on a U-Pb evolution diagram, define a linear trend that intersects the concordia curve at about 4.4 and 3.9 billion years and is characterized by an initial $^{206}Pb/^{207}Pb$ ratio of about 0.684 (Tera and Wasserburg, 1974). Data for fractions of sample 78155 fall on a line that differs significantly from this line, and the initial $^{206}Pb/^{207}Pb$ value indicated is the lowest yet found in a lunar rock. If the Moon had a homogeneous lead isotopic composition when it formed, multistage U-Pb evolution during the first 0.6 billion years of lunar history would have been required to generate the variety of initial leads observed. The initial lead composition in sample 78155 further indicates that some portions of the Moon evolved in a relatively uranium-rich environment during this period.

The U-Th-Pb concentrations and the lead isotopic ratios were determined by Nunes (1975) in two samples of soil breccia 70019, a glassy separate from this same breccia, an agglutinate-rich separate from soil 72701, and five Apollo 16 North Ray Crater bulk soil samples. The U-Th data for the 70019 rock samples suggest that this breccia consists of a mixture of comminuted mare basalt and highland material. The U-Pb analyses for the 70019 rock samples plotted on a U-Pb evolution diagram do not fall on the linear trend mentioned above as characterizing most lunar rocks; the initial value of the $^{206}Pb/^{207}Pb$ ratio indicated is distinctly lower than the characteristic value of 0.684. Analyses of the 70019 and 72701 glass concentrates indicate that the formation of these glasses by impact melting took place less than 200 million years ago and was accompanied by substantial losses of lead relative to uranium. The bulk U-Th-Pb analyses of Apollo 16 soils also appear to reflect the vaporization of lead, which occurred during the formation of the agglutinate glass particles present within the soils.

REMOTE SENSING AND ADVANCED TECHNIQUES

EARTH RESOURCES OBSERVATION SYSTEMS PROGRAM

The Earth Resources Observation Systems (EROS) program continued to support and coordinate the applications research involved in Landsat experiments and to conduct demonstrations of remote-sensing applications within Bureaus and Offices of the Department of the Interior. Special emphasis was placed on making the program more responsive to users' needs. Significant improvements were made at the EROS Data Center in Sioux Falls, S. Dak., in production scheduling and in reproducing remote-sensing data; the number and types of training programs were increased, and staffing to assist users with application problems was improved.

Comprehensive services, including assistance in ordering and analyzing data, and access to data-manipulation equipment and basic remote-sensing literature are now available at six locations in the United States and the Canal Zone.

LINEAMENT MAP OF THE UNITED STATES

A preliminary lineament map of the United States based on an analysis of the 1:1,000,000-scale Landsat mosaic prepared by the U.S. Department of Agriculture's (USDA) Soil Conservation Service was completed. The study combined the work of W. D. Carter, B. K. Lucchitta, and G. G. Schaber. A dotted line on the map indicates that only one investigator identified a particular linear feature; a dashed line indicates that two investigators agreed on the same feature; a solid line indicates that all three investigators agreed on the same feature. The study demonstrates that, although there is general agreement on major lineaments expressed by well-defined valleys and prominent escarpments, there are many more straight, arcuate, and circular features that are less well defined and on which there is less agreement.

Reduction of the map to 1:2,500,000 scale to fit the tectonic map of the conterminous United States was successful. The map is now being prepared for publication in the Miscellaneous Investigations series. Digitization of the lineaments on a 1° grid pattern to facilitate frequency analyses by a computer using the ASMAP (Azimuth Analysis Map) program will enable rapid plotting at other scales and will be useful in map revision as lineaments are confirmed as faults or eliminated as a result of fieldwork or geophysical investigations.

WESTERN REGION

Remote sensing applied to forest succession on Hawaii

W. G. Rohde (Technicolor Graphic Services, Inc.) assessed the impact of the decline of the Ohia forest on forest succession on the island of Hawaii. Landsat and aircraft photography were used to classify and map forest vegetation communities. Digital analysis techniques, including clustering and maximum likelihood classifiers, were used to develop training signatures and to produce a vegetation map from Landsat data. The clustering procedures were modified to develop training signatures for the vegetation classes. Initial results were unsatisfactory because the method of locating photographic plots on Landsat data was inaccurate and resulted in inadequate training for some vegetation classes.

Additional clustering analyses were completed, and the results were sent to cooperating investigators in Hawaii for evaluation. Software being developed for the Image–100 to calculate geometric transformations will improve the accuracy of plot locations and facilitate subsequent subsampling for assessing successional trends.

Targeting of mineral exploration

C. M. Trautwein (Technicolor Graphic Services, Inc.) reported that an analysis of data gathered by Landsat, Skylab, and aircraft over southwestern Idaho resulted in the identification of structural trends that appear to have influenced the development of volcanically affiliated epigenetic-, base-, and precious-metal mineralization in the Silver City area. Landsat imagery and Skylab photography revealed structural relationships suggesting a pure shear system with compressive forces bearing S. 7° E. and N. 7° W. in southwestern Idaho and adjacent southeastern Oregon. Major transcurrent lineaments identified with this system trend N. 40° W. with apparent right-lateral displacement and N. 25° E. with apparent left-lateral displacement. NASA aircraft photography covering the Silver City Range of the Owyhee Mountains showed right-lateral displacements along major N. 40° W. shears and spatially related N. 5° W. oblique-slip faults. The disposition of these structural elements in the northern Owyhee Mountains suggests a simple shear system controlled by a regional N. 40° W. right-lateral stress couple. An elliptical caldera (7.8×6.0 km) is coincident with the intersection of a major N. 40° W. lineament and a N. 5° W. lineament. The downdropped caldera block is bounded on the north and east by Jordon Creek. The major axis of the caldera is oriented N. 10° W., in close agreement with extensional oblique-slip faulting. USGS low-altitude aircraft photography covering the Silver City area revealed exogenous domes and mining prospects alined on the N. 5° W. structural trends. The correlation of structural symmetry on the three scales of analysis and the association of volcanic centers and spatially related mineralization with major extensional oblique-slip faults support the hypothesis that tectonic control of base- and precious-metal mineralization in the Silver City area is regional.

J. V. Taranik (USGS) reported that a methodology has been developed for the interactive computer classification and enhancement of Landsat CCT data over the Goldfield area of Nevada. An interactive multispectral analyzer with a cathode-ray-tube display was used to rapidly develop image ratios and hybrid ratios and to perform parallelepiped classification of altered areas. Alteration zones in the Goldfield area were successfully enhanced and classified by these techniques. This approach to mineral exploration was demonstrated at the EROS Data Center to attendees at the First Annual William T. Pecora Memorial Symposium.

CENTRAL REGION

Land-use inventory of South Dakota using Landsat data

The South Dakota State Planning Bureau and the EROS Data Center are cooperating in a project to incorporate statewide land-use inventory data into a geographic system being developed by the State. D. R. Hood reported that level I data have been entered into the system and that maps showing land-use and land-cover patterns have been completed (Lund and others, 1975). Level II and partial level III land-use and land-cover data, extracted by digital classification of Landsat CCT's, are now being entered; completion of this activity will allow the refinement of digital techniques and the incorporation of greater detail in urban areas. Tessar and others (1975) and Tessar and Lund (1975) presented the methodologies used and details of the demonstration project.

Red River flood analysis

J. V. Taranik (USGS) reported that an analysis of the 1975 Red River Valley flood in North Dakota and Minnesota was being conducted with aircraft and satellite data. Landsat–1 and Landsat–2 data acquired on May 12 and June 26, 1975, were compared with Landsat data acquired in previous years; the comparison showed that the Red River Valley experienced a wet spring in 1975. According to the U.S. Weather Service, the Fargo, N. Dak.-Moorhead, Minn., area received between 380 and 635 mm of rainfall during a 3-day interval in late June. Landsat–1 data acquired on July 5 showed several different types of flooding: (1) Overbank flooding caused by high streamflow along tributaries of the Red River, (2) overbank flooding caused by log jams on tributaries, and (3) flooding caused by in-place accumulation of water behind manmade structures. The almost flat topography of ancient glacial Lake Agassiz, coupled with the complex nature of flooding and the extremely slow movement of the flood, made it almost impossible to use conventional ground-based flood-mapping procedures. Landsat–2 data acquired on July 14 showed large areas of standing water, areas of extensive crop damage, and the movement of the flood crest down the Red River. Landsat–2 data acquired on August 10 showed that the latent effects of flooding on agriculture could be evaluated 30 days after the flood had crested in Fargo. Aerial color-infrared photography acquired by NASA on July 10 at an altitude of 18,000 m showed the distribution of flood inundation throughout the Red River Valley. Contractor-acquired color-infrared photographs of the flooded areas on July 13 and 17 and September 15 allowed changing landscape-cover conditions to be evaluated.

Taranik and Morris Deutsch (USGS) reported that digital processing of Landsat CCT data through an interactive digital analysis system at the EROS Data Center increased the interpretability of Landsat data and allowed analysts to rapidly extract acreage data on flood extent and flood damage to agriculture. This digital processing included (1) linear and equal-area contrast enhancements of brightness values to assist the interactive interpretation of flood-related phenomena and (2) supervised interactive classification of flood effects to extract information on the impacts of flooding on agriculture. Taranik and Deutsch reported that developed optical photographic enhancement techniques were applied to Landsat imagery to document approaches to flood analysis that might be more available to the less sophisticated user. These optical techniques included photographic enhancement of image contrast and development of temporal color composites. The temporal composites show the impact of flooding on agriculture and the movement of the flood crest through time. Landsat-1 and Landsat-2 data are currently being used to evaluate the long-term effects of the 1975 flooding on agriculture in the Red River Valley.

W. G. Rohde (Technicolor Graphic Services, Inc.) and Taranik reported that Bayesian statistics were applied to the classification of Landsat CCT data for the Red River flood, using the maximum likelihood classification algorithm and the LARSYS terminal at the EROS Data Center. Preliminary results using this approach suggested that acreage estimates and damage classes can be determined rapidly for a flood of this kind.

EASTERN REGION

Environmental study of Cape Cod through satellite imagery

R. S. Williams, Jr. (1976a), completed an initial environmental study of the Cape Cod area of Massachusetts using Landsat imagery. Because Cape Cod is a dynamic geologic environment, conventional maps of the area require frequent and accurate updating. Landsat imagery provides important geologic and hydrologic information necessary for the revision of maps at 1:125,000 scale and smaller. Landsat imagery has been determined to have the following advantages:

- It provides synoptic, nearly instantaneous imagery of large coastal areas at different times in the tidal cycle.
- It provides cyclic and frequent imagery at a relatively low cost.
- It permits the regional planimetric mapping of marshes (wetlands), tidal flats, shoals, sandbars, and harbor channels not normally shown on maps at 1:125,000 scale and smaller.
- It portrays the environment at the correct scale initially and thus eliminates the subjective differences caused by generalizing features in cartographic representations.
- It provides resource managers with the relevant and current data that they need to make wise decisions by periodically recording types of environmental information that can be rapidly converted to a map or another form of presentation.

Geologic features on satellite imagery of Pennsylvania

W. S. Kowalik made a detailed geological map along the trace of the Everett lineament in southern Pennsylvania. The lineament, which was first recognized on a mosaic of Landsat images, appears to be similar to a lineament running through Tyrone, Pa., along which some mineralization occurs. Kowalik found that there are major breaks in the Valley and Ridge province along this feature and that the plunges of several anticlines occur along the line.

The discovery on the 1:1,000,000-scale USDA Landsat mosaic of a crudely circular feature in the vicinity of Lake Wallenpaupak in northeastern Pennsylvania was also checked in the field. Although dip and strike measurements in the vicinity were inconclusive, aeromagnetic data showed an anomalous structure. Gravity measurements are planned for the area.

Forest defoliation mapping and damage assessment

W. G. Rohde and G. R. Johnson (Technicolor Graphic Services, Inc.) reported that classification of Landsat CCT data has been completed for approximately 485 km^2 of forest land in eastern Pennsylvania that was defoliated by the gypsy moth (*Porthetria dispar*). The analysis was done on the LARSYS maximum likelihood processor at the EROS Data Center. Three classes of defoliation (light, moderate, and heavy) and nondefoliated hardwood forest were mapped. The correlation between Landsat estimates of defoliated forest and a photographic estimate of defoliation was approximately 0.95. A two-phase probability sampling scheme is now being used to derive estimates of the acreage of defoliated forest.

FOREIGN AREAS

Landsat data maps Australian land systems

C. J. Robinove, in cooperation with scientists from the Department of Primary Industries in Queensland, Australia, analyzed digital Landsat imagery in order to map land systems in southwestern Queensland. Land-systems mapping involves differentiating and mapping land units that are unique combinations of geomorphic features, vegetation, and soils. The resulting small-scale maps are used to determine cattle-grazing density and the erosion potential of the land. Results to date show that Landsat data can be digitally processed to enhance and classify land systems; the integrated radiance from a pixel-sized area on the ground correlates better with an integrated land-mapping unit than with shape, vegetation, or soils alone. Land systems can be mapped more accurately in upland areas in the wet season than in the dry season because of the more vigorous growth of vegetation. Field checking shows that, in many instances, the digitally produced maps are more complete than a published land-system map made by aerial photograph interpretation and ground checks. It is now suggested that a first step in land-systems mapping should be the enhancement and classification of Landsat images, followed by field checks and sampling. Research is continuing on the application of this technique in the United States.

Archaeological remote sensing in Great Britain

R. S. Williams, Jr. (USGS), collaborated with J. N. Hampton (Royal Commission on Historical Monuments, London), John Vickers (John Vickers Studio, London), and E. K. Ralph (Museum Applied Science Center for Archaeology, University of Pennsylvania) on an experiment in multispectral aerial photography related to archaeological research in Great Britain. Williams recommended types of aerial photographic films and filters to be used over four different archaeological sites in Great Britain. He also suggested the time of year, the type of aerial camera, and the survey altitudes best suited for the investigations. The actual aerial surveys used 8 different aerial films (black and white, black-and-white infrared, color, and color infrared) and 6 of the 14 filters originally recommended.

An archaeological site can be detected by remote sensing at aircraft altitudes if its natural ecology has been subtly altered in response to "alien" cultural materials. From an archaeological viewpoint, the cultural alterations must have been extensive enough to have persisted; from a remote-sensing viewpoint, the remote sensor must be sensitive enough to detect disturbances of the natural ecology. Plus-X, black-and-white infrared, color, and color-infrared aerial photographs of each site were eventually acquired. Where limestone (or marble) was suspected as a building material, 400- to 500-nm filtered aerial photography was suggested because limestone has a higher reflectivity than other natural materials at the shorter wavelengths (<500 nm). A sixth aerial photographic film-filter combination (600- to 700-nm filtered aerial photography) was recommended to show variations in forested areas to best advantage. Low-Sun-angle, conventional Plus-X aerial photography was suggested to accentuate any micromorphological detail through "low-shadow" enhancement. Hampton (1975) found that, for archaeological research, the optimum use of various film-filter combinations was heavily influenced by the season and the weather. He favored Plus-X and false-color infrared films (both with minus-blue filters) overall, the latter being the most useful under average conditions.

Diversion of lava by water cooling

R. S. Williams, Jr., and J. G. Moore (1976a, b; Williams, 1976b) documented the effort to divert the flow of lava away from the town of Vestmannaeyjar on the island of Heimaey, Iceland, between February and July 1973 by spraying massive quantities of seawater onto the advancing lava flows. Although manmade barriers and explosives have been used with limited success to divert lava flows in Italy and Hawaii, the lava-cooling operations on Heimaey established that the natural course of an effusive volcanic eruption could be successfully altered if plentiful water and appropriate mechanical equipment are available and if continuous ground and frequent aerial photographic surveys are carried out to monitor the course of the eruption. It was also determined that the economic benefit, in terms of the manmade structures saved, greatly exceeds the direct cost of the lava cooling.

Remote sensing in Iceland

In continuation of a long-term research project, R. S. Williams, Jr. (1976c, d), prepared three experimental Landsat image maps of Vatnajökull with a best-fit grid and at a scale of 1:500,000, in cooperation with the Icelandic Geodetic Survey and the Icelandic National Research Council. The maps show Vatnajökull, the largest temperate icecap in the world, during the winter, summer, and fall of 1973 and graphically illustrate the dynamic geologic and hydrologic environment of this large icecap and the potential for regional and even global glaciological studies now made possible through Landsat imagery.

A special Landsat image map of Vatnajökull, at a scale of 1:250,000 and with a fitted grid, is currently being prepared to serve as an image base map for scientific studies of the icecap.

Resource mapping in the Andes Mountains

Potential mineral deposits in the Andes Mountains of South America were studied extensively during the year by means of the Image–100 interactive computer. Special emphasis was placed on supervised signature analysis of Andean salars. The Landsat product closely matched earlier detailed maps made from surface mapping and aerial photographic interpretations. In unmapped areas such as the Salar of Uyuni, the largest in the Andes, the surface was divided into nine spectral classes. Sampling is currently underway to explain the differences and similarities observed in these classes.

A color-composite mosaic of the Santiago, Chile-Mendoza, Argentina, area between 32°–36° S. and 66°–72° W. was completed and is being used to study lineaments of the Andean and Argentine pampa. W. D. Carter recognized a suspected anticline south of San Luis, Argentina, that may be of interest to petroleum geologists.

REMOTE-SENSING APPLICATIONS DEMONSTRATIONS BY OTHER BUREAUS

Use of Landsat CCT's to inventory kaolin mines

The initial phase of a pilot study to identify active and inactive kaolin mines in Aiken County, South Carolina, by using Landsat CCT's was conducted by H. W. Sheffer (Bureau of Mines) and H. W. Beam (South Carolina Land Resources Commission) in cooperation with the USGS. Mines were located by means of a computer-assisted multispectral analysis of Landsat digital data. The areas of the active and inactive mines were then calculated by computer and compared with planimetric calculations of the same areas made by using low-altitude aerial photographs. When areas greater than 40 ha were compared, the accuracy in several instances exceeded 99 percent. An error of 12 percent (the largest found) was obtained for an area of approximately 5 ha. It appears that digitized data can be used to identify, classify, and measure the extent of active and inactive surface mining of nonmetallic minerals.

Monitoring cloud formations for the High Plains Cooperative Program

Supported in part by the EROS program as an applications demonstration, real-time geosynchronous satellite imagery was received from SMS–2 and GOES–1 during the past year. Preliminary tests of the real-time applications of satellite observations of clouds and cloud systems affecting the Bureau of Reclamation High Plains Cooperative Program (HIPLEX) showed that satellite imagery provides useful operational information for convective weather modification experiments. This information includes descriptions of cloud types, mesoscale organization of clouds, and convective triggering mechanisms and the location and movement of clouds and cloud systems affecting each of the three HIPLEX sites. Satellite imagery received daily throughout the winter season was used to train personnel in the identification of cloud types and mesoscale systems. A daily catalog of synoptic and mesoscale conditions and cloud types proved helpful in quick examinations of various types of conditions and in retrieving examples for training purposes. The satellite receiver was transferred to the Bureau of Reclamation principal field site near Miles City, Mont., for direct support of field operations during the 1976 summer season. The data obtained will be used in concert with digital satellite imagery and radar, aircraft, and surface observations to reduce the scientific uncertainties of beneficially and acceptably managing precipitation from summer clouds.

Colorado River natural resource and land-use inventory

The purpose of this EROS-funded study is to establish within the Bureau of Reclamation a capability for making computer-assisted resource analyses using Landsat CCT's and other digital forms of remotely sensed data. To this end, the maximum likelihood decision classifier (CALSCAN) and the minimum distance decision classifier (ISOCLAS) were installed on the Bureau's CDC CYBER 70 computer under a contract with the University of California at Berkeley. Programs for reformatting Landsat bulk tapes into formats compatible with the classifier routines and for extracting data for study areas were installed on the Measurement and Analysis Central (MAC) minicomputer system. A review of color display systems interactive with the classifier programs was made, and the I^2S Model 70 was determined to be most compatible with Bureau needs and resources. A land-use classification using the CALSCAN program was made over the Palo Verde Irrigation District and the Colorado River Indian Reservation near Blythe, Calif. Plans for a multistage classification of the Grand Valley project at Grand Junction, Colo., were completed in anticipation of a CALSCAN classification of the area in the 1976 growing season.

Remote sensing and agricultural drainage

The use of remote sensing to detect near-surface ground water on irrigated lands (Ryland and others,

1975) was investigated by the South Dakota State University Remote Sensing Institute under an EROS-funded Bureau of Reclamation contract. The study found a significant correlation between water-table depth and remotely sensed data obtained by both aircraft and satellites. The multiregression and mode-seeking analysis classification of water-table depths on a two-class problem with a water table greater or less than 2 m was up to 91 percent correct. A multiregression equation developed for specific cornfields showed that Landsat data obtained from two overpasses (May and October 1973) made reliable predictions of water-table depths. This study may benefit irrigators by providing a way to detect potential waterlogging problems on irrigated land. Such early warning would give the Bureau time to program drainage facilities before the land became waterlogged and nonproductive.

APPLICATIONS TO GEOLOGIC STUDIES

Passive and active microwave techniques in remote-sensing geophysics

A. W. England and G. R. Johnson have been developing theories and techniques for using microwave technology in geophysical remote sensing. Because radiobrightness is profoundly affected by the amount and state of water in rock, soil, or vegetation, microwave radiometry can provide a map of soil moisture or of soil frost (Schmugge and others, 1974). England and Johnson's results show that, because structure, soil type, and thermally anomalous phenomena often influence the local distribution of soil moisture or ice, radiobrightness maps can be used to identify soil types and buried structures or to detect subtle thermal anomalies.

England (1975) completed his theoretical studies of thermal microwave emission from a scattering layer having a nonuniform temperature. The studies show that interfaces between layers, volume scattering, and a thermal gradient can each contribute significantly to the spectral gradient of radiobrightness. Lunar radiobrightness is particularly affected by volume scattering; thus, the contribution to the spectral gradient caused by scattering is nearly equal to that caused by the lunar thermal gradient. Therefore, Earth-based radiotelescopic observations of the Moon lead to unreliable interpretations of heat flow; heat flows calculated from the proposed lunar orbiting heat-flow experiment will be ambiguous.

Microwave studies of surficial anomalies associated with geothermal systems

A. W. England and G. R. Johnson studied microwave radiobrightness as a means of detecting subtle near-surface aspects of geothermal systems. They found that radiobrightness reliably measures soil moisture. In sandy soils, the depth to the frostline can be determined; in clay soils, radiobrightness measures soil moisture and indicates whether the ground is frozen.

England and Johnson also found that a center frequency to bandwidth ratio greater than 50 provides enough spectral resolution to obtain layer thickness from spectral radiobrightness; that a variability of layer thickness greater than 15 percent of the free-space wavelength in the area viewed by the radiometer will effectively eliminate an interference pattern; and that a diffuse interface whose thickness is 15 percent of the free-space wavelength is transparent to microwave, and so the effects of the interface will not appear in the radiobrightness spectrum.

Electromagnetic radiation

The basic nature of electromagnetic radiation and the manner in which it interacts with geologically important materials to produce spectral signatures were reviewed by G. R. Hunt from both a theoretical and a practical standpoint.

A study of the midinfrared (6–40 μm) spectra of a suite of metamorphic rocks and rock-forming minerals led to the identification of their molecular vibration bands. The extent of spectral scatter among different samples of the same rock was measured, and the extent to which such spectra are diagnostic of composition was determined.

Visible and near-infrared spectral data, collected from over 200 particulate mineral samples, were analyzed to provide a compilation of characteristic spectral features that allows rapid identification and interpretation of electronic and vibrational overtone and combination features in mineral and rock spectra.

An investigation of the infrared spectral behavior of finely particulate solids demonstrated that individual micrometer-sized particles emit most in the spectral region where they absorb most; as the particle size is increased, spectral features reverse their polarity. As the thickness of the particle layer is increased, emission maxima shift toward a maximum at the Christiansen frequency.

Mapping of altered rocks from Landsat images

L. C. Rowan and R. P. Ashley, in cooperation with the Jet Propulsion Laboratory in Pasadena, Calif., showed that mineralogical differences between altered rocks and most unaltered rocks in south-central Nevada cause visible and near-infrarad (0.45–2.4 μm) spectral reflectance differences that can be used to discriminate these broad categories of rocks in multispectral images. The most important mineralogical differences are the increased abundance of goethite, hematite, and jarosite and the presence of alunite, montmorillonite, and kaolinite in the altered rocks. Analysis of reflectance spectra recorded in the field showed that the altered rock spectra are characterized by (1) broad absorption bands in the 0.45- to 0.50-μm and 0.85- to 0.095-μm regions, which are caused by electronic processes in the iron ions, and (2) a band near 2.2 μm, which is caused by vibrational processes in the hydroxl ions. These features are absent or weak in most of the unaltered rock spectra. Therefore, the shapes of the 0.45- to 2.4-μm spectra for these altered and unaltered rocks are conspicuously different. Because of the wavelength positions and widths of the Landsat multispectral scanner (MSS) bands, however, these spectral differences are not apparent in individual or color-infrared composite MSS images.

The technique developed to enhance these subtle spectral differences combines ratioing the MSS bands and contrast stretching. The stretched-ratio values are used to produce black-and-white images that depict materials according to spectral reflectance; ratioing minimizes the influence of topography and overall albedo on the grouping of spectrally similar materials. Color compositing of two or more stretched-ratio images to form color-ratio composites provides additional enhancement. The most effective color-ratio composite for discriminating between altered and unaltered areas, as well as for discriminating among many of the unaltered rocks in south-central Nevada, was prepared according to the following diazo color and stretched-ratio image combination: blue for band 4 over band 5, yellow for band 5 over band 6, and magenta for band 6 over band 7. Altered areas appear green and brown in this combination.

Field evaluation of this color-ratio composite showed that (excluding alluvial areas) approximately 80 percent of the green and brown color patterns are related to hydrothermal alteration. The remaining 20 percent consist mainly of pink hematitic crystallized tuff (a result of vapor-phase crystallization) and tan and red ferruginous shale and siltstone. Discrimination of this unaltered tuff from the altered rocks may be possible in the 2.2-μm region because this absorption band is absent in the tuff spectra. Because the shale and siltstone are mineralogically and spectrally similar to the altered rocks, however, there appears to be little prospect of distinguishing these rocks from altered rocks in visible and near-infrared multispectral images.

Near-infrared reflectance anomalies in volcanic rocks of southern California

Certain volcanic rocks, chiefly andesites and basalts, in southern California show anomalously high reflectivities in the 1.0- to 2.6-μm portion of the spectrum. H. A. Pohn concluded, on the basis of a study of thin-section specimens of these rocks, that microcrystalline hematite in the rock is the fundamental cause of the high reflectivity. The spectral brightness of the rocks was measured in the laboratory and appeared to correlate well with the amount of hematite in the rocks.

Structure mapping from images

T. W. Offield's study of a Landsat image of southern Brazil demonstrated the marked superiority of computer-enhanced (contrast-stretched) products over the images normally available for lineament mapping. The image revealed a major east-west structural zone that had not been previously defined; the only known economic or near-economic deposits of copper, gold, and tin in the southern Precambrian shield occur on this zone. The relationship between features observed on the image and those depicted on existing maps can be adequately explained by hypotheses currently used to explain many geologic features of Tertiary porphyry copper occurrences elsewhere in the world. Structures observed in the enhanced image constitute specific exploration targets for copper.

The use of new pie-slice spatial filters with curved edges successfully eliminated the "ringing" or spurious diffraction effects produced by straight-edge filters that have typically plagued laser optical filtering experiments. Filtering to remove selectively certain directions of linear elements from images or contour maps can now be done rapidly and at very low cost. Application of the new filters to the aeromagnetic map of the Front Range in Colorado revealed subtle crosstrends that had not been previously apparent.

Remote-sensor analysis of the Mississippi Embayment

The landscape pattern of the northern part of the Mississippi Embayment, as revealed by Landsat images, represents a complex interrelationship of subaerial processes and structural controls. The forms and distributions of lineaments are particularly important as indicators of subsurface geologic phenomena. The geomorphic character of the lineaments and the fairly consistent statistical groupings of those that trend northwest throughout the area suggest the influence of jointing. The widely variable north- and northeast-trending groups suggest a variety of influences, including faulting. The lineament pattern along the eastern side of the Mississippi River appears to border a zone of active subsidence, indicated by seismicity and active alluviation. Lineaments mapped in this region closely parallel epicenter trends (Stauder and others, 1975) and suggest normal faulting with northern sides down. D. W. O'Leary and S. L. Simpson concluded that the embayment, as far south as the Quachita front, is dominated by block-faulted structures that have been surrounded and largely buried by Pleistocene sediments. Major lineaments intersect at the northern end of the embayment, where a complex pattern of faulting is present; this pattern appears to be genetically related to the landscape farther south and suggests that the embayment is an episodically opening, wedgelike feature.

A universally valid definition of a lineament has not been available, and present terminology, which confuses the terms "lineament," "linear," and "lineation," is inadequate. O'Leary, J. D. Friedman, and H. A. Pohn proposed the following formal definition for lineament: A mappable, simple or composite, linear feature of a surface, whose parts are alined in a rectilinear or slightly curvilinear relationship that differs distinctly from the patterns of adjacent features and presumably reflects a subsurface phenomenon. The lineament study of the Mississippi Embayment uses this definition.

Geologic applications of thermal infrared images

Thermal infrared images provide information about the near-surface physical state of geologic materials—particularly density, water content, and thermal properties. Extraterrestrial studies, conducted at fairly coarse resolutions, have been useful primarily in determining the distribution of rock fragments. Terrestrial studies based on satellite and aircraft data obtained at coarse to fine resolutions have been successful in (1) monitoring effusive volcanism, (2) delineating areas of steaming, altered ground, and hot-spring activity, (3) detecting fractures expressed hydrologically and topographically, and (4) distinguishing geologic materials on the basis of physical and compositional differences. Data were acquired under optimal meteorological conditions and at sites where the geologic materials were well exposed.

Interpretation of thermal images is complicated by the various types of physical processes involved (conduction, convection, radiation) and commonly requires an assessment of many different factors (including albedo, thermal inertia, emissivity, and topographic slope). A simple theoretical model was used by Kenneth Watson to provide a quantitative assessment of some of these factors, to predict optimum times for acquiring thermal data, and to determine quantitative values of various terrain properties. Two geologic applications studied in some detail were geothermal mapping and thermal inertia mapping. Initial results indicated that both applications have considerable potential, especially in reconnaissance studies.

Reconnaissance geothermal exploration with thermal infrared scanning

Calibrated thermal infrared imagery was acquired throughout the diurnal cycle of the Raft River in Idaho as part of a study to evaluate the utility of thermal scanning for reconnaissance geothermal exploration. A theoretical model of the diurnal surface temperature variations was used by Kenneth Watson to select optimum times for data acquisition and to develop a method to correct the infrared surface thermal flux for surface property variations.

An image was constructed with brightness values proportional to the surface flux corrected for reflectivity variations. Anomalously warm areas were seen in the image, and probe measurements made in the vicinity of one of these areas confirmed the presence of a true temperature anomaly. Other anomalies identified in the image were spurious, an indication that more accurate correction is needed for topographic and thermal property variations. Theoretical analysis suggested that thermal images acquired at three different times in the diurnal cycle would be required to effect this correction.

Presentation and interpretation of airborne radiometric data

J. S. Duval interpreted radiometric data from an airborne survey flown near Freer, in Duval County, Texas, by means of a statistical technique called factor analysis. This approach offers the geophysicist or the geologist a rapid and objective method whereby radiometric data can be synthesized to produce a single multifactor map rather than an individual map for each radioactive element and (or) ratio among elements.

The map based on the Texas data conformed reasonably well with mapped geology and emphasized geochemically anomalous areas. In this particular survey, the anomalous areas seemed to be fault controlled and related to the presence of oil and gas deposits.

A preliminary calibration for uranium and thorium (in parts per million) and potassium (in percent) was obtained by means of a truck-mounted gamma spectrometer. On the basis of this calibration, the uranium-thorium ratio of the Catahoula Tuff was found to be very near the crustal average of 4.0. This discovery suggests that the Catahoula Tuff is not greatly depleted in uranium.

Geologic interpretation of thermal infrared anomalies, Long Valley caldera, California

An assessment of aerial infrared (IR) images across the Long Valley caldera in California by J. D. Friedman indicated that IR anomalies are related to fracture systems cutting the area of resurgent volcanism and are distributed generally within the caldera and around its perimeter on the west. In the eastern part of the caldera, the anomalies outline the area of hydrologic discharge. Aerial IR images obtained in 1974 record several previously untabulated and unmapped thermal effluents and springs in addition to the known thermal features of the Long Valley caldera. The anomalics include (1) several dozen thermal effluents into Hot Creek; (2) the extent of the thermal zone along the Hot Creek drainage system; (3) significant temperature differences between the Northern and Southern Big Alkali Lakes; (4) the thermal structure of Lake Crowley, which shows the location of a number of thermal effluents into the lake and probable sublacustrine hot springs; and (5) the configuration of several active thermal zones associated with surface hydrothermal alteration zones between Little Antelope Valley and Casa Diablo Hot Springs in the Mount Morrison quadrangle.

Small-scale images in remote-sensor studies, Great Valley, California

A single Landsat frame encompassing the eastern side of the Great Valley and the Sierran foothills, from the San Joaquin River north to the Mokelumne River in California, was studied by C. A. Hodges in different enhanced versions for use in tectonics studies. The most promising enhancements for lineament discrimination are two-image color composites with a sinusoidal stretch. The appropriate band-color designations are (1) band 4 blue, band 5 green, and band 6 red and (2) band 5 blue, band 6 green, and band 7 red. A linear stretch composite is also useful. The band-color combinations are band 5 green, band 6 blue, and band 7 red. Drainage patterns and certain geologic units (for example, ultramafic bodies and alluvial fans) are conspicuous in these images. Relatively small textural lineaments are seen much more readily in U–2 positive transparencies, however, at scales of approximately 1:130,000. Topographic detail is well expressed in side-looking radar images, but the lack of color contrast is a drawback.

Discrimination of geologic materials using Skylab S–192 data

Skylab S–192 multispectral data were used by H. A. Pohn to examine the relative reflectivities of five different geologic materials; Basalt, andesite, welded tuff, playa, and salt-marsh deposits. He found that basalt can be distinguished from andesite by its lower density number—that is, its reflective brightness is a 256-step gray scale relative to andesites in two of the S–192 channels (0.52–0.56 and 12.0–13.0 μm). The high brightness value for andesite in the 0.52- to 0.56-μm band is probably caused by the relatively high concentration of ferric iron in the rock; the high brightness value in the 12.0- to 13.0-μm band is probably caused by the relatively low concentration of mafic components, which causes the andesites to have a lower density and hence a lower thermal inertia. Welded tuff can be distinguished from basalt and andesite because it has a higher density number in all channels.

The spectral brightness of playas is higher than that of salt-marsh deposits in all wavelengths, except in two channels (1.09–1.19 and 1.55–1.75 μm) where the relationship was reversed.

Near-infrared reflectance of volcanic materials in northern Arizona

In an attempt to determine whether there is a correlation between the age of materials and the brightness of those materials in the 1.0- to 2.6-μm part of the electromagnetic spectrum, H. A. Pohn studied the images from an infrared image survey flown over the San Francisco volcanic field in Arizona. The volcanic rocks ranged in age from 900 years to more than 6 million years. No correlation between age and image brightness was evident, but there may be a correlation between the brightness and the composition of the volcanic rocks. Basalt cones surrounding SP Crater appeared to be anomalously bright, but SP Crater, a basaltic andesite, showed only a very faint anomaly.

Skylab images of volcanic landforms in Kyushu, Japan, and of Sakura-zima eruption clouds

J. D. Friedman (USGS) and Grant Heiken (Los Alamos Scientific Laboratory) analyzed Skylab-4 Hasselblad photographs of terrestrial volcanic features and concluded that the vast depression (about 40 km in diameter) around the Kirisima Volcano complex and the Koshiki Bay west of Kagoshima, Kyushu, Japan, are of volcanotectonic origin. The photographs also suggested that the central segment of Kagoshima Bay between the Aira and Ata caldera complexes may have resulted from the collapse of a chain of overlapping calderas rather than from roof collapse over a linear volcanotectonic feature.

Hasselblad and Nikon stereographic photographs taken from Skylab between June 9, 1973, and February 1, 1974, also gave synoptic views of several entire eruption clouds emanating from Sakura-zima Volcano in Kagoshima Bay. Friedman and Heiken, working with Darryl Panderson (Air Resources Laboratory, NOAA) and D. S. McKay (Lyndon B. Johnson Space Center, NASA), reported that analytical plots of these stereographic pairs, studied in combination with meteorological data, indicated that the eruption clouds did not penetrate the tropopause and thus did not create a long-lasting stratospheric dust veil. These observations are the first direct evidence that an explosive eruption at an estimated energy level of about 10^{18} ergs per paroxysm may be too small, under atmospheric conditions similar to those prevailing over Sakura-zima, to cause volcanic effluents to penetrate low-level tropospheric temperature inversions and, consequently, the tropopause over northern middle latitudes. The maximum elevation of the volcanic clouds was determined to be 3.4 km. The cumulative thermal energy release in the rise of volcanic plumes for 385 observed explosive eruptions was estimated to be 10^{20} to 10^{21} ergs ($10^{13}-10^{14}$ J), but the entire thermal energy release associated with pyroclastic activity may be of the order of 2.5×10^{22} ergs (2.5×10^{15} J.).

APPLICATIONS TO HYDROLOGIC STUDIES

Satellite-data relay—a feasible and cost-effective method of collecting hydrologic data

The objective of the USGS Satellite-Data Relay Project is to determine the feasibility of using satellite relay as a method of collecting hydrologic data. According to D. M. Preble and R. W. Paulson, earlier studies showed that substantial manpower and travel can be saved by using automated satellite-relay methods. Landsat data-collection-system studies are underway in about 10 States. The SMS-GOES data-collection-system experiment includes the relay of data from about 100 hydrologic sites and the subsequent distribution of the data over the USGS telecommunications network.

Landsat imagery and space-relayed water-level data used to determine water depths in the Florida Everglades

A. L. Higer, E. H. Cordes, and A. E. Coker (USGS) and R. H. Rogers (Aerospace Division, Bendix Corporation) (1975) developed the algorithms needed to locate ground stations within the picture elements of Landsat imagery that represent different water depths and vegetative-cover types. The initial computer runs indicated that eight water depths within a 2,400-km^2 area are shown on Landsat imagery of the Florida Everglades.

Using Landsat imagery to calculate fire-hazard conditions in Everglades National Park

Using Landsat data, A. L. Higer and E. H. Cordes monitored the important parameters for defining a fire index (water level, rainfall, air temperature, and soil moisture) at two locations in Florida's Everglades National Park (L. J. Swayze, W. L. Bancroft, A. L. Higer, and E. H. Cordes, 1976). The USGS currently has seven Landsat stations collecting stage and rainfall data in the park. Two key stations, one on the western boundary and the other on the eastern boundary of the park, are electronically interfaced to measure air temperature and soil moisture in addition to rainfall and water level. Using rainfall and maximum air-temperature data from the two Landsat stations, Higer and Cordes calculated the drought index. Correlating the drought index and the soil moisture will determine the flammability of the soil for the eastern and western boundaries of the park.

Satellite measurement of snow cover for runoff prediction

Synoptic data obtained from satellite images for snow cover in mountain basins can be used to predict streamflow and to optimize the operation of irrigation and hydroelectric power reservoirs, according to M. F. Meier (1976). Plots of snow cover versus subsequent runoff during a melt season can be used to make seasonal runoff predictions, and plots of snow cover on specific dates (such as April 1, 1975) can be used to make summer runoff volume forecasts. Satellite data can be used to check and update computerized streamflow-synthesis models. Perhaps most important, satellite images can be combined with topographic maps to yield data on the altitude distributions of snow cover and thus permit improved hydrometeorological or energy-budget models for short-term predictions of snowmelt runoff.

Satellite snow-cover observations in central Arizona

H. H. Schumann reported that repetitive Landsat and SMS-GOES satellite imagery and aerial surveys are being evaluated to develop an operational capability for mapping snow-cover distribution in the Salt River and Verde River watersheds in central Arizona. Satellite telemetry also is being used for near-real-time relay of hydrologic data to aid in the management and operation of reservoirs on the Salt and Verde Rivers.

Aerial reconnaissance flights were conducted to collect data on snow-cover depth and distribution for use in analyses of the satellite imagery. A newly developed technique using oblique aerial photography of snow markers allowed rapid and economical determinations of snow depth to be made.

Landsat 1:1,000,000-scale imagery is relatively free of image distortion and provides sufficient resolution for snow-cover mapping in central Arizona. However, development of new procedures for rapid processing and delivery of the imagery will be required to allow its operational use for snow-cover mapping.

The small scale and relatively low resolution of NOAA VHRR and SMS-GOES meteorological satellite imagery make it difficult to use this imagery for operational snow-cover mapping in Arizona. Because the meteorological satellite imagery is available on a daily basis, however, it may be of significant value for monitoring large and rapid changes in snow cover.

The feasibility of using satellite telemetry to furnish near-real-time hydrologic data for use by water-management agencies in Arizona has been demonstrated successfully by the Landsat data-collection system. The SMS-GOES data-collection system offers an increased data-handling capacity and will be field tested in Arizona soon.

Different methods for estimating snow cover in forested mountain basins

Seven different methods of determining snow-covered areas on Landsat images of drainage basins in Oregon and Washington were compared by M. F. Meier (USGS) and W. E. Evans (Stanford Research Institute) (1975). Of the three manual methods used, visual estimates of snow-covered areas in cells or boxes 2.5×2.5 km in size proved best in overall precision, speed, relative cost, ability to recognize snow in shadow or forest, and production of useful supplemental information. Radiance-threshold settings, locally edited by reference to altitude contours and other images by using the Stanford Research Institute's Electronic Satellite Image Analysis Console, also produced excellent results, as did all-digital methods, which, however, were relatively expensive. Standard errors ranged from about 3 to over 12 percent of basin area, depending on the method and the snow-cover fraction used.

Landsat imagery shows large icings on eastern Arctic Slope of Alaska

Large icings on the eastern Arctic Slope of Alaska are visible on Landsat imagery. Certain bands of the imagery are particularly useful because they contrast ice with snow in winter or ice with nearby soil and vegetation in summer. C. E. Sloan used icing locations shown on Landsat imagery to plan a late-winter hydrologic reconnaissance of the area. Open-water leads or springs occurred at the sources of all the icings, and the only winter streamflow found was associated with icings visible on the imagery. One of the largest icings in the area is fed by springs that emerge from the alluvial fan of the Kongakut River. The Kongakut icing overflows sea ice in the coastal lagoon behind Icy Reef and extends for more than 16 km along the coast of the Beaufort Sea. The springs discharge calcium bicarbonate-type water, which is low in dissolved-solids concentrations and near saturation in DO.

Automatic categorization of Green Swamp cover types

A. L. Higer and A. E. Coker divided Landsat–1 and Skylab S–192 data for the Green Swamp area of central Florida into five classes—water, cypress, other wetlands, pine, and pasture. These categories were compared with similar categories shown on a detailed vegetation map derived from low-altitude aerial photographs. Agreement between Landsat categorized data and the vegetation map was 87 percent; agreement between Skylab data and the vegetation map was 83 percent. A vegetation-cover type in the Green Swamp may be widespread, but it is often found in numerous small isolated areas. Because Landsat data have greater resolution than Skylab data, they are better suited for mapping small areas of vegetation. Because of the greater number of spectral bands provided by Skylab S–192 data, however, it is possible for an investigator to categorize land- and water-cover types in a complex area such as the Green Swamp if he has sufficient on-site data to establish subcategories and merge them into logical composites.

Luminescence remote sensing of water contamination

R. D. Watson, R. C. Bigelow, and W. R. Hemphill reported that airborne tests of a redesigned Fraunhofer line discriminator (FLD) demonstrated that the instrument is capable of operating at selected Fraunhofer wavelengths throughout the visible spectrum and is sensitive enough to detect 0.25 ppb of Rhodamine-WT dye in 20°C water at a depth of 0.5 m. The improved FLD has been used to detect and discriminate several sources of water pollution, including (1) oil seeps in the Santa Barbara Channel of California, (2) treated and untreated sewer effluent at Denver, Colo., (3) sulfurized liquor in papermill effluent at Foley, Fla., and (4) gypsum and phosphate residue from phosphate plant operations in central Florida. These FLD measurements compare well with laboratory predictions of equivalent Rhodamine-WT dye concentrations:

Pollutant	*Laboratory results* (ppb)	*FLD results* (ppb)
Oil seep (Santa Barbara, Calif.)	5.70	4.00
Sewer effluent (Denver, Colo.)	2.00	1.00
Papermill effluent (Foley, Fla.)	.70	.90
Phosphate plant wastes (central Florida)	2.40	2.20

Tennessee wetlands classification and mapping

V. P. Carter reported that a wetland classification system based on hydrology, vegetation, and soils is being developed for Tennessee by the USGS in cooperation with the Tennessee Valley Authority (TVA). NASA high-altitude color-infrared photography is being used to map wetlands at four sites in western Tennessee according to this new classification system. The 15 maps nearing completion are 1:24,000-scale overlays on existing USGS 7½-min quadrangle maps; 12 wetland classes and adjacent land uses are being identified. Seasonal photographs are needed to detect water boundaries beneath deciduous trees and seasonally emergent vascular vegetation. Some of these wetland boundaries will be referenced to available long-term stage (water level) data to indicate the range of fluctuation. These maps should be useful to TVA resource managers and to the State of Tennessee because of growing concern over the loss of productive wetland habitat. They will also serve as a data base for evaluating Landsat wetland classification.

Remote-sensor data used to map the Great Dismal Swamp

High- and low-altitude aerial photography and Landsat digital data are being used to map vegetation in the Great Dismal Swamp of Virginia and North Carolina in cooperation with the U.S. Fish and Wildlife Service. According to V. P. Carter, a 1:100,000-scale vegetation map was prepared from seasonal color-infrared photography, and four 1:24,000-scale maps are in various stages of preparation. Landsat data for February and April and temporarily combined data are being used to classify the vegetation in anticipation of greater use of Landsat data to monitor future trends in vegetative succession in response to altered management practices.

Color-infrared photographs are also being used to select sites for shallow observation wells. Water-level data for these wells will be analyzed with reference to surface vegetation to evaluate possible correlations. These data should also prove useful in predicting the pattern of vegetation regeneration following fire or lumbering activity.

National wetland classification system

The USGS is cooperating with the U.S. Fish and Wildlife Service in using remote-sensing techniques to develop a new national wetland classification system for the upcoming Fish and Wildlife Service national inventory. Wetland habitat types, the lowest level of the new system, are based on vegetation, soils, and hydrology. The system will allow countrywide comparison of inventory data by ecosystem, by physiographic region, and by wetland class.

APPLICATIONS TO CARTOGRAPHIC STUDIES

During FY 1976, NASA, the EROS program of the Department of the Interior, and the USGS jointly sponsored continuing research into the cartographic applications of space imagery and high-altitude photography. As Landsat–2 continued its second year of operation and Landsat–1 ended its fourth, operational applications gained momentum.

SATELLITE IMAGE MAPS

Antarctica

In the continuing evaluation of the use of satellite imagery of remote and unmapped areas, Landsat image maps of portions of Antarctica were printed at scales of 1:250,000, 1:500,000, and 1:1,000,000. The McMurdo Sound region was mapped in black and white at all three scales; the Thurston-Thwaites area was mapped in black and white and the Victoria Land coast was mapped in blue at 1:1,000,000 scale; and the Ellsworth Mountains were mapped in blue at 1:500,000 scale. In addition, four satellite image maps of Alaska in IMW format (Fairbanks, Dawson, McKenzie, and Umiat) are nearing completion.

Arizona

The Phoenix 1°×2° quadrangle of Arizona was used to compare remote-sensor data from several sources. The 1:250,000-scale map prepared from Landsat imagery was printed in sepia and overprinted with hydrology in blue, grid and text in black, and culture in black and red. Earlier versions of the map were prepared from (1) Apollo 9 photographs, (2) U–2 photographs taken at 21,000 m, and (3) conventional aerial photographs and large-scale maps.

Connecticut

As was expected from the analysis of previous satellite color photographs, conventional color did not add to the information content in most areas and sometimes resulted in lower resolution. The 1:250,000-scale color-infrared photomap of the Hartford 1°×2° quadrangle of Connecticut shows that a more effective color portrayal of Skylab imagery can be obtained by combining two black-and-white records—S–190A photographs from the red band (0.6–0.7 μm) and from the infrared band (0.8–0.9 μm). Cultural features and soil patterns are prominent in the red band, whereas the infrared band is more sensitive to the boundary between water and land and penetrates haze and thin clouds. Thus, the combination of high-resolution panchromatic images and black-and-white images maximizes information content.

Florida

Eleven of the 22 nominal scenes of the Florida satellite image mosaic were printed as individual maps. The imagery was copied from bands 5 and 7 of the 1:500,000-scale images used in the Florida mosaic, except for the Florida Keys image, which was digitally processed by the Jet Propulsion Laboratory in Pasadena, Calif.

Georgia

A 1:500,000-scale satellite image mosaic of Georgia that clearly shows the flood plains was prepared for State use in regional geologic studies. There were fewer problems with this second experiment in mosaicking images from several Landsat orbits to cover large areas, but expertise in film montage was essential. Some 20 points from 1:24,000-scale topographic maps were used to control the aerotriangulation of 14 Landsat–1 scenes; measurements were made on 1:1,000,000-scale negatives of the band-7 images. The resultant positional RMSE is 162 m with reference to the UTM grid and 142 m with reference to the Lambert projection; well-defined features on the printed map were estimated to be within 200 m in relation to the grid. A 1:500,000-scale film montage was prepared for bands 5 and 7, which were printed in three colors to achieve the conventional color-infrared rendition. The next State to have a satellite image mosaic of this kind will be Wyoming, one of several key regions being studied for energy-resource development.

Upper Chesapeake Bay

The second edition of the Upper Chesapeake Bay satellite image map shows the result of computer image processing by the IBM Corporation of Gaithersburg, Md. From the same Landsat imagery (October 11, 1972) used for the first edition, the geometry was improved slightly, and the information content was increased by optimizing spectral differences to make them compatible with photographic and lithographic processes. Resolution of the two editions is basically the same for items of similar contrast. Positional accuracy of the printed image of the second edition in relation to the grid is 100 m (RMSE), somewhat improved over that of the first edition. The waveband treatment for the second printing omitted band 6 in black, so that band 4 was printed in yellow, band 5 in magneta, and band 7 in cyan.

Western United States

Several gridded satellite image maps of selected areas were prepared as color experimental prototypes (only photocopies available): Dry Fork of Cheyenne, Wyo.; Grand Canyon, Colo.; Tongue River, Mont.; and Yellowstone Lake, Wyo. Similar maps are planned for Denver, Colo. (winter and summer); Phoenix, Ariz.; Salt Lake City, Utah (north and south); and Seattle, Wash.

INVESTIGATIONS

Earth Resource Experiment Package

Skylab's Earth Resource Experiment Package included three systems of cartographic interest: Two frame film cameras (S–190A and S–190B) and a conical scanner (S–192).

- The S–190A—a six-band, 15-cm-f.l., multispectral camera imaging on 70-mm film—demonstrated the geometric fidelity necessary for 1:250,000-scale mapping and larger scale map revision. All six wavebands were recorded simultaneously: Four between 0.5 and 0.9 μm on black-and-white film, one on color film, and one on color-infrared film. On the basis of spatial and spectral resolution, 1:250,000 was found to be the largest scale suitable for general-purpose image presentation of the black-and-white records; the lower resolution of the color films suggested smaller scale uses. Cultural features such as secondary roads, railroads, and small buildings could not be reliably identified, thus preventing application to conventional line mapping.

- The S–190B—the 45-cm-f.l., 13-cm-format Earth Terrain Camera—produced higher resolution imagery than the S–190A and therefore could be applied to larger scale mapping projects. Black-and-white, color, and color-infrared films were exposed at an image scale of 1:950,000. The black-and-white film provided ground resolution equivalent to 15 m at low contrast, but certain features critical to map revision such as roads and railroads could not be positively identified. Relative accuracy was acceptable for revising planimetry at 1:24,000 scale, but overall accuracy was suitable for plotting at 1:50,000 scale. Since the color and color-infrared imagery had poorer resolution (in part owing to processing), the optimum scale recommended for its presentation is 1:100,000.
- The S–192—a conical multispectral scanner with 13 channels ranging from 0.4 to 12.5 μm—provided some cartographically significant results in spectral bands beyond those in common use. Band 11 (1.55–1.75 μm) penetrated thin clouds and haze and provided excellent contrast and rendition of cultural features, vegetation, and water bodies—a better single-band response to the Earth's surface than any single band shorter than 1.1 μm noted to date. The internal geometry of a conical scanner is simple and in many ways ideal for cartographic applications, but an image-recording device that properly reconstructs the conical sweep is essential to processing the S–192 data. Such hard-copy imagery is not generally available for evaluation, but the data merit further study.

Thematic mapping from Skylab imagery

Skylab imagery was applied to thematic mapping specifically to develop a photographic procedure for extracting themes of cartographic interest—open water, vegetation, ice and snow, and urban-suburban areas. Photomechanical isolation techniques were used with black-and-white film to extract themes from S–190A, S–190B, and S–192 images. Special extractions of transportation networks and water-wetland boundaries were also possible with images obtained just after a snowstorm; water-wetland boundaries were defined by snow accumulation on vegetation, and roads were defined by plowing and melting. Clouds and shadows inhibited accurate theme extraction by obscuring parts of pictures. Although the quality, geometry, and content of S–190A and S–190B images were adequate for small-scale mapping, the waveband cutoffs were not entirely appropriate for the special requirements of systematic theme extraction; S–192 wavebands are more appropriate, but linearizing the imagery during the printing process degrades resolution and geometry. The Skylab-image theme extractions were used as color separates for printing the 1:250,000-scale photoimage map of the Hartford 1°×2° quadrangle of Connecticut. This investigation of theme extraction was extended to include experiments with Landsat images for 1:250,000-scale mapping and with high-altitude photographs of Doboy Sound, Ga., for larger scale mapping.

Reference system for the Moon

In a joint effort by NASA, NOAA (NOS), and the USGS to establish a selenocentric reference system for the Moon, the positions of 5,325 lunar surface features were computed from Apollo photographs. The photographs were taken during the Apollo 15, 16, and 17 missions with a 76-mm-f.l. mapping camera that was rigidly coupled to a stellar camera for orientation and to a laser altimeter for scale. More than 51,000 image measurements from 1,244 photographs were used in the photogrammetric block adjustment. The stellar orientations and laser ranges were used as constraints; the spacecraft positions were not constrained in the solution because the orbit computed from ground tracking proved to be unreliable. Covariance propagation analysis indicated that 90 percent of the computed lunar positions should be accurate within 45 m in both position and elevation.

Digital image processing

The USGS in Flagstaff, Ariz., produced a stereopair from a single Landsat image of western Colorado. Digital image processing was used to introduce parallax in elements of the image based on digital elevation data from the 1:250,000-scale map of the Montrose 1°×2° quadrangle of Colorado. When the modified image is viewed with an unaltered image, a stereoview of the scene is presented for those interested in physiography. The technique should also enable cartographers to remove relief displacement from Landsat images, which amounts to as much as 10 percent of the elevation difference along the eastern and western edges of an image. If digital terrain data can be used to rectify the satellite image as it is processed, automated image mapping in truly orthographic form is possible.

Improvement of Landsat imagery resolution

Meade Technology Laboratories in Dayton, Ohio, investigated the possibility of improving the resolution of Landsat imagery by combining images of the same scene taken at different times. The test areas were the Chesapeake Bay Bridge in Maryland; Washington, D.C., and the Pentagon in Arlington, Va.; and Sun City and Sky Harbor in Phoenix, Ariz. Because of varying atmospheric conditions when the scenes were recorded, the image data had to be normalized to a common density range before each scene could be composited. An interlacing procedure was used to fit the data points of one image to those of another and thus reduce the pixel size in the composite. The resolution was improved for all scenes, most notably for the Chesapeake Bay Bridge composite, in which both bridges (not separately distinguishable in any single image) could be identified.

Interpretation of light flux

A correlation of Defense Meteorological Satellite Program images with a map of North America revealed that concentrations of light flux generally indicate population centers. The Aurora Borealis also was recorded across northern Canada. In British Columbia and Alberta, the light correlates with oil and gas fields and apparently indicates gas flaring; according to the Energy Resources Conservation Board of Alberta, nearly 80×10^6 m^3 of gas was flared there each month in 1975. Landsat–1 and Landsat–2 have not demonstrated the ability to monitor light flux; however, a requested night exposure over the northern Sahara Desert produced signals that probably relate to gas flaring.

Landsat imagery of the Caribbean Sea

Analyses of Landsat imagery of the Caribbean Sea verified that MSS band 4 can record bottom detail through 10 m of clear water. Moreover, high-gain settings requested and used in a NASA bathymetric experiment with Jacques Cousteau (Cousteau Society) demonstrated that 22 m of clear tropical sea can be penetrated. Analog analysis conducted for the USGS under contract by D. S. Ross (USGS), a specialist in image enhancement, generally confirmed the findings of the NASA-Cousteau experiment; however, changes in bottom reflectance, vegetation, and water clarity necessitate tight controls and calibration data within the area. The results of these experiments prompted the Defense Mapping Agency to request high-gain-setting coverage of sizable areas in the Caribbean and of an area in the Indian Ocean. An optimum water-penetration waveband (centered on 0.5 μm) was requested for follow-on Landsats.

USER SERVICES

The USGS has produced a set of indexes depicting worldwide Landsat coverage. Seven small-scale computer-generated maps in the World Plotting Series were used as bases and overprinted with selected Landsat cover information. The base maps are cast on Lambert conformal conic, Mercator, or polar stereographic projections at 1:18,000,000 scale (except for the Arctic Ocean at 1:9,000,000 scale). Major land and water features are shown along with selected cities and names. Index tapes of the imagery acquired from August 1972 to July 1974 were processed to determine the minimum cloud cover for each nominal scene. Symbols denoting different levels of cloud cover, orbital paths, and image rows were plotted automatically with the Gerber drafting system. Thus, only names and collar texts were applied by hand. Future editions depicting later coverage or other desired information will require little more than resorting the Landsat coverage tapes and plotting.

As part of the EROS program, the USGS maintains a user research facility at the National Center in Reston, Va. (Room 2–A–223B, telephone 703–860–6271), for government-agency, university, and industry investigators with approved projects. There is no charge, but investigators must provide their own materials and execute their own projects. Limited instruction on equipment operation is provided, but use is restricted to qualified operators. Equipment available includes:

- Bausch & Lomb zoom microscopes with magnification to 60× and stereo capability for 70-mm film only.
- Bausch & Lomb Zoom Transfer Scope with magnification to 14× and anamorphic correction.
- Bendix DataGrid Digitizer with a 48×60-in light-table, a Beseler CB–7 enlarger for projecting 70-mm film transparencies, and magnetic-tape or typewriter output.

- Joyce-Loebel Mark III–C microdensitometer with reflective optics attachment.
- Kern MK 2 monocomparator.
- Richards light-tables with takeup reels for film sizes to 23 cm.
- Spatial Data Systems Datacolor model 703.
- Wild PUG 3 point-transfer device.
- Wild M 5 stereomicroscope with 6× to 50× magnification and trinocular viewing.
- Zeiss point marker.

Reference materials include a comprehensive file of 470 Landsat color prints covering the conterminous United States and a selection of Skylab images obtained with the S–190A and S–190B cameras on missions 2, 3, and 4.

FOLLOW-ON LANDSATS

To insure that the needs of users of satellite data are considered in the early planning for follow-on missions, parameters and program requirements were drafted for NASA though the EROS program. The capabilities requested are as follows:

- Retain compatibility with present data so that the same processors can be used and new data can be compared with those already in the data bank.
- Make all data available to users in the United States and other countries.
- Retain time of equatorial crossing so that Sun angle and azimuth will be similar to those of present satellites, and terrain observations will be comparable.
- Maintain or increase orbital altitude to preserve or improve orthography of data and uniformity of spectral radiometry within a single scene.
- Maximize water-penetration capability for use in mapping shallow seas.
- Provide for acquiring images at very low Sun angles and at night for special experiments.
- Provide for recording additional spectral bands in the near-infrared and thermal-infrared regions.
- Improve spatial resolution gradually as scientific justification requires and cost permits.

Tests with digitally enhanced Landsat imagery indicated that far greater information content can be obtained in photographic form than with conventional imagery. Photographic and lithographic color experiments show that the conventional combining of bands 4, 5, and 7 into a color composite is not optimum. Also, the differences between band 4 and band 5 records, which are lost in conventional processing, can be enhanced to the point where dormant vegetation is recorded as green in color composites (see 1976 edition of Upper Chesapeake Bay image map). The critical problem is to determine when and how to convert Landsat signals from digital to analog form for wide distribution.

APPLICATIONS TO GEOGRAPHIC STUDIES

In 1976, one aspect of geographical research focused on comparative urban land-use analysis, primarily from aerial photography but also from machine classification of satellite data. Another aspect concentrated on the use of satellite data in digital form. Instead of focusing on urban areas, however, the latter study dealt with the techniques of analysis, change detection, and integration of results into a geographic information system for handling land-use and land-cover maps and data. A third aspect dealt with the application of these developments to the USGS national land-use and land-cover mapping and data compilation program; some needs of other users of land-resource information were also addressed, however.

In collaboration with the Appalachian Regional Commission, the EROS and Geography programs completed maps and data for 1973 land use in six counties of the greater Pittsburgh region of Pennsylvania. Land-use change from 1969 to 1973 in Allegheny County, Pennsylvania, was also mapped at 1:50,000 scale, and area measurements were compiled by census tracts. All of this work was accomplished by manual interpretation of aerial photography. Pittsburgh is the subject of the ninth and last in a series of comparative urban-area studies that includes analyses of census contemporaneous land use for Boston, Mass.; Cedar Rapids, Iowa; New Haven, Conn.; Phoenix and Tucson, Ariz.; Pontiac, Mich.; San Francisco, Calif.; and Washington, D.C. In 1975, land-use maps of six urban areas, including some maps showing land-use change, were placed on open file. Maps for San Francisco and Washington, D.C., were released earlier. A map of Washington, D.C., land-use changes from 1970 to 1972 was published at a scale of 1:100,000 (Wray, 1975).

An interagency team comprised of NASA and USGS personnel from the EROS and Geography programs and personnel from the Pacific Northwest Regional Commission Task Force on Land Resources Inventory undertook cooperative studies in agriculture, forestry, and rangeland and urban-area analysis mainly using machine processing of Landsat data in digital form.

Meanwhile, state-of-the-art research using Landsat digital data was conducted in collaboration with contractors at the Purdue University Laboratory for Applications of Remote Sensing and the University of Illinois Center for Advanced Computation. These researchers developed techniques that made the processing of Landsat digital data for image registration, geometric rectification, and classification more efficient. Spatial filtering techniques for use in detecting change were improved to supplement analysis of spectral data.

A primary thrust of this contract research, especially at Purdue, was the overlaying in a computer of Landsat digital data on data representing digitized statistical area boundaries, such as census tracts and hydrologic units.

In a program of land-cover monitoring, the digital data (combined with a geographic information system such as that being developed by the Geography program) permit classification of land cover, aggregation of data, preparation of map products and theme separations for map publication, and detection of change.

In addition to analyzing Landsat data, Geography program staff analyzed Skylab photographic data. V. A. Milazzo (1974) reported on the use of S–190A data for Phoenix, Duilio Peruzzi studied S–190A and S–190B data for San Francisco, and D. B. Gallagher (1976) reported on S–190B data for New Haven, Phoenix, and Washington, D.C.

LAND USE AND ENVIRONMENTAL IMPACT

MULTIDISCIPLINARY STUDIES IN SUPPORT OF LAND-USE PLANNING AND DECISIONMAKING

The program to develop and apply Earth-science information in support of planning and decision-making in urban areas has resulted in numerous reports and maps describing and explaining aspects of the natural environment that affect and are affected by man's use of the land.

GREATER PITTSBURGH REGION STUDIES

With the cooperation of the Appalachian Regional Commission, the USGS expanded its greater Pittsburgh region studies in Pennsylvania to include a series of 1:50,000-scale maps and evaluations in the 1,880-km^2 Allegheny County; some investigations were also conducted in adjacent counties.

By compiling and interpreting existing geological and soil information, W. R. Kohl and R. P. Briggs (1975) prepared a map of rock types found in the bedrock of Allegheny County. Accompanying tables provide both a general classification of engineering responses of the land and a detailed review of engineering characteristics of the rocks.

More than 260 km^2 of the county were identified as having a significant degree of susceptibility by J. S. Pomeroy and W. E. Davies (1975), who prepared a map of landslide susceptibility. An illustrated companion report by Briggs, Pomeroy, and Davies (1975) describes 15 selected landslide localities and includes a guide to landslide expression for the buyer, builder, and homeowner that is applicable to much of the Appalachian Plateaus area.

Information on the locations of mine-refuse piles, strip mines, underground mines, slag dumps, and other evidence of coal-mining activity was contained on a map of coal-mining features in Allegheny County prepared by Davies, Pomeroy, and Kohl (1976). About 600 km^2 are shown as undermined, and 80 km^2 are affected by surface mining.

Charts prepared by Seymour Subitzky (1975a, b, c, d, e) illustrate the relationship between the shallow ground-water regime, mining, landsliding, flooding, urbanization, and water quality in Allegheny County. One of the charts features a synoptic map inventory of landslides resulting from tropical storm Agnes in 1972.

Maps of landsliding, coal-mining features, and flood-prone areas were generalized and combined by Briggs and Kohl (1975) especially for nontechnical users. The text instructs readers on the use of the maps and on sources of more detailed information about the processes involved.

A basic-data contribution prepared under an urban study grant to the Pennsylvania Geological Survey (Cortis and others, 1975) was used in compiling 1:125,000-scale maps that show mining activity and other information relative to the Upper Freeport, Pittsburgh, and Redstone coal beds in Allegheny, Washington, and Westmoreland Counties (Bushnell, 1975a; Bushnell and Peak, 1975). In a third map, Bushnell (1975b) provided a general classification of the ground surface relative to the potential for damaging surface subsidence resulting from underground coal mining. Although the record of subsidence events is incomplete, tables include well over 100 incidents.

SAN FRANCISCO BAY REGIONAL STUDIES

The San Francisco Bay Region Environment and Resources Planning Study (SFBRS), jointly supported by the USGS and the U.S. Department of Housing and Urban Development (HUD) Office of Policy Development and Research, was formally concluded in July 1976. A series of interpretive Earth-science reports dealing with topics such as seismic zonation, flood inundation, flatland materials, slope stability, erosion and sedimentation, and land-based waste disposal has been completed and is now being processed for publication.

Flood-prone areas and land-use planning

A USGS-HUD report, "Flood-prone areas and land-use planning in the San Francisco Bay region, California," is being prepared by A. O. Waananen, J. T. Limerinos, W. J. Kockelman, W. E. Spangle, and M. L. Blair. The report defines the problem of flooding in the San Francisco Bay region, describes the preparation and use of various types of flood maps and flood information reports, lists sources of information on flooding and flood plains, and discusses flood-damage prevention and reduction measures as part of a comprehensive flood-plain management program. A case study of the Napa Valley shows how flood information is used by the several agencies involved in flood-plain management and illustrates the interaction among these various agencies.

Earth-science information in land-use planning

"Earth-science information in land-use planning —guidelines for earth scientists and planners" (William Spangle and Associates and others, 1976) was prepared to acquaint planners and Earth scientists with the needs and problems each group faces in working with the other. The report summarized the findings from an extensive nationwide sampling of Earth-science-information applications to urban land-use planning. The summary report presented a series of recommendations that provide a starting point for planners and Earth scientists who wish to work together more effectively. Several examples were cited to illustrate applications. Among the significant findings of this report were the following:

- Planners need Earth-science information relevant to, and in a form suitable for, application in land-use planning.
- Scale, accuracy, and detail of the Earth-science information required for planning vary according to jurisdictional level, environment diversity, and rate of development of the area.
- Planners should be aware of the limitations of data and any qualifications placed on its use and accuracy.
- Natural-resource planning is a necessary function of agencies at all jurisdictional levels with land-use planning responsibilities.
- Hazardous areas should be identified and evaluated for level of risk.
- Alternative measures to mitigate hazards should be evaluated for both environmental and economic impacts.
- Successful integration of Earth-science information in land-use planning requires a close working relationship between planners and Earth scientists.
- Land-capability studies to evaluate natural opportunities and constraints are basic to the integration of Earth-science information in land-use planning.

New approach to assessing land capability

An interesting and innovative approach to land-capability analysis was developed and applied by the Association of Bay Area Governments (ABAG), supported by the SFBRS. One of the major problems in land-capability analysis is quantification of a wide range of Earth-science considerations for a wide range of land-use types. The ABAG study sought to simplify previously devised rating and weighting systems by expressing Earth-science constraints and resources in terms of dollar cost and thus reducing the expression to a common denominator. By means of a matrix analysis, a range of expected costs was calculated for seven Earth-science considerations for each of eight representative land-use and development types. The Earth-science considerations were earthquakes, flooding, bearing-material problems, slope stability, erosion and sedimentation, and resource evaluation. The land-use types selected were rural or agricultural, semirural, single-family residential, multifamily residential, regional shopping centers, downtown commercial, light industrial, and freeways.

The method was applied in a demonstration area of the Santa Clara Valley. The Earth-science information was compiled at a scale of 1:125,000 and digitized into a network of grid cells, each cell comprising about 10 ha. A computer program was used to prepare land-capability maps for each of the eight selected land-use types.

San Francisco Bay Region Study evaluations

Arthur D. Little, Inc. (1975), under contract to HUD, evaluated the effectiveness of the SFBRS program by interviewing project personnel and product users and by drawing heavily on an evaluation of product use by the USGS (Kockelman, 1975). Their report concluded that the "program has been of significant value and service to the community at large."

The objectives of the USGS evaluation were (1) to determine and document the use of SFBRS products by local planning agencies in their planning and decisionmaking, (2) to evaluate the effectiveness of such uses and to analyze nonuse, misuse, or ineffective use, and (3) to suggest ways to achieve greater or more effective use of Earth-science information.

The study was conducted primarily through interviews with more than 220 officials in the 91 cities and 9 counties in the San Francisco Bay region. The thrust of the interviews was to discover the applications of available SFBRS products to specific planning activities. Other questions asked concerned additional data needs and suggested improvements in SFBRS products.

Examples of 17 selected applications of SFBRS products to various planning activities were illustrated and discussed. Kockelman concluded that the cities and counties in the Bay region exhibited considerable familiarity with, and made substantial use of, SFBRS products. The reports included suggestions about future energy resources and environmental planning and development studies having goals similar to those of the SFBRS. The suggestions covered such areas as technical assistance, map scales, user advisory committees, areas impacted by development, the need for interpretive data, and the need to anticipate user needs by monitoring the course of appropriate legislation and analyzing emerging critical issues.

GEOTECHNICAL AND GEOHYDROLOGICAL STUDIES IN FAIRFAX COUNTY, VIRGINIA

The Franconia area of Fairfax County, Virginia, under intensive study as part of an analysis of geologic and hydrologic conditions in the Fairfax County urban area, coincidentally included a planned housing development that was approved and rezoned by the County Board of Supervisors in mid-1975. The vacant tract, covering more than 400 ha within the study area, is situated about 16 km southwest of Washington, D.C., along the Fall Line.

The Franconia area, underlain by upper Tertiary to Quaternary gravels, is a plateaulike grassy upland, scarred by abandoned gravel pits and sharply incised along its margins by steeply sloping wooded gullies and ravines. A deeply weathered mantle of residual saprolite underlies the gravels along the western side of the upland; interbedded unconsolidated gravelly sands and silty clays of the Coastal Plain crop out along the steep eastern slopes.

Integrated geologic, engineering, and hydrologic studies in this area have defined relevant natural factors that are being used by the Fairfax County Office of Comprehensive Planning to plan and guide development in this potentially important region. The chief Earth-science factors bearing on planning or development problems relate to:

- Slope stability problems caused by montmorillonitic clays in the Potomac Group that coincide with steep gradients of the water table and contribute to slope failures by landslide, slump, and creep (Obermeier and Hollocher, 1976; Obermeier and Froelich, 1976).
- Foundation stability and drainage problems caused by the Potomac clays that swell when they are wet and shrink when they are dry in areas where the water table is high and fluctuating (Obermeier and Froelich, 1976; Johnston and Larson, 1976).
- Variability of foundation conditions beneath upland gravel or fill depending on subsurface distribution of Potomac sands and clays and the configuration of the water table (Obermeier and Froelich, 1976; Johnston and Larson, 1976).
- Evaluation of ground-water resources and selection of optimum sites for water wells in potential Potomac sand aquifiers and the distribution of ground-water runoff (Johnston and Larson, 1976).
- Storm-water management aspects, especially identification of flood-prone areas, favorable sites for surface retention ponds on clays, and recharge pits on sands for the disposal of excess runoff (Johnston and Larson, 1976).

Some of these natural factors—slope stability, drainage, and surface and subsurface distribution of clays—were combined by J. N. Van Driel, in a technique called computer composite mapping, to produce a land-capability map for planned development in the general Franconia area.

CONNECTICUT VALLEY URBAN AREA PROJECT

The Connecticut Valley Urban Area Project completed large-scale (1:24,000) mapping of selected natural-resource parameters for use in local and regional resource-management programs. Map subjects include geologic, hydrologic, and topographic parameters, with emphasis on depth to bedrock, unconsolidated materials, drainage areas, availability of ground water, and flood-prone areas. One or more such maps have been prepared for 82 of the 88 7½-min quadrangles in the project area—a total of 205 maps.

Intermediate-scale (1:62,500) maps similar to those prepared at 1:24,000 for parts of Connecticut and Massachusetts are being made for the Keene-Brattleboro area of New Hampshire and Vermont. The intermediate-scale map information will be released as a separate report in order to assess its usefulness for local and regional planning.

URBAN STUDIES IN OTHER AREAS

Work in the Baltimore, Md.-Washington, D.C., area; the Tucson and Phoenix area of Arizona; the Puget Sound area of Washington; and the Denver area of Colorado produced numerous reports and maps of the types described for the other urban-area studies.

SNAKE RIVER CANYON STUDY

The relative stability of canyon walls along the Snake River was investigated near Twin Falls, Idaho, where developments are beginning to encroach upon the walls and building conditions may be unstable and, possibly, hazardous. Three categories of relative stability were recognized. The most unstable canyon segment, east of Twin Falls between Milner and Hansen, is characterized by arcuate tensional cracks extending up to 25 m from the canyon rim, steep walls, and a talus-free canyon floor and is subject to the most frequent rockfalls. The middle segment, from Hansen to Twin Falls, is subject to moderately frequent rockfalls and is characterized by tensional cracks 3 m from the rim and moderate, partially vegetated talus deposits. The western segment, west of Twin Falls, is the most stable, having a low frequency of rockfalls, tensional cracks less than 2 m from the rim, and a wide canyon floor with high, well-vegetated talus slopes.

LAND-USE DATA AND ANALYSIS PROGRAM AND OTHER GEOGRAPHIC STUDIES

Land-use and land-cover mapping and data compilation and related research being carried out by the Geography program of the Land Information and Analysis Office can be divided into the following major activities:

- Release of land-use and land-cover maps and related overlays at scales of 1:250,000 or 1:000,000, depending on the availability of the new 1:100,000 maps at time of publication.
- Experimentation with and demonstration of land-use and land-cover mapping at scales larger than 1:100,000 for specific applications.
- Experimentation with Landsat data for consistent mapping results and measurement of spatial and temporal changes in land use and land cover.
- Research on and development of a Geographic Information Research and Analysis System (GIRAS) for handling land-use and land-cover data in conjunction with environmental, socioeconomic, demographic, and other data.
- Analytical and interpretative studies on land-use patterns, problems, and trends.

LAND-USE AND LAND-COVER MAPPING

The land-use and land-cover mapping and data compilation being conducted by the Geography program was initiated late in 1974 to provide a systematic and comprehensive collection and analysis of land use and land cover on a nationwide basis. The Geography program provides program development, specifications, quality control, accuracy checks, and consultation, while the basic compilation of land-use and land-cover maps is done in the Topographic Division's Mapping Centers.

Land-use and land-cover maps are being compiled at a scale of approximately 1:125,000. Overlays showing Federal land ownership, hydrologic units, counties, and census county subdivisions are also being compiled for each land-use and land-cover map produced. State land ownership is shown when such information is made available by the appropriate State agency. The land-use and land-cover maps and accompanying overlays are keyed to the standard topographic map series at 1:250,000 scale and, when they are available, to the new base maps being prepared at 1:100,000 scale by the Topographic Division. By June 1976, land-use and land-cover data had been compiled for 102 quadrangles, and 135 quadrangles were in production.

Land-use and land-cover data are categorized according to the classification system presented in Professional Paper 964 (Anderson and others, 1976), together with other established specifications. The minimum mapping unit for urban or built-up uses, water areas, confined feeding operations, other agricultural land, and strip mines, quarries, and gravel pits is 4 ha. All other categories are delineated with a minimum unit of 16 ha. Federal land holdings are shown for tracts of 16 ha or larger.

Land-use and land-cover maps and accompanying overlays are being digitized in a polygon format. Polygons can be converted to grid cells of varying sizes when desired.

Land-use maps and associated overlays, initially available as black-and-white products at 1:250,000 scale, are placed in open file at the USGS Mapping Centers. Enlargements to scales such as 1:125,000 can be requested from the Mapping Centers. When an enlargement is made, however, the positional accuracy of the base map on which the land-use and land-cover data have been plotted still remains that of the 1:250,000-scale map. The maps can be used for many purposes in the scale range 1:100,000 to 1:250,000.

After the land-use and land-cover data and other map overlays are digitized, computerized graphic displays and statistical data on current land use and land cover become available for use in conjunction with other data. Statistical data are compiled by counties for areas of Federal ownership, by river basins and subbasins, and by statistical units such as census tracts or other census county subdivisions.

The revised classification system (Anderson and others, 1976) includes expanded definitions for 9 Level I categories and the 37 Level II categories. Professional Paper 964 discusses methods of map presentation for the land-use and land-cover categories and includes illustrations of sample maps, as well as a selected bibliography.

This revision indicates more clearly the intermixing of land-use and land-cover terminology in the classification system. To some, this intermixture is undesirable. However, a careful evaluation of alternatives led to the conclusion that unfamiliar or infrequently used terms would be introduced if strict adherence to one terminology or the other were observed. This approach to land-use and land-cover mapping permits the aggregation of Level II categories into Level I. Even more important, it allows Level III categories to be added as desired by users. Such categories would represent further subdivision of the Level II land-use and land-cover categories already compiled.

For example, under a cooperative agreement with the State of Florida, land-use and land-cover data have been compiled at Level II. At the request of the Florida State Department of Planning, an overlay of selected Level III categories has been prepared. Some of the Level III categories being overlaid and fitted to the Level II categorization are (1) citrus groves separated from other groves, nurseries, and so forth, (2) mangrove swamps and cypress bogs separated out of the Level II Forested Wetland category, and (3) mudflats separated out of Nonforest Wetland.

COOPERATIVE LAND-USE MAPPING AND DATA PROJECTS

In 1976, a cooperative agreement between the USGS and the Ozarks Regional Commission was amended to provide land-use and land-cover maps and accompanying overlays for the entire State of Kansas.

Using land-use and land-cover data provided under an earlier amendment to this cooperative agreement, the Ozarks Regional Commission published statistical data for the State of Arkansas that were provided by the USGS Geography program. This report (Malloy and McCullough, 1976) separated land-use categories by counties and river basins.

Cooperative agreements have also been made with the States of Alabama, Georgia, Pennsylvania, and West Virginia for land-use and land-cover mapping.

CENTRAL ATLANTIC REGIONAL ECOLOGICAL TEST SITE PROJECT

The Central Atlantic Regional Ecological Test Site (CARETS) Project, a 5-year research, test, and demonstration project for developing land-use and environmental impact information programs, was completed during the past year. Results are summarized in 14 final reports being released by cosponsors NASA and USGS. Additional project results are contained in numerous publications, technical and progress reports, maps, data summaries, and computer tapes of land-use map information and related map overlays. Many procedures and subelements initiated and tested in the CARETS Project are currently incorporated into operational components of the Geography program.

This experiment focused on the evaluation and attempted solution of environmental problems associated with the use of the land in a specific region and on the consequent environmental impact; environmental and socioeconomic processes were stressed. The data sets were also used to describe and quantify land-use patterns and rates of change. A sequence of interconnected operations—including investigations of aspects of environmental quality dependent on land use and the organization of timely data on land use and land cover as obtained from remote sensors in aircraft and satellites—constituted the main portion of the CARETS regional demonstration project.

The CARETS Project was managed and coordinated by principal investigator R. H. Alexander. K. A. Fitzpatrick documented the costs and accuracy of land-use information obtained from 1:24,000-, 1:100,000-, and 1:250,000-scale maps derived from high-altitude aircraft photography as well as from Landsat imagery. H. K. McGinty assessed user requirements and user response to the array of products presented to a cross section of Federal, State, regional, and local resource planning and management agencies as well as to representative users from the private sector.

Applications of the new land-use data products to the study of coastal environmental processes, especially in light of the requirements for data to support the writing of environmental impact statements, were investigated by Robert Dolan and P. J. Buzzanell. The impact of land use on air quality was investigated by W. E. Reed and J. E. Lewis, Jr., while impact on streamflow was studied by E. J. Pluhowski. Certain climatological impacts of land-use patterns, with special reference to the urban "heat island," were investigated by Lewis, R. W. Pease, S. I. Outcalt, and C. B. Jenner. The climatological study was supported by a thermal scanner on the NASA Skylab mission. This study provided the first comparison of observed and simulated surface-temperature maps of an urban area (Baltimore, Md., vicinity). Other applications of Skylab data were studied by H. F. Lins, Jr., who compared aerial and space photography as sources of land-use information for urban planning. The project included a major experiment with computerized map-data digitizing and manipulation, in cooperation with the Canada Geographic Information System (Department of the Environment, Government of Canada). It was deemed necessary to automate at least a portion of the map-data-handling process because of the large quantities of data required for regional and other large-area assessments. In addition, the availability of land-use maps in digital form made it possible to experiment with labor-saving graphic output systems, which can potentially provide much more flexibility in formats, scales, and classification of land-use data for use in environmental decision-making.

GEOGRAPHIC INFORMATION SYSTEMS SOFTWARE DEVELOPMENT

The Geography program continued research and development work on a Geographic Information Research and Analysis System (GIRAS) to extend and improve its capability for computer-aided storage, editing, manipulation, and retrieval of a geographic data base for the land-use and land-cover mapping and data compilation effort and other USGS land-use and land-cover research projects. The system includes (1) digitization of land-use and land-cover maps and other environmental data; (2) editing and updating of the geographic data base; and (3) manipulation and retrieval of those data in order to perform area measurements, map compositing analyses, and statistical and other computer-aided operations.

The I/O Metrics Corporation, under contract to digitize land-use and other map sets, used the Geography program's graphic input procedure to edit and correct the digital records for 14 land-use overlays. A total of 4,200,000 bytes or 711,200 mm of line data for land-use overlays was involved. An additional 2,920,000 bytes or approximately 818,440 mm of line data were digitized, edited, and corrected for 146 overlays of environmental data to accompany the land-use overlays.

The interactive cartographic editing system acquired as an alternative procedure for digitizing, editing, and correcting land-use and land-cover maps was expanded and made operational with the acquisition of CART/8 Version 2 software, and the capability of the system was enhanced by the procurement of display and hard-copy hardware.

The GIRAS data-base structure was redesigned to facilitate the use of retrieval and manipulation processes and programs developed over the year. These included improvements and extended capabilities for graphic input procedure programs as well as manipulative programs designed to convert polygons to variable grid cells. One of the programs developed for retrieval demonstrated that color-separation plates can be developed directly from digital data; the need for hand scribing as part of the preparation for printing is thus obviated.

Work began on the review and analysis of digital geographic data-handling activities in the USGS under a grant to the International Geographical Union (IGU) Commission on Geographic Data Sensing and Processing. Following a determination of the status of USGS activities involving digital handling of spatial data, the IGU Commission issued its first report (International Geographical Union, 1975), which described 54 activities within the USGS. These data activities all have one or more geographical location identifiers within a data base, use a location identifier to manipulate the data, and have the potential to manipulate a data base on location identifiers. A working group of the IGU Commission compiled an inventory of computer software available for geographic data handling from governmental, private, and academic sources in the United States, Canada, and Europe. The inventory presented standardized descriptions of programs that are potentially useful for spatial data handling, including full systems, as well as programs for data management, data manipulation, data analysis, and mapping and graphics. A third activity undertaken under the grant was the design and management of a series of working seminars concerning spatial-data-handling problems within the USGS. The first five seminars were devoted to description of spatial-data-handling systems in the operating divisions and the Computer Center Division. The sixth seminar considered the characteristics of types of spatial data handled and estimated the overall size and cost of the spatial-data-handling task facing the USGS in the foreseeable future. The remaining seminars considered digitizing, data encoding, computer hardware, special output hardware, data manipulation, software, file structures, and the technical policy options for spatial-data handling in the USGS.

Technical assistance was provided to the States of Louisiana and Florida and to the Ozarks Regional Commission on the implementation and use of GIRAS programs and documentation for the production of statewide inventories of land use in support of planning groups wishing to use the USGS land-use and land-cover digital data base. Digitized land-use data for a four-county area of Arkansas were used in conjunction with data on soils capability, flood plains, mineral deposits, and fish and wildlife to provide nine levels of resource information in a statistical data development for the Ozarks Regional Commission.

ECONOMIC IMPACT ON COASTAL AREAS

D. W. Davis and J. L. Place studied the impact on land use in the Louisiana Coastal Plain resulting from the development of the oil and gas industry over the past 30 years. The research area is that part of the Coastal Plain south of lat 30° N., with an emphasis on the wetlands and the oil and gas industry served by boat, both on the coastal wetlands and offshore. They found that large areas of wetlands have been modified, that the population has increased, and that the economy of the region is now based on industry rather than on agriculture, fishing, and trapping. Strips containing service centers for the offshore oil and gas industry have been intensively developed on the better drained land, particularly along the distributary channels on the delta plain, and along old sand ridges farther west. One third of the employment in this region is directly related to the oil and gas industry. Development of the extractive and service areas for the oil industry has occupied land formerly used as cropland or as wetland-wildlife areas. Results of this research could be applied in planning offshore oil and gas development in other areas of the United States or abroad.

ENVIRONMENTAL IMPACT STUDIES

The Environmental Impact Analysis (EIA) program provides an integrated USGS response to the National Environmental Policy Act (NEPA) requirements for the preparation and review of environmental impact statements (EIS's). It (1) supplies direction, coordination, and expertise in the preparation of EIS's for which the USGS has lead or joint-lead responsibility; (2) furnishes technical information and expertise to support the preparation of EIS's to which the USGS is only a contributor; (3) provides technical analysis, review, and comment on EIS's prepared by the USGS and other agencies; and (4) stimulates, promotes, and conducts environmental research related to EIS's and the anticipated needs of the program.

During FY 1976, EIA administered the USGS lead and joint-lead responsibility for 20 EIS's; 17 of these were energy related (13 coal, 2 oil and (or) gas, 1 oil shale, and 1 uranium), and 3 concerned critical minerals, leasing, and regulations. Those completed during the year involved the Belle Ayr South coal mine in Wyoming; the Cordero coal mine in Wyoming; oil and gas development in the Santa Barbara Channel of California; coal operating regulations; and geological and geophysical OCS exploration regulations. The USGS participated in the preparation of 15 additional EIS's under the lead or joint lead of other Federal and State agencies—namely, Alaska, the Bureaus of Indian Affairs, Land Management, and Reclamation, and the U.S. Forest Service. Twelve of these statements were energy related, and the other 3 dealt with critical minerals; 1 was completed (El Paso coal mine and gasification plant in New Mexico), and 2 became inactive. The USGS also provided technical information to the Forest Service for 7 EIS's on geothermal energy resources and to the Bureau of Land Management for 12 EIS's on oil and gas leasing on the OCS.

EIA program staff members reviewed and commented on 2,812 statements and related documents to support in-house environmental studies and to assist other agencies in areas of USGS jurisdiction and expertise. They also (1) conducted three seminars on task-force management and EIS preparation; (2) completed and distributed a guidance manual on task-force management; (3) completed a preliminary draft of a guidance manual on surface-mining EIS preparation; (4) completed a study on reducing the bulk, time, cost, and manpower requirements of EIS's and on improving their readability; (5) established an improved system of time and cost accounting for EIS preparation; and (6) improved technical-level contracting capability.

Idaho phosphate EIS research results

Detailed descriptions of research conducted by F. J. Anderson, W. W. Emmett, L. P. Gough, R. A. Gulbrandsen, and R. C. Severson supplied necessary information for the southeastern Idaho phosphate resources EIS (U.S. Geological Survey, 1976). Anderson worked on seismicity and seismic hazards in the Pocatello and Soda Springs areas of Idaho; Emmett studied the application of streamflow and sediment-transport estimating techniques to streams in southeastern Idaho; Gulbrandsen reevaluated phosphate resources in southeastern Idaho; Severson and Gough assessed environmental implications of element emissions from phosphate processing operations in southeastern Idaho. J. E. Lewis synthesized background information to provide a framework from which to view the research projects and also summarized how the research fills voids in the existing data base but does not eliminate the need for gathering additional data through an integrated monitoring program.

As an extension of his EIS contribution, Gulbrandsen also described and assessed the previously unidentified thallium resources in the Meade Peak Phosphatic Shale Member of the Phosphoria Formation.

Impacts of phosphate development to be monitored

A method for monitoring the potential impacts of phosphate development in southeastern Idaho is being developed cooperatively by EIA and the Federal, State, and local agencies responsible for responding to these impacts. This project, under the leadership of L. G. Marcus, answers the need, identified by the interagency task force that prepared the Idaho phosphate EIS (U.S. Geological Survey, 1976), for a coordinated impact monitoring methodology. The project is aimed at identifying the impacts that should be monitored and at defining data needs by data type, quantitative indicator, frequency of collection, level of detail or accuracy, location, and format for reporting results. The data needs are limited to information that will directly assist agencies in carrying out their responsibilities for decisionmaking, planning, and regulation and enforcement. Data availability is being investigated to identify data gaps and duplication of data collection. Participating agencies are supplying information on their current monitoring activities and research and are identifying areas that require additional research.

In conjunction with this project, EIA funded two demonstration studies on the use of remote sensing for monitoring environmental impact. D. M. Carneggie investigated the feasibility of combining analytical approaches, using imagery obtained from satellites and aircraft, to monitor locations, areas, and types of strip-mining activities, as well as the resultant changes in vegetation and wildlife habitat. D. B. Gallagher demonstrated the use of aerial photography for monitoring land-use change. To the extent practicable, both studies were designed to fit the information needs of potential data users in the study area.

Clinker investigation for eastern Powder River coal basin EIS's

R. A. Farrow and C. H. Miller conducted magnetic and seismic studies to determine the quality and quantity of selected in-place clinker deposits in the Powder River coal basin of Wyoming—specifically, the physical properties and areal extent of the clinker, the empirical relationships between these properties and the amplitude and character of magnetic anomalies, and the correlation between engineering properties and seismic-refraction velocities. The results are being incorporated into three EIS's on proposed new coal mines.

Possible impact on fossils assessed for EIS

The Colorado Department of Highways, in preparing an EIS on proposed routes for an interstate highway in the southwestern Denver metropolitan area, requested information regarding the types and scientific value of fossils that might be found in excavations during construction. On the basis of geologic mapping in the area, G. R. Scott and R. M. Lindvall observed that dinosaur remains are common in the Denver and Dawson Formations of Late Cretaceous and Paleocene age and that varied mammalian fossils occur in Pleistocene deposits in the area.

INTERNATIONAL COOPERATION IN THE EARTH SCIENCES

International cooperation in the Earth sciences continues to form a modest but important part of USGS operations. Through technical assistance to strengthen Earth-resource institutions and programs in the developing countries, scientific and technical cooperation on subjects of mutual concern, and participation in international commissions and programs, the USGS attempts to apply Earth sciences in support of U.S. policies and in cooperation with national and international organizations abroad. The scope of such cooperation changes from year to year to meet the changing needs of sponsoring agencies, USGS interests, and the concerns of counterpart agencies in other countries. During the past year, response to natural disasters in other countries has been a highly visible and significant part of the USGS international effort and a dramatic illustration of the USGS commitment to apply Earth sciences for the betterment of mankind.

DISASTER RESPONSE

Natural phenomena such as volcanic eruptions, earthquakes, landslides, and floods cause severe economic and social problems and result in great loss of life and property. Many serious natural disasters have occurred in less developed countries, which have limited technical capability for studying the nature of the catastrophic occurrence. Without such studies, the capacity for mitigating the effects of future disasters and learning how to predict them is not advanced. The experience gained by these studies helps not only the afflicted country but also all countries, including the United States.

The USGS conducts intensive research on methods of predicting and minimizing the effects of natural disasters. Because of this program, the USGS has both the capability to respond to natural disasters abroad and the interest in studying disaster phenomena for the benefit of all countries subject to such disasters.

In carrying out these studies, the USGS attempts to mobilize and dispatch field teams to an affected country as rapidly as possible when USGS assistance is authorized by the Department of State and the host country. Operations are conducted in coordination with the Foreign Disaster Assistance Coordinator of the U.S. Agency for International Development (USAID) and in cooperation with counterpart agencies and scientists in the host country.

Objectives of the field teams include (1) working with local authorities to obtain timely on-the-spot information directed toward reducing loss of life and property damage; (2) studying ephemeral effects that may become obscured or lost within a short time after a disaster; and (3) advising on emergency measures and reconstruction programs. The teams also obtain data that can be used to assess hazards in other similar geologic environments, both abroad and in the United States. In meeting this objective, the USGS has developed procedures whereby teams of preselected experts can be dispatched promptly to the scene of a disaster.

In recent years, the USGS has greatly expanded its capability to monitor and study disaster-generating phenomena through remote-sensing techniques and communications satellites. A study of possible worldwide disaster warning and assessment systems using Earth Resources Technology Satellites was made at the request of USAID. The resulting report (Robinove, 1975) discussed the uses of satellite imagery in studying floods, earthquakes, volcanoes, drought, fire, crop disaster, hail storms, glacial activity, and water pollution.

The USGS response to foreign disasters has become more frequent in recent years as its expertise and technology have become better recognized, and support of these activities has increased. Of the 23 natural disasters that have been studied in foreign countries since 1946, 11 occurred during the decade 1960–70, and 8 occurred since 1970.

As a follow-up of its investigation of the Managua, Nicaragua, earthquake of 1972 (Brown and others, 1973; Schmoll and others, 1975), the USGS assisted the Government of Nicaragua in establishing a Center for Earthquake Hazard Reduction capable of monitoring seismic activity. This work, sponsored by USAID, involved the installation, operation, and maintenance of equipment and assistance in interpreting the records obtained from that equipment.

On February 4, 1976, a devastating earthquake struck central Guatemala, killing an estimated 23,000 people and leveling or seriously damaging numerous villages and small cities. The quake, which measured 7.5 on the Richter scale, was one of the most severe to hit the Americas in recent years. A team of eight men, including geologists, seismologists, and structural engineers, was quickly dispatched to Guatemala. The team was able to determine the cause, nature, and extent of damage, measure the size, nature, and location of aftershocks, and make preliminary recommendations to the Government of Guatemala (Espinosa, 1976). The epicenter of the earthquake was close to the Motagua fault, a major tectonic feature of Central America. Displacement was traced for 240 km by aerial observation and on aerial photographs. A preliminary report on the earthquake was prepared and transmitted to the Government of Guatemala.

In July 1975, Cotopaxi Volcano, 5,791 m high and 56 km from Quito, Ecuador, began to show activity of the type that normally precedes an eruption. Concern for the surrounding area led to a request for USGS assistance. A study of this potential hazard was undertaken by D. R. Mullineaux, C. D. Miller, and David Harlow (1976). The team concluded that the volcano would erupt, but the level of seismic activity showed that an eruption was not imminent (as of March 1976). Recommendations were made for minimizing loss of life and property if and when an eruption occurs.

As part of its research on earthquake hazards, the USGS manages and coordinates a worldwide network of more than 140 seismological observatories. Some are USGS owned and operated, but most are operated by universities and government agencies with technical assistance from the USGS. This network makes it possible for the USGS to record worldwide earthquake activity, report seismic events that may be destructive, and provide data on the seismicity of major fault zones around the world. Through the use of such data, areas of frequent earthquakes can be delineated and areas of potential earthquakes can be identified.

Seismograms produced by most of these observatories are microfilmed by the National Oceanic and Atmospheric Administration Environmental Data Service, which furnishes copies to subscribing organizations at a nominal cost. These seismograms provide an essential world data base for seismological investigations and research. Nearly 40,000 readings a month are used by the National Earthquake Information Service (NEIS) to prepare the twice-weekly publication "Preliminary Determination of Epicenters" and the weekly publication "Earthquake Data Report." Immediate readings are obtained from many observatories and used by NEIS for early earthquake reporting.

USGS personnel have installed nearly all the data systems at the 140 observatories. Continuing USGS support to the observatories usually consists of supplying operating materials and replacement parts, repair services, general technical advice and assistance, training, and, in some caes, on-site maintenance.

TECHNICAL ASSISTANCE AND PARTICIPANT TRAINING

During FY 1976, the USGS continued its program of providing cooperative technical assistance to less developed nations. Several long-term projects continued to be active, although some phases of the work were accomplished by short-term (2–6 months) assignments of USGS personnel. Continuing programs were conducted in remote-sensing methods and training, largely in Southeast Asia. Other aspects of overseas work involved short-term assignments not related to continuing long-range programs. These covered a wide range of Earth-science disciplines and were sponsored by various domestic and international agencies and foreign governments. In addition, cooperative programs with Algeria, Bolivia, and Peru were initiated.

Several noteworthy short-term assignments were completed in Latin America. J. J. Ritter (USGS), sponsored by the Organization of American States (OAS), visited parts of Argentina, Bolivia, and Paraguay to study sediment transport and channel morphology in the Río Pilcomayo Inferior basin. At the invitation of the Government of Chile, B. F. Grossling (USGS) visited Santiago to advise the Chilean National Oil Company on implementing Chile's new petroleum legislation. W. D. Carter (USGS) served as a member of an International Development Bank team investigating agencies responsible for mapping renewable resources in the five member countries (Costa Rica, El Salvador, Guatemala, Honduras, and Nicaragua) of the Central American Economic Group. Initial plans stress the training of Central Americans in the use of remote-sensing techniques and the purchase of equipment so that the participating countries can develop meaningful programs; complex future programs should lead to a total inventory of surface information relating to natural resources.

In Africa, under the sponsorship of the Food and Agriculture Organization (FAO), D. M. Carneggie (USGS) assisted FAO personnel in conducting a remote-sensing workshop in the Somali Republic. A 1-day field trip was included to compare Landsat images with ground features. Carneggie also assessed the remote-sensing needs of Somalian and Ethiopian governmental agencies in relation to rangeland development and agriculture.

In Bolivia, Peru, and Iran, USGS specialists made short visits as part of long-term programs. Under a long-term Memorandum of Agreement between the Bolivian Ministry of Mines and Metallurgy and the USGS, Harold Kirkemo (USGS) spent July of 1975 in Bolivia reviewing the current mining and exploration situation and evaluating present Bolivian scientific, technical, and financial capacity. On the basis of this information, he prepared a preliminary report on a general plan for implementing a proposed Mineral Exploration Fund. A new Memorandum of Understanding with Peru provided for a long-term study of copper deposits in the Morococha District. A preliminary analysis of the district, with emphasis on computer modeling of the Toro Mocho porphyry copper, was completed. Under NASA sponsorship, D. B. Krinsley (USGS) completed a short tour in Iran, where he advised the Iranian National Geographic Organization on the practical uses of Landsat imagery. Playa lakes in particular were studied as a source of water; the use of playa surfaces for roads and airfields was also investigated. Krinsley was invited to help locate a route for a major road to be built in the Great Kavir to connect northern and central Iran.

The USGS has for several years cooperated with the Central Treaty Organization (CENTO) in providing summer field-training courses for trainees from member countries (Iran, Pakistan, and Turkey). The 8th Annual CENTO Training Course was held at the Keban lead-silver-zinc mine in Turkey under the direction of E. H. Bailey (USGS) (Bailey and others, 1975). Instruction given in evaluating a mineral deposit covered mining methods, reserve calculation, and mining feasibility. Studies made as part of this 8-year program resulted in discoveries of minerals whose value far exceeds the cost of the program.

The long-term cooperative program (1945–75) with Brazil was completed in FY 1976; program activity continued at a high level up to the completion date of the project. The USGS was requested by Brazilian agencies to provide specialists for short assignments in several fields. As many as 17 temporary-duty assignments were completed during FY 1976, and three courses—geophysics and geology, economic geology, and the Third Annual Field Course—were taught by USGS scientists, with excellent results. In May 1976, a "Statement of principles for technical cooperation in the Earth sciences between the Governments of Brazil and the United States" was signed by the Brazilian Minister of Mines and Energy, the Acting Secretary of the Interior, and the Acting Director of the USGS.

The fourth extension of the Work Agreement between the Saudi Arabian Ministry of Petroleum and Mineral Resources and the USGS was signed July 10, 1975, and will be in effect until June 6, 1978. This extension calls for an expansion of USGS effort —128.25 professional man-years of work to be done in a 3-year period. Primary emphasis will be on mineral exploration and evaluation of mineral resources. For the first time since the project began in 1963, work has been scheduled in areas other than the Arabian Shield. In addition to a wide range of short-term activities, the USGS will continue a number of long-range programs involving geologic mapping, mineral exploration and drilling, aeromagnetic and gravity studies, analytical laboratory and petrologic support, topographic support activities, computer services, publications, and geochronology.

As a separate program under the auspices of the U.S.-Saudi Arabian Joint Commission on Economic Cooperation, G. F. Brown and T. G. McLaughlin (USGS) made a feasibility study of the development of irrigation in Wadi Dawasir as part of an interdepartmental team.

In the final stages of the recently completed long-term assistance program in Colombia, several USGS specialists visited that country during FY 1976. A four-man team gave a 3-week series of lectures at the postgraduate level covering mineral exploration, mine development, and mineral-deposit evaluation for 160 professional Earth scientists. A comprehensive manual was prepared and distributed to the participants. J. B. Cathcart (USGS) made a short visit to advise the Colombian Instituto Nacional de Investigaciones Geológico-Mineras on contracts for chemical testing of phosphate rock; this visit was one part of a 3-month phosphate investigation that took Cathcart to Brazil, Ecuador, and Mexico.

S. J. Gawarecki (USGS) led a 1-week seminar and workshop on the interpretation of satellite imagery for the East Asia IDOE transects in Bangkok, Thailand. The seminar was sponsored by the

U.N. Committee for Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP), in which the USGS has been active. Gawarecki was assisted during the sessions by T. W. C. Hilde (CCOP) and Prayong Angsuwathana (Thai Department of Mineral Resources) and logistically by J. O. Morgan (USGS). Eight representatives from CCOP countries were present: Thailand (1), Maylasia (2), Indonesia (2), the Philippine Islands (1), Japan (1), and Korea (1). The objective of the seminar and workshop was to instruct the participants in the use of Landsat imagery to improve existing geologic maps of selected transect areas of the island-arc systems of the CCOP countries. Transect maps were begun that will eventually supplement offshore geophysical data being gathered under the International Decade of Ocean Exploration (IDOE) program. The final result will be a structural cross section along the transect lines and a better understanding of the tectonics and mineralization of the Asian arc systems.

Following the CCOP sessions, Gawarecki, Morgan, R. B. McEwen, and T. M. Ragland (USGS) and S. A. Morain (University of New Mexico) lectured at the Second Thai National Remote Sensing Seminar and Workshop in Bangkok. The seminar, which concentrated on Landsat data applications in the fields of geology and hydrology, cartography, satellite technology, and agriculture, land use, and forestry, was attended by 109 registered participants, including 1 U.N. and 3 Nepalese representatives. Sixty-seven participants attended the workshops that followed. The seminar and workshop were sponsored by the Thai National Research Council and the U.S. Operations Mission to Thailand. The session was coordinated by Morgan in Thailand and staffed by Gawarecki.

After the Thai seminars, J. O. Morgan (USGS), at the request of USAID/Nepal, arranged a week-long informal Landsat technology and applications seminar and workshop in Kathmandu, Nepal. The instruction staff included Morgan, Morain, Mervin Stevens (FAO/U.N. Development Programme Forestry Officer), and Sathit Washarakitti (Forestry Department, Kasetsart University, Bangkok). The sessions were attended by 30 Nepalese government scientists having responsibilities in forest management and ecology, soil and water conservation, agriculture, watershed management and erosion control, irrigation, land use, and geology.

The fourth and fifth International Training Courses on Remote Sensing were held in May and September 1975 at the EROS Data Center in Sioux Falls, S. Dak. A total of 63 scientists from 31 countries attended the courses, which emphasized interpretation and use of photographs and other data acquired from spacecraft and aircraft for analysis of environmental conditions and Earth resources.

As part of the USGS technical assistance and cooperative programs abroad, 117 Earth scientists and engineers from 37 countries pursued academic, observation, or intern experience in the United States during FY 1976. Types of assistance to, or exchange of scientific experience with, each country during the fiscal year are summarized in table 3. Under USGS guidance, 1,700 participants from 97 countries had completed research, observation, academic, or intern-training programs in the United States as of June 1976.

Since the beginning of technical assistance work in 1940, more than 2,350 technical and administrative documents authored by USGS personnel have been issued. During calendar year 1975, 130 administrative and (or) technical documents were prepared, and 81 reports or maps were published or released in open files (see table 4).

TABLE 3.—*Technical assistance to other countries provided by the USGS during FY 1976*

Country	USGS personnel assigned to other countries			Scientists from other countries trained in United States	
	Number	Type	Type of activity[1]	Number	Field of training
Latin America					
Argentina	1	Hydrologist	D	1	Electronics; mass spectrometry.
				2	
Bolivia	1	Geologist	D	1	Uranium exploration.
	1	Hydrologist	D	-	
Brazil	10	Geologist	A	3	Mineral economics.
	5	Hydrologist	A	6	Mineral exploration.
	3	Chemist	A	1	Chemistry of uranium.
	1	Geophysicist	A	1	Geomagnetic and related studies.
				1	Remote sensing.
				1	Phosphates.
				1	Hydrology.
				1	Geology.
				1	Analytical techniques.
				3	Surface-water techniques.

See footnote at end of table.

TABLE 3.—*Technical assistance to other countries provided by the USGS during FY 1976*—Continued

Country	USGS personnel assigned to other countries			Scientists from other countries trained in United States	
	Number	Type	Type of activity [1]	Number	Field of training
			Latin America—Continued		
Central America	1	?	?	-	
Chile	1	Geophysicist	C	1	Remote sensing.
Colombia	5	Geologist	A	-	
		?	A	-	
Costa Rica	2	Geophysicist	C	-	
	1	Electronics engineer	C	-	
Dominican Republic				1	Remote sensing.
Ecuador	1	Geophysicist	C	-	
	3	Geologist	C	-	
Guatemala	2	Geologist	C		
	5	Geophysicist	C		
	1	Physical scientist	C		
	1	Electronics technician	C		
Mexico	10	Geologist	C	3	Remote sensing.
	2	Hydrologist	C		
	1	Computer programmer	C		
	3	Research chemist	C		
	1	Spectrographer	C		
	1	Data clerk	C		
	1	Geophysicist	C		
Nicaragua	1	Geophysicist	A	-	
Panama				1	Geochemistry.
Paraguay				1	Artificial recharge.
Peru	4	Geologist	C	-	
Uruguay				1	Remote sensing.
			Africa		
Egypt				1	Field mineral surveys.
				3	Remote sensing.
Ethiopia	1	Research forester	A	-	
Ghana				1	Remote sensing.
Kenya	1	Hydrologist	A, B	-	
Kuwait	1	Hydrologist		1	Remote sensing.
Malagasy				1	Seismology.
Niger	1	Hydrologist	D	-	
Somali Republic	1	Geophysicist	C	-	
Swaziland				1	Remote sensing.
			Near East and South Asia		
CENTO/Turkey	2	Geologist	C, D	-	
	1	Hydrologist	C		
CENTO/Turkey and Iran	1	Geologist	C	-	
India	1	Hydrologist	D	1	Isotope geology.
				1	Lithography and photolab process.
				1	Exploration geochemistry.
				7	Remote sensing.
				1	Geologic cartography and lithography.
Iran	1	Geologist	C	8	Remote sensing.
Iraq				1	Remote sensing.
Jordan	1	Hydrologist	A, B	-	
Lebanon				1	Remote sensing; photogrammetry.
Nepal	1	Hydrologist	A, D	-	
	3	Remote-sensing specialist	D		
Pakistan				1	Remote sensing.
				1	Uranium exploration.
				1	Nuclear analysis.
Qatar	1	Hydrologist	D	-	
Saudi Arabia	6	Hydrologist	A, D	8	Remote sensing.
	19	Geologist	A, B, D	1	Printing and reproduction.
	1	Water economist	D	1	Intensive English.
	1	Desalination expert	D	1	Accounting and administration.
	1	Civil engineer	D	3	Geophysics.
	5	Administrative officer	A, B	3	Computer.
	2	General services officer	A, B	1	Editing and publications.
	7	Geophysicist	A, B	1	Cartography.
	1	Rock properties specialist	A, B		
	2	Remote-sensing specialist	A, B		
	2	Editor	A, B		
	4	Cartographer	A, B		
	2	Cartographic technician	A, B		

See footnote at end of table.

TABLE 3.—*Technical assistance to other countries provided by the USGS during FY 1976*—Continued

Country	USGS personnel assigned to other countries			Scientists from other countries trained in United States	
	Number	Type	Type of activity[1]	Number	Field of training
Near East and South Asia—Continued					
Saudi Arabia (Cont'd.)	3	Chemist	A, B		
	2	Electronics specialist	A, B		
	1	Computer specialist	A, B		
	1	Driller	A, B		
	2	Topographic engineer	A, B		
	2	Mathematician	A, B		
Turkey	1	Geologist	C	1	Seismology.
				4	Remote sensing.
Yemen	1	Hydrologist	A, B	2	Institutional development (water).
	1	Geologist	C		
	1	Hydrologist	C		
Far East					
Burma				1	Mineral exploration.
				1	Photogeology.
				1	Geology.
China, Republic of				6	Remote sensing.
Indonesia	1	Chemist	A	1	Ground-water investigations.
				2	Remote sensing.
Japan				1	U-Pb isotopic systems.
				2	Remote sensing.
Malaysia	1	Geologist	D	-	
	1	Engineer	D		
Philippine Islands				2	Remote sensing.
				1	Geochemistry.
Thailand	1	Geologist	A	4	Remote sensing.
	6	Remote-sensing specialist	A		
	1	Chemist	A		
Other					
Australia				1	Engineering geology.
				1	Fission-track dating.
				1	Seismology.
Canada				1	Remote sensing.
CENTO (Pakistan, Turkey, Iran)	1	Geologist	C	-	
Poland	4	Geologist	C	-	
Portugal				1	Remote sensing.
Romania				1	Remote sensing.
Spain				3	Remote sensing.
Sweden				1	Remote sensing.
Switzerland				1	Geochronology; isotope geology.
United Kingdom				1	Remote sensing.
				1	Petrochemistry of rhyolite obsidians.
Yugoslavia	4	Geologist	C	1	Airborne magnetometrics.

[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.

SCIENTIFIC AND TECHNICAL COOPERATION

A Memorandum of Agreement between the USGS and the Bundesanstalt für Geowissenshaften und Rohstoffe (BGR) of the Federal Republic of Germany, signed in July 1975, provides a mechanism for exchanging information regarding activities and scientific results of ongoing projects and for cooperating on projects of mutual interest. R. E. von Huene (USGS) visited the BGR in Hanover, Germany, to identify specific areas in which USGS-BGR cooperation would be mutually beneficial. Potential fields of interest are ocean-floor mineral deposits, continental margin tectonics, and geophysical instrumentation and data-reduction techniques.

A 3-year program with Spain, sponsored by the National Science Foundation, began in 1973. The objectives of this program were to acquire marine geologic information needed to evaluate the resource potential and physical characteristics of parts of the Continental Shelf of Spain. Preliminary interpretation of seismic-reflection profiles by H. G. Greene (USGS) and counterparts indicated that the Almeria fault may be a transform fault and may be the modern boundary between the Iberian and African plates. The data will be useful to the USGS

TABLE 4.—*Technical and administrative documents issued in calendar year 1975 as a result of USGS technical and scientific cooperative programs*

Country	Project administrative reports	Reports or maps prepared: Approved for publication by USGS or counterpart agencies	Published in technical journals	Published by USGS
Afghanistan	2	1	--	--
Africa	1	2	--	2
Bolivia	1	--	--	1
Brazil	7	3	--	3
Colombia	4	1	--	5
Costa Rica	--	1	--	--
Indonesia	2	--	2	2
Jordan	1	--	--	1
Kuwait	1	--	--	--
Liberia	2	11	1	3
Mexico	--	1	--	1
Nicaragua	--	--	--	1
Pakistan	1	22	--	24
Saudi Arabia	13	23	10	14
Thailand	1	1	4	--
Turkey	--	1	--	--
Yemen	1	--	--	--
General	10	16	1	6
Total	47	83	18	63

domestic investigations of ocean basins in the Gulf of Mexico and the Caribbean Sea.

Under the Special Foreign Currency Program (SFCP), work in Poland yielded important results on base metals in carbonate rocks and on mining hydrology. SFCP activities in Yugoslavia yielded innovative geophysical methods for defining permeability and tracing underground caverns and streams and for making deep seismic soundings fundamental to understanding the structure of the crust and upper mantle in relation to mineral deposits and metallogenic processes.

Funded by the National Science Foundation and the University of New Orleans, William Back, B. B. Hanshaw, and Meyer Rubin (USGS) continued a cooperative program to study the regional geologic controls of the hydrologic system in the Yucatan peninsula and the Sierra del Burro region of Mexico Their work will be the basis for planning studies and water development of carbonate aquifers in the United States and Mexico.

R. D. Regan and A. H. Chidester (USGS) and B. D. Marsh (Johns Hopkins University) traveled to the Central African Republic to conduct a ground investigation of the Bangui magnetic anomaly. This interesting anomaly, first discovered by satellite measurements and confirmed by aircraft surveys, encompasses most of the Republic. With the cooperation of the government of the Central African Republic and the Office de la Recherche Scientifique et Technique of France, a field investigation was conducted over a road traverse distance of approximately 1,500 km. Selected rock samples were collected and shipped to the United States. Ground magnetometer readings and magnetic susceptibility measurements were obtained at regular intervals throughout the road traverse. The entire data set (satellite, aircraft, and ground measurements) will be combined in a detailed analysis of this major magnetic anomaly. A detailed report will be sent to the Government of the Central African Republic.

INTERNATIONAL COMMISSIONS AND REPRESENTATIONS

The USGS accepted the lead role in a Working Group on the Precambrian under the auspices of the Subcommission on the Precambrian, part of the Commission on Stratigraphy of the International Union of Geological Sciences. The Working Group was asked to cover the United States and Mexico and to cooperate closely with a similar group being established in Canada. An organizational meeting held in Salt Lake City, Utah, in October 1975 established as a first goal the preparation of chronometric geologic charts to show the state of knowledge concerning the geochronologic age of Precambrian rock bodies and correlations in seven Precambrian "provinces" in the United States and Mexico.

To a small extent, the USGS participates in the International Atomic Energy Agency through membership in two Working Groups of the Working Party on Uranium Resources. H. C. Granger is a member of Working Group I (chemical and physical mechanisms in formation of uranium mineralization, geochronology, isotope geology, and mineralogy); F. C. Armstrong represents the USGS in Working Group V (other uranium deposits). R. W. Schnabel attended the Joint Nuclear Atomic Energy-International Atomic Energy Agency Committee meeting in Vienna, Austria, as a spectator in anticipation of full USGS membership on the committee.

A report on the Seminar on Volcanic and Seismic Risk, held in San José, Costa Rica, July 13–18, 1975, was sent to the Secretary General of the Pan American Institute of Geography and History (PAIGH) and to the Secretary General of the OAS, primary sponsors of the seminar. J. N. Jordan, U.S. National Member of the PAIGH Commission on Geophysics, was the PAIGH coordinator for the seminar, which was attended by 105 people from 22 countries.

A. H. Chidester and P. W. Guild attended the 3d Annual Conference on African Geology, which was sponsored by the Geological Society of Africa.

The 1975 CENTO Working Group for Study of Intrusive Rocks and their Relation to Mineral Deposits spent 12 days in the Guleman-Maden area of Turkey and 11 days in the Faryab-Esfandagheh area of Iran studying chromite and copper deposits in ophiolites. N. J. Page was the U.S. coordinator. Recommendations were made regarding types of exploration techniques that should be undertaken. A. F. Holzle participated in the 14th Meeting of the CENTO Advisory Group on Minerals Development in December 1975 in Ankara, Turkey.

The USGS continued to participate in activities of the International Geological Correlations Program (IGCP). J. A. Reinemund served as a member of the IGCP Board, which held its 1976 meeting in Ibadan, Nigeria, and P. W. Guild served as a member of IGCP Scientific Committee 3, which met in Paris, France. P. C. Bateman is the leader of an IGCP project on circum-Pacific plutonism for which meetings were held in Vancouver, British Columbia, and Kuala Lumpur, Malaysia. R. B. Neuman participated in the project on the Caledonian orogen, and W. P. Irwin took part in the project on ophiolites. A new IGCP project on standards for computer applications in resource studies was initiated under the leadership of A. L. Clark, and a project on remote sensing and mineral exploration was authorized under the leadership of L. C. Rowan and W. D. Carter.

At the request of the Economic and Social Commission for Asia and the Pacific and the U.N. Development Programme (UNDP), F. H. Wang participated in the UNDP Technical Mission to member countries of the Committee for Coordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas (CCOP/SOPAC) in December 1975 to assess offshore prospecting activities, evaluate the potential for marine resources and marine environmental utilization, consider further UNDP assistance, and formulate guidelines for the project. Wang also organized a seminar on petroluem-data storage and retrieval systems held in April 1976 in Jakarta, Indonesia, under the auspices of the Coordinating Committee for Joint Prospecting of Mineral Resources in East Asian Offshore Areas (CCOP/EA). This seminar was the preparatory phase prior to feasibility studies and systems design for establishing national petroleum-data centers and sample repositories. These systems are urgently needed by CCOP member governments to handle the voluminous amounts of exploration and drilling data provided by private companies.

M. J. Terman, C. D. Masters, R. E. Garrison, and J. A. Reinemund attended the 12th session of the CCOP in Tokyo, Japan. F. H. Wang served as Principal Marine Geologist of the CCOP Secretariat. Wang, S. J. Gawarecki, and J. O. Morgan participated in a CCOP Workshop on Interpretation of Satellite Imagery for East Asia IDOE Transects held in Bangkok, Thailand.

USGS support of the international Circum-Pacific Map Project sponsored by the Circum-Pacific Council for Energy and Mineral Resources included coordination of the work of the five panels of Earth scientists in the Pacific region who are compiling the maps.

Geographic maps at a scale of 1:10,000,000 covering five overlapping areas (four quadrants and Antarctica) of the Pacific basin and bordering lands and one map at a scale of 1:20,000,000 of the entire region were compiled by the USGS and are being edited. They were plotted on an equal-area projection. The five maps will serve as base maps for geologic, tectonic, energy, and mineral maps, compilations of which are to be completed in 1978. A geologic, tectonic, and resource synthesis will be made on the 1:20,000,000-scale Pacific basin map, following compilation of the other maps.

During the year, a geologic map of the Caribbean area was submitted by J. E. Case for the northeastern quadrant. A computer plot of seismic epicenters was made by A. C. Tarr for the northwestern quadrant; similar plots of the other quadrants are in progress. The geology of the eastern two-thirds of China was compiled by M. J. Terman for the northwestern quadrant map.

G. I. Smith, J. D. Sims, and T. N. V. Karlstrom attended the International Symposium on Global-Scale Paleolimnology and Paleoclimate in Kyoto, Japan.

SUMMARY BY COUNTRIES

BOLIVIA

I. E. Klein made a preliminary engineering geology reconnaissance of sites for multipurpose reservoirs on Río Pilcomayo and Río Pilaya in Bolivia. Although the areas studied are believed to be generally favorable, additional onsite studies will be required to determine the feasibility of using them for reservoir sites.

BRAZIL

New structural zone identified

Mapping of linear and circular features on Landsat computer-enhanced images of southern Brazil by T. W. Offield revealed a previously unknown major east-west structural zone. This zone extends 185 km across the entire image and probably extends farther eastward along a straight river course to the Atlantic coast. Its eastward projection coincides in position with a break in the narrow Continental Shelf and a major South Atlantic transform fault. A field visit showed that the zone contains most of the economically significant copper, gold, and tin localities in the State of Río Grande do Sul. Within the zone, mineral veins and mineralized greisen generally trend east. Area fracture patterns change across the zone, and breaks or alinements in magnetic trends and gamma-ray anomalies occur along the zone. Formation of the zone predates upper Precambrian rocks, but it clearly has affected much younger tectonic events. Other major lineaments mapped from the images trend northeast and northwest; some are extensions of known faults, and others are newly defined. They generally show in the aeromagnetic patterns; some of them, together with circular features, are spatially associated with andesite and rhyolite intrusive and extrusive rocks.

Hydrologic analysis

Early in FY 1976, O. G. Lara conducted a workshop in Brazil on methods and techniques of hydrologic analysis, which were applied to study the hydrologic characteristics of the Río Ibicuí basin.

COLOMBIA

A geological and geochemical reconnaissance by J. G. Evans and geologists of the Instituto Nacional de Investigaciones Geológicas-Mineras (Ingeominas) indicated widespread gold mineralization in the Eastern Cordillera northeast of Bucaramanga, Colombia. The area studied included about 400 km^2 of the Santander Massif (Precambrian Bucaramanga Gneiss, Triassic quartz diorite, Jurassic-Triassic alaskite and quartz monzonite, and post-Early Cretaceous monzonite porphyry). The California and Vetas Districts, which have produced gold since at least the middle 1500's and possibly from pre-Colombian times, are within this area.

The gold occurs in relatively high concentrations in hematite and pyritiferous quartz veins along breccia zones and parallel to the foliation of the gneiss and is disseminated in zones of hydrothermally altered igneous and metamorphic rock. In the California District, the gold is associated with large but subeconomic deposits of copper.

Zones of extensive argillic alteration in the crystalline rocks and soil samples containing relatively high concentrations of gold- and copper-bearing minerals also are encountered beyond the limits of the known mining areas. The economic potential of this mineralization is not known but merits additional study.

INDONESIA

Volcanic rocks in the Padang area of Indonesia along the mountainous western coast of Sumatra, studied by G. W. Leo, include (1) andesite associated with young, historically active volcanoes and with seemingly older (dissected and (or) extinct) volcanoes; (2) andesite and associated tuff possibly related to fissure vents; and (3) younger rhyolitic and andesitic pumice tuff overlying andesite (Kastowo and Leo, 1973). Andesites throughout the area are two-pyroxene rocks of fairly uniform composition (SiO, 55.9 to 61.2 percent; K_2O, 1.13 to 2.05 percent). Five K-Ar whole-rock age determinations by R. F. Marvin and one by J. D. Obradovich on andesite samples from extinct volcanoes and possible fissures flows show a range of 0.45 ± 0.02 to 0.81 ± 0.2 million years; rhyolitic pumice tuff gave an age (determined by Obradovich) of 0.19 ± 0.04 million years. The $^{87}Sr/^{86}Sr$ ratios, determined by C.E. Hedge on a total of 12 samples including the older and younger tuffs, fall generally into two groups—0.7044 to 0.7048 and 0.7060 to 0.7066.

The lower ratios, which are on the high side of normal for island-arc volcanic rocks, represent three older tuffs and two volcanoes. The higher ratios, representing most of the lavas as well as the younger tuffs, are well above those of most island-arc volcanic rocks; instead, they resemble those of continental andesites. These high $^{87}Sr/^{86}Sr$ ratios could reflect crustal contamination; however, although older granitic and metasedimentary rocks are abundant in the region, their distribution does not obviously relate to the divergent $^{87}Sr/^{86}Sr$ ratios in the volcanic rocks.

In the same suite of volcanic rocks, abundances of rare-earth elements show enrichment in light lanthanides in all the samples, in addition to a moderate negative europium anomaly suggesting significant differentiation prior to eruption.

KENYA

N. E. McClymonds, in cooperation with the Kenyan Ministry of Water Development, made reconnaissance ground-water studies in Kenya's Northeastern Province. Six test holes were drilled to depths ranging from 109 to 195 m. Two were converted to production wells.

MEXICO

Definition of mineral target areas

In cooperation with the Mexico Consejo de Recurso Minerales, M. D. Kleinkopf, G. L. Raines, D. W. O'Leary, and counterparts found that a combination of techniques helped to define mineral target areas, which are blind intrusives and associated mineralization in areas covered by pediment gravels and volcanic debris. Reconnaissance gravity data and 1-km-spaced aeromagnetic data defined possible areas of buried intrusives or volcanic centers. Lineaments on Landsat images were analyzed statistically to define areas of mineral potential on the basis of multiple intersections of trends known to be geologically significant. For some areas of lineament intersection and gravity and magnetic anomalies, mineral alteration was indicated on color-ratio composites made from computer enhancement of Landsat images through stretching and ratioing of the spectral bands. Verification of mineral potential was tested geochemically and included sampling of soil gas, vegetation, stream sediment, rocks, and soils.

Landsat–1 land-use mapping project

According to D. T. Lauer, image interpretation and map compilation of land use for all of Mexico, at a scale of 1:1,000,000 using color-composite Landsat–1 imagery, are nearly finished. Final map sheets have been compiled for the large central regions of the country. In addition, the image interpretation work for the northwestern, southern, and southeastern regions is finished and is being rechecked with the aid of recently collected ground data.

Lauer spent 1 day in the field in the vicinity of Villa Hermosa, with Landsat–1 images in hand, studying land-use features and conditions in the States of Tabasco and Chiapas. This tropical region in southeastern Mexico has been difficult to map with Landsat–1 imagery because of cloud-cover problems and the homogenous appearance of the dense, complex jungle vegetation on the imagery. Field observations proved useful for verifying map results and for suggesting new approaches (that is, manual-computer analysis) for making an assessment of the resources in the tropical regions of Mexico.

PALAU ISLANDS (TRUST TERRITORIES)

Gilbert Corwin, H. S. Ladd, and W. S. Cole concluded that the present distribution and relations of the upper Tertiary and Quaternary limestone of the Palau Islands are explained best by a geologic history of rapid reef growth and solution in an environment of continuing deformation and fluctuating emergence and submergence of the reefs relative to sea level. Older Miocene limestone forms axial ridges that have tilted crests and are flanked by untilted upper Miocene and Quaternary limestone that compose ridges and platforms at successively lower elevations down to the level of existing reef flats. Lineaments that may be identified on aerial photographs and that commonly involve offsets of the ridges have dominant trends that may be attributed to post-Miocene deformational stresses. The pattern of these trends, extrapolation of structural data for the volcanic islands, and differences in elevations of the flanking limestone ridges and platforms permit reconstruction of a geologic history for the limestone islands that begins with disruption of extensive middle Miocene reef flats and a relatively long period of emergence prior to the establishment of flanking reefs during the late Miocene. The intensity of deformation and relative movements may relate in part to structural evolution of the Yap arc to the east.

NEPAL

H. M. Babcock visited Nepal for consultation and review of the results of the recently completed 6-year program of ground-water investigation and development sponsored by the USGS and USAID.

NIGER

Say Arrondissement in Niger illustrates some of the hydrologic problems that are common to much of the Sahel of Africa. Although the area receives up to 750 mm of rain annually, seasonal precipitation patterns, high evaporation rates, stands of brush and trees that intercept most of the water that enters the ground before percolation to the water table, and extensive areas of lateritic duricrust inhibit recharge of ground water. Even though they have not been tested, the Precambrian crystalline rocks that underlie the area are unlikely to yield water freely to wells. J. R. Jones, after a reconnaissance of the area, advised that test holes be drilled before a program to construct wells for village and livestock supply is planned. He also advised that some seasonal surface runoff should be spread on tilled fields, that some should be concentrated in stock ponds and cisterns, and that opportunities for artificial recharge should be explored.

Several applications of Landsat (ERTS) imagery to range- and water-management problems in the Sahelian region were described by Cooley and Turner (1975). These include support of disease vector control measures (for example, for tse-tse and river blindness fliesñ); bush-burning evaluation; analysis of accelerated erosion problems and those associated with the annual flood of the Niger River; and the identification of localities favorable for the accumulation and production of ground-water supplies.

PAKISTAN

M. J. Mundorff, P. H. Carrigan, Jr., T. D. Steele, and A. D. Randall (1976) evaluated Salinity Control and Reclamation Projects (SCARP) in the Indus Plain of Pakistan. They concluded that SCARP has been notably successful in lowering the water table, in providing supplemental water for irrigation and for leaching of salinized soils, and in improving crop production. During the latter part of the 19th century and the first few decades of the 20th, recharge from unlined irrigation canals raised the water table until much of the agricultural land was severely waterlogged or salinated; during the late 1950's, agricultural land was being damaged at a rate of 20,000 to 40,000 ha/yr. SCARP, while it has reversed the trend of deterioration, has caused some changes in water quality at some places, but these, as of 1972, had not significantly affected the utility of the water for irrigation. Problems associated with reclamation include control of deterioration in the performance of tubewells and their rehabilitation, local brackish- or saline water encroachment, and maintenance of a favorable balance in the ground-water system.

Rapid growth of shallow (0–60 m) private tubewell development has introduced complicating factors into the reclamation planning of the early 1960's, which had emphasized public deep (60–120 m) tubewell development through the SCARP program. However, the long-term response of the water table is the same since it depends upon the total volume of water pumped, not upon the depth or capacity of the wells. Neither type of pumping regime has any definite advantage with respect to water quality. The diversion of high-quality water from the Chenāb and Jhelum Rivers during periods of surplus flow would provide the opportunity to recharge the Punjab aquifer. Such recharge would be of much better quality than water percolating downward from irrigated fields.

PERU

A map showing the distribution of earthquake damage in metropolitan Lima, Peru, has been constructed, according to A. F. Espinosa. This map is based on field observations of different types of structures that were damaged in the October 3, 1974, Lima earthquake. A scale has been developed that classifies damage into a three-parameter distribution: (1) degree of damage, from negligible to collapse; (2) type of structure, from adobe to quincha to reinforced concrete; and (3) type of materials used in construction (adobe, bricks, masonry, reinforced concrete, steel-rod reinforcement, and so forth). The maps shows three major areas of intense damage: the suburbs of Callao, La Molina, and Chorrillos-Barranco.

QATAR

John Vecchioli (1976) evaluated a plan for using desalinated water for the artificial recharge of Qatar's principal aquifer. To maximize the use of the desalinated water and to minimize the amount of energy used to put the desalinated water underground, Vecchioli suggested that the desalinated water be distributed for agricultural use and that only the surplus should be recharged to the aquifer.

SAUDI ARABIA

Geochronology

R. J. Fleck, in a study of the Arabian Shield, found that Rb-Sr ages from plutonic rocks in the shield range from 600 million years to more than 1.2 billion years. The oldest rocks are diorite and quartz diorite batholiths intruded into a sequence of mafic to intermediate volcanic and volcanoclastic rocks. Granodiorite orthogneisses, probably emplaced during the period of greatest tectonism, intrude both the volcanic terrane and the diorites and yield ages of 700 to 800 million years. Late- or post-orogenic plutons, referred to the Pan-African "event," range in age from 620 to 680 million years and represent the last major intrusive event affecting the Arabian Shield.

Newly discovered copper-zinc deposit

Detailed surface mapping and study of drill cores were completed at Kutam, Saudi Arabia, by C. W.

Smith. The studies, which emphasized the structural control of mineralization, indicated that the copper-zinc mineralization formed at the juncture of three regional shear systems that strike N. 20° W., N. 45° W., and N. 65° W. and that all dip steeply to the west.

The mineralized area is 120×350 m; it is bounded by faults in quartz porphyry that has been intensely sheared, foliated, and brecciated; the rocks are extremely altered, including silicification and formation of chlorite, sericite, biotite, muscovite, and garnet. Sphalerite, chalcopyrite, pyrite, and pyrrhotite are introduced along vein-fault systems, especially where two or more fractures join. Locally, the sulfides replace chlorite pods and seams.

Diamond drilling and geophysical surveying are being used to evaluate the Kutam prospect. One hole, laid out to test an induced potential anomaly and the northwestern continuation of the mineralized zone, was drilled to a depth of 263.70 m. Although the core did not indicate material of ore grade, it showed that copper mineralization is more extensive in the northwestern part of the deposit than investigators had previously known.

A second hole was drilled in the opposite direction in the same plane to test the fault zone that bounds the southwestern side of the Kutam deposit and that, in other holes, contains zones enriched in zinc. The hole also was intended to test an electromagnetic anomaly, which appeared to coincide with the surface trace of the fault. Traces of malachite were found in core from the oxidized zone, and the interval from 143 to 166 m, across the fault zone, contains pyrite and intensely altered rock. No concentrations of ore minerals were seen, and analytical data from the core are not yet available.

A third hole tested a strong electromagnetic anomaly along the southeastern projected extension of the Kutam deposit.

The deepest hole intersected a good grade of copper ore at a downdip length of 230 m below old outcrop workings. The core showed copper mineralization across a true thickness of 100 m of deposit.

The mineralization, faults, dikes, and chloritized and silicified zones can be correlated from drill hole to drill hole and can be projected to the surface. The mineralization is zoned—higher zinc values are on the hanging-wall area, and higher copper values are on the footwall. The zoning is confirmed by surface geochemistry and assays of drill-core samples. Lineations along shear-plane intrusions plunge 30° to 60° to the southeast and appear to control metallization. Consequently, the intensely sheared, altered, and mineralized zone at the surface plunges steeply to the southeast of the ancient workings, and extensions will be found only by deep drilling.

Genesis of sulfide deposits

Studies of disseminated and massive base- and ferrous-metal deposits in volcanogenic terranes of late Precambrian age in Saudi Arabia by R. J. Roberts, in collaboration with B. R. Doe and M. H. Delevaux, identified the major classes of deposits: syngenetic, epigenetic, and deposits of dual origin (that is, both syngenetic and epigenetic).

The syngenetic deposits are extensive, stratiform, fine grained (0.001–0.5 mm), and commonly of simple mineralogy, mostly pyrite-pyrrhotite or chalcocite-pyrite. They resemble the Red Sea metalliferous muds in texture and structure and are thought to have formed on the sea floor. Pyrrhotite-pyrite deposits in Wadi Wasat and chalcocite-pyrite deposits in Wadi Yiba have been assigned to this class.

The epigenetic base-metal deposits are lenticular or podlike, disseminated, or massive bodies in shear zones. They consist of coarse-grained (1–5 mm) pyrite, sphalerite, and chalcopyrite with minor amounts of gold and silver. Deposits in the Wadi Bidah district and Kutam are representative of this class.

Base-metal deposits that may be both syngenetic and epigenetic are lenticular or pipelike and locally crosscut bedding or layering. They are characterized by complex sulfide, sulfosalt, telluride, and native metal-mineral assemblages that occur as fine-grained laminated ores and as coarse-grained aggregates. Associated alteration facies are an inner sericitic-chloritic zone and an outer montmorillonite-zeolite zone; the inner metal zonation is copper and zinc, and the outer metal zonation is lead, gold, and silver. Jabal Sayid and Nuqrah are typical of this class.

These Saudi Arabian base-metal deposits of dual origin may have started as low-temperature syngenetic deposits on the sea floor. As volcanism and sedimentation continued, following deposition of the base-metal-bearing beds, the environment changed from an open system at the seawater interface to a partly closed system below the sea floor. Continued flow of hydrothermal solutions through the mineralized beds and volcanic and sedimentary pile resulted in recrystallization and reequilibration of the original low-temperature mineral and alteration assemblages and formation of higher temperature assemblages. The original syngenetic deposit may thereby have been changed into a predominantly epigenetic deposit. Isotopic ratios of lead in these deposits closely resemble those from nearby epigenetic gold- and silver-bearing veins. The terms epigenetic-volcanogenic or epivolcanic are proposed to designate these distinctive deposits.

Mahd adh Dhahab

Mahd adh Dhahab is the largest of the numerous ancient gold mines scattered through the Precambrian shield of Saudi Arabia and the only one having recent production. During the period 1939–54, 21,708 kg of fine gold and 28,406 kg of silver were produced by the Saudi Arabian Mining Syndicate. An approximately equal amount was taken during ancient times.

Mineralization at Mahd adh Dhahab includes free gold and silver, tellurides, pyrite, sphalerite, and chalcopyrite in and associated with a system of north-trending quartz veins and quartz veinlet stockworks. Country rocks are a north-dipping sequence of pyroclastic and transported pyroclastic rocks of the Murdamam Group that are locally highly silicified and potassium-feldspathized.

The prime target for this exploration program was a north-trending zone of quartz veins and breccias, faults, alteration, and metallization approximately 400 m wide and 1,000 m long. The ancient and recent mine workings are located in the northern part of this zone. Although the quartz veins and alteration cut all rock types, the major metallization is confined to the intersection of veins and agglomerate. Ten diamond drill holes explored geochemical and geological targets in the zone.

A significant new zone of metallization was discovered 700 m south of the ancient and recent mine workings and within the same major zone of quartz veins, alteration, and faults. Metallization in this southern mineralized zone occurs at the intersection of quartz veins and a distinctive and highly altered agglomerate. The total zone of vein and agglomerate intercept is potentially metallized and comprises a block of ground 10 m thick, 400 m wide along strike of the agglomerate, and 250 m long downdip. Tonnage of this block is 15.6 million tonnes. The explored part contains a total of 4.1 million tons that averages 6 g/t Au and 22 g/t Ag. High-grade bodies within the explored portion have a potential resource of 1.0 million tonnes containing 27 g/t Au and 73 g/t Ag.

Red Sea continental margin

The contact between oceanic crust and continental crust is well exposed in the vicinity of Jizan in southwestern Saudi Arabia. This exposed position of the continental margin is mutually affirmed by (1) reconnaissance geologic mapping (G. F. Brown, R. O. Jackson, R. G. Coleman, D. G. Hadley, and D. L. Schmidt), (2) petrology, geochemistry, and geochronology (Coleman and R. J. Fleck), (3) a gravity survey (Mark Gettings and H. R. Blank, Jr.), and (4) a synthesis of aeromagnetic surveys of the Red Sea (S. A. Hall and G. E. Andreasen).

A tholeiitic sheeted dike-on-dike complex is in contact with Phanerozoic sedimentary rocks and underlying Precambrian shield rocks in the Red Sea coastal plain. This contact exposure is about 4 km wide by 150 km long and extends southeastward into Yemen. A northeasterly transform fault, formed during the initial opening of the Red Sea, displaces the continental margin at the northwestern end of the sheeted-dike exposure. A few tholeiitic dikes, about parallel to the contact, intrude the continental crust adjacent to the sheeted-dike complex. The Jabal at Tirf layered tholeiitic gabbro and granophyre body intrudes into the sheeted-dike complex; at least one other similarly situated body of gabbro is exposed. Hence, three elements of an ophiolitic suite characteristic of oceanic crust are exposed.

Particular credence is given to the on-shore position of the continental margin by a coincident gravity step of 140 to 150 mGal (gradient 4–5 mGal/km). The age of the initial opening can be inferred by extrapolating the sea-floor magnetic-stripe chronology from an identifiable anomaly of 26 to 27 million years to the contact. If a reasonable spreading rate is assumed, the initial new crust can be dated at about 30 million years old. The sea-floor magnetic-stripe chronology then suggests that a first-stage opening of the Red Sea extended from 30 to 22 million years ago.

Plateau basalt of the As Sirat was extruded penecontemporaneously with the first-stage spreading. The As Sirat alkali basalts (basanite to hawaiite) form an erosional remnant stack of flows about 580 m thick and lying about 100 km northeast of the sheeted-dike complex. The lower flows are dated at about 29 million years and the upper flows as exposed at about 24 million years.

Cessation of the initial opening of the Red Sea about 22 million years ago and the relaxation of stable lateral-spreading forces resulted in a tensional zone along the newly formed edge of the continental crust. Highly differentiated alkalic gabbro intruded as spectacularly continuous, linear dikes along a zone about 100 km wide by 1,500 km long on the eastern edge of the Red Sea coast in the continental crustal rocks. The dikes are well demarcated by sharp, linear aeromagnetic anomalies.

The tensional zone of alkalic dike emplacement may have been a hinge line with subsequent deposition of several kilometers of Miocene sediments and evaporites in a Red Sea basin to the west and with appreciable erosion across the continental margin to the east, such that the hypabyssal layered gabbro plutons near the edge of the newly formed oceanic floor and the hypabyssal alkalic dikes near the edge of the continental margin became exposed. Later, during the Miocene, the sedimentation in the Red Sea basin transgressed across the eroded continental margin and deposited the Baid Formation. The Baid contains a thin basal part of immature conglomerate, sandstone, and limestone, and a thick middle(?) argillaceous part that suggest only modest relief on the continental shield to the east. The upper part as exposed contains abundant white tuffaceous sediments that may have been derived from several rhyolitic(?) eruptive centers that cut the Baid rocks near the above-mentioned transform fault. Alkalic basalt flows are also part of the Baid Formation, and diabasic dikes and sills are emplaced into the Baid as well. The rhyolite(?) is intensely altered and pyrititized, and its position near the transform fault suggests the prospect of metallization in the vicinity.

Subsequently, the Baid rocks were moderately deformed, perhaps at the same time that the thick Miocene deposits of the Red Sea basin were extensively block faulted. This deformation seems to coincide with the initiation of second-stage spreading about 5 million years ago and with the high uplift (1 to 2 km) of the escarpment area east of the continental margin. This, in turn, initiated the erosion that resulted in the rugged Red Sea Escarpment of today. The second-stage spreading continues today and has resulted in the 50-km-wide axial trough of the Red Sea.

Alternative sources of water supply for Ar Riyāḍ

The USGS is the lead agency in a study of alternative sources of water supply for the city of Ar Riyāḍ (Riyadh), Saudi Arabia, conducted under the auspices of the U.S.-Saudi Arabian Joint Commission on Economic Cooperation. S. S. Papadopulos is the leader of the team that is carrying out the study. Other USGS members of the team are T. G. McLaughlin and G. F. Brown.

The team members spent the period of January 15–February 29, 1976, in Ar Riyāḍ reviewing reports and collecting the data needed for the study.

Water-resource development

J. T. Callahan reviewed the operations of the Water Resources Development Department of the Ministry of Agriculture and Water of the Kingdom of Saudi Arabia and made suggestions to improve the Department's effectiveness. He also made suggestions for training professional and technical personnel and formulated tentative plans and programs of investigation and development of the country's ground-water resources. The review program is under the direction of the U.S.-Saudi Arabian Joint Commission on Economic Cooperation.

Ground-water potential and development

P. E. Ward (1976) assisted the U.S. Corps of Engineers in evaluating the ground-water potentialities and the methods for its development in the two wadis (river valleys) supplying the public water systems of Jiddah and the holy city of Mecca in Saudi Arabia. The water-system facilities in both wadis—Khulays and Fatimah—were severely damaged by floodflows resulting from unusually heavy rainfall during late March and early April 1975.

Agricultural development of Wadi Dawasir

T. G. McLaughlin served as one of the U.S. Government team members of the U.S.-Saudi Arabian Joint Commission on Economic Cooperation (1975) in a study of the agricultural development of Wadi Dawasir in south-central Saudi Arabia.

THAILAND AND LAOS

R. J. Hite has been working in Thailand and Laos intermittently for the last 5 years to evaluate the potash potential of the Khorat Plateau. This investigation was conducted in cooperation with the Thai Department of Mineral Resources under the auspices of USAID, on behalf of the U.N. committee for the coordination of investigations of the Lower Mekong Basin. On the basis of studies of stratigraphy, structure, and geochemistry and a knowledge of evaporite geology, Hite recommended a drilling program in northeastern Thailand. The first hole revealed a deposit of carnallite 30 m thick at a depth of only 85 m. Subsequent drilling has greatly extended the limits of the carnallite deposit and, in addition, has resulted in the discovery of a rich sylvite deposit. Preliminary evaluation of these deposits suggests that they may form one of the largest and richest accumulations of potash in the world. This discovery has special significance because there are no other known potash deposits in this part of the world. It is impossible at this time to even estimate the total value of the deposits. Hite estimated a yearly export value of at least $100,000,000 for the carnallite deposit alone.

According to Hite, the deposits may also constitute a major source of boron. Unlike other potash deposits of marine origin, the Khorat contains a water-insoluble fraction that consists principally of the mineral boracite ($Mg_6Cl_2B_{14}O_{26}$). Select intervals at the top of the deposit run as high as 10 percent boracite by weight. In one core hole near Vientiane, Laos, the potash ore is high-grade sylvite. The upper 2.69 m of this deposit averages about 3.192 percent by weight water-insoluble material, about 95 percent of which is boracite. The boracite could easily be removed as a byproduct of potash-ore processing.

YEMEN ARAB REPUBLIC

Geologic investigations

With the cooperation of the Mineral and Petroleum Authority of the Ministry of Economy of the Yemen Arab Republic (YAR), M. J. Grolier and W. C. Overstreet completed nine single-scene preliminary geologic Landsat-imagery geologic maps of adjacent areas in Yemen. The maps cover a total of approximately 145,039 km². Overstreet, with Grolier, J. A. Domenico, G. C. Tibbitts, Jr., and M. M. Ibrahim, studied trace elements in samples of bedrock, saprolite, gossan, and slag as a guide to evaluating mineral resources in YAR economic-development programs. The chemical composition (Overstreet and others, 1976), as well as physical properties, mineralogy, geologic setting, and source rocks, appears to identify the iron ore as hematitic and geothitic gossan developed from massive pyrite and pyrrhotite. It is inferred that Precambrian massive sulfide deposits are the source of the gossan used for iron ore in the Sa'dah area—and doubtless of the iron ore mined near Majadh about 25 km northwest of Sa'dah—and that they are enclosed in host rocks that are extensions of the rocks containing large massive sulfide deposits being investigated in the Kingdom of Saudi Arabia at Wadi Wasat (Overstreet and Rossman, 1970) and Wadi Qatan (Dodge and Rossman, 1975) about 125 km north-northeast of Sa'dah. Iron ore has been mined in Yemen from gossans that extend intermittently at least as far as 60 km north of Sa'dah.

The sulfide deposits in Saudi Arabia are of probable syngenetic origin and are restricted to particular beds of Precambrian volcano-sedimentary rocks. Inasmuch as these favorable rocks can be seen from aerial photographs and from Landsat–1 high-altitude imagery to strike southward into the Sa'dah area, it is inferred that the gossan near Sa'dah is equivalent to that at Wadi Wasat and Wadi Qatan. The region underlain by these rocks in Yemen is a logical target to be explored geologically for massive sulfide deposits, some of which are enriched in nickel, like those at Wadi Qatan in Saudi Arabia.

Ground-water survey

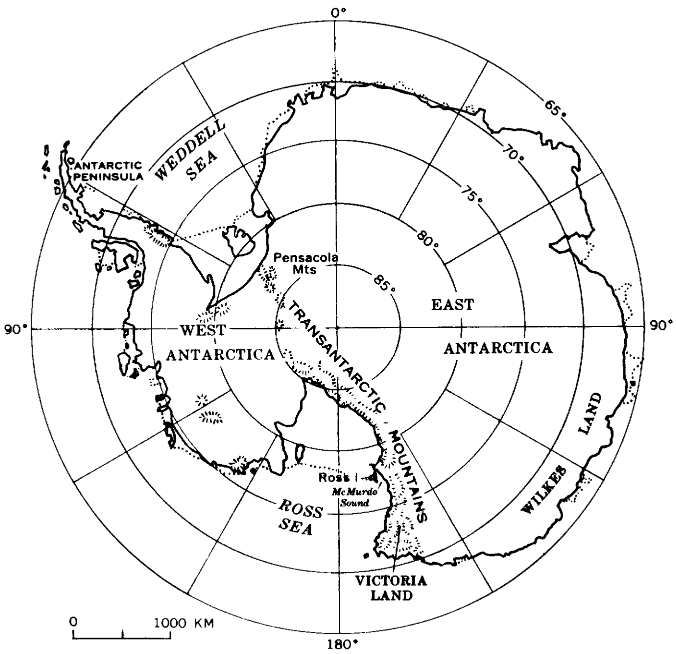
G. C. Tibbitts, Jr., in cooperation with the Ministry of Agriculture and the Mineral and Petroleum Authority of the Yemen Arab Republic, is making a ground-water survey north of lat 15° N. Test drilling is concentrated in the Amran valley, a basalt-filled graben. A block of limestone surrounded by basalt was dry to below water levels in the surrounding basalt. The deepest test hole yielded water freely from limestone that had not been completely penetrated at the total depth of 343 m. In August 1975, the heaviest rains of a 13-year period caused damaging floods in and near Şan'ā'. Thirty-six people were killed. Water levels rose in response to recharge but resumed their downward trend within a few weeks.

ANTARCTIC PROGRAMS

Geologic field studies were not undertaken by USGS personnel during the 1975–76 austral summer in Antarctica. Work continued, however, in map compilation and in laboratory studies on the petrology, geochemistry, geochronology, and paleontology of samples collected during previous expeditions to the southern part of the Antarctic Peninsula and to the Pensacola Mountains (see index map). Petrologic studies were also carried out on material recovered by the drill ship GLOMAR CHALLENGER on its first cruise to Antarctica during Leg 28 of the Deep Sea Drilling Project. These continuing studies, which are part of the U.S. Antarctic Research Program (USARP), are conducted in cooperation with the Office of Polar Programs of the National Science Foundation. Progress in Antarctic aerial photography and topographic mapping, which are functions of the USGS, is reported in the chapter "Topographic Surveys and Mapping."

Iron-titanium oxides, Dufek intrusion, Pensacola Mountains

Iron-titanium oxides of cumulus origin are abundant in the upper part of the layered gabbroic Dufek intrusion of Antarctica. Petrographic studies by A. B. Ford (USGS) and G. R. Himmelberg (University of Missouri) indicated that they first ap-



peared as a cumulus phase about 1,500 m above the base of the layered sequence and that they continued crystallizing through later consolidation stages. Electron-microprobe analysis by Himmelberg showed that they consist of predominantly titaniferous magnetite and ferrian ilmenite in composite grains and of lesser amounts of the ilmenite in discrete grains. The magnetite contains abundant lamellae of ilmenite. The composite grains may represent extreme unmixing of an original homogeneous titaniferous magnetite. Compositions suggest that subsolidus equilibration took place in an approximate temperature range of 590° to 790°C (Himmelberg and Ford, 1975).

Crystalline basement rocks, central Ross Sea

Calcareous metamorphic rocks of a continental-type crystalline basement were recovered by the GLOMAR CHALLENGER's drilling at Site 270 in the south-central Ross Sea. Calc-gneiss, of amphibolite-facies metamorphic rank, and overlying marble in the lowest 10 m of core were tentatively correlated by A. B. Ford (USGS) and P. J. Barrett (Victoria University of Wellington, New Zealand) with calcareous metasedimentary rocks of similar rank in the lower Paleozoic(?) Skelton Group near McMurdo Sound (Ford and Barrett, 1975). The occurrence provides evidence that at least this part of the deep Ross Sea reentrant into the almost circular plan of Antarctica is not a rift feature but is an integral part of the continent. A deep regolith formed on the basement rocks in pre-Oligocene time, before depression of at least 1,000 m resulted in the accumulation of a thick section of Tertiary Continental Shelf sediments.

Antarctic deep-sea basalt volcanism

Oceanic basalt was recovered by the GLOMAR CHALLENGER at several sites on the southern flank of the Southeast Indian Ridge, the South Indian Basin, and the Balleny Basin (Ford, 1975). Inferred age of the basalt decreases away from the ridge axis, as the ages of overlying sediments indicate. Basalts from Balleny Basin are flow breccias of tholeiitic character but are chemically distinct from the tholeiites at other sites. They are believed by A. B. Ford to be related to the volcanism that built the nearby Balleny Islands. The basalts are commonly highly altered, probably by seawater interactions, and many are highly oxidized and contain abundant secondary minerals. The alteration may also account for K_2O values that are unusually high in comparison with those reported for ridge-axis and ridge-flank basalts elsewhere.

TOPOGRAPHIC SURVEYS AND MAPPING

FIELD SURVEYING

AUTOMATED SURVEYING SYSTEMS

The Aerial Profiling of Terrain System (APTS) is being developed for the USGS by the Charles Stark Draper Laboratory of Cambridge, Mass., to carry a three-coordinate scheme of reference in a light aircraft with an accuracy of 0.15 m vertically and 3 m horizontally. Design of the system was prompted by a need for obtaining terrain profiles for flood-plain delineation, but other potential field applications include establishing map control and obtaining map-elevation information. The contract work has focused on achieving maximum accuracy with lightweight, low-power elements, and the design phase was expected to be completed by December 1976. A cost-effectiveness study projected through 1989 indicated that APTS would provide significant manpower savings and modest cost savings.

The Litton Auto-Surveyor, owned by the Bureau of Land Management (BLM) and used throughout the summer of 1975 in Alaska to establish control for land-net surveys, was brought to Denver, Colo., for testing during the fall and winter. In return for USGS logistical and technical support, BLM executed two tests oriented toward USGS requirements. The first test ran 32 km up a mountain road, starting west of Golden and ending near Blackhawk. It contained 21 test points, started at an elevation of 1,720 m, and ended at 2,820 m. Four round-trip runs were made with a zero-velocity-update interval of 3 or 4 min. The test was intended to reveal the system's vertical accuracy in steep mountainous terrain. The second test was to determine the Auto-Surveyor's effectiveness in testing the horizontal accuracy of maps. A 7½-min quadrangle near Limon, Colo., that had been tested previously by conventional ground surveys was selected; over 20 test points were established. Fieldwork was completed for both tests, and analysis is underway.

GEODETIC DATA

A study of the inconsistencies in the coordinate systems for the 1:100,000-scale county maps showed that most of the position differences are caused by distortions in the UTM coordinate system. The problem occurs when 30×60-min quadrangle maps cast on the UTM projection are fitted together to form a county map and the State plane-coordinate system (SPCS) is indicated by ticks along the margin. There are two major sources for the positional discrepancies:

- Toward the zone edges, the meridians bow in the UTM system, whereas they appear straight or nearly straight in the SPCS. The maximum difference for a map spanning 1° of latitude in the Southern United States is 0.1 mm at 1:100,000 scale, an acceptable amount. The meridian bowing also causes an overlap at the join of two east-west quadrangle maps when the join line is a UTM zone boundary. Although the problem is more severe because of land being "lost," it is also acceptable because of the small amount of overlap under the conditions given. In latitudes covering the 48 conterminous States, the bowing distortion is given by the following approximate equation:

  $$e = 0.1\ \Delta\phi^2\ \text{mm}$$

  at 1:100,000 scale, where $\Delta\phi$ is the latitude span in degrees.
- The east-west scale change of the UTM causes distortion when two 1:100,000-scale quadrangle maps cast on adjacent UTM zones are fitted together. The map formed this way has roughly the same scale on the eastern and western edges but a larger scale in the middle. A straight line joining SPCS ticks on left and right margins is incorrect in the middle because of this effect. For a 1°×2° county map in Arizona, the distortion reaches a maximum of 0.3 mm at the northern and southern edges. The problem can be eliminated by showing SPCS ticks along the UTM zone-boundary meridian.

The project to transfer all USGS geodetic control to the National Geodetic Survey is proceeding slowly because of several technical problems, such as the lack of compatible computer programs. The effort needed to transfer all horizontal control by 1980 was estimated at 50 man-years. Vertical control is another problem because tectonic forces change local elevations significantly over short periods, and historical records of elevation are therefore becoming important in evaluating phenomena never before considered. One big problem remains—supplying a geographic position for each bench mark. The only feasible approach is to scale coordinates on maps, and equipment is being obtained to do the job efficiently.

The Oroville area of California suffered an earthquake in August 1975, and a 1942 USGS line was releveled and extended into the Sacramento Valley. The releveling indicated crustal changes of up to 18 cm near the fault zone. Leveling comparisons showed the valley area to be relatively stable, with an apparent upward movement of the Sierra Nevada Range. A second releveling of this same line 6 months later revealed a small amount of continuing vertical creep in the vicinity of the fault line.

Adjustment of the U.S. horizontal control network to a new North American Datum is underway at the National Geodetic Survey; completion is scheduled for 1983. The new datum and adjustment will change the accepted values of latitude and longitude of almost all points in North America. The exact magnitudes of the changes are not yet known because the network errors are not known. However, fairly good estimates are based on the following assumptions: (1) The new datum will be Earth centered; (2) the new ellipsoid will entail a whole-Earth fit; and (3) the network errors are small, estimated to be 20 m maximum. Thus, the longitude changes will vary from +107 m on the west coast to −33 m on the east coast. In the Southern United States, the latitude will increase up to 47 m, but the change will be negligible for mapping along the Canadian border. These position changes indicate that most USGS 7½-min maps will need a datum shift and that this series will pose the largest problem; other main series—15 min and 1:250,000 scale—comprise fewer maps and have the advantage of smaller scale.

MAPPING STANDARDS

The USGS has been studying metrication and its complications for several years. Adoption of the metric system (International System of Units) in the United States is inevitable, and the necessary changes are in the active planning stage. Public Law 94–168 (Dec. 1975) attracted much interest, although it leaves metrication voluntary; it includes establishment of a U.S. Metric Board composed of 16 individuals of various backgrounds and interests. Private industry is already considerably engaged in metrication, and the Metric Board will no doubt speed up the conversion. New maps around Anchorage, Alaska, are being made at 1:25,000 scale with metric contour intervals. Maps of Puerto Rico have been completely metric for years at the scale of 1:20,000. All maps have contained the metric UTM grid ticks for nearly 2 decades. A questionnaire was recently circulated to map users for comments on scales, contour intervals, and timing of metrication.

Procedures are being established to test the accuracy of the vertical data on the Defense Mapping Agency digital terrain tapes. Test data were obtained for 21 tapes, and an analysis will determine the type of test points that should be selected (tops, hillsides, or spot elevations), the distribution and number of points, and the relationship between the vertical accuracy of map data and digital data.

The test course of positions and elevations around the National Center in Reston, Va., was enlarged to a network of 24 control points. The marks are used for evaluating new instruments, for training, and for compiling a large-scale metric topographic map of the area.

EQUIPMENT

After successful trials of a prototype last year, five more vans were custom fitted to provide efficient mobile work stations for field revision, interpretation, and completion surveys. The vans contain all the instruments, equipment, and conveniences needed to do a thorough job on site.

The Motorola Mini Ranger III, an automatic distance-measuring system that can interrogate up to 16 transponders in seconds, was field tested in Arizona over a network of established control stations. Three methods of operation were tested: (1) Static, which compared readings of each transponder with those of an Electrotape; (2) a four-range system with the master unit installed in the USGS Hoversight-equipped SL3 helicopter; and (3) a range-loop system with two switchable transponders on control stations, the master at the other end of the base, and four transponders (two carried by helicopter and two by truck) roving to test points around the two bases. The data are being abstracted for computation.

PHOTOGRAMMETRIC TECHNIQUES

AEROTRIANGULATION

With over 375 quad-centered photographs and sparse horizontal control, a simultaneous block adjustment of models can provide pass points accurate enough to bridge across a 45×60-min area. Such a project—Hampton, Oreg.—was incorporated into one block by forming analytical double models from Zeiss PSK2 stereocomparator data; the use of double models rather than single models did not significantly impair the horizontal adjustment. The accumulation of systematic vertical errors, however, makes this technique undesirable for obtaining elevations. Thus, across 160 orthophotoquads, the horizontal RMSE for 68 held control points was 1.40 m, and the tie-point RMSE was 1.15 m. The resultant pass-point coordinates should be within 3 m and consequently will be used as horizontal control for new topographic mapping.

A unique decking procedure was developed for use with the direct-geodetic-constraint adjustment, to allow broken flight strips to be bridged and larger blocks of data to be processed with a minimum of ground control. Thus the aerial photography contractor need not be limited to specified allowable locations and a certain number of flight breaks, and the cost of photography planned for fully analytical aerotriangulation can be held down.

The newer 500-photograph version of the computer program for direct-geodetic-constraint aerotriangulation is producing results similar to those of the smaller capacity versions. Although banding the normal equations is considerably more economical for larger blocks of photographs, a realistic limit appears to be 250 photographs. Larger blocks require preprocessing in smaller blocks or strips to provide accurate estimates of camera-station orientation parameters, which are needed to minimize computer iterations and cost.

IMAGE CORRELATION

Subroutines were derived for the direct-geodetic-constraint aerotriangulation programs that analytically determine the instrument settings for relative and absolute model orientation. Even though the operator may still need to make fine adjustments, the analytical procedure cuts setup time in half. The technique is particularly useful in setting up models with rugged terrain, excessive tilt, or scale considerably changed from the previous model. The orientation subroutines were verified for the Wild B8, Kern PG2, Zeiss C5, and Jena Topocart; those for the Wild A7 and E4 rectifier and the double-model case for the C5 and Topocart are currently being tested. Also, the Kelsh stereoplotter is being analyzed for modifications that would allow use of computed orientation parameters.

Further study of density factors that inhibit automatic image correlation attested to the complexity of the problem. The more easily detectable losses of correlation generally resulted from slight and irregular density changes over long stretches of light or dark terrain, significant density variations over practically level terrain, and density peaks caused by objects or shadows that appear on only one photograph.

CAMERA CALIBRATION

During the past year, the services of the USGS optical calibration laboratory were in heavy demand —nearly 90 aerial mapping cameras and 20 lenses were calibrated. Laboratory instrumentation was improved in a number of ways:

- To test high-resolution, long-focal-length lenses, the multicollimator camera calibrator was modified for increased range, $\cos^4$ correction, and high-contrast chart reticles. The resolution test range was extended to 470 lines/mm.
- Camera shutter-speed calibration equipment was updated with a Bell & Howell 509–1 photodetector-amplifier/frequency-synthesizer system of USGS design, a Tectronix 7313 oscilloscope, and a Polaroid C–50/C–70 camera.
- Three additional camera mounts were acquired—a Wild RC–10 mount, a Zeiss MRB mount, and a special mount supplied by the Mark Hurd Company that simulates the Learjet door mount.
- A new system was devised for measuring camera-calibration plates that comprises a Mann 422 comparator, an Altek digitizer, and a Univac card punch.

The format of the USGS camera-calibration report was changed to provide clearer and more complete information. Two changes, which should be of special interest to those who use fully analytical aerotriangulation, are as follows:

- Radial distortion, computed by a least-squares method, is referred to the calibrated principal point (point of symmetry) instead of the principal point of autocollimation.
- Fiducial-mark measurements are reported in a coordinate system.

The camera-calibration data bank was started. By the end of 1975, the bank contained data on 266 camera/magazine calibrations dating from 1967; 51 of these were calibrated for fully analytical aerotriangulation. Since July 1975, all camera-calibration data were processed to provide punchcard data for direct input to the bank.

To evaluate a method for camera calibration during aerotriangulation, DBA Systems, Inc. (Melbourne, Fla.), reaerotriangulated the Louisburg, N.C., project. The superwide-angle camera used on the project had extreme asymmetrical radial lens distortion, an aspheric platen surface, poor resolution, and lens aberration at the format edges. USGS aerotriangulation of this project in 1974 was satisfactory only after the radial lens and platen distortions were corrected according to a specially developed distortion grid. Supplied with the photocoordinates for all points, the calibrated focal length, and horizontal and vertical ground control, DBA performed analytical aerotriangulation with their "in-flight" camera-calibration techniques. With this technique, camera and film errors are determined and compensated as part of the aerotriangulation solution. The resultant accuracies at test points were nearly identical to USGS results, which had been obtained at considerably lower computer cost.

EQUIPMENT AND MATERIALS

The Itek Visual Edge Match Comparator was evaluated for measuring the resolution and contrast of aerial photographs. The test photographs were taken with Wild and Zeiss 15- and 30-cm cameras and with Kodak 2402 and 2405 films. Results indicated that resolution can be accurately determined for a project provided that more than five photographs are measured. Consistent and accurate contrast measurements can be made by trained operators using 25×, 40×, or 100× magnification.

A prototype of the Bausch & Lomb Mini-Marker was evaluated for marking film and glass diapositives. The mark is a circle (330-μm outside diameter) of 50-μm line weight with a 40-μm dot in the center. A sharp, symmetrical, and accurate bull's-eye is made when the heated marking head comes in contact with the emulsion. The minimarks were read equally well as PUG drill holes when viewed in the Wild A7 and Kern PG2; the 350-μm ring around the floating mark in the Zeiss PSK2 circles the minimark and makes it difficult to place the floating mark on the ground. The prototype Mini-Marker is considered less convenient to use and slower in production.

Greater use of film diapositives required modification of the Kelsh stereoplotter. Danko Arlington (Baltimore, Md.) designed and built correction cams to compensate for error introduced by the stage plate holding the film. Also, for superwide-angle photographs, corrected film diapositives were made by printing on films bonded (with adhesive) to glass stage plates.

An online system for map measurement was put together that includes a coordinatograph with encoders, a digitizer, a card reader, a programable calculator, an output typewriter, and an interface unit now called the Digital Multiplexer MKII. The system is applied to scaling orthophotos, testing map accuracy, and calibrating copy cameras and pantographs.

PHOTOIMAGE MAPPING

IMAGE QUALITY

To learn more about factors affecting the resolution of aerial photographs, tests were conducted with the Itek Visual Edge Match Comparator. The consistent loss in actual resolution as compared with the resolution obtained in calibration tests is attributed to in-flight vibrations and aircraft speed. Contractors are advised to use maximum aperture and shutter speed to reduce this effect (resolution falloff due to using the larger portion of the lens with maximum aperture is insignificant).

A new continuous-tone diazo paper now on the market yields an excellent tonal range with high resolution. Scott Graphics, Inc., of Holyoke, Mass., manufactures Technifoto (TPL–101) plastic-coated paper with a nonsilver molecular-imaging sensitizer. The paper can be processed conveniently in daylight with ammonia-developing, diazo-type systems. With a library of orthophotoquad film positives, this type of material would make it possible to fill requests for quality prints quickly and without the expense of maintaining inventories of large lithographic or photographic prints.

Du Pont's new Cromalin negative proofing system provides the best simulation of the printed color image map. The dry lamination process is the same as the positive-working method now used widely for map proofing, but the negative film and newly developed toners will produce the truest possible rendition of imagery lithoprinted in color.

IMAGE PROCESSING

Success in applying color to spectral bands recorded by the Landsat multispectral scanner (MSS) shifted attention back to an early method of obtaining color pictures from black-and-white records. That method is to obtain spectrally filtered records on black-and-white film and play back the images through color filters or apply suitable color inks on a press. In this way, color can be added to the orthophotoquad, even though color contrast in the visible spectrum is reduced to a few hues, mostly blue, at the flight heights required for quad-centered photographs. Real contrast and high resolution are obtained by taking simultaneous pictures, one with black-and-white panchromatic film filtered to record the visible spectrum between 0.5 and 0.7 μm and the other with black-and-white infrared film filtered to record the near infrared between 0.7 and 0.85 μm. The photos are rectified—either simply or differentially, depending on the type of terrain—and the resulting negatives are enlarged to 1:24,000 scale and processed to a density range of 0.4 to 1.4. Three halftone positives are made by screening the panchromatic negative twice, for yellow and magenta, and by screening the infrared once, for cyan. Printing plates are made from the halftone positives, and a black plate is made for grid, text, and collar information. The printed map is a 1:24,000-scale color orthophotoquad that simulates the rendition of color infrared film. It is also possible to simulate the rendition of conventional color film and present other combinations of color.

The Optical Sciences Center of the University of Arizona at Tucson is under contract to make a comparative evaluation of digital and analog processing of Landsat imagery. As a result, the hardware and software used for image processing by the Jet Propulsion Laboratory in Pasadena, Calif., and the USGS Center for Astrogeology Image Processing Facility in Flagstaff, Ariz., will be fully documented. The major considerations are MSS geometrical corrections, fitting to ground control, radiometric enhancement, and color image products.

EQUIPMENT AND TECHNIQUES

New orthophoto-producing systems—the Jenoptik Orthophot B, the Wild PP08, and the Gestalt GPM2—were acquired for standard quadrangle mapping. The Jenoptik system consists of the Topocart B stereoplotter interfaced with the Orthophot differential rectifier; the orthophoto can be produced at 1:24,000 scale from a double-bridged model of quad-centered photographs, which eliminates mosaicking and copy-camera scaling. The PP08 film capacity limits 1:24,000-scale scanning to one model per film sheet, so that film mosaicking is necessary; modified with x, y, z shaft encoders and readout, model orientation is achieved numerically. The Gestalt system is designed to do more than produce orthophotos; with its own computer (Nova 800), the GPM2 correlates the imagery and digitizes the terrain model.

ORTHOPHOTO PRODUCTS

The user of an orthophotoquad must interpret what he sees; when the aerial view is unfamiliar to the interpreter, color contrasts help. The production of color orthophotoquads from black-and-white film evolved as a practical technique because no color processing is needed and because the technique can be incorporated into present orthophotomapping without changes in equipment or manpower. For the first experiments, NASA supplied two high-altitude simultaneous photographs, one taken on panchromatic film with a Wratten 25 filter and the other taken on infrared film with a Wratten 89B filter. The scene was Livingston, Tex., where relief ranges from 15 to 100 m. The photographs were first simply rectified and enlarged; the color-composite Cromalin proofs showed good register, resolution, and color contrast. Now the photographs are being differentially rectified with the Gestalt GPM2 for a comparative analysis. NASA also provided two-camera photographs of Georgia wetlands; a minus-blue filter was used with the panchromatic film to record more of the visible spectrum. Thus, both the standard orthophotoquad and a color rendition can be prepared for comparison.

Because of the increased border traffic expected in connection with the 1976 Olympics, the U.S. Customs Service requested that color image maps be prepared for a 320-km strip of the Canadian-U.S. border from St. Regis, N.Y., to the Maine-New Hampshire line. The border photographs were taken at 10,600 m from a Falcon jet equipped with two RC–10 15-cm mapping cameras with synchronized shutters. One camera contained Kodak Plus-X Aerographic 2402 film with a 525-nm (minus-blue) filter for recording the visible portion of the spectrum between 0.5 and 0.7 μm (green and red). The other camera contained Kodak Infrared Aerographic 2424 film with a 705-nm filter for recording the near infrared between 0.7 and 0.85 μm. Four exhibits of the multispectral (two-camera) color image maps were produced. No color processing was needed; color was arbitrarily assigned to the panchromatic and infrared records in various combinations. Each image map has a UTM grid and minimal cartographic information (names of major cities, highways, and water bodies and all Customs stations) overprinted on the imagery. The maps, available on request to the USGS, are:

- A black-and-white image map from simply rectified photographs.
- A color image map from simply rectified photographs. The response of conventional color-infrared film was simulated by combining the panchromatic record printed in yellow and magneta with the infrared record printed in cyan.
- A color image map from simply rectified photographs. The earthy color rendition was achieved by combining the panchromatic record and highlights of the infrared record printed in yellow and black with the infrared record printed in yellow and magenta.
- A color image map from photographs rectified at 1:24,000 scale with the GZ1 orthphotoprinter. The grassy color rendition was achieved by combining the panchromatic record printed in yellow and black with the infrared record printed in yellow and magenta.

Large-scale special-format orthophotographic maps were prepared for Fort Wayne, Ind.; Charleston, S.C.; Frederick, Md.; San Francisco, Calif.; and Chicago, Ill. Local officials provided feedback on map uses and on preferences as to scale, content, imagery, contours, and revision. With these requirements and those expressed through other Federal programs for cartographic data, large-scale mapping guidelines are evolving that will eventually take the form of a handbook.

Orthophotos have become as much a mapping tool as a map. In the production of conventional topographic maps and orthophotomaps, the quad-centered orthonegative is used as (1) halftone imagery printed with watercoat on opaque scribecoat film, (2) a film positive for use under a transparent scribecoat film, and (3) continuous-tone imagery printed on a scribable film. Simultaneously compiling and color-separating planimetric details are expected to result in significant savings.

Preparing a 1:100,000-scale mosaic of orthophotos from high-altitude photographs taken over 11 months was a trial in tone matching. An intermediate step was added in the mosaicking process: 1:70,000-scale film positives were dodged with the LogEtronic MK–4 printer to produce more even-toned negatives. Paper prints made from the intermediate negatives were mosaicked in blocks and then reduced to 1:100,000 scale. The final mosaic of the Atlanta area of Georgia will be assembled by film montage—alternately masking and exposing each block onto a single piece of film—and will be a companion product to a new topographic map at the same scale.

For coal development studies of North Dakota, the Bureau of Land Management requested 228 orthophotoquads as screened film positives. The bases are being prepared in one photographic step by masking and screening when the film is exposed on the Wild E4 rectifier.

MAP DESIGN

INTERMEDIATE-SCALE MAPPING

Intermediate-scale topographic map production got off to a brisk start with requests from Federal and State agencies for several hundred quadrangle maps. The first experimental 1:100,000-scale quadrangle maps—Reno Junction, Wyo.; Gillette, Wyo.; and Healdsburg, Calif.—are now available to the public. The maps are normally derived from larger scale maps and cast on the UTM projection in a 30×60-min format; county or regional formats are optional. What makes this series unique is that it offers users the opportunity to select the content, as well as the scale and format, that will best suit their needs. Mapping specifications call for compiling from 13 to 21 manuscripts per map, with separation on the basis of categories of features. Other new treatments include the use of new typefaces, symbols modified for digitization, and combined reproduction negatives.

The Killdeer, N. Dak., map was the first fully metric edition to be published in the intermediate-scale map series. The 20-m contours were interpolated from the 10- and 20-ft contours of 7½-min maps; elevations were rounded to the nearest meter. The interpolation and final contour scribing were done simultaneously. All future 1:100,000-scale topographic maps will be metric.

Some users require both 1:50,000- and 1:100,000-scale versions of the same map. Map content, symbolization, and line weights are considered in determining specifications that most nearly satisfy acceptable cartographic treatment at both scales and that avoid duplicate operations. One solution is to compile the map at 1:75,000 scale in two steps: the 1:100,000-scale content is first scribed and then photocopied; the additional content required is then scribed at 1:50,000 scale. Future experiments will resolve standards for interchangeable line weights, type sizes, tint treatment, and symbols.

COASTAL AND WETLAND MAPPING

Three versions of a topographic-bathymetric map of the Fort Pierce, Fla., 7½-min quadrangle—an orthophotoquad, an orthophotomap, and an interim-revised line map—were completed for State evaluation. The National Ocean Survey provided bathymetric data, including the mean high and mean low water lines. The maps have 2-m contours and 1-m depth curves, both with half-interval supplementals. Hypsographic and bathymetric detail on the orthophotoquad is shown in white. On the orthophotomap and the line map, the basic depth curves are black with supplementals in blue; gradient blue tints also show water depth in 5-m steps. The relative usefulness of these experimental maps and the acceptability of metric data are being judged by land-use planners, conservationists, surveyors, oceanographers, and others having an interest in wetland, coastal, and offshore environments.

A draft edition of the "Coastal Zone Mapping Handbook," compiled in cooperation with NOAA, was sent to 200 Federal and State agencies for review and comment. The handbook includes guidelines for mapping coastal areas, sources of technical assistance and data, and examples of products. Planners and managers of coastal programs should find this new reference particularly helpful for determining mapping requirements, selecting suitable map and chart formats, and communicating with mapmakers.

SPECIAL MAPPING PROJECTS

The McMurdo Sound, Antarctica, IMW won a blue ribbon in the 1976 American Congress on Surveying and Mapping map-design competition for its original combination of high-quality imagery with conventional IMW treatment. The 1:1,000,000-scale map was prepared from 1:250,000-scale topographic maps and Landsat band-7 imagery that offers spectacular views of volcanic mountains jutting out of the polar ice and of sea ice breaking up along the fringes of the Ross Ice Shelf.

Land-use map overlays are being sought at a range of scales. To date, 195,000 km^2 of level II information was registered to 1:250,000-scale maps. Levels III and IV were delineated for 72,800 km^2 of Florida to complement 1:24,000-scale maps. For the greater Atlanta region of Georgia, level II information was compiled to complement the 1:100,000-scale map and 18 1:24,000-scale bases. Generally, land-use information was compiled by viewing through scribecoat (preprinted with planimentry) the film positives of rectified high-altitude photographs. At 1:24,000 scale, land use was successfully compiled on K&E Contone printed with the orthophoto.

The format for State map indexes is being redesigned to improve readability and economy of maintenance. The Virginia prototype index map in black, gray, and red is much easier to read than the current pastel-green rendition. One standard 8½×11-in fold will replace 11 fold sizes now in use. New type styles were chosen, and insets were added to show coverage in several map series. Two companion catalogs—Maps and Map Data—with detachable order forms are being prepared to accompany each index map.

A folded and jacketed map (1:50,000 scale) of Mt. Rainier National Park in Washington was prepared for distribution during 1976. With the help of the National Park Service, the USGS will try to gage user response to the 14×23-cm packet. The jacket is an original design and was printed in brown and green on durable tagboard.

EQUIPMENT

A patent was granted for an orbital-lens slope-mapping device that attaches to a standard cartographic camera. Five units were fabricated, one of which will be tested by the U.S. Army for use in producing slope maps in mobile units.

A straightedge tool was devised for precision scribing of parallel grid lines. Map manuscripts up to 75×100 cm can be gridded by working from both sides of the drafting table and rotating the sheet 90° only once.

AUTOMATED CARTOGRAPHY

HARDWARE

The USGS recently acquired the Gestalt Photo Mapper II (GPM2), which automates the transformation of aerial imagery into an orthographic projection of the terrain, photographic and (or) digital. The heart of the GPM2 is a special-purpose computer system that applies analytical photogrammetry, unique electronic scanning transformations, and sophisticated digital and analog circuitry for correlation and control. The analytical model is scanned and continuously transformed according to electronic correlator measurements until the corresponding images from both cameras for a 9×8-mm patch are in register. In the process of registering images, a dense digital terrain model is generated—2,400 points on 182-μm centers. Thus, by systematically transforming the model patch-by-patch, a complete orthophoto and contour plot of the overlap area can be recorded photographically at photoscale; simultaneously, a digital terrain model can be recorded on magnetic tape. The entire process is executed in real time under computer control, but the operator intervenes in those instances where the intelligence of the system is limited. Production time is related to image quality, photoscale, base-height ratios, and steepness of terrain and can range from 30 minutes to 2 hours but averages 1 hour for the overlap area.

The Digital Profile Recording and Output System (formerly the Digital Orthophoto System) was developed in-house to provide digital terrain profiles and control offline production of orthophotos, contours, slope maps, and more. The electronics design is sufficiently flexible to accommodate several types of profiling instruments and exposing units. The first production system comprises a Zeiss C5 Stereoplanigraph equipped with two-axis servomotors and three-axis encoders; two consoles with magnetic-tape transports that control scanning, recording, and playback of the digital profile data; and a GZ1 Orthoprojector equipped with three-axis servomotors and encoders. The GZ1 can be operated at 10 speeds up to 2.5 cm/s with good resolution; one double model (a complete 7½-min orthophotoquad) can be exposed in 1 hour on the average. As a test, the system was used to produce both the panchromatic and the infrared orthophotos for the Highgate Center, Vt., color image map being prepared for the U.S. Customs Service. The resulting color composite has excellent register and good resolution; scan lines are subdued in some areas and completely undetectable in others.

To automate a number of routine measurements in map production as well as to digitize mapped information, Instronics Gradicon digitizing tables were purchased. These systems have considerable data-processing power and can output data on magnetic tape, cards, or paper tape. In addition, a three-axis digitizing system, the Altek AC89, was adapted to a Kern PG2 stereoplotter and evaluated for digital-mapping potential, particularly for digitizing directly from the stereomodel.

A high-speed Calcomp drafting system was purchased to complement the low-speed Gerber system already in use. With its somewhat lower precision (0.003 in) and more limited data-processing power, the Calcomp is used for verification and medium-accuracy plotting. The Gerber system is used almost exclusively for drafting orthophotoquad collars—about 20 collars/d with two-shift operation. A program for generating custom-designed Lambert conformal conic transformations was incorporated into a special Gerber plotting program; the resultant plotting accuracy is sufficient for 1:24,000-scale mapping.

With the help of the Defense Mapping Agency Aerospace Center, in St. Louis, Mo., the AS–11A analytical stereoplotters are being modified with modern minicomputers, new servosystems for all stage and coordinatograph axes, and a new computer interface; four AS–11A1 stereoplotters now on order will also contain these features. All together, six complete systems will enable greater use of unconventional source materials for mapping. Other compatible components will be acquired—an automatic correlation system, a Nistri TA3/P1 stereocomparator system, a digital-data editing system, and a voice data-entry system. The dedicated computer is being enlarged to 512-k memory with 300 megabytes of online disk storage.

USGS mapping centers now telecommunicate orders for map type to the Mergenthaler VIP 7245–2A phototypesetting system. The phototypesetter, located at the National Center, offers 49 fonts of 96 characters each with a range of 6 to 72 points. Type can be either right- or left-reading and is exposed on film or paper. Software will be available soon that will automatically adjust common character combinations, easily generate special typefaces, and reduce manual keyboarding.

SOFTWARE

The core of future cartographic production will be a digital cartographic data base—desirably, a structure that will enable users to interactively extract data from the base and produce the needed graphic or computer model. One such structure was proposed and is being widely reviewed. An interim structure is being designed for use with newly acquired Instronics digitizers; new batch cartographic editing software will reduce the need for interactive editing hardware. To handle the greater demand for small-scale map bases, the Cartographic Automatic Mapping program developed by the CIA is being adapted for a variety of cartographic plotting tasks; in addition, several other cartographic data bases are being acquired, such as World Data Bank II and the new Bureau of the Census county file.

Digital terrain models on magnetic tape will soon be available for any area of the conterminous United States. The job of copying and reformatting the digital data supplied by the Defense Mapping

Agency Topographic Center in Washington, D.C., is 80 percent completed. The data, which were originally derived from 1:250,000-scale topographic maps, are being applied by numerous public and private organizations to tasks such as landscape planning and devising a safe-altitude warning system for aviators.

The National Cartographic Information Center developed the software for an aerial photography summary record system—a computer bank of data that describes assorted collections of aerial photographs. The records note photographs acquired, projects in progress or planned and their geographic extent, and important technical data. Participating government agencies and private organizations provide the data in a format suitable for direct input to the system. Computer listings and graphics are generated regularly, and special listings meeting specified criteria can also be generated.

The Geographic Names Information System (GNIS) was devised to streamline the name-research phase of mapping. The software is the General Information Processing System (GIPSY) developed at the University of Oklahoma. GIPSY provides the tools to build and maintain such a file and accepts upper- and lower-case common language as well as a wide range of special characters. GNIS is an outgrowth of the Massachusetts experimental GEONAMES file; it currently includes name records for Massachusetts (12,000) and Alaska (26,000) and name decisions made from 1935 to 1959 by the Board of Geographic Names (10,000). A typical name record includes location data, a feature description, historical references, and name variants. GNIS also permits the retrieval of name records according to various criteria. Computer output can be printed lists, magnetic tape, punchcards, or microfiche; the complete Alaska name file is contained on two microfiche. Colorado and Kansas name information is currently being formatted for GNIS. Once completed, the estimated 3 million name records obtained from USGS maps will form an influential basic reference for arbitrating name controversies and establishing usage.

EXPERIMENTS

One objective of the Federal Energy Program is a computerized National Coal Resources Information System that would serve developers by readily providing statistics on deposits and overburden. Such a system must necessarily evolve from a digital cartographic base. An experiment was undertaken to determine how best to digitize the required terrain elevations and planimetric data (roads, drainage, and political boundaries). Two approaches were tested on the Jewell Ridge 7½-min quadrangle of Virginia and the White Tail Butte 7½-min quadrangle of Wyoming (both 1:24,000 scale)—one to digitize directly from the stereomodel and the other to digitize from the map. In the first experiment, the stereomodels were scanned both manually with a Kern PG2 (fitted with a three-axis digitizing system) and automatically with the Gestalt GPM2. Digital terrain models were formed by data-resampling techniques, and contours were computed and plotted. The planimetry was compiled as usual and then digitized with the Bendix DataGrid; planimetric digital cartographic files were constructed by Dual Independent Map Encoding. The parallel experiment used the Dynamap CART/8 system to digitize and edit the planimetric data; the IOM Sweepnik laser scanner was used both to digitize the contour lines and to play them back. Although time limitations hampered the tests, the experiment served to emphasize the need for a single recording format, batch-editing software, and an interactive editing device.

To find an effective, practical, and less costly method of producing shaded-relief renditions of a map, various manual, photomechanical, and computer techniques are being evaluated. The test map was White Tail Butte, Wyo. For all tests, illumination was assumed to be westerly and 30° above the horizon. Traditionally, shaded-relief drawings are prepared with an airbrush by a skilled artisan who is guided by aerial photographs and contour lines. A similar technique currently used by NOAA combines airbrushing for shading and erasing for highlighting and is worked on a gray board; this test is still in progress. The Defense Mapping Agency technique for shading aeronautical charts was also tried; it incorporates embossing and a series of photographic operations. USGS photomechanical techniques were applied to terrain shading; an acceptable rendition was prepared by combining unidirectionally enhanced contour lines with a manually compiled mask. Last, and uniquely, digital terrain data were used to generate the shading under computer control. When the comparative evaluation is completed, it should provide valuable information for wide application.

The relative ease of generating shaded-relief renditions under computer control spurred an experiment to compare the effects of varying the angle and direction of illumination. The digital terrain data were converted to values of slope, which were used to compute brightness levels. Brightness, being a function of the Sun and observer angle, was predefined; image contrast was changed by redefining the brightness levels. From assigned values of brightness recorded on magnetic tape, an Optronics Photowrite produced the shaded image as a negative or a positive. The USGS Office of Telegeology at Flagstaff, Ariz., developed the technique and generated the imagery. The digital terrain data for the tests came from the Defense Mapping Agency terrain tapes and from the GPM2 with greater density. Four types of terrain, from flat to rugged, were imaged from three Sun angles and two directions. Color shaded-relief composites were prepared for maps ranging from 1:24,000 to 1:250,000 scale.

The USGS joined the U.S. Army Engineer Topographic Laboratories of Fort Belvoir, Va., to investigate vectorizing raster-scanned data for plotting. The Goodyear Aerospace Corporation of Akron, Ohio, conducted the tests with the STARAN associative array processor to determine if map drawings could be converted to a digital form that could be plotted by either vector or raster. Through a series of scanning, separating, and editing operations based on line thickness, data arrays were formed that can be accessed from two directions and thus processed in a parallel fashion. STARAN efficiently discriminated linear symbols of various widths between 0.004 and 0.026 in and vectorized the data for base storage; difficulties were encountered particularly at line junctions. The results of associative array processors applied to cartographic tasks promise a significant improvement over the performance of conventional computers.

Land-use information is being digitized by the IOM Corporation of Sunnyvale, Calif., in a pilot project in map digitization. To date, 200 1:250,000-scale map separates have been digitized with the Sweepnik laser scanner. Two sets of 1:24,000-scale hypsographic, hydrographic, and planimetric map separates will be similarly digitized for technical-feasibility and cost-analysis studies.

INTERNATIONAL ACTIVITIES

ANTARCTICA

The U.S. Antarctic Research Program is administered and funded by the Division of Polar Programs of the National Science Foundation. During the 1975–76 austral summer, USGS engineers were in Antarctica for the 19th consecutive year to participate in geophysical and glaciological studies and to establish geodetic positions for mapping. Two projects were planned: (1) A continuation of Geoceiver-derived position support for the Ross Ice Shelf Project (RISP) and (2) a joint project with the British Antarctic Survey (BAS) to establish positions along an airplane-supported Geoceiver traverse over a vast area along the Antarctic Peninsula and eastern Ellsworth Land.

Since reduced LC–130 airplane support forced cancellation of the RISP assignment, M. Y. Ellis (USGS) was assigned a second project—a mirror-flash experiment to reflect the Sun's rays into a multispectral scanner aboard Landsat–2. The result is a Landsat image in which the location of the mirror contrasts sharply with the surrounding area and thereby targets the point. Although Landsat images were successfully targeted at the National Center, lack of air support in Antarctica caused cancellation of January experiments, and cloudy weather prevented November targeting. Antarctic plans for the 1976–77 season include another attempt at flashing Landsat–2.

The USGS project with BAS was more successful. The project was designed to maximize the resources of both countries in order to achieve common goals. While the USGS provided scientific equipment, data preparation and analysis, and engineers trained and experienced in Geoceiver observations and conventional field surveys, BAS supplied extensive logistical support, including accommodations and supplies from Adelaide Island, airplane and ship transportation, and support personnel. J. W. Schoonmaker, Jr., and K. W. Gatson (USGS) were carried by a Twin Otter plane to remote, scattered control sites from Seymour Island in the northern Antarctic Peninsula southward to the Ellsworth Mountains. Each site was preselected to tie previously independent surveys together or to provide control for Landsat image mosaics and maps. At 31 Doppler control stations, Geoceiver observations on naval navigation satellites established latitudes, longitudes, and elevations.

Austral winter assignments continued at South Pole and Casey Stations. Doppler observations at the South Pole were conducted in support of ice movement, scintillation, and polar motion studies and at Casey in support of the International Antarctic Glaciological Project. J. A. Hinely and W. F. Graser (USGS) are wintering over at South Pole Station after relieving R. G. Boschert and J. E. Sorensen (USGS). According to the data acquired by Boschert and Sorensen, the true geographic South Pole (TGSP) is about 530 m from the present Geoceiver antenna, which is near the geodesic dome of South Pole Station. Ice movement appears to be about 10 m/yr along the 43° W. meridian. Using this information, Hinely, Graser, and an assistant, Keith Belt (U.S. Navy), may be the first to know that they set foot on the true geographic South Pole. They ran a site survey with a T2 theodolite to stake out the TGSP; to verify their survey site for the TGSP position, they established a remote tent camp and sledged the Geoceiver, a portable generator, and other equipment to the site. At temperatures around −37°C, they monitored the Geoceiver for 3 days to obtain data from 37 consecutive passes of primary navigational satellites. The resulting data, transmitted to the United States for reduction, show that the stake is within 10 m of 90° S. A further refinement of the TGSP position will be attempted when the Sun rises next austral summer.

R. J. Neff (USGS), working with the Australians at Casey Station, spent about 6 months on the plateau operating the Geoceiver on three traverses (autumn, midwinter, and spring). He reoccupied 15 ice stations established during the 1973 and 1974 traverses by R. F. Wilson and D. L. Schneider (USGS). Neff also participated in normal camp duties—manhauling traverses and taking aerial photographs at Casey and Macquarie Island. This year saw the end of USGS participation in the International Antarctic Glaciological Project. All data were reduced, and the geographic positions were transmitted by teletype to Casey Station and to the director of the Australian National Antarctic Research Expedition.

In accordance with Resolution 3 of the Third Meeting of the Scientific Committee on Antarctic Research (SCAR) Working Group on Geodesy and Cartography, the USGS will continue to supply published materials and maps of Antarctica to SCAR member nations. A collection of maps and related materials from SCAR members are available through the Antarctic SCAR Library at the National Cartographic Information Center (507 National Center, Reston, VA 22092).

The status of USGS mapping in Antarctica is shown in figure 10. Compilation continues on four 1:250,000-scale maps of the coast of Marie Byrd Land and on a 1:500,000-scale sketch map of Palmer Land at the base of the Antarctic Peninsula. Several 1:250,000-scale maps were approved for printing, but a publication date has not been set. A 1:1,000,000-scale map of the McMurdo Sound area, formatted on the IMW series, was published, as were two shaded-relief quadrangles at 1:250,000 scale in the Kohler Range area of Antarctica (the Crary Mountains and Mount Takahe quadrangles).

ALGERIA

An amendment to an agreement between the Ministry of Hydraulics and the U.S. Department of the Interior was signed by representatives of both agencies on April 23, 1976. The agreement provides for preparing Landsat mosaics, training Algerian personnel in Algeria and the United States, and establishing a technical user-assistance facility for Landsat data and other remote-sensing data. The U.S.-Algerian agreement will go into effect following an exchange of diplomatic notes between the U.S. Ambassador in Algeria and the appropriate Algerian officials.

MEXICO

In keeping with Item 7 of the USGS/CETENAL (Comision de Estodios del Territorio Nacional) mapping agreement, USGS officials met with officials from CETENAL in Mexico City, Mexico, in May 1976 to discuss mapping activities in progress along the international boundary. Both agencies agreed to an addendum to the present USGS/CETENAL agreement concerning orthophotoquads, photoimage products, and aerial photographs.

SAUDI ARABIA

The USGS continued to assist the Ministry of Petroleum and Mineral Resources of the Kingdom of Saudi Arabia in assessing and developing the mineral potential of the Precambrian shield of central and western Saudi Arabia. R. C. Nixon and C. M. Robins will complete their 2-year tour of duty early in FY 1977 and will be relieved by J. C. Horton and F. J. Fuller. Cartographic work on the Phosphate Area I quadrangle is progressing satisfactorily. The USGS produced two topographic map manuscripts of Jabal at Tirf (545 km^2) at 1:25,000 scale with 10-m basic contours.

UNITED NATIONS CARTOGRAPHIC CONFERENCE

The First United Nations Regional Cartographic Conference for the Americas was held in Ciudad de Panama, Panama, March 8–19, 1976. The U.S. delegation was headed by R. B. Southward (USGS). Other members were Vice Chairman E. A. Stoneman (Department of State), C. H. Andregg (Defense Mapping Agency), J. W. Park, Jr. (Inter American Geodetic Survey), Ludvik Pfeiffer (National Geodetic Survey), and J. P. Randall (National Ocean Survey). The conference was attended by 151 representatives and observers from 38 nations, 2 specialized agencies, 3 intergovernmental organizations, 4 international scientific organizations,

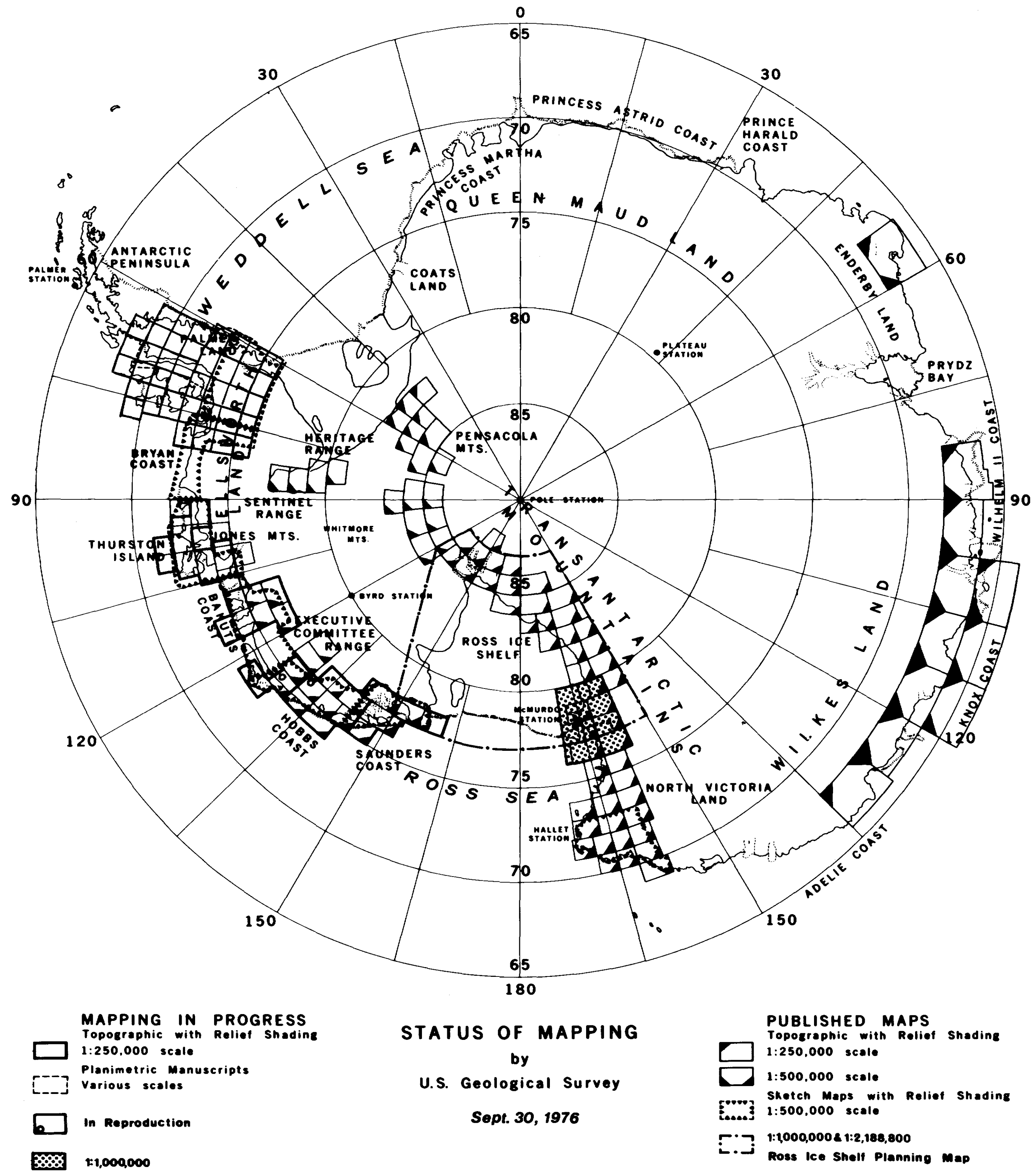


FIGURE 10.—Index map of Antarctica showing status of topographic mapping.

and the U.N. Development Programme. Nations represented at the conference included 17 from the Americas, 14 from Europe, 5 from Africa, and 2 from Asia.

CANADA/MEXICO/UNITED STATES TECHNICAL EXCHANGE MEETING

Representatives to the Canada/Mexico/United States Technical Exchange Meeting on Surveying and Mapping, held in March 1976 at the National Center, discussed (1) the status of the readjustment of the North American Datum, (2) the effect of the datum shift on maps and charts at scales smaller than 1:20,000, (3) the effect of the datum shift on maps and charts at scales of 1:20,000 or larger, (4) the effect of the datum shift on navigational aids, (5) the effect of the datum shift on digital cartographic data, and (6) existing cartographic and technical exchange agreements.

PAN AMERICAN INSTITUTE OF GEOGRAPHY AND HISTORY

The USGS continued to provide administrative and staff support for the U.S. National Member of the Commission on Cartography of the Pan American Institute of Geography and History (PAIGH) and for the Chairman of the Committee on Topographic Maps and Aerophotogrammetry of PAIGH. Meetings of the Directing Council of PAIGH were held in Mexico City, Mexico, in July 1975 and in Lima, Peru, in June 1976. Members of the U.S. National Section on the Commission on Cartography met in Reston, Va., on August 8, 1975, to meet the new Chairman of the U.S. National Section of PAIGH and again in April to discuss (1) the First United Nations Regional Cartographic Conference for the Americas, held in Ciudad de Panama, Panama, March 8–19, 1976, (2) the Meeting of the Authorities of PAIGH, held in January 1976 in Mexico City, and (3) the XI General Assembly and the XIII Consultation on Cartography, to be held in August 1977 in Quito, Ecuador.

TRAINING AND TOURS

The USGS helped train participants from other countries in various phases of topographic mapping. Training programs were arranged for four foreign trainees from Iran, Lebanon, the Philippine Islands, and Thailand. Also, tours were arranged for 329 visitors to Topographic Division facilities in the National Center.

COMPUTER TECHNOLOGY

With its scientists engaged in research into every existing and potential source of energy, the USGS is increasingly charged with providing direction to both government and industry in all phases of energy-related exploration, development, and production. Concomitantly, USGS requirements for increased computational capacity accelerated in FY 1976. This growth pattern was typified by a transition from rudimentary batch-processing techniques to more sophisticated interactive processing methods using time-sharing systems and the use of database-management software packages. The Computer Center Division (CCD) continued its expansion of computational facilities to meet the needs of the USGS scientific community. Future expansion and related planning activities were described in a comprehensive planning document, "The USGS Automatic Data Processing Management Plan," that identified requirements for a 5-year period (1977–81).

COMPUTER FACILITIES

RESTON BATCH PROCESSING

A second IBM 370/155 system was installed in July 1975 to accommodate increased batch-processing requirements and was operational in September 1975. Both IBM 370/155 systems are configured identically to ensure that either processor can execute any current or future program. The second IBM 370/155 is an interim computer system, as was the initial system. The combined capacity of the two computers will experience saturation in March 1977. Accordingly, the CCD plans to procure a more powerful central processing unit (CPU) to replace the two IBM 370/155 CPU's.

RESTON DISK STORAGE

The requirements for users of the Reston batch-processing system to access their data in an online mode continued to grow during FY 1976. The CCD acquired 16 units of double-density disk drives to overcome physical space, power, and air-conditioning constraints in order to accommodate this growth. Each double-density drive has a storage capacity of 200 million bytes as compared with a capacity of 100 million bytes on existing drives. Hence, twice the storage capacity can be obtained for approximately the same physical space, power, and air-conditioning requirements. The double-density drives were installed in May 1976. The CCD plans to procure additional mass storage capacity that uses higher density recording technology to accommodate future growth.

TIME-SHARING SYSTEMS

To provide automatic data-processing support to its energy program and related activities, the USGS procured three fully compatible time-sharing-oriented computers for Denver, Colo.; Menlo Park, Calif.; and Reston, Va. All three computers will be accessed by numerous terminals. Sixteen large data bases will be maintained on the computers. Image-manipulation techniques using cathode ray tube graphic devices and minicomputers monitoring scientific instrumentation will be used in support of scientific computations. The procurement proceeded on schedule during FY 1976. A contract was awarded in August 1976 to Honeywell Information Systems, Inc. for three Multics time-sharing systems. The first computer was installed at Denver in November 1976 and the second at Menlo Park in December 1976. The third was installed at Reston in January 1977.

EROS DATA CENTER

The EROS Data Center in Sioux Falls, S. Dak., maintains an extensive data base of photographic and electronic imagery data. The Burroughs B6700 computer system, installed in September 1975, is used in a multiprogramming environment to maintain and add to the primary imagery data base and to provide nationwide terminal access to those data for processing of customer inquiries, orders, and accounts. The B6700 will also support digital-image-analysis activities through use of a maximum likelihood algorithm for image classification. The existing system was augmented in mid-1976 by additional core memory and disk storage and an additional central processor, the result being a comprehensive, general-purpose multiprocessing system capable of supporting a variety of data-processing activities.

FLAGSTAFF IMAGE-PROCESSING FACILITY

The approach to image processing in the Flagstaff, Ariz., facility is to clean up and enhance spatial data for presentation as images for scientific interpretation.

The purposes of the facility include:

- Providing cartographic digital-image enhancements of Mariner spacecraft pictures to photographic interpreters to support preparation of geologic base maps.
- Providing custom enhancements of Landsat pictures containing areas of special geologic interest to investigators in the USGS and other agencies.
- Conducting basic research in image-processing methods.
- Providing general computational support to investigators at the Flagstaff Field Center.
- Providing custom enhancements of nonimage digital data sets by digital-image-processing methods. These data sets are reconstituted as televisionlike images in which data point values or their derivatives are represented as "brightness" values in an image roster. Examples are sets of terrain, magnetic, gravity, or similar data represented as shaded-relief, stereoscopic, or three-color images.

Actual processing does not require elaborate CPU capacity. Two independent systems are used—a DEC PDP 11/20 and a DEC PDP 11/45. An Electrak 100 digitizing system is used offline in the development of data sets for experimental work. Optronics Photowrite P–1500 devices are used to convert magnetic tape images to film.

Within the last year, selected products have been delivered to the EROS Data Center, where copies are available to the general public for a nominal charge.

COM MICROFICHE FACILITY

The CCD has installed a Computer-Oriented-Microform (COM) facility that generates microfiche from standard print-image tapes. The production of microfiche provides significant user benefits in terms of data storage, data accessibility, and data distribution.

Each piece of microfiche measures approximately 4×6 in and can hold the equivalent of 269 pages of computer printout (over 17,000 lines of print). Thus, a drawer of microfiche about the size of a shoebox could store the equivalent of over a half million pages of printout or a stack of paper over 100 ft high.

The indexing techniques used in microfiche allow access to any one of the 269 pages of images on a particular microfiche, typically within 4 seconds. For files that span several pieces of microfiche, an eye-readable title across the top of each microfiche provides rapid access to any particular fiche. Thus, the inherent indexing and titling capabilities of microfiche, together with the simplicity and ease of operation of microfiche readers, provide an overall access operation that is far superior to methods involving bulky computer printouts.

The CCD facility can produce two types of microfiche—masters and duplicates. Master microfiche are created on a Quantor 105 Offline Microfiche Recorder/Processor on silver-halide film and are of archival quality. Duplicate microfiche are produced from masters on a Zidex D–80 Microfiche Duplicator using diazo film. Although the diazo duplicates do not have the full archival qualities of the silver-halide masters, they are suitable for normal operating and storage environments. The cost of the diazo duplicates is approximately one-tenth the cost of multiple copies of an original report. This advantage, together with the compactness inherent in the microfiche format, allows for significant cost savings in situations involving large distribution of computer-generated reports.

U.S. GEOLOGICAL SURVEY PUBLICATIONS

PUBLICATIONS PROGRAM

Books and maps

Results of research and investigations conducted by the USGS are made available to the public through professional papers, bulletins, water-supply papers, circulars, miscellaneous reports, and several map and atlas series, most of which are published by the USGS. Books are printed by the Government Printing Office, and maps are printed by the USGS; both books and maps are sold by the USGS.

All books, maps other than topographic quadrangle maps, and related USGS publications are listed in the catalog "Publications of the Geological Survey, 1879–1961" and "Publications of the Geological Survey, 1962–1970" and in yearly supplements, available on request, that keep the catalogs up to date.

New publications, including topographic quadrangle maps, are announced monthly in "New Publications of the Geological Survey." A free subscription to this list may be obtained on application to the *U.S. Geological Survey, 329 National Center, Reston, VA 22092.*

State list of publications on hydrology and geology

"Geologic and Water-Supply Reports and Maps, [State]," a series of booklets, provides a ready reference to these publications on a State basis. The booklets also list libraries in the subject State where USGS reports and maps may be consulted; these booklets are available free on request to the USGS.

Surface-water, quality-of-water, and ground-water-level records

Surface-water records through water year 1970 were published in a series of water-supply papers titled "Surface-Water Supply of the United States"; through water year 1960, each volume covered a single year, but the period 1961–70 was covered by two 5-year volumes (1961–65 and 1966–70).

Quality-of-water records through water year 1970 were published in an annual series of water-supply papers titled "Quality of Surface Waters of the United States."

Both surface-water and quality-of-water records for water years 1971–74 were published in a series of annual reports titled "Water Resources Data for [State]." Some of these reports contained both types of data in the same volume, but others were separated into two parts, "Part 1: Surface-Water Records" and "Part 2: Water-Quality Records." Limited numbers of these reports were printed, as they were intended for local distribution only. Since the data in these reports will not be republished in the water-supply paper series, reports will be made available for sale by the National Technical Information Service in Springfield, Va.

Records of ground-water levels in selected observation wells through calendar year 1974 were published in the series of water-supply papers titled "Ground-Water Levels in the United States." Through 1955, each volume covered a single year, but, during the period 1956–74, most volumes covered 5 years.

Starting with water year 1975, records for surface water, quality of water, and levels of ground-water observation wells are all published under one cover in a series of annual reports issued on a State-boundary basis. Reports for water year 1975 and subsequent water years will appear in a series that will carry an identification number consisting of a two-letter state abbreviation, the last two digits of the water year, and the volume number. These reports are titled "Water-Resources Data for [State]"; they are sold by the *National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161.*

State hydrologic unit maps

State hydrologic unit maps, which are overprints of the 1:500,000-scale State base maps, show culture in black, hydrography in blue, hydrologic subdivision boundaries and codes in red, and political (FIPS county) codes in green. The Alaska State maps are at 1:250,000 scale, and Puerto Rico maps are at 1:240,000 scale. All river basins having drainage areas greater than 700 mi² are delineated on the maps. The hydrologic boundaries depict (1) water-resources regions, (2) water-resources subregions, (3) National Water-Data Network accounting units, and (4) cataloging units of the USGS "Catalog of Information on Water Data." These maps are available for every State and Puerto Rico.

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 programs in the 50 States and Puerto Rico, the U.S. Virgin Islands, Guam, and American Samoa. As the programs change, the folders are revised. The folders are available free on request to the *U.S. Geological Survey, 439 National Center, Reston, VA 22092* or to the Water Resources Division district offices listed on p. 358.

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. Since May 1974, all reports and maps released only in the open files have been listed monthly in "New Publications of the Geological Survey," which also lists places of availability for consultation. Reports issued before May 1974 were listed annually in the circular series. Most open-file reports are placed in one or more of the three USGS libraries: Room 4–A–100, National Center, 12201 Sunrise Valley Drive, Reston, Va. 22092; 1526 Cole Boulevard at West Colfax Avenue, Golden, Colo. (mailing address: Stop 914, Box 25046, Federal Center, Denver, CO 80225); and 345 Middlefield Road, Menlo Park, Calif. 94025. Other depositories may include one or more of the USGS offices listed on p. 353 and interested State agencies. Many open-file reports are superseded later by formally printed publications.

Journal of Research of the U.S. Geological Survey

The "Journal of Research of the U.S. Geological Survey" is a bimonthly periodical designed to provide relatively rapid publication of short scientific papers by USGS personnel. It replaces the short-papers chapters of the annual "Geological Survey Research" series of professional papers, issued from 1960 through 1972.

Earthquake publications

The "Earthquake Information Bulletin" is published bimonthly by the USGS to provide information on earthquakes and seismological activities of interest to both general and specialized readers. It also lists pertinent publications and selected future professional meetings of Earth-science groups.

The USGS National Earthquake Information Service locates most earthquakes above magnitude 5.0 on a worldwide basis. A chronological summary of location and magnitude data for each located earthquake is published in the monthly listing "Preliminary Determination of Epicenters."

"Earthquakes in the United States" is published quarterly as a USGS circular. The circulars supplement the information given in the monthly listing "Preliminary Determination of Epicenters" to the extent of providing detailed felt and intensity data as well as isoseismal maps for U.S. earthquakes.

PUBLICATIONS ISSUED

During FY 1976, the USGS published 4,539 maps comprising some 18,481,864 copies:

Kind of map printed	*Number*
Topographic	4,162
Geologic and hydrologic	281
Maps for inclusion in book reports	15
Miscellaneous (including maps for other agencies)	81
Total	4,539

In addition, 7 issues of the "Journal of Research" comprising about 24,500 copies, 9 issues of the "Earthquake Information Bulletin" comprising about 36,000 copies, 208 technical book reports, and 1,184 leaflets and maps of flood-prone areas were published.

At the beginning of FY 1976, more than 94.3 million copies of maps and book reports were on hand in the USGS distribution centers. During the year, 11,024,074 copies of maps, including 601,575 index maps, were distributed. Approximately 8.4 million maps were sold, and $3,751,261 was deposited to Miscellaneous Receipts in the U.S. Treasury.

The USGS also distributed 336,784 copies of technical book reports, without charge and for official use, and 2,108,424 copies of booklets, free of charge, chiefly to the general public; 242,160 copies of the monthly publications announcements and 50,000 copies of a sheet showing topographic map symbols were sent out.

The total distribution resulted from receipt of 675,795 individual orders. The following table compares USGS map and book distribution (including booklets but excluding map-symbol sheets and monthly announcements) during FY 1975 and FY 1976:

Number of maps and books distributed

Distribution points	Fiscal year 1975	Fiscal year 1976	Change (percent)
Eastern (Arlington, Va.)	6,499,087	7,204,608	+11
Central (Denver, Colo.)	4,938,330	4,812,543	−3
Alaska (Fairbanks)	129,949	148,344	+14
Other USGS offices	857,234	782,792	−9
Total	12,424,600	12,948,287	+4

HOW TO OBTAIN PUBLICATIONS

OVER THE COUNTER

Book reports

Book reports (professional papers, bulletins, water-supply papers, "Topographic Instructions," "Techniques of Water-Resources Investigations," and some miscellaneous reports) can be purchased from the *Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, Va. 22202,* and from the USGS Public Inquiries Offices listed on p. 357 (authorized agents of the Superintendent of Documents).

Some book publications that can no longer be obtained from the Superintendent of Documents are available for purchase from the above authorized agents of the Superintendent of Documents.

Maps and charts

Maps and charts may be purchased at the following USGS offices:

1200 South Eads Street, Arlington, Va.
1400 Independence Road, Rolla, Mo.
Building 41, Federal Center, Denver, Colo.
345 Middlefield Road, Menlo Park, Calif.
310 First Avenue, Fairbanks, Alaska
Public Inquiries Offices listed on p. 357.

USGS maps are also sold by some 1,550 commercial dealers throughout the United States. Prices charged are generally higher than those charged by USGS offices.

Indexes showing topographic maps published for each State, Puerto Rico, the U.S. Virgin Islands, Guam, American Samoa, and Antarctica are available free on request. Publication of revised indexes to topographic mapping is announced in the monthly "New Publications of the Geological Survey." Each index also lists special and U.S. maps, as well as USGS offices and commercial dealers from which maps may be purchased.

Maps, charts, folios, and atlases that are out of print can no longer be obtained from any official source. These may be consulted at many libraries, and some can be purchased from secondhand-book dealers.

BY MAIL

Book reports

Technical book reports and some miscellaneous reports can be ordered from the *Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202.* Prepayment is required and should be made by check or money order in U.S. funds payable to the U.S. Geological Survey. Postage stamps are not accepted; please do not send cash. On orders of 100 copies or more of the same report sent to the same address, a 25-percent discount is allowed. Circulars, publications of general interest (such as leaflets, pamphlets, and booklets), and some miscellaneous reports may be obtained free from the Branch of Distribution.

Maps and charts

Maps and charts, including folios and hydrologic atlases, are sold by the USGS. Address orders to *Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202* for maps of areas east of the Mississippi River, including Minnesota, Puerto Rico, and the U.S. Virgin Islands, and to *Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225* for maps of areas west of the Mississippi, including Alaska, Hawaii, Louisiana, Guam, and American Samoa. Residents of Alaska may also order maps of their State from the *Alaska Distribution Section, U.S. Geological Survey, 310 First Avenue, Fairbanks, AK 99701.*

Prepayment is required. Remittances should be by check or money order in U.S. funds payable to the U.S. Geological Survey. On an order amounting to $300 or more at the list price, a 30-percent discount is allowed. Prices are quoted in lists of publications and in indexes to topographic mapping for individual States. Prices include the cost of surface transportation.

Journal of Research, Earthquake Information Bulletin, and Preliminary Determination of Epicenters

Subscriptions to the "Journal of Research of the U.S. Geological Survey," the "Earthquake Information Bulletin," and the "Preliminary Determination of Epicenters" 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 be purchased from the *Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202.*

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. Requests for the indexes or inquiries concerning the availability of advance material should be directed to the *National Cartographic Information Center, U.S. Geological Survey, 507 National Center, Reston, VA 22092.*

EROS Data Center materials

USGS aerial photography, NASA aircraft photography and imagery, Landsat (formerly ERTS) imagery, and Skylab imagery and photography are sold by the USGS, as are copies of the photography and imagery produced on 16-mm browse film, which are designed for prepurchase evaluation. Landsat data in digital form and Landsat Standard Catalogs are also sold. Address requests for price list, additional information, and orders to *EROS Data Center, U.S. Geological Survey, Sioux Falls, SD 57198.* Prepayment is required for orders. Remittances should be made payable in U.S. funds to the U.S. Geological Survey.

National Technical Information Service

Some USGS reports, including computer programs, data and information supplemental to map or book publications, and data files, are released through the National Technical Information Service (NTIS). These reports, available either in paper copies or microfiche or sometimes on magnetic tapes, can be purchased only from the *National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161.* USGS reports that are released through NTIS, together with their NTIS order numbers and prices, are announced in the monthly "New Publications of the Geological Survey."

REFERENCES CITED

Albee, A. L., Chodos, A. A., Dymek, R. F., Gancarz, A. J., Goldman, D. C., Papanastassiou, D. A., and Wasserburg, G. J., 1974, Dunite from the lunar highlands—Petrography, deformational history, Rb-Sr age, *in* Lunar science V: Houston, Tex., Lunar Sci. Inst., p. 3–5.

Albee, A. L., Dymek, R. F., and De Paolo, D. J., 1975, Spinel symplectites—High-pressure solid-state reaction or late stage magmatic crystallization, *in* Lunar science VI: Houston, Tex., Lunar Sci. Inst., p. 1–3.

Albers, J. P., and Bawiec, W. J., 1975, Non-fuel minerals and materials needed by the U.S. energy industry, 1975–1990: U.S. Geol. Survey open-file rept., 112 p.

Aldrich, L. T., Davis, G. L., and James, H. L., 1965, Ages of minerals from metamorphic and igneous rocks near Iron Mountain, Michigan: Jour. Petrology, v. 6, p. 445–472.

Anderson, J. R., Hardy, E. E., Roach, J. T., and Witmer, R. E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geol. Survey Prof. Paper 964, 28 p.

Armbruster, J. T., 1976a, An infiltration index useful in estimating low-flow characteristics of drainage basins: U.S. Geol. Survey Jour. Research, v. 4, no. 5, p. 533–538.

——— 1976b, Technical manual for estimating low-flow frequency characteristics of streams in the Susquehanna River basin: Springfield, Va., U.S. Dept. Commerce, Natl. Tech. Inf. Service, PB–255 455/AS, 71 p.

Armbrustmacher, T. J., 1975, Thorium deposits in the Wet Mountains area, Fremont and Custer Counties, Colorado [abs.], *in* Craig, L. C., Brooks, R. A., and Patton, P. C., eds., Abstracts for the 1975 Uranium and Thorium Research and Resources Conference: U.S. Geol. Survey open-file rept., p. 4.

Arthur D. Little, Inc., 1975, An evaluation of the San Francisco Bay Region Environment and Resources Planning Study: Washington, D.C., U.S. Dept. Housing Urban Devel., Office Policy Devel. Research, 93 p.

Ashenden, D. D., 1973, Stratigraphy and structure, northern portion of the Pelham Dome, north-central Massachusetts: Amherst, Mass., Univ. of Mass. Geology Dept., Contr. 16.

Averett, R. C., and Iwatsubo, R. T., 1975, Notes on water chemistry and aquatic biology of Redwood Creek and selected tributaries: U.S. Geol. Survey open-file rept., 66 p.

Axelrod, D. I., 1956, Mio-Pliocene floras from west-central Nevada: California Univ. Pubs. Geol. Sci., v. 33, 321 p.

Back, William, Hanshaw, B. B., Pyle, T. E., and Weidie, A. E., 1976, Preliminary results of a geochemical and hydrologic study of Caleta Xel Ha, Quintana Roo, Mexico, *in* Yucatan guidebook: New Orleans, La., New Orleans Geol. Soc. [In press.]

Bagnold, R. A., 1954, Experiments on a gravity-free dispersion of large solid spheres in a Newtonian fluid under shear: Royal Soc. [London] Proc., ser. A, v. 225A, p. 49–63.

Bailey, E. H., Barnes, J. W., and Nackowski, M. P., 1975, The CENTO field course in applied mining geology: Assoc. Geoscientists Internat. Devel. News, no. 5, p. 28–30.

Ball, S. H., 1906, Precambrian rocks of the Georgetown quadrangle, Colorado: Am. Jour. Sci., ser. 4, v. 21, p. 371–389.

Barnes, D. F., 1976, Bouguer gravity map of Alaska: U.S. Geol. Survey open-file rept., 1 sheet, scale 1:2,500,000.

Barnes, F. F., 1966, Geology and coal resources of the Beluga-Yentna region, Alaska: U.S. Geol. Survey Bull. 1202–C, 54 p.

Barnes, P. W., and Reimnitz, Erk, 1974, Sedimentary processes on arctic shelves off the northern coast of Alaska, *in* Reed, J. C., and Sater, J. E., eds., The coast and shelf of the Beaufort Sea: Arlington, Va., Arctic Inst. North America, p. 439–476.

Barraclough, J. T., and Jensen, R. G., 1976, Hydrologic data for the Idaho National Engineering Laboratory site, Idaho, 1971–73: U.S. Geol. Survey open-file rept., 52 p.

Bearden, H. W., 1972, Ground water in the Hallandale area, Florida: Florida Dept. Nat. Resources Bur. Geology Inf. Circ. 77, 32 p.

——— 1974, Ground water resources of Hollywood area, Florida: Florida Dept. Nat. Resources Bur. Geology Rept. Inv. 77, 35 p.

Beikman, H. M., 1974a, Preliminary geologic map of the southeast quadrant of Alaska: U.S. Geol. Survey Misc. Field Studies Map MF–612, 2 sheets, scale 1:1,000,000.

——— 1974b, Preliminary geologic map of the southwest quadrant of Alaska: U.S. Geol. Survey Misc. Field Studies Map MF–611, 2 sheets, scale 1:1,000,000.

——— 1975a, Preliminary geologic map of southeastern Alaska: U.S. Geol. Survey Misc. Field Studies Map MF–673, 2 sheets, scale 1:1,000,000.

——— 1975b, Preliminary geologic map of the Alaska Peninsula and Aleutian Islands: U.S. Geol. Survey Misc. Field Studies Map MF–674, 2 sheets, scale 1:1,000,000.

Bell, K. G., and Alvord, D. C., 1976, Pre-Silurian stratigraphy of eastern Massachusetts, *in* Page, L. R., ed., Stratigraphy of New England: Geol. Soc. America Mem. 148. [In press.]

Bell, P. M., Mao, H. K., Roedder, Edwin, and Weiblen, P. W., 1975, The problem of the origin of symplectites in olivine-bearing lunar rocks, *in* Lunar science VI: Houston, Tex., Lunar Sci. Inst., p. 231–248.

Bennison, A. P., and Milton, Charles, 1954, Preliminary geologic map of the Fairfax, Virginia, and part of the Seneca, Maryland-Virginia, quadrangles: U.S. Geol. Survey open-file rept., scale 1:62,500.

Benson, D. G., 1974, Geology of the Antigonish Highlands, Nova Scotia: Canada Geol. Survey Mem. 376, 92 p.

Berg, H. C., and Cobb, E. H., 1967, Metalliferous lode deposits of Alaska: U.S. Geol Survey Bull. 1246, 254 p.

Berry, L., 1954, The crystal structure of covellite, CuS, and klockmannite, CuSe: Am. Mineralogist, v. 39, p. 504–509.

Billings, M. P., 1956, The geology of New Hampshire, pt. 2, Bedrock geology: Concord, N.H., New Hampshire State Plan. Devel. Comm., 203 p.

Bingham, J. W., and others, 1970, Geologic investigation of faulting in the Hanford region, Washington: U.S. Geol. Survey open-file rept., 104 p.

Blackwelder, Eliot, 1915, Post-Cretaceous history of the mountains of central-western Wyoming: Jour. Geol., v. 32, nos. 2, 3, and 4, p. 97–117, 193–217, and 307–340.

Blake M. C., Jr., Irwin, W. P., and Coleman, R. G., 1967, Upside-down metamorphic zonation, blueschist facies, along a regional thrust in California and Oregon, *in* Geological Survey research 1967: U.S. Geol. Survey Prof. Paper 575–C, p. C1–C9.

Boning, C. W., 1974, Users guide for a U.S. Geological Survey rainfall-runoff model: U.S. Geol. Survey open-file rept., 234 p.

Bortleson, G. C., and Wilson, R. T., 1976, Table of data on water quality of Baker Lake near Mount Baker, Washington: U.S. Geol. Survey open-file rept., 11 p.

Boudier, F., and Nicolas, A., 1972, Fusion partielle gabbroique dans la lherzolite de Lanzo (Alpes Piemontaises): Mineral. Petrog. Suisse Bull., v. 52, p. 39–56.

Bowen, R. W., and Botbol, M. J., 1975, Geologic Retrieval and Synopsis Program (GRASP): U.S. Geol. Survey Prof. Paper 966, 87 p.

Boyce, J. M., 1975a, Chronology of major flow units in the western nearside maria [abs.], *in* Origin of mare basalts and their implication for lunar evolution: Houston, Tex., Lunar Sci. Inst., p. 11–14.

——— 1975b, Relative ages of units in Mare Imbrium based on a quantitative measure of crater degradation [abs.], *in* Lunar science VI: Houston, Tex., Lunar Sci. Inst., p. 71–73.

Boyce, J. M., and Dial, A. L., Jr., 1975, Relative ages of flow units in Mare Imbrium and Sinus Iridum: Geochim. et Cosmochim. Acta, suppl. 6, v. 3, p. 2585–2596.

Boyce, J. M., Dial, A. L., Jr., and Soderblom, L. A., 1974, Relative ages of lunar nearside plains: Geochim. et Cosmochim. Acta, suppl. 5, v. 1, p. 11–23.

Bredehoeft, J. D., and Pinder, G. F., 1970, Digital analysis of areal flow in multiaquifer groundwater systems—A quasi three-dimensional model: Water Resources Research, v. 6, no. 3, p. 883–888.

Brew, D. A., 1974, Preliminary results of studies in the Tracy Arm-Fords Terror Wilderness Study Area, *in* Carter, Claire, ed., U.S. Geological Survey Alaska Program, 1974: U.S. Geol. Survey Circ. 700, p. 56.

Brew, D. A., and Ovenshine, A. T., 1974, Summary of recent studies in Glacier Bay National Monument, Alaska, *in* Carter, Claire, ed., U.S. Geological Survey Alaska Program, 1974: U.S. Geol. Survey Circ. 700, p. 53–54.

Brew, D. A., Ford, A. B., Grybeck, Donald, and Nutt, C. J., 1975, Coast Range transect in Tracy Arm-Fords Terror Wilderness Study Area contains seven major belts of rock, *in* Yount, M. E., ed., U.S. Geological Survey Alaska Program, 1975: U.S. Geol. Survey Circ. 722, p. 53.

Briggs, R. P., and Kohl, W. R., 1975, Map of zones where land use can be affected by landsliding, flooding, and undermining, Allegheny County, Pennsylvania: U.S. Geol. Survey Misc. Field Studies Map MF–685–D, 2 sheets, scale 1:50,000.

Briggs, R. P., Pomeroy, J. S., and Davies, W. E., 1975, Landsliding in Allegheny County, Pennsylvania: U.S. Geol. Survey Circ. 728, 18 p.

Brosgé, W. P., and Whittington, C. L., 1966, Geology of the Umiat-Maybe Creek region, Alaska: U.S. Geol. Survey Prof. Paper 303–H, 638 p.

Brown, C. E., 1969, New talc deposit in St. Lawrence County, New York: U.S. Geol. Survey Bull. 1272–D, p. D1–D13.

Brown, C. E., 1975, Aeromagnetic survey of Ogdensburg and vicinity, New York: U.S. Geol. Survey open-file rept., 16 pls.

Brown, R. P., Ward, P. L., and Plafker, George, 1973, Geologic and seismologic aspects of the Managua, Nicaragua, earthquakes of December 23, 1972: U.S. Geol. Survey Prof. Paper 838, 34 p.

Buddington, A. F., 1929, Granite phacoliths and their contact zones in the northwest Adirondacks: New York State Mus. and Sci. Service Bull. 281, p. 51–107.

——— 1939, Adirondack igneous rocks and their metamorphism: Geol. Soc. America Mem. 7, 354 p.

Bukry, J. D., 1976, Coccolith and silicoflagellate stratigraphy, central North Atlantic Ocean, Deep Sea Drilling Project Leg 37: Deep Sea Drilling Proj. Initial Repts., v. 37. [In press.]

Burchett, R. R., Reed, E. C., Dreeszen, V. H., and Prichard, G. E., 1975, Bedrock geologic map showing thickness of overlying Quaternary deposits, Fremont quadrangle and part of Omaha quadrangle, Nebraska: U.S. Geol. Survey Misc. Geol. Inv. Map I–905, 1 sheet, scale 1:250,000.

Bushnell, K. O., 1975a, Map showing depths to the Pittsburgh coal bed, mining activity, and related surface subsidence, Allegheny, Washington, and Westmoreland Counties, Pennsylvania: U.S. Geol. Survey Misc. Field Studies Map MF–693–A, 1 sheet, scale 1:125,000.

——— 1975b, Map showing areas that correlate with subsidence events due to underground mining of the Pittsburgh and Upper Freeport coal beds, Allegheny, Washington, and Westmoreland Counties, Pennsylvania: U.S. Geol. Survey Misc. Field Studies Map MF–693–C, 1 sheet, scale 1:125,000.

Bushnell, K. O., and Peak, J. R., 1975, Map showing depths to the Upper Freeport coal bed, mining activity, and related surface subsidence, and the Redstone coal bed mines, Allegheny, Washington, and Westmoreland Counties, Pennsylvania: U.S. Geol. Survey Misc. Field Studies Map MF–693–B, 1 sheet, scale 1:125,000.

Byerlee, J. D., Lockner, D. A., and Weeks, J. D., 1975, Tension fractures and shear fractures produced during hydraulic fracture [abs.]: EOS (Am. Geophys. Union Trans.), v. 56, no. 12, p. 1060.

Calderwood, K. W., and Fackler, W. C., 1972, Proposed stratigraphic nomenclature for Kenai Group, Cook Inlet Basin, Alaska: Am. Assoc. Petroleum Geologists Bull., v. 56, no. 4, p. 739.

Campbell, J. A., 1975, Uranium potential in the Permian rocks of the southwestern United States, *in* Craig, L. C., Brooks, R. A., and Patton, P. C., eds., Abstracts for the 1975 Uranium and Thorium Research and Resources Conference [abs.]: U.S. Geol. Survey open-file rept., p. 10.

Campbell, W. J., 1975, Polar ice fields, *in* Matthews, R. E., ed., Active microwave workshop: U.S. Natl. Aeronautics and Space Adm. Spec. Pub. SP–376, p. 214–220.

——— 1976a, Morphology of Beaufort Sea ice, *in* Williams, R. S., Jr., and Carter, W. D., eds., ERTS–1, a new window on our planet: U.S. Geol. Survey Prof. Paper 929, p. 350–355.

——— 1976b, Seasonal metamorphosis of sea ice, *in* Williams, R. S., Jr., and Carter, W. D., eds., ERTS–1, a new window on our planet: U.S. Geol. Survey Prof. Paper 929, p. 343–345.

——— 1976c, Tracking ice floes by sequential ERTS imagery, *in* Williams, R. S., Jr., and Carter, W. D., eds., ERTS–1, a new window on our planet: U.S. Geol. Survey Prof. Paper 929, p. 337–339.

——— 1976d, Lead and polynya dynamics, *in* Williams, R. S., Jr., and Carter, W. D., eds., ERTS–1, a new window on our planet: U.S. Geol. Survey Prof. Paper 929, p. 340–342.

——— 1976e, Dynamics of arctic ice shear zones, *in* Williams, R. S., Jr., and Carter, W. D., eds., ERTS–1, a new window on our planet: U.S. Geol. Survey Prof. Paper 929, p. 346–349.

Campbell, W. J., Ramseier, R. O., Weeks, W. F., and Gloersen, Per, 1975, Geophysical studies of floating ice by remote sensing: Jour. Glaciology, v. 15, no. 73, p. 305–328.

——— 1976, An integrated approach to the remote sensing of floating ice: Internat. Astronautical Cong. of the Internat. Federation of Astronautics, 26th, Lisbon, Portugal, 1975, Proc. [In press.]

Carpenter, A. B., Trout, M. L., and Pickett, E. E., 1974, Preliminary report on the origin and chemical evolution of lead and zinc-rich oil field brines in central Mississippi: Econ. Geology, v. 69, p. 1191–1206.

Chaffee, M. A., 1975, The zonal distribution of selected elements above the Kalamazoo porphyry copper-molybdenum deposit, San Manuel, Arizona [abs.]: Econ. Geology, v. 70, no. 1, p. 243.

Chao, E. C. T., 1976, The Ries Crater, a model for the interpretation of the source areas of lunar breccia samples [abs.], *in* Lunar science VII: Houston, Tex., Lunar Sci. Inst., p. 126–128.

Chao, E. C. T., Minkin, J. A., and Thompson, C. L., 1976, The petrology of 77215, a noritic impact breccia, *in* Lunar science VII: Houston, Tex., Lunar Sci. Inst., p. 129–131.

Chao, E. C. T., Minkin, J. A., Thompson, C. L., and Huebner, J. S., 1975, The petrogenesis of 77115 and its xenocrysts—Description and preliminary interpretation: Geochim. et Cosmochim. Acta, suppl. 6, v. 1, p. 498–515.

Cheng, R. T., 1975, A transient three-dimensional circulation model of large lakes or reservoirs [abs.]: Canada Centre for Inland Waters Symposium on Modeling of Transport Mechanisms in Oceans and Lakes, Burlington, Canada, 1975, Program, p. 4.

——— 1976, A numerical model of the time-dependent, three-dimensional structure of circulation in large lakes: Am. Soc. Civil Engineers Ann. Mtg. Water Resources Ocean Eng., San Diego, Calif., 1976, Mtg. preprint, 27 p.

Christian, R. P., Berman, Sol, Dwornik, E. J., Rose, H. J., Jr., and Schnepfe, M. M., 1976, Composition of some Apollo 14, 15, and 16 lunar breccias and two Apollo 15 fines, *in* Lunar science VII: Houston, Tex., Lunar Sci. Inst., p. 138–140.

Christiansen, R. L., and Miller, C. D., 1976, Volcanic evolution of Mt. Shasta, California [abs.]: Geol. Soc. America Abs. with Programs, v. 8, p. 527

Churkin. Michael, Jr., and Eberlein, G. D., 1975, Geologic map of the Craig C–4 quadrangle, Alaska: U.S. Geol. Survey Geol Quad. Map GQ–1169, 1 sheet, scale 1:63,360.

Clark, B. L., 1930, Tectonics of the Coast Ranges of middle California: Geol. Soc. America Bull., v. 41, no. 4, p. 747–828.

Cobb, E. H., 1974a, Molybdenum occurrences in Alaska: U.S. Geol. Survey Mineral Inv. Resource Map MR–59, 3 p., 1 map, scale 1:2,500,000.

——— 1974b, Cobalt occurrences in Alaska: U.S. Geol. Survey Mineral Inv. Resource Map MR–61, 1 p., 1 map, scale 1:2,500,000.

——— 1974c, Copper occurrences in Alaska: U.S. Geol. Survey Mineral Inv. Resource Map MR–62, 18 p., 1 map, scale 1:2,500,000.

——— 1974d, Nickel occurrences in Alaska: U.S. Geol. Survey Mineral Inv. Resource Map MR–63, 2 p., 1 map, scale 1:2,500,000.

——— 1974e, Tin occurrences in Alaska: U.S. Geol. Survey Mineral Inv. Resource Map MR–65, 4 p., 1 map, scale 1:2,500,000.

———1975a, Occurrences of platinum-group metals in Alaska: U.S. Geol. Survey Mineral Inv. Resource Map MR–64, 2 p., 1 map, scale 1:2,500,000.

——— 1975b, Tungsten occurrences in Alaska: U.S. Geol. Survey Mineral Inv. Resource Map MR–66, 5 p., 1 map, scale 1:2,500,000.

——— 1975c, Zinc occurrences in Alaska: U.S. Geol. Survey Mineral Inv. Resource Map MR–67, 9 p., 1 map, scale 1:2,500,000.

——— 1975d, Chromite occurrences in Alaska: U.S. Geol. Survey Mineral Inv. Resource Map MR–68, 2 p., 1 map, scale 1:2,500,000.

——— 1975e, Lead occurrences in Alaska: U.S. Geol. Survey Mineral Inv. Resource Map MR–69, 12 p., 1 map, scale 1:2,500,000.

——— 1975f, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Bendeleben quadrangle, Alaska: U.S. Geol. Survey open-file rept., 123 sheets.

——— 1975g, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Teller quadrangle, Alaska: U.S. Geol. Survey open-file rept., 141 sheets.

——— 1975h, Summary of mineral occurrences (other than mineral fuels and construction materials) in five quadrangles in west-central Alaska (Hughes, Kotzebue, Melozitna, Selawik, Shungnak): U.S. Geol. Survey open-file rept., 57 p.

——— 1975i, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in northern Alaska: U.S. Geol. Survey open-file rept., 106 p.

Colby, B. R., and Hembree, C. H., 1955, Computations of total sediment discharge, Niobrara River near Cody, Nebraska: U.S. Geol. Survey Water-Supply Paper 1357, 187 p.

Collier, A. J., Hess, F. L., Smith, P. S., and Brooks, A. H., 1908, The gold placers of parts of Seward Peninsula, Alaska, including the Nome, Council, Kougarok, Port Clarence, and Goodhope precincts: U.S. Geol. Survey Bull. 328, 343 p.

Condra, G. E., and Elias, M. K., 1944, Occurrence of the Russian genus *Rhombotrypella* in Utah: Jour. Paleontology, v. 18, p. 148–155.

Connor, J. J., and Shacklette, H. T., 1975, Background geochemistry of some rocks, soils, plants, and vegetables in the conterminous United States, *with sections on field studies by* Ebens, R. J., Erdman, J. A., Miesch, A. T., Tidball, R. R., and Tourtelot, H. A.: U.S. Geol. Survey Prof. Paper 574–F, p. F1–F168.

Conomos, T. J., and Peterson, D. H., 1976, Suspended-particle transport and circulation in San Francisco Bay: Internat. Estuarine Research Federation Conf., 3d, Galveston, Tex., 1975, Proc. [In press.]

Cook, H. E., and Taylor, M. E., 1975, Early Paleozoic continental margin sedimentation, trilobite biofacies, and the thermocline, western United States: Geology, v. 3, no. 10, p. 559–562.

Cooley, M. E., and Turner, R. M., 1975, Applications of ERTS products in range and water management problems, Sahelian Zone, Mali, Upper Volta, and Niger: U.S. Geol. Survey open-file rept., 68 p.

Cordell, L. E., and Henderson, R. G., 1968, Iterative three dimensional solution of gravity anomaly data using a digital computer: Geophysics, v. 33, no. 4, p. 596–601.

Cormier, R. F., 1974, Radiometric age of the Keppoch Formation, Browns Mountain Group, northern mainland of Nova Scotia: Canadian Jour. Earth Sci., v. 11, p. 1325–1329.

Cortis, S. E., Alexander, T. B., Edmunds, W. E., and Craft, J. L., 1975, Greater Pittsburgh region maps of mined-out areas and thickness of rock over the Pittsburgh coal: Pennsylvania Topog. and Geol. Survey Map 45, 2 sheets, scale 1:125,000. (Released as Basic Data Contribution 39 of the Greater Pittsburgh Region Urban Area Study.)

Cox, Allan, 1969, Geomagnetic reversals: Science, v. 163, p. 237–345.

Cragwall, J. S., Jr., 1976, The National Stream Quality Accounting Network: Mil. Engineer, v. 68, no. 441, p. 25–27.

Craig, L. C., 1975, Uranium possibilities of the Burro Canyon Formation, western Colorado [abs.], *in* Craig, L. C., Brooks, R. A., and Patton, P. C., eds., Abstracts for the 1975 Uranium and Thorium Research and Resources Conference: U.S. Geol. Survey open-file rept., p. 12.

Damon, P. E., Shafiqullah, M., and Leventhal, J. S., 1974, K–Ar chronology of the San Francisco volcanic field and rate of erosion of the Little Colorado River, *in* Karlstrom, T. N. V., Swann, G. A., and Eastwood, R. L., eds., Geology of northern Arizona with notes on archaeology and paleoclimate: Geol. Soc. America Rocky Mtn. Sect. Ann. Mtg., Flagstaff, Ariz., 1974, Guidebook 27, pt. 1, p. 221–235.

Davies, W. E., Pomeroy, J. S., and Kohl, W. R., 1976, Map of coal-mining features in Allegheny County, Pennsylvania: U.S. Geol. Survey Misc. Field Studies Map MF–685–C, 2 sheets, scale 1:50,000.

Dawdy, D. R., Lichty, R. W., and Bergmann, J. M., 1972, A rainfall-runoff simulation model for estimation of flood peaks for small drainage basins: U.S. Geol. Survey Prof. Paper 506–B, 28 p.

Desborough, G. A., and Pitman, J. K., 1975, Interpretation of Fischer assay data for the evaluation of analcime-bearing oil shale in the Green River Formation, Colorado and Utah: U.S. Geol. Survey open-file rept., 26 p.

Detterman, R. L., Reiser, H. N., Brosgé, W. P., and Dutro, J. T., 1975, Post-Carboniferous stratigraphy, northeastern Alaska: U.S. Geol. Survey Prof. Paper 886, 46 p.

Dickey, J. S., Jr., 1970, Partial fusion products in alpine-type peridotites—Serrania de la Ronda and other examples: Mineralog. Soc. America Spec. Pub. 3, p. 33–49.

Dickinson, K. A., 1976, Geologic controls of uranium deposition, Karnes County, Texas: U.S. Geol. Survey open-file rept., 16 p.

Diment, W. H., Urban, T. C., Sass, J. H., Marshall, B. V., Munroe, R. J., and Lachenbruch, A. H., 1975, Temperatures and heat contents based on conductive transport of heat, *in* White, D. E., and Williams, D. L., eds., Assessment of geothermal resources of the United States—1975: U.S. Geol. Survey Circ. 726, p. 84–103.

Dobbin, C. E., Bowen, C. F., and Hoots, H. W., 1929, Geology and coal and oil resources of the Hanna and Carbon Basins, Carbon County, Wyoming: U.S. Geol. Survey Bull. 804, 88 p.

Dodge, F. C. W., and Rossman, D. L., 1975, Mineralization in the Wadi Qatan area: U.S. Geol. Survey open-file rept., 71 p.

Doig, Ronald, 1970, An alkaline province linking Europe and North America: Canadian Jour. Earth Sci., v. 7, p. 22–28.

Donnelly, J. M., McLaughlin, R. J., Goff, F. E., and Hearn, B. C., 1976, Active faulting in The Geysers-Clear Lake area, northern California: Geol. Soc. America Abs. with Programs, v. 8, no. 3, p. 369–370.

Donovan, T. J., Noble, R. L., Friedman, Irving, and Gleason, J. D., 1975, A possible petroleum-related geochemical anomaly in surface rocks, Boulder and Weld Counties, Colorado: U.S. Geol. Survey open-file rept., 11 p.

Drake, C. M., Ewing, Maurice, and Sutton, G. H., 1959, Continental margins and geosynclines—The east coast of North America north of Cape Hatteras, *in* Physics and chemistry of the Earth: New York, Pergamon Press, v. 3, p. 110–198.

Duffield, W. A., 1975a, Late Cenozoic ring faulting and volcanism in the Coso Range area of California: Geology, v. 3, no. 6, p. 335–338.

——— 1975b, Structure and origin of the Koae fault system, Kilauea Volcano, Hawaii: U.S. Geol. Survey Prof. Paper 856, 12 p.

Durum, W. H., Hem, J. D., and Heidel, S. G., 1971, Reconnaissance of selected minor elements in surface waters of the United States, October, 1970: U.S. Geol. Survey Circ. 643, 49 p.

Eberlein, G. D., and Churkin, Michael, Jr., 1970, Paleozoic stratigraphy in the northwest coastal area of Prince of Wales Island, southeastern Alaska: U.S. Geol. Survey Bull. 1284, 67 p.

Eccles, L. A., 1976, Sources of arsenic in streams tributary to Lake Crowley, California: U.S. Geol. Survey Water-Resources Inv. 76–36, 55 p.

Eikenberry, S. E., and Davis, L. G., 1976, A technique for estimating the time of travel of water in Indiana streams: U.S. Geol. Survey Water-Resources Inv. 76–9, 44 p.

Einstein, H. A., 1950, The bed-load function for sediment transportation in open channel flows: U.S. Dept. Agriculture Tech. Bull. 1026, 70 p.

Elsheimer, H. N., Fabbi, B. P., and Espos, L. F., 1975, Quantitative analysis of ten major elements in silicate rocks through use of a computerized automatic X-ray spectrograph: Pacific Conf. on Chemistry and Spectroscopy, Hollywood, Calif., 1975.

Elston, W. E., 1957, Geology and mineral resources of Dwyer quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 38, 86 p.

——— 1968, Terminology and distribution of ash-flows of the Mogollon-Silver City-Lordsburg region, New Mexico: Geol. Soc. America Cordilleran Sect. Ann. Mtg., Southern Arizona guidebook, p. 231–240.

Emerson, B. K., 1917, Geology of Massachusetts and Rhode Island: U.S. Geol. Survey Bull. 597, 298 p.

Emery, K. O., Uchupi, Elazar, Phillips, J. D., Brown, C. O., Bunce, E. T., and Knott, S. T., 1970, Continental rise off eastern North America: Am. Assoc. Petroleum Geologists Bull., v. 54, no. 1, p. 44–108.

Emmett, W. W., 1976, Bedload transport in two large, gravel-bed rivers, Idaho and Washington: Federal Inter-Agency Sedimentation Conf., 3d, Denver, Colo., 1976, Proc., p. 4-101–4-114.

Emmet, W. W., Druffel, L. A., Schneider, V. R., and Skinner, J. V., 1976, Laboratory hydraulic calibration of the Helley-Smith bedload sampler: U.S. Geol. Survey open-file rept., 50 p.

England, A. W., 1975, Thermal microwave emission from a scattering layer: Jour. Geophys. Research, v. 80, p. 4484–4496.

Epstein, A. G., Epstein, J. B., and Harris, L. D., Conodont color alteration—An index to organic metamorphism: U.S. Geol. Survey Prof. Paper 995, 27 p.

Espenshade, G. H., and Clarke, J. W., 1976, Geology of the Blue Ridge anticlinorium in northern Virginia: Geol. Soc. America Joint Mtg. of the Northeast and Southeast Sects., Fieldtrip guidebook 5, 26 p.

Espinosa, A. F., ed., The Guatemalan earthquake of February 4, 1976, a preliminary report: U.S. Geol. Survey Prof. Paper 1002, 90 p.

Ewing, John, and Ewing, Maurice, 1959, Seismic-refraction measurements in the Atlantic Ocean basins, in the Mediterranean Sea, on the Mid-Atlantic Ridge, and in the Norwegian Sea: Geol. Soc. America Bull., v. 70, p. 291–318.

Ewing, Maurice, Woollard, G. P., Vine, A. C., and Worzel, J. L., 1946, Recent results in submarine geophysics: Geol. Soc. America Bull., v. 57, no. 10, p. 909–934.

Fahlquist, Frank, 1935, Geology of the region in which Quabbin Aqueduct and Quabbin Reservoir are located: App. Rept. Chief Engineer, Ann. Rept. Metropolitan Dist. Water Supply Comm., Commonwealth Massachusetts Public Doc. 147.

Ferguson, H. G., 1927, Geology and mineral deposits of the Mogollon mining district: U.S. Geol. Survey Bull. 787, 100 p.

Finkelman, R. B., 1976, Mineralogy and petrography of the sub-30 m fraction of the Apollo 16 regolith, *in* Lunar science VII: Houston, Tex., Lunar Sci. Inst., p. 254–256.

Fisher, G. W., 1970, The metamorphic and sedimentary rocks along the Potomac River near Washington, D.C., *in* Fisher, G. W., and others, eds., Studies of Appalachian geology, central and southern: New York, Interscience Pub., 480 p.

Fleming, R. S., Jr., and Sumner, J. R., 1975, Interpretation of geophysical anomalies over the arcuate Appalachians [abs.]: Geol. Soc. America Abs. with Programs, v. 7, no. 1, p. 58.

Flippo, H. N., Jr., 1975, Flood of June 22–23, 1972, at Lock Haven, Pennsylvania: U.S. Geol. Survey Hydrol. Inv. Atlas HA–541, 1 sheet, scale 1:12,000.

Folger, D. W., Hathaway, J. C., Poag, C. W., Valentine, P. C., Weed, E. G. A., Rhodehamel, E. C., and Barrett, W., 1976, Mesozoic stratigraphic test, Nantucket Island, Massachusetts [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 60, no. 4, p. 672.

Foose, M. P., and Brown, C. E., 1976, A preliminary synthesis of structural, stratigraphic, and magnetic data from part of the northwest Adirondacks, New York: U.S. Geol. Survey open-file rept., 22 p.

Ford, A. B., 1975, Antarctic deep-sea basalt, southeast Indian Ocean and Balleny Basin, DSDP Leg 28, *in* Hayes, D. E., Frakes, L. A., and others, Initial reports of the Deep Sea Drilling Project: Washington, D.C., U.S. Govt. Printing Office, v. 28, p. 835–859.

Ford, A. B., and Barrett, P. J., 1975, Basement rocks of the south-central Ross Sea, Site 270, DSDP Leg 28, *in* Hayes, D. E., Frakes, L. A., and others, Initial reports of the Deep Sea Drilling Project: Washington, D.C., U.S. Govt. Printing Office, v. 28, p. 861–868.

Ford, A. B., and Brew, D. A., 1973, Preliminary geologic and metamorphic-isograd map of the Juneau B–2 quadrangle, Alaska: U.S. Geol. Survey Misc. Field Studies Map MF–527, 1 sheet, scale 1:31,680.

Frank, D. G., and Post, A. S., 1976, Documentation of thermal changes by photographs of snow and ice features at Mount Baker, Washington [abs.]: EOS (Am. Geophys. Union Trans.), v. 57, no. 2, p. 87.

Freethey, G. W., 1976, Preliminary report on water availability in the lower Ship Creek basin, Anchorage, Alaska—with special reference to the fish hatchery on Fort Richardson and a proposed fish-hatchery site near the Elmendorf Air Force Base powerplant: U.S. Geol. Survey Water-Resources Inv. 48–75, 21 p.

Fretwell, M. C., 1976, Water quality sampling and analysis activities related to Mount Baker's recent volcanic activity [abs.]: EOS (Am. Geophys. Union Trans.), v. 57, no. 2, p. 89.

Frickel, D. G., Shown, L. M., and Patton, P. C., 1975, An evaluation of hillslope and channel erosion related to oil-shale development in the Piceance basin, northwestern Colorado: Colorado Water Conserv. Board Water-Resources Circ. 30, 37 p.

Friedman, Irving, and Smith, R. L., 1960, A new dating method using obsidian, pt. 1, The development of the method: Am. Antiquity, v. 25, no. 4, p. 476–522.

Fuller, R. H., 1975a, Trace metal release from lake sediments —The effect of aerobic versus anaerobic environments [abs.]: Geol. Soc. America Abs. with Programs, v. 7, no. 7, p. 1081.

——— 1975b, Selected water-quality data from Fallen Leaf Lake, El Dorado County, California, June through October, 1974: U.S. Geol. Survey open-file rept., 38 p.

Furcron, A. S., 1939, Geology and mineral resources of the Warrenton quadrangle, Virginia: Virginia Geol. Survey Bull. 54, 94 p.

Gallagher, D. B., 1976, Land use analysis of U.S. urban areas using high-resolution imagery from Skylab: Springfield, Va., U.S. Dept. Commerce, Natl. Tech. Inf. Service, E76–10321, 32 p.

Ganapthy, R., and Anders, E., 1974, Bulk compositions of the Moon and Earth, estimated from meteorite: Geochim. et Cosmochim. Acta, suppl. 5, v. 2, p. 1181–1206.

Gawthrop, W. H., 1975, Seismicity of the central California coastal region: U.S. Geol. Survey open-file rept., 87 p.

Gibbs, J. F., Fumal, T. E., and Borcherdt, R. D., 1975, In-situ measurements of seismic velocities at twelve locations in the San Francisco Bay region: U.S. Geol. Survey open-file rept., 87 p.

Gloersen, Per, Campbell, W. J., Ramseier, R. O., Webster, W. J., and Wilheit, T. T., 1975, Beaufort Sea ice zones by means of microwave imagery: Greenbelt, Md., NASA Goddard Space Flight Center Rept. No. X–910–75–80, 29 p.

Goff, F. E., Donnelly, J. M., Thompson, J. M., and Hearn, B. C., 1976, The Konocti Bay fault zone, California—Potential area for geothermal exploration: Geol. Soc. America Abs. with Programs, v. 8, no. 3, p. 375–376.

Goldich, S. S., Hedge, C. E., and Stern, T. W., 1970, Age of the Morton and Montevideo gneisses and related rocks, southwestern Minnesota: Geol. Soc. America Bull., v. 81, p. 3671–3696.

Gooley, R., Brett, P. R., Warner, J., and Smyth, J. R., 1974, Sample 76535, a deep lunar crustal rock: Geochim. et Cosmochim. Acta, v. 38, p. 1329–1340.

Gordon, Mackenzie, Jr., 1970, Carboniferous ammonoid zones of the south-central and western United States: Cong. Internat. Stratigraphie Géologie du Carbonifère, 6th, Sheffield, England, 1967, Compte rendu, v. 2, p. 817–826.

Gore, R. Z., 1976, The Ayer crystalline complex at Ayer, Harvard, and Clinton, Mass., *in* Lyons, P. C., and Brownlow, A. M., eds., Contributions to New England geology: Geol. Soc. America Mem. 146, 374 p.

Grantz, Arthur, McHendrie, A. G., Nilsen, T. H., and Yorath, C. J., 1974, Seismic reflection profiles 1973 on the continental shelf and slope between Bering Strait and Barrow, Alaska, and Mackenzie Bay, Canada: U.S. Geol. Survey open-file rept., 49 folded charts, 2 folded maps.

Great Lakes Basin Commission Power Work Group, 1975, Great Lakes framework study, app. 10, Power: Ann Arbor, Mich., Public Inf. Office, Great Lakes Basin Comm., p. 36.

Green, A. W., Jr., Stearns, C. O., and Troitskaya, V. A., 1975, The relationship between world wide Pi2 characteristics and magnetotail parameters: EOS (Am. Geophys. Union Trans.), v. 56, no. 12, p. 1044.

Greenwood, H. J., 1963, The synthesis and stability of anthophyllite: Jour. Petrology, v. 4, p. 317–351.

Grew, E. S., 1973, Stratigraphy of the Pennsylvanian and pre-Pennsylvanian rocks of the Worcester area, Mass.: Am. Jour. Sci., v. 273, p. 113–129.

Haire, W. J., 1975a, Floods in the Carolina-Río Grande area, northeastern Puerto Rico: U.S. Geol. Survey Hydrol. Inv. Atlas HA–533, 1 sheet, scale 1:20,000.

——— 1975b, Floods in the Fajardo-Luquillo area, northeastern Puerto Rico: U.S. Geol. Survey Hydrol. Inv. Atlas HA–545, 1 sheet, scale 1:20,000.

Hall, C. A., Jr., 1975, San Simeon-Hosgri fault system, coastal California—Economic and environmental implications: U.S. Geol. Survey open-file rept., 12 p.

Hall, W. E., Batchelder, John, and Douglass, R. C., 1974, Stratigraphic section of the Wood River Formation, Blaine County, Idaho: U.S. Geol. Survey Jour. Research, v. 2, no. 1, p. 89–95.

Hamilton, W. B., and Neuerburg, G. J., 1956, Olivine-sanidine trachybasalt from the Sierra Nevada, California: Am. Mineralogist, v. 41, p. 851–873.

Hampton, J. N., 1975, An experiment in multispectral air photography for archaeological research, *in* Harp, Elmer, Jr., ed., Photography in archaeological research: Albuquerque, N. Mex., Univ. New Mexico School of Am. Research Advanced Seminar Series, p. 157–210.

Hanna, W. F., Rupple, B. D., McHendrie, A. G., and Sikora, R. F., 1974, Residual magnetic anomaly and free-air gravity anomaly profiles, 1973, on continental shelf and slope between Bering Strait and Barrow, Alaska, and MacKenzie Bay, Canada: U.S. Geol. Survey open-file rept., 6 pls., scale 1:1,000,000.

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

Hanson, L. G., 1970, The origin and development of Moses Coulee and other scabland features on the Waterville Plateau, Washington: Seattle, Wash., Univ. Washington Ph. D. thesis, 137 p.

Harbeck, G. E., Jr., 1964, Estimating forced evaporation from cooling ponds: Am. Soc. Civil Engineers Proc. Jour. Power Div., v. 90, no. P03, p. 1–9.

Harris, L. D., 1976, Thin-skinned tectonics and potential hydrocarbon traps—Illustrated by a seismic profile in the Valley and Ridge of Tennessee: U.S. Geol. Survey Jour. Research, v. 4, no. 4, p. 379–386.

Harrison, J. E., Griggs, A. B., and Wells, J. D., 1974, Tectonic features of the Precambrian Belt basin and their influence on post-Belt structures: U.S. Geol. Survey Prof. Paper 866, 16 p.

Have, M. R., 1975a, Some limnological aspects of 20 selected lakes in Eagan and Apple Valley, Minnesota: U.S. Geol. Survey open-file rept., 44 p.

——— 1975b, A water-quality assessment of the Burnham Creek watershed, Polk County, Minnesota: U.S. Geol. Survey open-file rept., 15 p.

Hazlewood, R. M., 1974, Preliminary report of seismic refraction survey along the east side of the San Francisco Bay, Alameda County, California: U.S. Geol. Survey open-file rept., 10 p.

Hazlewood, R. M., and Joyner, W. B., 1973, Preliminary report of seismic refraction survey, Redwood Shores, San Mateo County, California: U.S. Geol. Survey open-file rept., 9 p.

Helm, D. C., 1976, One-dimensional simulation of aquifer-system compaction near Pixley, California, pt. 2, Stress-dependent parameters: Water Resources Research, v. 12, no. 3, p. 375–391.

Helz, A. W., 1973, Spectrochemical computer analysis-instrumentation: U.S. Geol. Survey Jour. Research, v. 1, no. 4, p. 475–482.

Hernon, R. M., Jones, W. R., and Moore, S. L., 1964, Geology of the Santa Rita quadrangle, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–306, scale 1:24,000.

Hevly, R. H., and Karlstrom, T. N. V., 1974, Southwest paleoclimate and continental correlations, *in* Karlstrom, T. N. V., Swann, G. A., and Eastwood, R. L., eds., Geology of northern Arizona with notes on archaeology and paleoclimate: Geol. Soc. America Rocky Mtn. Sect. Mtg., Flagstaff, Ariz., 1974, Guidebook 27, pt. 1, p. 257–295.

Higer, A. L., Cordes, E. H., Coker, A. E., and Rogers, R. H., 1975, Water-management models in Florida from Landsat–1 data, National Aeronautics and Space Administration, *in* NASA Earth Resources Survey Symposium, June 1975, Houston, Texas: NASA Rept. TMX–58168, v. 1D, p. 2407–2442.

Himmelberg, G. R., and Ford, A. B., 1975, Petrologic studies of the Dufek intrusion, Pensacola Mountains—Iron-titanium oxides: Antarctic Jour. U.S., v. 10, p. 241–244.

Hines, W. G., Rickert, D. A., McKenzie, S. W., and Bennett, J. P., 1975a, Formulation and use of practical models for river-quality assessment: U.S. Geol. Survey Circ. 715–B, 13 p.

——— 1975b, Formulation and use of practical models for river-quality assessment: Water Pollution Control Federation Jour., v. 47, no. 10, p. 2357–2370.

Hiss, W. L., 1974, Reduction of ground-water flow through the Capitan and Goatseep limestones by incised contemporaneous submarine canyons [abs.]: Geol. Soc. America Abs. with Programs, v. 6, no. 7, p. 797.

——— 1975a, Evaluation and proposed study of potential ground-water supplies, Gallup area, New Mexico: U.S. Geol. Survey open-file rept., 153 p.

——— 1975b, Thickness of the Permian Capitan aquifer, southeastern New Mexico and western Texas: New Mexico Bur. Mines and Mineral Resources Resource Map 5, 1 sheet.

——— 1975c, Water-quality data from oil and gas wells in part of the Permian basin, southeastern New Mexico and western Texas: U.S. Geol. Survey open-file rept., 658 p.

Holdaway, M. J., 1971, Stability of andalusite of the aluminum silicate phase diagram: Am. Jour. Sci., v. 271, p. 97–131.

Hollyday, E. F., 1976, Improving estimates of streamflow characteristics using Landsat–1 imagery: U.S. Geol. Survey Jour. Research, v. 4, no. 5, p. 517–531.

Hooper, P. R., 1974, Petrology and chemistry of the Rock Creek flow, Columbia River Basalt, Idaho: Geol. Soc. America Bull., v. 85, p. 15–26.

Hoover, D. B., and Long, C. L., 1975, Audiomagnetotelluric methods in reconnaissance geothermal exploration: U.S. Geol. Survey open-file rept., 25 p.

Hoover, D. B., Batzle, M. L., and Rodriquez, Rudy, 1975, Self-potential map, Steamboat Hills, Nev.: U.S. Geol. Survey open-file rept., 1 pl.

Hopkins, D. M., 1967, Quaternary marine transgressions in Alaska, *in* Hopkins, D. M., ed., The Bering land bridge: Palo Alto, Calif., Stanford Univ. Press, p. 47–90.

Hopson, C. A., 1964, The crystalline rocks of Howard and Montgomery Counties, *in* The geology of Howard and Montgomery Counties: Baltimore, Md., Maryland Geol. Survey, p. 27–215.

Howell, D. G., ed., 1976, Aspects of the geologic history of the California continental border land: Am. Assoc. Petroleum Geologists Pacific Sect. Misc. Pub. 24, 561 p.

Houston, R. S., and Ridgley, J. L., 1976, Mineralogical layering suggests multiple injection of magma in Lake Owens Mafic Complex, Wyoming, *in* Geological Survey research 1975: U.S. Geol. Survey Prof. Paper 975, p. 155.

Huber, N. K., and Rinehart, C. D., 1967, Cenozoic volcanic rocks of the Devil's Postpile quadrangle, eastern Sierra Nevada, California: U.S. Geol. Survey Prof. Paper 554–D, p. D1–D21.

Hufford, G. L., and others, 1974, Physical oceanography of the western Beaufort Sea, *in* An ecological survey in the Beaufort Sea: U.S. Coast Guard Oceanog. Rept. C. G. 373–64.

Hummel, C. L., 1975, Mineral deposits, occurrences, and associated altered rocks in southwest Seward Peninsula, west-central Alaska: U.S. Geol. Survey open-file rept., 1 pl., scale 1:125,000.

Hunter, R. N., 1975, Earthquakes and sidereal period reevaluated: Jour. Geophys. Research, v. 80, p. 3375–3377.

Hurr, R. T., 1975, Effects of water-management practices on the flow of the South Platte River, Colorado, *in* International Symposium on the Hydrological Characteristics of River Basins and the Effects on these Characteristics of Better Water Management: Internat. Assoc. Hydrological Sci. Pub. 117, p. 611–618.

Hurr, R. T., Schneider, P. A., Jr., and Minges, D. R., 1975, Hydrology of the South Platte River valley, northeastern Colorado: Colorado Water Conserv. Board Water Resources Circ. 28, 24 p.

Hyde, J. H., and Crandell, D. R., 1975, Origin and age of postglacial deposits and assessment of potential hazards from future eruptions of Mount Baker, Washington: U.S. Geol. Survey open-file rept., 22 p.

International Geographical Union, Commission on Geographic Data Sensing and Processing, 1975, First interim report on digital geographic data handling activities in the U.S. Geological Survey: Washington, D.C., Internat. Geog. Union, 274 p.

Isherwood, W. F., 1975, Gravity and magnetic studies of The Geysers-Clear Lake geothermal region, California: U.S. Geol. Survey open-file rept., 37 p.

Ishikawa, Y., 1962, Magnetic properties of ilmenite-hematite system at low temperature: Phys. Soc. Japan Jour., v. 17, p. 1835–1844.

Iwatsubo, R. T., Nolan, K. M., Harden, D. R., Glysson, G. D., and Janda, R. J., 1975, Redwood National Park studies, data release no. 1, Redwood Creek, Humboldt County, California, September 1, 1973–April 10, 1974: U.S. Geol. Survey open-file rept., 120 p.

Iyer, H. M., 1975, Anomalous delays of teleseismic *P* waves in Yellowstone National Park: Nature, v. 253, p. 425–427.

Iyer, H. M., and Evans, J. R., 1975, Evidence for the presence of deep low-velocity material under the Yellowstone caldera using teleseismic data [abs.]: Interdisciplinary Symposia, Internat. Union Geodesy Geophysics Gen. Assembly, 16th, Grenoble, France, 1975, Papers, p. 109.

Iyer, H. M., and Hitchcock, Tim, 1975, Teleseismic residuals at The Geysers geothermal area [abs.]: EOS (Am. Geophys. Union Trans.), v. 56, no. 12, p. 1020.

Jackson, E. D., 1970, The cyclic unit in layered intrusions—A comparison of repetitive stratigraphy in the ultramafic parts of the Stillwater, Muskox, Great Dyke, and Bushveld complexes: Geol. Soc. South Africa Spec. Pub. no. 1, p. 391–424.

Jacob, A. F., 1975, Reconnaissance for uranium in Paleozoic rocks in the Appalachian Basin, *in* Craig, L. C., Brooks, R. A., and Patton, P. C., eds., Abstracts for the 1975 Uranium and Thorium Research and Resources Conference: U.S. Geol. Survey open-file rept., p. 23.

Jahns, R. H., 1941, Outwash chronology in northeastern Massachusetts [abs.]: Geol. Soc. America Bull., v. 52, p. 1910.

——— 1952, Stratigraphy and sequence of igneous rocks in the Lowell-Ayer region, Massachusetts: Geol. Soc. America Ann. Mtg., 1952, Guidebook for field trips in New England, p. 108–112.

Jahns, R. H., Kottlowski, F. E., and Kuellmer, F. J., 1955, Volcanic rocks of south-central New Mexico, *in* New Mexico Geological Society Guidebook, 6th Field Conference: p. 92–95.

James, H. L., 1955, Zones of regional metamorphism in the Precambrian of northern Michigan: Geol. Soc. America Bull., v. 66, p. 1455–1487.

James, O. B., 1975, Petrography of the matrix of light gray (consortium) breccia 73215, *in* Lunar science VI: Houston, Tex., Lunar Sci. Inst., p. 438–440.

——— 1976, Petrology of aphanitic lithologies in consortium breccia 73215, *in* Lunar science VII: Houston, Tex., Lunar Sci. Inst., p. 420–422.

James, O. B., and others, 1975a, Consortium studies of matrix of light gray breccia 73215, *in* Lunar science VI: Houston, Tex., Lunar Sci. Inst., p. 547–577.

——— 1975b, Consortium studies of matrix of light gray breccia 73215: Houston, Tex., Lunar Sci. Inst., p. 435–437.

Janda, R. J., 1975a, Recent man-induced modifications of the physical resources of the Redwood Creek unit of Redwood National Park, California, and the processes responsible for those modifications: U.S. Geol. Survey open-file rept., 10 p.

——— 1975b, Statement to the California State Board of Forestry relative to physical events and processes in Redwood National Park, Humboldt County, California: U.S. Geol. Survey open-file rept., 8 p.

Janda, R. J., Nolan, K. M., and Harden, D. R., 1975, Graphic and tabular summaries of water and suspended-sediment discharge during eight periods of synoptic storm sampling in the lower drainage basin of Redwood Creek, Humboldt County, California: U.S. Geol. Survey open-file rept., 21 p.

Janda, R. J., Nolan, K. M., Harden, D. R., and Colman, S. M., 1976, Watershed conditions in the drainage basin of Redwood Creek, Humboldt County, California, as of 1973: U.S. Geol. Survey open-file rept., 267 p.

Jobson, H. E., 1975, Canal evaporation determined by thermal modeling: Am. Soc. Civil Engineers Symposium on Modeling Techniques, San Francisco, Calif., 1975, Proc., p. 729–743.

Johnson, C. G., and Tasker, G. D., 1974, Flood magnitude and frequency of Massachusetts streams: U.S. Geol. Survey open-file rept., 41 p.

Johnson, K. G., 1974, Floods in eastern Lajas Valley and the lower Río Loco basin, southwestern Puerto Rico: U.S. Geol. Survey Hydrol. Inv. Atlas HA–532, 1 sheet, scale 1:20,000.

Johnston, R. H., and Larson, J. D., 1976, Preliminary appraisal of ground water in the Franconia area, Virginia: U.S. Geol. Survey open-file rept., 19 p.

Kachadoorian, Reuben, 1965, Effects of the earthquake of March 27, 1964, on the Alaska highway system: U.S. Geol. Survey Prof. Paper 545–C, 66 p.

Kalbskopf, R., Pertlik, F., and Zeeman, J., 1975, Verfeinerung der Kristallstruktur des Covellins, CuS, mit Einkristalldaten: Tschermaks Mineralog. u. Petrog. Mitt., v. 22, p. 242–249.

Karlstrom, T. N. V., Gumerman, G. J., and Euler, R. C., 1974, Paleoenvironmental and cultural changes in the Black Mesa region, northeastern Arizona, *in* Karlstrom, T. N. V., Swann, G. A., and Eastwood, R. L., eds., Geology of northern Arizona with notes on archaeology and paleoclimate: Geol. Soc. America Rocky Mtn. Sect. Mtg., Flagstaff, Ariz., Guidebook 27, pt. 2, p. 768–792.

Kastowo, and Leo, G. W., 1973, Geologic map of the Padang quadrangle, Sumatra: Bandung, Indonesia, Indonesia Geol. Survey, scale 1:250,000.

Katzer, T. L., Glancy, P. A., and Harmsen, Lynn, 1976, A brief hydrologic appraisal of the July 3–4, 1975, flash flood in Las Vegas Valley, Nevada: U.S. Geol. Survey open-file rept., 46 p.

Kauffman, E. G., and Runnegar, Bruce, 1975, *Atomodesma* (Bivalvia) and Permian species of the United States: Jour. Paleontology, v. 49, no. 1, p. 23–41.

Keith, T. E. C., and Foster, H. L., 1973, Basic data on the ultramafic rocks of the Eagle quadrangle, east-central Alaska: U.S. Geol. Survey open-file rept., 4 sheets.

Kelleher, John, 1972, Rupture zones of large South American earthquakes and some predictions: Jour. Geophys. Research, v. 77, p. 2087–2103.

Kelly, T. E., 1966, Ground-water resources, *in* Geology and ground-water resources, Barnes County, North Dakota: North Dakota Water Comm. County Ground Water Study 4, pt. 3, 67 p.

Keulegan, G. H., 1938, Laws of turbulent flow in open channels: U.S. Natl. Bur. Standards Jour. Research, v. 21, p. 707–741.

Kharaka, Y. K., and Smalley, W. C., 1976, Flow of water and solutes through compacted clays: Am. Assoc. Petroleum Geologists Bull., v. 60. [In press.]

Kimmel, G. E., and Harbaugh, A. W., 1975, Analog-model analysis of hydrologic effects of sewerage in southeast Nassau and southwest Suffolk Counties, Long Island, New York: U.S. Geol. Survey open-file rept., 22 p.

King, E. R., 1975, A typical cross section based on magnetic data of lower and middle Keweenawan volcanic rocks, Ironwood area, Michigan: U.S. Geol. Survey Jour. Research, v. 3, no. 5, p. 543–546.

Kinoshita, W. T., Swanson, D. A., and Jackson, D. B., 1974, The measurement of crustal deformation related to volcanic activity at Kilauea Volcano, Hawaii, *in* Physical volcanology: New York, Elsevier, chap. 4, p. 87–115.

Kirschner, C. E., and Lyon, C. A., 1973, Stratigraphic and tectonic development of Cook Inlet petroleum province, *in* Arctic geology: Am. Assoc. Petroleum Geologists Mem. 19, p. 396–407.

Klopp, H. C., 1975, Petrographic analysis of the Sunniland Formation, an oil producing formation in south Florida: Brigham Young Univ. Geology Studies, 27 p.

Klovan, J. E., and Imbrie, John, 1971, An algorithm and FORTRAN–IV program for large-scale *Q*-mode factor analysis and calculation of factor scores: Jour. Math. Geology, v. 3, no. 1, p. 61–77.

Klovan, J. E., and Miesch, A. T., 1975, Extended CABFAC and QMODEL computer programs for *Q*-mode factor analysis of compositional data: Computers and Geosciences, v. 1, no. 3.

Knutilla, R. L., and Swallow, L. A., 1975a, Flood of April 1975 at East Lansing, Michigan: U.S. Geol. Survey open-file rept., 10 p.

——— 1975b, Flood of April 1975 at Meridian Township, Michigan: U.S. Geol. Survey open-file rept., 9 p.

——— 1975c, Flood of April 1975 at Williamston, Michigan: U.S. Geol. Survey open-file rept., 12 p.

Kockelman, W. J., 1975, Use of USGS Earth-science products by city planning agencies in the San Francisco Bay region, California: U.S. Geol. Survey open-file rept., 110 p.

Kohl, W. R., and Briggs, R. P., 1975, Map of rock types in bedrock of Allegheny County, Pennsylvania: U.S. Geol. Survey Misc. Field Studies Map MF–685–A, 2 sheets, scale 1:50,000.

Kohout, F. A., Walker, E. H., Bothner, M. H., Folger, D. W., Hathaway, J. C., and Weed, E. G. A., 1976, Fresh ground water under the Continental Shelf—Implications from a deep test at Nantucket Island, Massachusetts [abs.]: EOS (Am. Geophys. Union Trans.), v. 57, no. 4, p. 248.

Konikow, L. F., 1976, Preliminary digital model of ground-water flow in the Madison Group, Powder River Basin and adjacent areas, Wyoming, Montana, South Dakota, North Dakota, and Nebraska: U.S. Geol. Survey Water-Resources Inv. 63–75.

Koteff, Carl, 1970, Surficial geologic map of the Milford quadrangle, Hillsborough County, N.H.: U.S. Geol. Survey Geol. Quad. Map GQ–881, scale 1:62,500.

——— 1974, The morphological sequence concept and deglaciation of southern New England, *in* Coates, D. R., ed., Glacial geomorphology, a proceedings volume of the 5th Annual Geomorphology Symposia Series held at Binghamton, N.Y.: State Univ. New York Pubs. Geomorphology, p. 121–144.

Krebs, C. E., 1914, Kanawha County: West Virginia Geol. Survey County Rept., 679 p.

Lanphere, M. A., and Dalrymple, G. B., 1971, A test of the $^{40}Ar/^{39}Ar$ age spectrum technique on some terrestrial materials: Earth and Planetary Sci. Letters, v. 12, p. 359–372.

LaPoint, P. J., 1975, Photogeologic study of volcanic and structural features of the eastern Snake River Plain, Idaho [abs.]: Geol. Soc. America Abs. with Programs, v. 7, no. 5, p. 620.

Lasky, S. G., and Webber, B. N., 1949, Manganese resources of the Artillery Mountains region, Mohave County, Arizona: U.S. Geol. Survey Bull. 961, 86 p.

Lathram, E. H., Loney, R. A., Condon, W. H., and Berg, H. C., 1959, Progress map of the geology of the Juneau quadrangle, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I–303, scale 1:250,000.

Lee, D. E., and Van Loenen, R. E., 1971, Hybrid granitoid rocks of the southern Snake Range, Nevada: U.S. Geol. Survey Prof. Paper 668, 48 p.

Lee, D. E., Brandt, E. L. M., Van Loenen, R. E., and Rose, H. J., Jr., 1973, The chemistry of five accessory rock-forming apatites: U.S. Geol. Survey Jour. Research, v. 1, no. 3, p. 267–272.

Lee, K. W., Kapple, G. W., and Dawdy, D. R., 1975, A study of the rainfall-runoff relationship for Redwood Creek above Orick, California: U.S. Geol. Survey open-file rept., 14 p.

Lee-Moreno, J. L., Caire, L. F., and Chaffee, M. A., 1975, Results of geochemical investigations comparing samples of stream sediment, panned concentrates, and vegetation in the vicinity of the Caridad porphyry copper deposit, northern Sonora, Mexico [abs.]: Mining Eng., v. 27, no. 12, p. 68.

Leo, G. W., 1974, Metatrondhjemite in the northern part of the Glastonbury Gneiss dome, Massachusetts and Connecticut [abs.]: Geol. Soc. America Abs. with Programs, v. 6, no. 1, p. 47–48.

Leo, G. W., Brookins, D. B., Schwarz, L. J., and Rowe, J. J., 1976, Geochemistry, origin, and age of the Glastonbury Gneiss body, Massachusetts and Connecticut [abs.]: Geol. Soc. America Abs. with Programs, v. 8, no. 2, p. 217.

Leopold, L. B., and Maddock, Thomas, Jr., 1953, The hydraulic geometry of stream channels and some physiographic implications: U.S. Geol. Survey Prof. Paper 252, 56 p.

Lescelius, R. H., Rohret, D. H., Sneddon, R., Towle, J., and Fitterman, D., 1976, Geomagnetic array control circuit: U.S. Geol. Survey open-file rept., 5 p.

Lind, C. J., and Hem, J. D., 1975, Effects of organic solutes on chemical reactions of aluminum: U.S. Geol. Survey Water-Supply Paper 1827–G, 83 p.

Loney, R. A., Brew, D. A., and Lanphere, M. A., 1967, Post-Paleozoic radiometric ages and their relevance to fault movements, northern southeastern Alaska: Geol. Soc. America Bull., v. 78, p. 511–526.

Loney, R. A., Brew, D. A., Muffler, L. J. P., and Pomeroy, J. S., 1975, Reconnaissance geology of Chichagof, Baranof, and Kruzof Islands, southeastern Alaska: U.S. Geol. Survey Prof. Paper 792, 105 p.

Lovering, T. S., 1929, Geologic history of the Front Range, Colorado: Colorado Sci. Soc. Proc., v. 12, no. 4, p. 59–111.

Lovering, T. S., and Morris, H. T., 1965, Underground temperatures and heat flow in the East Tintic district, Utah: U.S. Geological Survey Prof. Paper 504–F, p. F1–F28.

Lowdon, J. A., Stockwell, C. H., Tipper, H. W., and Wanless, R. K., 1963, Age determinations and geologic studies: Canada Geol. Survey Paper 62–17, 140 p.

Lucchitta, B. K., 1975a, Tycho and the Apollo 17 landing site [abs.]: EOS (Am. Geophys. Union Trans.), v. 56, p. 389.

——— 1975b, Dark mantles on the Moon, a review [abs.], *in* Origins of mare basalts and their implications for lunar evolution: Houston, Tex., Lunar Sci. Inst., p. 104–106.

Lucchitta, B. K., and Sanchez, A. G., 1975, Crater studies in the Apollo 17 region: Geochim. et Cosmochim. Acta, suppl. 6, v. 3, p. 2427–2441.

Lund, O. M., Tessar, P. A., and Eidenshink, J., 1975, South Dakota land use patterns, spring 1973: Pierre, S. Dak., South Dakota State Plan. Bur., 1 sheet, scale 1:1,000,000.

Lupe, R. D., 1975, Depositional environments of the Chinle Formation, San Rafael Swell, Utah [abs.], *in* Craig, L. C., Brooks, R. A., and Patton, P. C., eds., Abstracts for the 1975 Uranium and Thorium Research and Resources Conference: U.S. Geol. Survey open-file rept., p. 26.

MacBeth, J. H., and Schmidt, R. A. M., 1973, Upper Cretaceous foraminifera from Ocean Point, northern Alaska: Jour. Paleontology, v. 47, p. 1047–1061.

MacKevett, E. M., Jr., Brew, D. A., Hawley, C. C., Huff, L. C., and Smith, J. G., 1971, Mineral resources of Glacier Bay National Monument, Alaska: U.S. Geol. Survey Prof. Paper 632, 90 p.

MacLeod, N. S., Walker, G. W., and McKee, E. H., 1975, Geothermal significance of eastward increase in age of upper Cenozoic rhyolitic domes in southeastern Oregon: U.S. Geol. Survey open-file rept., 21 p.

MacNeil, F. S., 1957, Cenozoic megafossils of northern Alaska: U.S. Geol. Survey Prof. Paper 294–C, p. 99–126.

Major, T. J., Kerbs, Lynda, and Penley, R. D., 1975, Water-level records for Colorado, 1971–75: Colorado Water Conserv. Board Water-Resources Basic-Data Release no. 37, 356 p. [1976].

Malloy, M. A., and McCullough, B. A., 1976, Natural resource inventory for Arkansas: Little Rock, Ark., Ozarks Regional Comm., 49 p.

Malone, S. D., and Frank, D. G., 1975, Increased heat emission from Mount Baker, Washington: EOS (Am. Geophys. Union Trans.), v. 56, no. 10, p. 679–685.

Mariner, R. H., and Willey, L. M., 1976, Geochemistry of thermal waters in Long Valley, Mono County, California: Jour. Geophys. Research, v. 81, no. 5, p. 792–800.

Mariner, R. H., Presser, T. S., and Evans, W. C., 1976, Chemical data for eight springs in northwestern Nevada: U.S. Geol. Survey open-file rept., 13 p.

Mariner, R. H., Rapp, J. B., Willey, L. M., and Presser, T. S., 1974, The chemical composition and estimated mineral thermal reservoir temperature of the principal hot springs of northern and central Nevada: U.S. Geol. Survey open-file rept., 32 p.

Mark, R. K., Hu, C. L., Bowman, H. R., Asaro, F., McKee, E. H., and Coats, R. R., 1975, A high $^{87}Sr/^{86}Sr$ mantle source for low alkali tholeiite, northern Great Basin: Geochim. et Cosmochim. Acta, v. 39, no. 12, p. 1671–1678.

Martel, R. R., 1965, Earthquake damage to type 3 buildings in Long Beach, 1933, *in* Carder, D. S., ed., Earthquake investigations in the Western U.S., 1931–1964: U.S. Coast and Geod. Survey Pub. 41–2, p. 213–222.

Matthews, W. H., 1947, "Tuyas," flat-topped volcanoes in northern British Columbia: Am. Jour. Sci., v. 245, no. 9, p. 560–570.

Mattson, P. H., 1973, Middle Cretaceous nappe structures in Puerto Rican ophiolites and their relation to the tectonic history of the Greater Antilles: Geol. Soc. America Bull., v. 84, p. 21–37.

McCain, J. F., and Jarrett, R. D., 1976, Manual for estimating flood characteristics of natural-flow streams in Colorado: Colorado Water Conserv. Board Tech. Manual no. 1. [In press.]

McCoy, H. J., 1975, Summary of hydrologic conditions in Collier County, Florida, 1974: U.S. Geol. Survey open-file rept., 100 p.

McCulloch, D. S., and Bonilla, M. G., 1970, Effects of the earthquake of March 27, 1964, on the Alaska railroads: U.S. Geol. Survey Prof. Paper 545–D, 161 p.

McDougall, Ian, 1976, Geochemistry and origin of basalts of the Columbia River Group, Oregon and Washington: Geol. Soc. America Bull., v. 87, no. 5, 777–792.

McDowell, F. W., 1971, K-Ar ages of igneous rocks from the Western United States: Isochron/West, no. 2, p. 2–16.

McGreevy, L. J., and Sloto, R. A., 1976, Selected hydrologic data, Chester County, Pennsylvania: U.S. Geol. Survey open-file rept., 4 figs.

McGuire, R. K., 1976, Methodology for incorporating parameter uncertainties in seismic hazard analyses for loss risk design intensities: Internat. Symposium on Earthquake Structural Engineering, Proc., 15 p.

McKee, Bates, and Stradling, Dale, 1970, The sag flowout—A newly described volcanic structure: Geol. Soc. America Bull., v. 81, p. 2035–2044.

McKee, E. H., and Anderson, C. A., 1971, Age and chemistry of Tertiary volcanic rocks in north-central Arizona and relation of the rocks to the Colorado Plateaus: Geol. Soc. America Bull., v. 82, p. 2767–2782.

McLane, J. E., Finkelman, R. B., and Larson, R. R., 1976, Mineralogical examination of particulate matter from the fumaroles of Sherman Crater, Mt. Baker, Washington (State) [abs.]: EOS (Am. Geophys. Union Trans.), v. 57, no. 2, p. 89.

McLaughlin, R. J., 1976, Significance of age relationships of rocks above and below Upper Jurassic ophiolite in The Geysers-Clear Lake area, California [abs.]: Geol. Soc. America Abs. with Programs, v. 8, no. 3, p. 394.

McLean, J. S., 1971, The microclimate in Carlsbad Caverns, New Mexico: U.S. Geol. Survey open-file rept., 65 p.

———1976, Factors altering the microclimate in Carlsbad Caverns, New Mexico: U.S. Geol. Survey open-file rept., 59 p.

Meier, M. F., 1976, Satellite measurement of snowcover for runoff prediction: Am. Water Resources Conf., 11th, Baton Rouge, La., 1975, Proc. [In press.]

Meier, M. F., and Evans, W. E., 1975, Comparison of different methods for estimating snowcover in forested, mountainous basins using Landsat (ERTS) images, *in* Rango, Albert, ed., Operational applications of satellite snowcover observations: U.S. Natl. Aeronautics and Space Adm. Spec. Pub. SP–391, p. 215–234.

Mercer, J. W., and Faust, C. R., 1975, Simulation of water- and vapor-dominated hydrothermal reservoirs: Am. Inst. Mining Metall. Petroleum Engineers, Soc. Petroleum Engineers Ann. Fall Mtg., 50th, Dallas, Tex., 1975, 16 p.

Merewether, E. A., Cobban, W. A., and Ryder, R. T., 1975, Lower Upper Cretaceous strata, Bighorn Basin, Wyoming and Montana, *in* Geology and mineral resources of the Bighorn Basin: Wyoming Geol. Assoc. Guidebook, 27th Ann. Field Conf., p. 73–84.

Merkel, R. H., and Head, W. J., 1976, Computer analysis of geophysical logs in evaluation of ground water for secondary recovery of oil in Powder River basin, Wyoming [abs.]: Canadian Inst. Mining, Canadian Soc. Petroleum Geologists Symposium, Calgary Canada, 1976, Proc. [In press.]

Middleton, G. V., 1970, Experimental studies related to problems of flysch sedimentation, *in* Lajoie, J., ed., Flysch sedimentology in North America: Geol. Assoc. Canada Spec. Paper no. 7, p. 253–272.

Miesch, A. T., 1975, *Q*-mode factor analysis of compositional data: Computers and Geosciences, v. 1, no. 3.

Milazzo, V. A., 1974, Some findings in the applications of ERTS and Skylab imagery for metropolitan land use analysis: Internat. Symposium on Remote Sensing of Environment, 9th, Ann Arbor, Mich., 1974, Proc., v. 1, p. 569–585.

Miller, F. K., 1970, Geologic map of the Quartzite quadrangle, Yuma County, Arizona: U.S. Geol. Survey Geol. Quad. Map GQ–841, scale 1:62,500.

Miller, J. B., and Swallow, L. A., 1975, Flood of April 1975 at Lansing, Michigan: U.S. Geol. Survey open-file rept., 10 p.

Misch, Peter, and Hazzard, J. C., 1962, Stratigraphy and metamorphism of Late Precambrian rocks in central northeastern Nevada and adjacent Utah: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 3, p. 289–343.

Mitchell, W. D., 1962, Effect of reservoir storage on peak flow: U.S. Geol. Survey Water-Supply Paper 1580–C, 25 p.

Mitten, H. T., 1971, Ground-water pumpage in parts of Yolo, Sacramento, Solano, Sutter, Colusa, and Napa Counties, California, 1966–68: U.S. Geol. Survey open-file rept., 4 p.

——— 1972a, Ground-water pumpage, San Joaquin Valley, California, 1967–68: U.S. Geol. Survey open-file rept., 6 p.

——— 1972b, Estimated ground-water pumpage in the northern part of the Sacramento Valley, California, 1966–69: U.S. Geol. Survey open-file rept., 6 p.

——— 1973, Estimated ground-water pumpage in the northern part of the Sacramento Valley, California, 1970–71: U.S. Geol. Survey open-file rept., 4 p.

——— 1974, Estimated ground-water pumpage in the southern part of the Sacramento Valley, California, 1969–71: U.S. Geol. Survey open-file rept., 4 p.

Mitten, H. T., and Ogilbee, William, 1971, Ground-water pumpage in parts of Merced, Madera, Fresno, Kings, and Tulare Counties, California, 1962–66: U.S. Geol. Survey open-file rept., 8 p.

Moore, H. J., II, and Schaber, G. G., 1975, An estimate of the yield strength of the Imbrium flows: Geochim. et Cosmochim. Acta, suppl. 6, v. 1, p. 101–118.

Moore, H. J., II, and Tyler, G. L., 1973, Comparison between photogrammetric and bistatic-radar slope-frequency distributions, *in* Apollo 17 preliminary science report: U.S. Natl. Aeronautics and Space Adm. Spec. Pub. 330, pt. C, p. 33-17–33-26.

Moore, H. J., II, Tyler, G. L., Boyce, J. M., Shorthill, R. W., Thompson, T. W., Walker, A. S., Wilhelms, D. E., Wu, S. S. C., and Zisk, S. H., 1975, Correlation of photogeology and remote sensing data along the Apollo 14 bistatic-radar ground track, pt. 1—A working compendium: U.S. Geol. Survey open-file rept., 88 p.

Moore, J. G., 1975, Mechanism of formation of pillow lava: Am. Scientist, v. 63, no. 3, p. 269–277.

Morey, G. B., and Sims, P. K., 1976, Boundary between two Precambrian W terranes in Minnesota and its geologic significance: Geol. Soc. America Bull., v. 87, p. 141–152.

Morton, D. M., 1969, The Lakeview Mountains pluton, southern California batholith, pt. 1, Petrology and structure: Geol. Soc. America Bull., v. 80, p. 1539–1552.

Mosier, E. L., 1975, Use of emission spectroscopy for the semiquantitative analysis of trace elements and silver in native gold, *in* Ward, F. N., ed., New and refined methods of trace analysis useful in geochemical exploration: U.S. Geol. Survey Bull. 1408, p. 97–105.

Mosier, E. L., Antweiler, J. C., and Nishi, J. M., 1975, Spectrochemical determination of trace elements in galena: U.S. Geol. Survey Jour. Research, v. 3, no. 5, p. 625–630.

Mullineaux, D. R., Miller, C. D., and Harlow, David, 1976, Reconnaissance study of volcanic hazards from Cotopaxi Volcano, Ecuador: U.S. Geol. Survey open-file rept., 20 p.

Mundorff, M. J., Carrigan, P. H., Jr., Steele, T. D., and Randall, A. D., 1976: Hydrologic evaluation of salinity control and reclamation projects in the Indus Plain, Pakistan —A summary: U.S. Geol. Survey Water-Supply Paper 1608–Q, 69 p.

Murata, K. J., Friedman, Irving, and Gleason, J. D., 1976, Oxygen isotope relations between diagenetic silica minerals in Monterey Shale, Temblor Range, California: Am. Jour. Sci. [In press.]

Murray, C. R., 1975, Effects of 1974 oil embargo on water use for electric-utility energy production, *in* Geological Survey research 1975: U.S. Geol. Survey Prof. Paper 975, p. 121.

Naplin, C. E., 1973, Ground-water resources of the Ellendale area, Dickey County, North Dakota: North Dakota Water Comm. Ground Water Study 75, 128 p.

Nash, J. T., and Lehrman, N. J., 1975, Geology of the Midnite uranium mine, Stevens County, Washington—A preliminary report: U.S. Geol. Survey open-file rept., 36 p.

Nathenson, Manuel, and Muffler, L. J. P., 1975, Geothermal resources in hydrothermal convection systems and conduction-dominated areas, *in* White, D. E., and Williams, D. L., eds., Assessment of geothermal resources of the United States—1975: U.S. Geol. Survey Circ. 726, p. 104–121.

National Academy of Sciences, 1973, Water quality criteria, 1972: Washington, D.C., Environmental Protection Agency Rept. EPA–R3–73–033, 594 p.

Naylor, R. S., 1969, Age and origin of the Oliverian domes, central-western New Hampshire: Geol. Soc. America Bull., v. 80, p. 405–428.

Naylor, R. D., Boone, G. M., Boudette, E. L., Ashenden, D. D., and Robinson, Peter, 1973, Pre-Ordovician rocks in the Bronson Hill and Boundary Mountain anticlinoria, New England, U.S.A. [abs.]: EOS (Am. Geophys. Union Trans.), v. 54, p. 495.

Nieter, William, Nemickas, Bronius, Koszalka, E. J., and Newman, W. S., 1975, The late Quaternary geology of the Montauk peninsula—Montauk Point to Southampton, Long Island, New York, *in* Wolff, M. P., ed., Guidebook to field excursions conducted at the 47th annual meeting of the New York State Geological Association: Hempstead, N.Y., Hofstra Univ., p. 129–156.

Nolan, K. M., Harden, D. R., and Colman, S. M., 1976, Erosional landform map of the Redwood Creek basin, Humboldt County, California, 1947–74: U.S. Geol. Survey open-file rept., 11 p.

Nordstrom, D. K., Jenne, E. A., and Averett, R. C., 1976, Heavy metal discharges into Shasta Lake and Keswick Reservoirs on the upper Sacramento River, California—A reconnaissance during low flow: U.S. Geol. Survey Water-Resources Inv. [In press.]

Nunes, P. D., 1975, Pb loss from Apollo 17 glassy samples and Apollo 16 revisited, *in* Lunar science VI: Houston, Tex., Lunar Sci. Inst., p. 1491–1499.

Nunes, P. D., Tatsumoto, M., and Unruh, D. M., 1975, U-Th-Pb systematics of anorthositic gabbros 78155 and 77017—Implications for early lunar evolution, *in* Lunar science VI: Houston, Tex., Lunar Sci. Inst., p. 1431–1444.

Oberbeck, V. R., and Morrison, R. H., 1974, Laboratory simulation of the herringbone pattern associated with lunar secondary crater chains: Moon, v. 9, p. 415–455.

Obermeier, S. F., and Froelich, A. J., 1976, Preliminary geologic and engineering review of the Franconia area, Fairfax County, Virginia: U.S. Geol. Survey open-file rept., 11 p.

Obermeier, S. F., and Hollocher, Kurt, 1976, Map of landslides in Coastal Plain deposits of the Franconia area, Fairfax County, Virginia: U.S. Geol. Survey open-file rept., 15 p.

Offield, T. W., 1975, Remote sensing in uranium exploration, *in* Craig, L. C., Brooks, R. A., and Patton, P. C., eds., Abstracts for the 1975 Uranium and Thorium Research and Resources Conference: U.S. Geol. Survey open-file rept., p. 33.

Oftedal, I., 1932, The crystal structure of covellite: Zeitschr. Kristallographie, v. 83, p. 9–25.

Ogilbee, William, and Mitten, H. T., 1970, A continuing program for estimating ground-water pumpage in California —Methods: U.S. Geol. Survey open-file rept., 22 p.

Ogilbee, William, and Rose, M. A., 1969a, Ground-water pumpage in Kern County, California, 1962–66: U.S. Geol. Survey Basic Data Rept., 5 p.

——— 1969b, Ground-water pumpage on the west side of the San Joaquin Valley, California, 1962–66: U.S. Geol. Survey Basic Data Rept., 7 p.

O'Hara, C. J., and Oldale, R. N., 1976, Basement morphology and pre-Holocene sedimentary structure of Cape Cod Bay, Massachusetts [abs.]: Geol. Soc. America Abs. with Programs, v. 8, no. 2, p. 238.

Oldale, R. N., and O'Hara, C. J., 1975, Postglacial fluvial erosion, marine planation, and marine deposition of Cape Cod Bay, Massachusetts [abs.]: Geol. Soc. America Abs. with Programs, v. 7, p. 1218–1219.

Ovenshine, A. T., and Brew, D. A., 1972, Separation and history of the Chatham Strait fault, southeast Alaska, North America: Internat. Geol. Cong., 24th, Montreal, Canada, 1972, Proc., sect. 3, p. 245–254.

Ovenshine, A. T., Lawson, D. E., and Bartsch-Winkler, S. R., 1976, The Placer River—An intertidal deposit caused by the 1964 Alaska earthquake: U.S. Geol. Survey Jour. Research, v. 4, no. 2, p. 151–162.

Overstreet, W. C., and Rossman, D. L., 1970, Reconnaissance geology of the Wadi Wasat quadrangle, Kingdom of Saudi Arabia: U.S. Geol. Survey open-file rept., 68 p.

Overstreet, W. C., Domenico, J. A., Grolier, M. J., Tibbitts, G. C., Jr., and Ibrahim, M. M., 1976, Trace elements in some rocks and slag from the Yemen Arab Republic and their bearing on the iron ore near Sa'dah: U.S. Geol. Survey open-file rept., 74 p.

Page, N. J., Johnson, M. G., Haffty, Joseph, and Ramp, Len, 1975, Occurrence of platinum-group metals in ultramafic rocks of the Medford-Coos Bay 2° quadrangle, southwestern Oregon: U.S. Geol. Survey Misc. Field Studies Map MF–694, 1 sheet, scale 1:250,000.

Palmer, A. R., 1971, The Cambrian of the Appalachian and eastern New England regions, eastern United States, *in* Holland, C. H., ed., Cambrian of the new world: New York, Interscience Publishers, p. 169–217.

Papadopulos, S. S., Wallace, R. H., Jr., Wesselman, J. B., and Taylor, R. E., 1975, Assessment of onshore geopressured-geothermal resources in the northern Gulf of Mexico basin, *in* White, D. E., and Williams, D. L., eds., Assessment of geothermal resources of the United States—1975: U.S. Geol. Survey Circ. 726, p. 125–140.

Parker, P. E., 1968, Geologic investigation of the Lincoln and Bluemont quadrangles, Virginia: Virginia Div. Mineral Resources Rept. Inv. 14, 23 p.

Parks, Harold, and Banami, A. M., 1971, Gravity survey of Columbia Plateau ring dikes [abs.]: EOS (Am. Geophys. Union Trans.), v. 52, no. 5, p. 433.

Pascale, C. A., 1975, Hydrogeologic data collected during the construction of a deep-well waste-injection system, Santa Rosa County, Florida: U.S. Geol. Survey open-file rept., 34 p.

Patterson, S. H., 1962, Investigations of ferruginous bauxite and plastic clay deposits on Kauai and a reconnaissance of ferruginous bauxite deposits on Maui, Hawaii: U.S. Geol. Survey open-file rept., 86 p.

——— 1971, Investigations of ferruginous bauxite and other mineral resources on Kauai and a reconnaissance of ferruginous bauxite deposits on Maui, Hawaii: U.S. Geol. Survey Prof. Paper 656, 74 p.

Patton, W. W., Jr., 1970, A discussion of "Tectonic history of northern Alaska" by I. L. Tailleur and W. P. Brosgé, *in* Proceedings of the geological seminar on the North Slope of Alaska: Los Angeles, Calif., Am. Assoc. Petroleum Geologists Pacific Sect., p. E20.

——— 1973, Reconnaissance geology of the northern Yukon-Koyukuk province, Alaska: U.S. Geol. Survey Prof. Paper 774–A, 17 p.

Patton, W. W., Jr., and Hoare, J. M., 1968 The Kaltag fault, west-central Alaska: U.S. Geol. Survey Prof. Paper 600–D, p. D147–D153.

Pearson, W. B., 1964, The crystal structures of semiconductors and a general valence rule: Acta Cryst., v. 17, p. 1–15.

Pease, M. H., Jr., 1972, Geologic map of the Eastford quadrangle, Windham and Tolland Counties, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ–1023, scale 1:24,000.

Peck, D. L., 1964, Preliminary geologic map of the Merced Peak quadrangle, California: U.S. Geol. Survey Misc. Field Studies Map MF–281, 1 sheet, scale 1:48,000.

——— 1975, Recoverability of geothermal energy directly from molten igneous systems, *in* White, D. E., and Williams, D. L., eds., Assessment of geothermal resources of the United States—1975: U.S. Geol. Survey Circ. 726, p. 122–124.

Peck, J. H., 1975, Preliminary bedrock geologic map of the Clinton quadrangle, Worcester County, Massachusetts: U.S. Geol. Survey open-file rept., 3 pls., scale 1:24,000, 30 p. text.

——— 1976, Silurian and Devonian stratigraphy in the Clinton quadrangle, central Massachusetts, *in* Page, L. R., ed., Stratigraphy of New England: Geol. Soc. America Mem. 148. [In press.]

Peper, J. D., Pease, M. H., Jr., and Seiders, V. M., 1975, Stratigraphic and structural relationships of the Brimfield Group in northeast-central Connecticut and adjacent Massachusetts: U.S. Geol. Survey Bull. 1389, 31 p.

Pessl, Fred, Jr., 1971, Till fabrics and till stratigraphy in western Connecticut, *in* Goldthwait, R. P., ed., Till—A symposium: Columbus, Ohio, Ohio State Univ. Press, p. 93–105.

Pessl, Fred, Jr., and Schafer, J. P., 1968, Two-till problem in the Naugatuck-Torrington area, western Connecticut, Trip B–1, *in* Guidebook for fieldtrips in Connecticut: New England Intercoll. Geol. Conf. Ann. Mtg., 60th, New Haven, Conn., 1968, Geol. and Nat. History Survey Guidebook 2, 25 p.

Pickering, R. J., and Ficke, J. F., 1975, Design of nationwide water-quality monitoring networks: Internat. Conf. on Environmental Sensing and Assessment, Las Vegas, Nev., 1975, Proc., v. 1, paper 3–3, 4 p.

——— 1976, Design of nationwide water-quality-monitoring networks: Am. Water Works Assoc. Jour., v. 68, no. 2, p. 82–85.

Pitt, W. A. J., Jr., and Meyer, F. W., 1976, Ground-water quality at the site of a proposed deep-well injection system for treated waste water, West Palm Beach, Florida: U.S. Geol. Survey open-file rept., 44 p.

Pomeroy, J. S., and Davies, W. E., 1975, Map of susceptibility to landsliding, Allegheny County, Pennsylvania: U.S. Geol. Survey Misc. Field Studies Map MF–685–B, 2 sheets, scale 1:50,000.

Poole, F. G., 1974, Flysch deposits of the Antler foreland basin, western United States, *in* Dickinson, W. R., ed., Tectonics and sedimentation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 22, p. 58–82.

Poole, F. G., and McKee, E. H., 1974, Metamorphic ages of Cambrian phyllite in south-central Neveda, *in* Geological Survey research 1974: U.S. Geol. Survey Prof. Paper 900, p. 46.

Poole, F. G., Baars, D. L., Drewes, Harald, Hayes, P. T., Ketner, K. B., McKee, E. D., Teichert, Curt, and Williams, J. S., 1967, Devonian of the southwestern United States, *in* Oswald, D. H., ed., International Symposium on the Devonian System: Calgary, Canada, Alberta Soc. Petroleum Geologists, v. 1, p. 879–912.

Porter, S. C., 1976, Pleistocene glaciation in the southern part of the North Cascade Range, Washington: Geol. Soc. America Bull., v. 87, p. 61–75.

Prostka, H. J., 1975, Structure and origin of the eastern Snake River Plain, Idaho [abs.]: Geol. Soc. America Abs. with Programs, v. 7, no. 5, p. 637.

Prych, E. A., and Haushild, W. L., 1975, Water-quality model of a salt-wedge estuary, *in* Am. Soc. Civil Engineers Symposium on Modeling Techniques: New York, v. II, p. 1138–1155.

Putnam, W. C., 1955, Pleistocene overflow channels at Little Lake, California [abs.]: Geol. Soc. America Bull., v. 66, no. 12, p. 1607.

Raisz, E. J., 1945, The Olympic-Wallowa lineament: Am. Jour. Sci., v. 243A, p. 479–485.

Ramp, Len, and Brooks, H. C., 1969, Platinum group metals, *in* Mineral and water resources of Oregon: U.S. 90th Cong., 2d sess., Senate Comm. Interior and Insular Affairs, Comm. Print, p. 167–171.

Ramsay, J. G., 1967, Folding and fracturing of rocks: New York, McGraw-Hill, 568 p.

Rankin, D. W., 1975, Opening of the Iapetus Ocean—Appalachian salients and recesses as Precambrian triple junctions [abs.]: Geol. Soc. America Abs. with Programs, v. 7, no. 7, p. 1238.

Ratté, J. C., Landis, E. R., Gaskill, D. L., and Raabe, R. G., 1969, Mineral resources of the Blue Range Primitive Area, Greenlee County, Arizona, and Catron County, New Mexico: U.S. Geol. Survey Bull. 1261–E, 91 p.

Ray, R. G., 1954, Geology and ore deposits of the Willow Creek mining district, Alaska: U.S. Geol. Survey Bull. 1004, 86 p.

Reed, J. C., and Jolly, Janice, 1963, Crystalline rocks of the Potomac River gorge near Washington, D.C.: U.S. Geol. Survey Prof. Paper 414–H, 16 p.

Reed, J. C., Jr., and Zartman, R. E., 1973, Geochronology of Precambrian rocks of the Teton Range, Wyoming Range, Wyoming: Geol. Soc. America Bull., v. 84, p. 561–582.

Reed, V. S., and Wolfe, E. W., 1975, Origin of the Taurus-Littrow massifs: Geochim. et Cosmochim. Acta, suppl. 6, v. 3, p. 2443–2461.

Regan, R. D., and Cain, J. C., 1975, Global magnetic anomaly map: Jour. Geophys. Research, v. 80, no. 5, p. 794.

Reimnitz, Erk, Wolf, S. C., and Rodeick, C. A., 1972, Preliminary interpretation of seismic profiles in the Prudhoe Bay area, Beaufort Sea, Alaska: U.S. Geol. Survey open-file rept., 11 pp.

Renner, J. L., White, D. E., and Williams, D. L., 1975, Hydrothermal convection systems, *in* White, D. E., and Williams, D. L., eds., Assessment of geothermal resources of the United States—1975: U.S. Geol. Survey Circ. 726, p. 5–57.

Reynolds, R. L., 1975, Alteration of iron-titanium oxide minerals associated with uranium deposits in sandstone [abs.], *in* Craig, L. C., Brooks, R. A., and Patton, P. C., eds., Abstracts for the 1975 Uranium and Thorium Research and Resources Conference: U.S. Geol. Survey open-file rept., p. 38.

Rice, D. D., 1975, Origin of and conditions for shallow accumulations of natural gas, *in* Geology and mineral resources of the Bighorn Basin: Wyoming Geol. Assoc. Ann. Field Conf., 27th, Guidebook, p. 267–271.

Richardson, S. W., Gilbert, M. C., and Bell, P. M., 1969, Experimental determination of kyanite-andalusite and andalusite-sillimanite equilibria—The aluminum silicate triple point: Am. Jour. Sci., v. 267, p. 259–272.

Richter, D. H., Albert, N. R. D., Barnes, D. F., Griscom, Andrew, Marsh, S. P., and Singer, D. A., 1975, The Alaskan Mineral Resource Assessment Program—Background information to accompany folio of geologic and mineral resource maps of the Nabesna quadrangle, Alaska: U.S. Geol. Survey Circ. 718, 11 p.

Rickert, D. A., and Hines, W. G., 1975, A practical framework for river-quality assessment: U.S. Geol. Survey Circ. 715–A, 17 p.

Rickert, D. A., Hines, W. G., and McKenzie, S. W., 1975a, Effects of secondary waste-water treatment on a large river—A case study of dissolved oxygen and algal conditions in the Willamette River, Oregon: Internat. Assoc. Hydrological Sci. Pub. 117, p. 669–679.

——— 1975b, Methods and data requirements for river-quality assessment: Water Resources Bull., v. 11, no. 5, p. 1013–1039.

——— 1975c, Planning implications of dissolved oxygen depletion in the Willamette River, Oregon: Am. Water Resources Assoc. Symp. on Urbanization and Water Quality Control, Rutgers, N.J., 1975, Proc., p. 70–84.

Roberts, A. A., 1975, Helium surveys over known geothermal resource areas in the Imperial Valley, California: U.S. Geol. Survey open-file rept., 6 p.

Roberts, A. A., Friedman, Irving, Donovan, T. J., and Denton, E. H., 1975, Helium survey, a possible technique for locating geothermal reservoirs: Geophys. Research Letters, v. 2, no. 6, p. 209–210.

Robertson, J. B., 1975, Numerical modeling of subsurface radioactive solute transport from waste seepage ponds at the Idaho National Engineering Laboratory, Idaho [abs.], *in* Hem, J. D., chm., Symposium on solute transport in subsurface water—Field verification of models and experimental studies of relevant processes: EOS (Am. Geophys. Union Trans.), v. 56, no. 12, p. 980.

Robinove, C. J., 1975, Worldwide disaster warning and assessment with Earth Resources Technology Satellites: Springfield, Va., U.S. Dept. Commerce, Natl. Tech. Inf. Service, PB–244 382/AS, 69 p.

Robinson, Keith, 1973, Thallium, *in* Brobst, D. A., and Pratt, W. P., eds., United States mineral resources: U.S. Geol. Survey Prof. Paper 820, p. 631–636.

Robinson, Peter, Tracy, R. J., and Ashwal, L. D., 1975, Relict sillimanite-orthoclase assemblage in kyanite-muscovite schist, Pelham dome, west-central Massachusetts [abs.]: EOS (Am. Geophys. Union Trans.), v. 56, p. 466.

Rodgers, John, 1968, The eastern edge of the North American continent during the Cambrian and Early Ordovician, *in* Zen, E-an, and others, eds., Studies of Appalachian geology—Northern and maritime: New York, Interscience Publishers, p. 141–149.

Rodis, H. G., and Land, L. F., 1976, The shallow aquifer—A prime freshwater resource in eastern Palm Beach County, Florida: U.S. Geol. Survey Water-Resources Inv. 76–21. [In press.]

Roedder, Edwin, and Smith, R. L., 1965, Liquid water in pumice vesicles, a crude but useful dating method [abs.]: Geol. Soc. America Spec. Paper 82, p. 164.

Roedder, Edwin, and Weiblen, P. W., 1973, Apollo 17 orange soil and meteorite impact on liquid lava: Nature, v. 244, p. 210–211.

Rohret, D. H., Lescelius, R. H., and Frischknecht, F. C., 1975, Schematic diagrams and parts list for portable telluric current profiler: U.S. Geol. Survey open-file rept., 7 p.

Ross, C. P., 1963, The Belt series in Montana: U.S. Geol. Survey Prof. Paper 346, 122 p.

Rossman, D. L., 1959, Geology and ore deposits of northwestern Chichagof Island, Alaska: U.S. Geol. Survey Bull. 1058–E, p. 139–216.

——— 1963, Geology and petrology of two stocks of layered gabbro in the Fairweather Range, Alaska: U.S. Geol. Survey Bull. 1121–F, 50 p.

Rush, F. E., 1975, Washoe City folio, hydrologic map: Nevada Bur. Mines and Geology, Environmental Ser., 1 sheet.

Ryland, D. W., Schmer, F. A., and Moore, D. G., 1975, Investigation of remote sensing to detect near-surface ground water on irrigated lands: South Dakota State Univ. Remote Sensing Inst. Rept. SDSU–RSI–75–10, 40 p.

Sadeh, D. S., and Meidav, M., 1973, Search for periodicity in earthquake occurrences: Jour. Geophys. Research, v. 78, p. 7709–7716.

Sadlick, Walter, 1966, Biostratigraphy of the Chainman Formation (Carboniferous), eastern Nevada and western Utah: Salt Lake City, Utah, Utah Univ., Ph. D. dissert., 228 p.

Sainsbury, C. L., 1953, Geology of the Olds Mountain-Clark Peak area, Juneau vicinity, Alaska: U.S. Geol. Survey open-file rept., 43 p.

——— 1975, Geology, ore deposits, and mineral potential of the Seward Peninsula, Alaska: U.S. Bur. Mines open-file rept., 108 p.

Sass, J. H., Galanis, S. P., Jr., Munroe, R. J., and Urban, T. C., 1976, Heat-flow data from southeastern Oregon: U.S. Geol. Survey open-file rept., 52 p.

Sass, J. H., Lachenbruch, A. H., Monroe, R. J., Greene, G. W., and Moses, T. H., Jr., 1971, Heat flow in the Western United States: Jour. Geophys. Research, v. 76, no. 26, p. 6376-6413.

Sass, J. H., Olmsted, F. H., Sorey, M. L., Wollenberg, H. A., Lachenbruch, A. H., Munroe, R. J., and Galanis, S. P., Jr., 1976, Geothermal data from test wells drilled in Grass Valley and Buffalo Valley, Nevada: U.S. Geol. Survey open-file rept., 43 p.

Sato, Motoaki, 1976, Oxygen fugacity values of Apollo 16 and 17 rocks, *in* Lunar science VII: Houston, Tex., Lunar Sci. Inst., p. 758–760.

Sato, Motoaki, Malone, S. D., Moxham, R. M., and McLane, J. E., 1976, Monitoring of fumarolic gas at Sherman Crater, Mt. Baker, Washington [abs.]: EOS (Am. Geophys. Union Trans.), v. 57, no. 2, p. 88.

Sauck, W. A., and Sumner, J. S., 1970, Residual aeromagnetic map of Arizona: Tucson, Ariz., Univ. Arizona Dept. Geosciences, scale 1:1,000,000.

Sauer, V. B., 1973, Unit-response method of open-channel flow routing: Am. Soc. Civil Engineers Proc. Jour. Hydraulics Div., v. 99, no. HY1, p. 179–193.

Schaber, G. G., Boyce, J. M., and Moore, H. J., II, 1976, The scarcity of mappable flow lobes on the lunar surface—Unique morphology of the Imbrium flows [abs.], *in* Lunar science VII: Houston, Tex., Lunar Sci. Inst., p. 767–769.

Schafer, J. P., and Hartshorn, J. H., 1965, The Quaternary of New England, *in* The Quaternary of the United States: Princeton, N.J., Princeton Univ. Press, p. 113–128.

Schmoll, H. R., and Dobrovolny, Ernest, 1972a, Generalized geologic map of Anchorage and vicinity, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I–787–A, 1 sheet, scale 1:24,000.

——— 1972b, Slope map of Anchorage and vicinity, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I–787–B, 1 sheet, scale 1:24,000.

——— 1974, Foundation and excavation conditions map of Anchorage and vicinity, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I–787–D, 1 sheet, scale 1:24,000.

Schmoll, H. R., Krushensky, R. D., and Dobrovolny, Ernest, 1975, Geologic considerations for redevelopment planning of Managua, Nicaragua, following the 1972 earthquake: U.S. Geol. Survey Prof. Paper 914, 23 p.

Schmugge, T., Gloerson, P., Wilheit, T., and Geiger, F., 1974, Remote sensing of soil moisture with microwave radiometers: Jour. Geophys. Research, v. 79, p. 317–323.

Schneidermann, Nahum, Pilkey, O. H., and Saunders, Craig, 1976, Sedimentation on the Puerto Rico insular shelf: Jour. Sed. Petrology, v. 46, no. 1, p. 167–173.

Scholl, D. W., and Hopkins, D. M., 1969, Newly discovered Cenozoic basins, Bering Shelf, Alaska: Am. Assoc. Petroleum Geologists Bull., v. 53, p. 2067–2078.

Scholz, C. H., Barazangi, Muawia, and Sbar, M. L., 1971, Late Cenozoic evolution of the Great Basin, western United States, as an ensialic interarc basin: Geol. Soc. America Bull., v. 82, no. 11, p. 2979–2990.

Schrader, F. C., 1904, A reconnaissance in northern Alaska: U.S. Geol. Survey Prof. Paper 20, 139 p.

Scott, D. H., 1974, The geologic significance of some lunar gravity anomalies: Geochim. et Cosmochim. Acta, suppl. 5, v. 3, p. 3025–3036.

Scott, D. H., Diaz, J. M., and Watkins, J. A., 1975, The geologic evaluation and regional synthesis of metric and panoramic photographs: Geochim. et Cosmochim. Acta, suppl. 6, v. 3, p. 2531–2540.

Scott, D. H., Lucchitta, B. K., and Carr, M. H., 1972, Geologic maps of the Taurus-Littrow region of the Moon: U.S. Geol. Survey Misc. Geol. Inv. Map I–800, 2 sheets, scales 1:250,000 and 1:50,000.

Seiders, V. M., Mixon, R. B., Stern, J. W., Newell, M. F., and Thomas, C. B., Jr., 1975, Age of plutonism and tectonism and a new minimum age limit on the Glenarm Series in the northeast Virginia Piedmont near Occoquan: Am. Jour. Sci., v. 275, p. 481–511.

Shackelford, T. J., 1975, Late Tertiary gravity sliding in the Rawhide Mountains, western Arizona [abs.]: Geol. Soc. America Abs. with Programs, v. 7, no. 3, p. 372.

Shawe, D. R., 1966, Arizona-New Mexico and Nevada-Utah beryllium belts, *in* Geological Survey research 1966: U.S. Geol. Survey Prof. Paper 550–C, p. C206–C213.

Sheppard, R. A., and Gude, A. J., III, 1969, Authigenic fluorite in Pliocene lacustrine rocks near Rome, Malheur County, Oregon, *in* Geological Survey research 1969: U.S. Geol. Survey Prof. Paper 650–D, p. D69–D74.

Shirane, G., Cox, D. E., Takei, W. J., and Ruby, S. L., 1962, A study of the magnetic properties of the $FeTiO_3$-αFe_2O_3 system by neutron diffraction and Mossbauer effect: Jour. Phys. Soc. Japan, v. 17, p. 1598–1611.

Shorthill, R. W., 1973, Infrared atlas charts of the eclipsed Moon: Moon, v. 7, p. 22–45.

Shouldice, D. H., 1971, Geology of the western Canadian Continental Shelf: Bull. Canadian Petroleum Geology, v. 19, no. 2, p. 405–436.

Silberling, N. J., and Roberts, R. J., 1962, Pre-Tertiary stratigraphy and structure of northwestern Nevada: Geol. Soc. America Spec. Paper 72, 58 p.

Silver, L. T., and Anderson, T. H., 1974, Possible left-lateral early to middle Mesozoic disruption of the southwestern North American craton margin [abs.]: Geol. Soc. America Abs. with Programs, v. 6, no. 7, p. 955–956.

Sims, P. K., and Peterman, Z. E., 1976, Geology and Rb-Sr ages of reactivated Precambrian gneisses and granite in the Marenesco-Watersmeet area, northern Michigan: U.S. Geol. Survey Jour. Research, v. 4, no. 4, p. 405–414.

Skinner, J. V., and Beverage, J. P., 1976, Instrumentation—Automatic collection of sediment data, Symposium 7, *in* Proceedings of the Third Federal Inter-Agency Sedimentation Conference 1976: Springfield, Va., U.S. Dept. Commerce, Natl. Tech. Inf. Service, PB-245 100, 974 p.

Skipp, B. A., 1975, Paleozoic rocks adrift in south-central Idaho [abs.]: Geol. Soc. America Abs. with Programs, v. 7, no. 5, p. 641–642.

Slawson, W. F., and Nackowski, M. P., 1959, Trace lead in potash-feldspar associated with ore deposits: Econ. Geology, v. 54, no. 8, p. 1543–1555.

Slodowski, T. R., 1956, Geology of the Yauco area, Puerto Rico: Princeton, N.J., Princeton Univ., unpub. Ph. D. dissert., 130 p.

Smith, D. B., Otlet, R. L., Downing, R. A., Monkhouse, R. A., and Pearson, F. J., Jr., 1975, Stable carbon and oxygen isotope ratios of groundwaters from the Chalk and Lincolnshire Limestone: Nature, v. 257, no. 5529, p. 783–784.

Smith, R. L., and Shaw, H. R., 1975, Igneous-related geothermal systems, *in* White, D. E., and Williams, D. L., eds., Assessment of geothermal resources of the United States—1975: U.S. Geol. Survey Circ. 726, p. 58–83.

Smoot, G. F., Davidian, Jacob, and Billings, R. H., 1974, Urban storm rainfall-runoff-quality instrumentation: Internat. Assoc. Sci. Hydrology Pub. 112, p. 44–47.

Soderblom, L. A., and Boyce, J. M., 1976, Distribution and evolution of global color provinces on the moon [abs.], *in* Lunar science VII: Houston, Tex., Lunar Sci. Inst., p. 822–844.

Soderblom, L. A., and Lebofsky, L. A., 1972, Technique for rapid determination of relative ages of lunar areas from orbital photography: Jour. Geophys. Research, v. 77, no. 2, p. 279–296.

Sorey, M. L., 1975, Numerical modeling of liquid geothermal systems: U.S. Geol. Survey open-file rept., 60 p.

Sorey, M. L., and Lewis, R. E., 1976, Convective heat flow from hot springs in the Long Valley caldera, Mono County, California: Jour. Geophys. Research, v. 81, no. 5, p. 785–791.

Spence, W. J., 1975, Aleutian arc tectonics [abs.]: Interdisciplinary Symposia: Internat. Union Geodesy Geophysics Gen. Assembly, 16th, Grenoble, France, 1975, Abs. of papers, p. 16.

Spence, W. J., Giesecke, A., Langer, C. J., Ocola, L., Dillinger, W. H., and Jordan, J. N., 1975, The Lima, Peru, 1974 earthquake series [abs.]: Geol. Soc. America Abs. with Programs, v. 7, no. 3, p. 424.

Stankowski, S. J., Schopp, R. D., and Velnich, A. J., 1975, Flood of July 21, 1975, in Mercer County, New Jersey: U.S. Geol. Survey Water-Resources Inv. 51–75, 52 p.

Stanley, W. D., Jackson, D. B., and Hearn, C. B., Jr., 1973, Preliminary results of geoelectrical investigations near Clear Lake, California: U.S. Geol. Survey open-file rept., 20 p.

Stauder, William, Kramer, M., Fischer, G., Schaefer, S., and Morrissey, S., 1975, Southeast Missouri Regional Seismic Network Quarterly Bulletin 4, 2d quarter, 1 April–30 June 1975: St. Louis, Mo., Dept. Earth Atmospheric Sci., St. Louis Univ.

Stewart, D. B., 1975, Apollonian metamorphic rocks—The products of prolonged subsolidus equilibration, *in* Lunar science VI: Houston, Tex., Lunar Sci. Inst., p. 774–776.

Stewart, J. H., and Carlson, J. E., 1974a, Preliminary geologic map of Nevada: U.S. Geol. Survey Misc. Field Studies Map MF–609, 4 sheets, scales 1:500,000 and 1:1,000,000.

——— 1974b, Preliminary geologic map of Nevada: U.S. Geol. Survey open-file rept., 2 color photographs.

Stewart, D. B., and Wones, D. R., 1974, Bedrock geology of northern Penobscot Bay area, *in* Osberg, P. H., ed., Geology of east-central and north-central Maine: New England Intercoll. Geol. Conf. Ann. Mtg., 66th.

Stone, H. K., 1968, Iterative solution of implicit approximations of multidimensional partial differential equations: Soc. Indus. Appl. Mathematics Jour. Numerical Analysis, v. 5, no. 3, p. 530–558.

Stuckless, J. S., Bunker, C. M., and Nkomo, I. T., 1975, Uranium mobility in a uraniferous granite from the Granite Mountains, Wyoming [abs.]: Geol. Soc. America Abs. with Programs, v. 7, p. 1286–1287.

Subitzky, Seymour, 1975a, Summary of hydrogeologic regime and environmental characteristics, Allegheny County, Pennsylvania: U.S. Geol. Survey Misc. Field Studies Map MF–641–A, 1 sheet.

——— 1975b, Hydrogeologic framework and ground-water system, Allegheny County, Pennsylvania: U.S. Geol. Survey Misc. Field Studies Map MF–641–B, 2 sheets.

——— 1975c, Mining and related problems of the shallow hydrogeologic regime, Allegheny County, Pennsylvania: U.S. Geol. Survey Misc. Field Studies Map MF–641–C, 1 sheet.

——— 1975d, Heavy storm precipitation and related mass movement, Allegheny County, Pennsylvania: U.S. Geol. Survey Misc. Field Studies Map MF–641–D, 1 sheet.

——— 1975e, Aspects of water quality in McLaughlin Run and Painters Run, Allegheny County, Pennsylvania: U.S. Geol. Survey Misc. Field Studies Map MF–641–E, 1 sheet.

Summers, R. S., Winkler, K. W., and Byerlee, J. D., 1975, Permeability changes during fluid flow through hot granite [abs.]: EOS (Am. Geophys. Union Trans.), v. 56, no. 12, p. 1060.

Sun, R. J., 1975, Geohydrologic evaluation of a site for disposal of radioactive wastes by grout injection and hydraulic fracturing at Holifield National Laboratory (formerly Oak Ridge National Laboratory), Oak Ridge, Tennessee: U.S. Geol. Survey open-file rept., 77 p.

——— 1976, Hydrodynamic dispersion and movement of injection water, *in* Artificial recharge through a well in fissured carbonate rock, West St. Paul, Minnesota: U.S. Geol. Survey Water-Supply Paper 2004, p. 52–75.

Sutton, R. L., 1974, The geology of Hopi Buttes, Arizona, *in* Karlstrom, T. N. V., Swann, G. A., and Eastwood, R. L., eds., Geology of northern Arizona with notes on archaeology and paleoclimate: Geol. Soc. America Rocky Mtn. Sect. Ann. Mtg., Flagstaff, Ariz., Guidebook 27, pt. 2, p. 647–671.

Swanson, D. A., Wright, T. L., and Clem, Richard, 1975, Intracanyon flows of Yakima Basalt along the Snake River, southeast Washington [abs.]: Geol. Soc. America Abs. with Programs, v. 7, no. 5, p. 645.

Swanson, D. A., Wright, T. L., and Helz, R. T., 1975, Linear vent systems and estimated rates of magma production and eruption for the Yakima Basalt on the Columbia Plateau: Am. Jour. Sci., v. 275, p. 877–905.

Swayze, L. J., Bancroft, W. L., Higer, A. L., and Cordes, E. H., 1976, The application of Landsat data from collection platforms and Landsat imagery for fire management, Everglades National Park, Florida: Springfield, Va., U.S. Dept. Commerce, Natl. Tech. Inf. Service, N 76–18580.

Swift, C. H., III, 1975, Estimation of stream discharges preferred by steelhead trout for spawning and rearing in western Washington: U.S. Geol. Survey open-file rept., 50 p.

Takasaki, K. J., 1976, Elements needed in design of a groundwater-quality monitoring network in the Hawaiian Islands: U.S. Geol. Survey Water-Supply Paper 2041, 23 p.

Tera, F., and Wasserburg, G. J., 1974, U-Th-Pb systematics on lunar rocks and inferences about lunar evolution and the age of the Moon, *in* Lunar science V: Houston, Tex., Lunar Sci. Inst., p. 1571–1599.

Tessar, P. A., and Lund, O. M., 1975, Innovative methods for the generation of state and regional land-use information—An operational Landsat demonstration project: Am. Inst. Planners Ann. Conf., 57th, San Antonio, Tex., 1975, Conf. Paper 10, 28 p.

Tessar, P. A., Hood, D. R., and Todd, W. J., 1975, The South Dakota cooperative land use effort—A state level remote sensing demonstration project: NASA Johnson Space Center Earth Resources Survey Symposium, Houston, Tex., 1975, Proc., v. I–C, p. 1499–1523.

Thomas, C. P., 1975, A minicomputer-based emission spectrographic analysis system [abs.]: Federation Anal. Chem. Spectrographic Soc. Natl. Mtg., 2d, Abs. 124.

Thompson, M. E., Roach, C. H., and Meyrowitz, R., 1958, Sherwoodite, a mixed vanadium (IV)-vanadium (V) mineral from the Colorado Plateau: Am. Mineralogist, v. 43, p. 749–755.

Tilling, R. I., 1974, Composition and time relations of plutonic and associated volcanic rocks, Boulder batholith region, Montana: Geol. Soc. America Bull., v. 85, p. 1925–1930.

Tilling, R. I., Holcomb, R. T., Lockwood, J. P., and Peterson, D. W., 1975, Recent eruptions of Hawaiian volcanoes and evolution of basaltic landforms: Internat. Colloquium Planetary Geology, Rome, Italy, 1975, Program, p. 149–152.

Toler, L. G., 1967, Fluoride in water in the Alafia and Peace River basins, Florida: Florida Dept. Nat. Resources, Bur. Geology Rept. Inv. 46, 46 p.

Trainer, F. W., 1975, Mixing of thermal and non-thermal waters in the margin of the Rio Grande rift, Jemez Mountains, New Mexico: New Mexico Geol. Soc. Ann. Field Conf., 26th, Las Cruces County, N. Mex., 1975, Guidebook, p. 213–218.

Trescott, P. C., 1973, Iterative digital model for aquifer evaluation: U.S. Geol. Survey open-file rept., 19 p.

——— 1975, Documentation of finite-difference model for simulation of three-dimensional ground-water flow: U.S. Geol. Survey open-file rept., 30 p.

Trescott, P. C., Pinder, G. F., and Larson, S. P., 1976, Finite-difference model for aquifer simulation in two dimensions with results of numerical experiments, *in* Automated data processing and computation: U.S. Geol. Survey Techniques of Water-Resources Inv., TWI 7–C1, 116 p.

Urban, T. C., and Diment, W. H., 1975, Heat flow on the south flank of the Snake River rift [abs.]: Geol. Soc. America Abs. with Programs, v. 7, no. 5, p. 648.

Urban, T. C., Jamieson, I. M., Diment, W. H., and Sass, J. H., 1975, Heat flow at The Geysers, California [abs.]: U.N. Symposium on the Devel. and Use of Geothermal Resources, 2d, San Francisco, Calif., 1975, Abs. v., p. III–89.

U.S. Bureau of Land Management, 1975, Resource and potential reclamation evaluation—Taylor Creek study site—Axial basin coal field: Bur. Land Management EMRIA Rept. 3, 89 p.

U.S. Department of Health, Education, and Welfare, 1962, Public Health Service drinking water standards, 1962: Public Health Service Pub. 956, 61 p.

U.S. Geological Survey, 1975a, Coal resources, *in* Resource and potential reclamation evaluation, Otter Creek Study Site: Bur. Land Management EMRIA Rept. 1, p. 43–79.

——— 1975b, Coal, *in* Resource and potential reclamation evaluation, Hanna Basin Study Site: Bur. Land Management EMRIA Rept. 2, p. 33–59.

——— 1975c, Coal resources, *in* Resource and potential reclamation evaluation, Alton Study Site: Bur. Land Management EMRIA Rept. 4, p. 59–82.

——— 1975d, Geochemical survey of the Western coal regions, second annual progress report, July 1975: U.S. Geol. Survey open-file rept., 132 p.

——— 1976, Draft environmental impact statement [on the] development of phosphate resources in southeastern Idaho: Washington, D.C., U.S. Govt. Printing Office.

United States-Saudi Arabian Joint Commission on Economic Cooperation, 1975, Wadi Dawasir—An approach to agricultural development in Saudi Arabia: Washington, D.C., 65 p.

Van Schmus, W. R., and Woolsey, L. L., 1975, Rb-Sr geochronology of the Republic area, Marquette County, Michigan: Canadian Jour. Earth Sci., v. 12, p. 1723–1733.

Vine, J. D., 1975a, Are lithium resources adequate for energy self-sufficiency?: U.S. Geol. Survey open-file rept., 14 p.

——— 1975b, Lithium in sediments and brines—How, why, and where to search: U.S. Geol. Survey Jour. Research, v. 3, no. 4, p. 479–485.

Vine, J. D., Tourtelot, E. B., Glanzman, R. K., Bohannon, R. G., Davis, J. R., and Meier, A. L., 1975, Are lithium-rich sedimentary rocks and brines related to tectonic activity?: Internat. Cong. Sedimentology, 9th, Nice, France, 1975, Theme 9, p. 105–110.

Van Alstine, R. E., 1968, Tertiary trough between the Arkansas and San Luis Valleys, Colorado, *in* Geological Survey research 1968: U.S. Geol. Survey Prof. Paper 600–C, p. C158–C160.

Van Schmus, W. R., Thurman, E. M., and Peterman, Z. E., 1975, Geology and Rb-Sr chronology of middle Precambrian rocks in eastern and central Wisconsin: Geol. Soc. America Bull., v. 86, p. 1255–1265.

Vecchioli, John, 1976, Preliminary evaluation of the feasibility of artificial recharge in northern Qatar: U.S. Geol. Survey open-file rept., 47 p.

von Huene, Roland, Smith, Rodney, Hampton, Monty, Moore, George, and Dolton, Gordon, 1975, A preliminary summary of petroleum potential, environmental geology, and the technology, time-frame, and infrastructure for exploration and development of the western Gulf of Alaska: U.S. Geol. Survey open-file rept., 52 p.

Wagner, H. C., 1974, Marine geology between Cape San Martin and Point Sal, south-central California offshore—A preliminary report: U.S. Geol. Survey open-file rept., 17 p.

Walker, G. W., 1973, Preliminary geologic and tectonic maps of Oregon east of the 121st meridian: U.S. Geol. Survey Misc. Field Studies Map MF–495, 2 sheets, scales 1:500,000 and 1:1,000,000.

Waller, B. G., Miller, W. L., and Beaven, T. R., 1975, Water-quality data for canals in eastern Broward County, Florida, 1969–74: U.S. Geol. Survey open-file rept., 156 p.

Walthall, F. G., 1974, Spectrochemical computer analysis program description: U.S. Geol. Survey Jour. Research, v. 2, no. 1, p. 61–71.

Ward, P. E., 1976, Ground water development and potential in Wadis Khulays and Fatimah, Saudi Arabia: U.S. Geol. Survey open-file rept., 22 p.

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

Wentworth, C. K., 1925, The geology of Lanai: Bernice P. Bishop Mus. Bull., v. 24, 72 p.

White, D. E., 1968, Environments of generation of some base-metal ore deposits: Econ. Geology, v. 63, p. 301–335.

White, D. E., and Williams, D. L., eds., 1975, Assessment of geothermal resources of the United States—1975: U.S. Geol. Survey Circ. 726, 155 p.

Wilhelms, D. E., 1976, Secondary craters of lunar basins [abs.], *in* Lunar science VII: Houston, Tex., Lunar Sci. Inst., p. 935–938.

Willey, L. M., Kharaka, Y. K., Presser, T. S., Rapp, J. B., and Barnes, Ivan, 1975 Short chain aliphatic acid anions in oil field waters and their contribution to the measured alkalinity: Geochim. et Cosmochim. Acta, v. 39, p. 1707–1711.

William Spangle and Associates, F. Beach Leighton and Associates, and Baxter, McDonald and Company, 1976, Earth-science information in land-use planning—Guidelines for Earth scientists and planners: U.S. Geol. Survey Circ. 721, 28 p.

Williams, Alwyn, 1973, Distribution of brachiopod assemblages in relation to Ordovician palaeography, *in* Hughes, N. F., ed., Organisms and continents through time: Palaeont. Assoc. Spec. Paper 12, p. 241–269.

Williams, Howel, 1936, Pliocene volcanoes of the Navajo-Hopi country (Arizona): Geol. Soc. America Bull., v. 47, no. 1, p. 111–172.

Williams, P. L., Mabey, D. R., Zohdy, A. A. R., Achermann, Hans, Hoover, D. B., Pierce, K. L., and Oriel, S. S., 1975, Geology and geophysics of the southern Raft River Valley geothermal area, Idaho: U.S. Geol. Survey open-file rept., 31 p.

Williams, R. S., Jr., 1976a, Cape Cod and Cape Cod National Seashore, Massachusetts, *in* Williams, R. S., Jr., and Carter, W. D., eds., ERTS–1, a new window on our world: U.S. Geol. Survey Prof. Paper 929, p. 307–309.

——— 1976b, Diversion of lava by watercooling during the eruption of Eldfell Volcano, Heimaey, Iceland [abs.]: Geol. Soc. America Abs. with Programs, v. 8, no. 2, p. 300–301.

——— 1976c, Dynamic environmental phenomena in southwestern Iceland, *in* Williams, R. S., Jr., and Carter, W. D., eds., ERTS–1, a new window on our world: U.S. Geol. Survey Prof. Paper 929, p. 109–112.

——— 1976d, Vatnajökull icecap, Iceland, *in* Williams, R. S., Jr., and Carter, W. D., eds., ERTS–1, a new window on our world: U.S. Geol. Survey Prof. Paper 929 p. 183–193.

Williams, R. S., Jr., and Moore, J. G., 1976a, Iceland chills a lava flow, *in* Tank, Ronald, ed., Focus on environmental geology—A collection of case histories and readings from original sources, 2d ed.: New York, Oxford Univ. Press, p. 45–58.

——— 1976b, Man against volcano—The eruption on Heimaey, Vestmann Islands, Iceland: U.S. Geol. Survey Inf. 75–22, 19 p.

Wilson, Druid, 1964, Caloosahatchee beds of Florida believed to be Tertiary, *in* Geological Survey research 1964: U.S. Geol. Survey Prof. Paper 501–A, p. A75.

Winter, T. C., 1976, The hydrologic setting of lakes in Minnesota and adjacent States, with emphasis on the interaction of lakes and ground water: U.S. Geol. Survey open-file rept., 237 p.

Winterburg, F., 1973, Micro-fission explosions and controlled release of thermonuclear energy: Nature, v. 241, p. 449–450.

Wise, D. J., 1963, An outrageous hypothesis for the tectonic pattern of the North America Cordillera: Geol. Soc. America Bull., v. 74, p. 357–362.

Witkind, I. J., 1975, Geology of a strip along the Centennial fault, southwestern Montana and adjacent Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map I–890, 1 sheet, scale 1:62,500.

Wray, J. R., 1975, Land use change map, 1970–72, Washington urban area, D.C., Md., and Va.: U.S. Geol. Survey Misc. Inv. Map I–858–D, 1, sheet, scale 1:100,000.

Wu, S. S. C., 1975, The effect of illumination on the precision of photogrammetric measurements using Apollo metric camera photographs: Am. Soc. Photogrammetry, Phoenix, Ariz., 1975, Proc., p. 99–118.

Zartman, R. E., 1974, Lead isotopic provinces in the cordillera of the western United States and their geologic significance: Econ. Geology, v. 69, no. 6, p. 792–805.

Zartman, R. E., and Naylor, R. S., 1972, Structural implications of some U-Th-Pb zircon isotope ages of igneous rocks in eastern Massachusetts [abs.]: Geol. Soc. America Abs. with Programs, v. 4, no. 1, p. 54–55.

Zenone, Chester, Schmoll, H. R., and Dobrovolny, Ernest, 1974, Geology and ground water for land-use planning in the Eagle River-Chugiak area, Alaska: U.S. Geol. Survey open-file rept., 36 p.

Zohdy, A. A. R., and Bisdorf, R. J., 1976, Schlumberger soundings in the Upper Raft River and Raft River Valleys, Idaho and Utah: U.S. Geol. Survey open-file rept., 5 p.

Zwart, H. J., Corvalan, J., James, H. L., Miyashiro, A., Saggerson, E. P., Sobolev, V. S., Subramaniam, A. P., and Vallance, T. G., 1967, A scheme of metamorphic facies for the cartographic representation of regional metamorphic belts: Internat. Union Geol. Sci. Geol. Newsletter, v. 1967, no. 2, p. 57–72.

COOPERATORS AND OTHER FINANCIAL CONTRIBUTORS DURING FISCAL YEAR 1976

[Cooperators listed are those with whom the U.S. Geological Survey had a written agreement for fiscal cooperation in fiscal year 1976, cosigned by responsible officials of the Geological Survey and the cooperating agency. Agencies with whom the Geological Survey had research contracts and to whom it supplied funds for such research are not listed. Parent agencies are listed separately from their subdivisions where separate cooperative agreements for different projects were made with the parent agency and with a subdivision of the parent agency]

FEDERAL COOPERATORS

Department of Agriculture:
- Agriculture Research Service
- Forest Service
- Soil Conservation Service
- Statistical Reporting Service

Department of the Air Force:
- AFWL/PRP Kirtland AFB
- Air Force Academy
- Air Force Headquarters, Washington, D.C.
- Headquarters (AF-SC)
- Headquarters (AFTAC/AC)
- Headquarters Pacific Air Forces
- Headquarters 321st Combat Support Group (SAC)
- Homestead Air Force Base
- Vandenburg Air Force Base

Department of the Army:
- Army Research Office
- Corps of Engineers
- Rocky Mountain Arsenal
- White Sands Missile Range

Department of Commerce:
- Bureau of the Census
- National Oceanic and Atmospheric Administration:
  - Economic Development Administration
  - Environmental Research Laboratories
  - National Ocean Survey
  - National Weather Service
  - Old West Regional Commission

Department of Defense:
- Advanced Research Projects Agency
- Defense Civil Preparedness Agency
- Defense Intelligence Agency
- Defense Mapping Agency (IAGS)
- Defense Nuclear Agency
- U.S. Arms Control and Disarmament Agency

Department of Health, Education, and Welfare, Public Health Service

Department of Housing and Urban Development

Department of the Interior:
- Alaska Power Administration
- Bonneville Power Administration

Department of the Interior—Continued
- Bureau of Indian Affairs
- Bureau of Land Management
- Bureau of Mines
- Bureau of Reclamation
- Fish and Wildlife Service
- National Park Service
- Office of Land Use and Water Planning
- Office of Library Services
- Water Resources Council

Department of the Navy:
- Marine Corps, Camp Pendleton
- Naval Facilities Engineering Command
- Naval Weapons Center
- Underwater Systems Center

Department of State:
- Agency for International Development
- International Joint Commission

Department of Transportation:
- Federal Aviation Administration
- Federal Highway Administration
- Federal Railroad Administration
- Office of the Secretary

Department of the Treasury, Customs Service

Energy Research and Development Administration:
- Albuquerque Operations Office
- Division of Applied Technology
- Division of Procurement
- Idaho Operations Office
- Nevada Operations Office
- Oak Ridge Operations Office
- Richland Operations Office
- Rocky Flats Division
- Savannah River Operations Office

Environmental Protection Agency:
- Enforcement Division
- National Environmental Research Center
- Office of Energy, Minerals, and Industry
- Office of Radiation Programs
- Office of Research and Development
- Office of Water Programs
- Pacific Northwest Environmental Research Laboratory
- Technical Services Branch

Executive Office of the President, Council on Environmental Quality

Federal Energy Administration

Federal Power Commission

General Services Administration

National Academy of Sciences

National Aeronautics and Space Administration

National Science Foundation

Nuclear Regulatory Commission

Tennessee Valley Authority

Upper Mississippi River Basin Commission

STATE, COUNTY, AND LOCAL COOPERATORS

Alabama:
- Alabama Development Office
- Alabama Highway Department
- Commission of Jefferson County
- Geological Survey of Alabama

Alaska:
- Alaska Department of Fish and Game
- Alaska Department of Highways
- Alaska Geological and Geophysical Survey
- Alaska Pipeline Coordination Office
- City of Anchorage
- Department of Environmental Conservation
- Greater Anchorage Area Borough
- Kenai Borough
- North Star Borough
- University of Alaska

Arizona:
- Arizona Game and Fish Department
- Arizona Highway Department
- Arizona Water Commission
- City of Flagstaff
- City of Nogales
- City of Safford
- City of Tucson
- Department of Health Services
- Flood Control District of Maricopa County
- Gila Valley Irrigation District
- Maricopa County Municipal Water Conservation District No. 1
- Pima County Board of Supervisors
- Salt River Valley Water Users' Association
- San Carlos Irrigation and Drainage District
- Show Low Irrigation Company
- University of Arizona

Arkansas:
- Arkansas Department of Pollution Control and Ecology
- Arakansas 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
- California Department of Conservation, Division of Mines and Geology
- California Department of Transportation
- California Department of Water Resources
- California Division of Highways, Materials and Research Department
- California Water Resources Control Board
- Casitas Municipal Water District
- City and County of San Francisco:
  - Hetch Hetchy Water Supply
  - Water Department
- City of Lompoc
- City of Merced
- City of Modesto, Public Works Department
- City of San Diego
- City of San Rafael
- City of Santa Barbara, Public Works Department
- Coachella Valley County Water District
- Contra Costa County Flood Control and Water Conservation District
- County of Fresno
- County of Madera, Flood Control and Water Conservation Agency
- County of Modoc, Department of Public Works
- County of San Diego, Department of Sanitation and Flood Control
- County of San Mateo, Engineer and Road Commissioner
- Desert Water Agency
- East Bay Municipal Utility District
- Georgetown Divide Public Utility District
- Goleta County Water District
- Humboldt County, Department of Public Works
- Imperial County Department of Public Works
- 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
- Marin County Department of Public Works
- Merced Irrigation District
- Metropolitan Water District of Southern California
- Mojave Water Agency
- Montecito County Water District
- Monterey County Flood Control and Water Conservation District
- Napa County Flood Control and Water Conservation District
- North Marin County Water District
- Orange County Environmental Management Agency
- Orange County Water District
- Oroville-Wyandotte Irrigation District
- Pacheco Pass Water District

California—Continued
- Paradise Irrigation District
- Riverside County Flood Control and Water Conservation District
- San Benito County Water Conservation and Flood Control District
- San Bernardino County Flood Control District
- San Bernardino Valley Municipal Water District
- San Luis Obispo County Engineering Department
- Santa Barbara County Flood Control and Water Conservation District
- Santa Barbara County Water Agency
- Santa Clara Valley Water District
- Santa Margarita and San Luis Rey Watershed Planning Agencies
- Santa Maria Valley Water Conservation District
- Santa Ynez River Water Conservation District
- Siskiyou County Flood Control and Water Conservation District
- Terra Bella Irrigation District
- Tulare County Flood Control District
- Turlock Irrigation District
- Twentynine Palms Water District
- United Water Conservation District
- University of California:
  - School of Forestry and Conservation
- 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
- Boulder City-County Department of Health
- 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
- Colorado City Water and Sanitation District
- Colorado Department of Local Affairs, Division of Planning
- 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
- Denver Regional Council of Governments
- Eagle County Commissoners
- El Paso County:
  - County Board of Commissioners
  - County Water Association
- Jefferson County Health Department
- Kiowa-Bijou Groundwater Management District
- Metro Denver Sewage Disposal District No. 1
- Park County Board of County Commissioners
- Pikes Peak Area Council of Governments
- Pitkin County Board of County Commissioners

Colorado—Continued
- Rio Grande Water Conservation District
- Southeastern Colorado Water Conservancy District
- Southern Ute Indian Tribe
- Southwestern Water Conservation District
- State of Colorado, Department of Highways
- Urban Drainage and Flood Control District

Connecticut:
- City of Hartford, Department of Public Works
- City of New Britain, Board of Water Commissioners
- City of Torrington
- Connecticut Geological and Natural History Survey
- Department of Environmental Protection
- Department of Transportation
- Town of Fairfield
- Town of Farmington
- Town of Manchester
- Town of Newton
- Town of South Windsor
- Town of Wilton

Delaware:
- Delaware Geological Survey, University of Delaware
- Department of Highways and Transportation, 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
- Charlotte County
- City of Boca Raton
- City of Boynton Beach
- 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-Dade Water and Sewer Authority and the City of Miami Beach
- 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 West Palm Beach
- Collier County
- Collier County Water Management District No. 1
- Collier County Water Management District No. 7
- Department of Administration
- Department of Environmental Regulations
- Department of Pollution Control

Florida—Continued
- Englewood Water District
- Escambia County
- Florida Department of Natural Resources:
  - Bureau of Geology
  - Division of Parks and Recreation
- Florida Department of Transportation
- Florida Keys Aqueduct Authority
- Hendry County
- Hillsborough County
- Jacksonville Area Planning Board
- Lake County
- Lake Worth Drainage District
- Lee County
- Loxahatchee River Environmental Control District
- Manasota Basin Board
- Manatee County, Board of County Commissioners
- Martin County
- Metropolitan Dade County
- Northwest Florida Water Management District
- Old Plantation Drainage District
- Orange County
- Palm Beach County
- Pinellas County
- Reedy Creek Improvement District
- Sarasota County
- Seminole County
- Southwest Water Management District
- St. John River Water Management
- Sunshine Drainage District
- Suwanee River Authority
- Town of Highland Beach
- Village of Tequesta
- Volusia County
- Walton County

Georgia:
- Chatham County
- City of Brunswick
- City of Valdosta
- 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
- Maui County, Department of Public Works
- State Department of Land and Natural Resources
- State Department of Transportation

Idaho:
- Idaho Bureau of Mines and Geology
- Idaho Department of Transportation
- Idaho Department of Water Resources
- Mann Creek Irrigation District

Illinois:
- Bloomington and Normal Sanitary District
- City of Springfield
- Cook County, Forest Preserve District
- DuPage County Highway Department
- Environmental Protection Agency

Illinois—Continued
- Fountain Head Drainage District
- Fulton County-East Liverpool Drainage and Levee District
- Kane County Highway Department
- Lake County Highway Department
- McHenry County Regional Planning Commission
- Metropolitan Sanitary District of Greater Chicago
- 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 Water Resources Management
- University of Illinois at Urbana-Champaign, Board of Trustees

Indiana:
- City of Indianapolis
- City of Logansport
- Indiana Board of Health
- Indiana Department of Natural Resources
- Indiana Highway Commission
- Town of Carmel

Iowa:
- City of Cedar Rapids
- City of Des Moines
- City of Fort Dodge
- Iowa Geological Survey
- Iowa Natural Resources Council
- Iowa State Highway Commission, Highway Research Board
- Iowa State University:
  - Department of Agricultural Engineering
  - Department of Science and Technology, Agricultural 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:
- Bureau of Highways, Department of Transportation
- Department of Natural Resources and Environmental Protection:
  - Division of Conservation
  - Division of Water Quality
- Kentucky Geological Survey, University of Kentucky

Louisiana:
- Capital Area Ground Water Conservation Commission
- Louisiana Department of Highways
- Louisiana Department of Public Works
- Sabine River Compact Administration

Maine:
- Department of Environmental Protection
- Greater Portland Council of Government, Androscoggin Regional Planning Agency

Maine—Continued
- Maine Department of Transportation
- Maine Public Utilities Commission
- South Kennebec Regional Planning Commission
- South Maine Regional Planning Agency

Maryland:
- City of Baltimore, Bureau of Engineering, Water Supply Division
- Maryland Department of Health and Mental Hygiene
- Maryland Department of Transportation, The State Highway Administration
- Maryland Geological Survey

Massachusetts:
- Department of Public Works:
  - Department of Research and Materials
  - 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:
  - Environmental Protection Branch
  - Geological Survey Division
  - Water Resources Commission

Minnesota:
- City of Lakeville
- Minnesota Department of Natural Resources:
  - Division of Natural Waters
  - Division of Waters, Soils, and Minerals
- Minnesota State Planning Agency

Mississippi:
- City of Jackson
- Harrison County Development Commission
- Jackson County Port Authority
- Marine Research Council
- Mississippi Air and Water Pollution Control Commission
- Mississippi Board of Water Commissioners
- Mississippi Geological Survey
- Mississippi Research and Development Center
- Mississippi State Highway Department
- Pat Harrison Waterway District
- Pearl River Valley Water Supply District

Missouri:
- Curators of the University of Missouri
- Department of Conservation
- Department of Natural Resources:
  - Division of Environmental Quality, Clean Water Commission
  - Division of Research and Technical Information
- Metropolitan St. Louis Sewer District
- Missouri State Highway Commission
- Springfield Sanitary District
- St. Louis County

Montana:
- Endowment and Research Foundation, Montana State University

Montana—Continued
- Flathead Drainage 208 Project
- Lewis and Clark County, Board of County Commissioners
- Missoula and Powell Counties
- Montana Bureau of Mines and Geology
- Montana Department of Health and Environmental Sciences
- Montana Department of Natural Resources, Environmental Protection Branch
- Montana State Fish and Game Department
- Montana State Highway Commission
- Yellowstone-Tongue Area Planning and Organization

Nebraska:
- Blue River Association of Ground Water Conservation Districts
- Clay County Ground Water Conservation District
- Filmore County Ground Water Conservation District
- Hamilton County Ground Water Conservation District
- Kansas-Nebraska Big Blue River Compact Administration
- Lower Elkhorn Natural Resources District
- Lower Platte South Natural Resources District
- Nebraska Department of Water Resources
- Nebraska Natural Resources Commission
- Seward County Ground Water Conservation District
- State Department of Roads
- University of Nebraska, Water Resources Institute
- Upper Big Blue Natural Resources District
- York County Ground Water Conservation District

Nevada:
- Department of Human Resources (Environmental Protection Services)
- Nevada Bureau of Mines and Geology
- Nevada Department of Conservation and Natural Resources
- Nevada State Highway Department

New Hampshire:
- New Hampshire Department of Resources and Economic Development
- New Hampshire Water Resources Board
- New Hampshire Water Supply and Pollution Control Commission
- Strafford-Rockingham Regional Council

New Jersey:
- Bergen County
- Camden County Board of Freeholders
- Delaware River Basin Commission
- Morris County Municipal Utilities Authority
- New Jersey Department of Agriculture, State Soil Conservation Committee
- New Jersey Department of Environmental Protection
- North Jersey District Water Supply Commission
- Passaic Valley Water Commission
- Rutgers State University
- Township of Cranford

New Mexico:
- 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—Continued
- New Mexico State Engineer
- New Mexico State Highway Commission
- Pecos River Commission
- Rio Grande Compact Commission

New York:
- Board of Hudson River, Black River Regulating District
- Central New York State Parks Commission
- City of Albany
- City of Auburn
- City of New York:
  - Board of Water Supply
  - Environmental Protection Administration
- City of Rochester, Water Bureau
- County of Chautauqua
- County of Cortland
- County of Dutchess, Department of Planning
- County of Nassau, Department of Public Works
- County of Onondaga:
  - Department of Public Works
  - Water Authority
- County of Orange, Department of Public Works
- County of Putnam Highway Department
- County of Rockland Drainage Agency
- County of Suffolk:
  - Department of Environmental Control
  - Water Authority
- County of Ulster
- County of Westchester, Department of Public Works
- Department of Environmental Conservation:
  - Bureau of Monitoring and Surveillance
  - Office of Program Development
  - Facilities and Construction Management
- Department of Transportation
- Monroe County Water Authority
- Nassau-Suffolk Regional Planning Board
- 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
- Susquehanna River Basin Commission
- Town of Waterford Commissioners

North Carolina:
- Board of Transportation
- 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
- State Department of Transportation
- University of North Carolina, Water Resources Research Institute

North Dakota:
- North Dakota Geological Survey
- Oliver County, Board of County Commissioners
- State Water Commission

Ohio:
- City of Canton
- City of Columbus, Department of Public Service
- City of Toledo
- Miami Conservancy District
- Ohio Department of Natural Resources
- Ohio Department of Transportation, Division of Highways
- Ohio Environmental Protection Agency
- Ohio River Valley Water Sanitation Commission
- Three Rivers Watershed District
- Toledo Metropolitan Area Council of Governments

Oklahoma:
- City of Oklahoma City, Water Department
- Oklahoma Department of Highways
- Oklahoma Geological Survey
- Oklahoma Water Resources Board
- State Department of Health, Environmental Health Service
- State Pollution Control Coordinating Board

Oregon:
- Burnt River Irrigation District
- City of Corvallis
- City of Eugene, Water and Electric Board
- City of McMinnville, Water and Light Department
- City of Portland:
  - Bureau of Water Works
  - Department of Public Utilities
- Columbia Region Association of Governments
- 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
- Department of Fish and Wildlife
- Douglas County, Board of Commissioners
- Lakeside Water District
- Lane County, Board of Commissioners
- Multnomah County, Board of County Commissioners
- Oregon State Highway Commission
- Oregon State Water Resources Department
- Rogue Valley Council of Governments

Pennsylvania:
- Chester County Water Resources Authority
- City of Bethlehem
- City of Easton
- City of Harrisburg
- City of Philadelphia, Water Department
- Department of Environmental Management
- Pennsylvania Department of Environmental Resources:
  - Bureau of Topographic and Geologic Survey
  - Bureau of Water Quality Management
  - Office of Resource Management
- Pennsylvania Department of Transportation
- Slippery Rock State College

Rhode Island:
- City of Providence, Department of Public Works
- State Department of Natural Resources:
  - Division of Planning and Development
- State Water Resources Board

South Carolina:
- Commissioners of Public Works, Spartanburg Water Works
- Department of Health and Environmental Control, Bureau of Waste Water and Stream Quality
- State Highway Department
- State Public Service Authority
- State Water Resources Commission

South Dakota:
- Black Hills Conservancy Subdistrict
- City of Sioux Falls
- City of Watertown
- East Dakota Conservancy Subdistrict
- South Dakota Department of Natural Resource Development
- South Dakota Department of Transportation and Board of Transport

Tennessee:
- Chickasaw Basin Authority
- City of Franklin
- City of Lawrenceburg
- City of Manchester
- City of Memphis, Board of Light, Gas, and Water Commissioners
- Lincoln County Public Utilities Board
- Metropolitan Government of Nashville and Davidson County, Department of Public Works
- Murfreesboro Water and Sewer Department
- Tennessee Department of Conservation:
  - Division of Geology
  - Division of Water Resources
- Tennessee Department of Public Health, Division of Water Quality Control
- Tennessee Department of Transportation
- Tennessee Wildlife Resources Agency
- University of Tennessee Water Resources Research Center

Texas:
- City of Austin
- City of Dallas, Public Works Department
- City of Fort Worth
- City of Houston
- County of Dallas
- Sabine River Compact Administration
- Texas Highway Department
- Texas Water Development Board

Utah:
- Bear River Commission
- Salt Lake County
- State Department of Natural Resources, Division of Water Rights
- Utah Geological and Mineralogical Survey

Vermont:
- City of Springfield
- State Department of Highways

Vermont—Continued
- 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:
  - 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 State Water Control Board

Washington:
- Chehalis Tribal Council
- City of Port Angeles
- City of Seattle, Department of Lighting
- City of Tacoma:
  - Department of Public Utilities
  - Department of Public Works
- Clark County:
  - Department of Public Works
  - Public Utility District
- Cowlitz County Public Utility District
- Kilsap County Board of Commissioners
- Lower Elwah Tribal Council
- Makah Tribal Council
- Municipality of Metropolitan Seattle
- Nisqually Indian Community Council
- Pacific County Board of County Commissioners
- Port Gamble Tribal Council
- Quilente Tribal Council
- Quinault Tribal Council
- Suquamish Tribal Council
- Swinomish Tribal Council
- The Evergreen State College
- Tulalip Tribe Board of Directors
- University of Washington
- Washington State Department of Ecology
- Washington State Department of Fisheries
- Washington State Department of Game
- Washington State Department of Highways
- Washington State Department of Natural Resources, Division of Mines and Geology
- Yakima Tribal Council

West Virginia:
- Clarksburg Water Board
- Morgantown Water Commission
- West Virginia Department of Highways
- West Virginia Department of Natural Resources, Division of Water Resources
- West Virginia Geological and Economic Survey

Wisconsin:
- City of Madison
- City of Middleton
- Dane County Regional Planning Commission
- Douglas County Soil and Water Conservation District

Wisconsin—Continued
- Southeastern Wisconsin Regional Planning Commission
- State Department of Natural Resources
- State Department of Transportation, Division of Highways
- State Soil and Water Conservation Districts
- The University of Wisconsin-Extension, Geological and Natural History Survey

Wyoming:
- City of Cheyenne, Board of Public Utilities
- Geological Survey of Wyoming
- State Highway Commission of Wyoming
- University of Wyoming, Water Resources Institute
- Wyoming Department of Economic Planning and Development
- Wyoming State Department of Agriculture
- Wyoming State Department of Environmental Quality
- Wyoming State Engineer

OTHER COOPERATORS AND CONTRIBUTORS

Council of State Governments

Government of Algeria

Government of Bolivia

Government of Brazil

Government of Canada

Government of Colombia

Government of Ecuador

Government of Kenya

Government of Nicaragua

Government of Peru

Government of Saudi Arabia

Government of Thailand

Government of Turkey

Government of Yemen

New England River Basins Commission

Ozarks Regional Commission

Puerto Rico:
- North Metropolitan 208 Area Wide Planning Commission
- Puerto Rico Aqueduct and Sewer Authority
- Puerto Rico Department of Natural Resources
- Puerto Rico Environmental Quality Board
- Puerto Rico Highway Authority

Virgin Islands:
- College of Virgin Islands
- Department of Public Works

United Nations

U.S. GEOLOGICAL SURVEY OFFICES

HEADQUARTERS OFFICES

Official and (or) office	*Name and telephone number*	*Address*
Director	V. E. McKelvey (703 860-7411)	101 National Center.
Associate Director	W. A. Radlinski (703 860-7411)	102 National Center.
Senior Scientist	Frank E. Clarke (202 343-3888)	Rm. 4441, Interior Bldg., Washington, DC 20240.
Assistant Director, Research	James R. Balsley (703 860-7488)	104 National Center.
Assistant Director, Programs	Dale D. Bajema (acting) (703 860-7435).	105 National Center.
Assistant Director, Environmental Conservation.	Henry W. Coulter (703 860-7491)	106 National Center.
Assistant Director, Administration	Edmund J. Grant (703 860-7201)	201 National Center.
Assistant Director	Montis R. Klepper (703 860-7481)	171 National Center.
Chief, Office of Land Information and Analysis.	James R. Balsley (703 860-7488)	104 National Center.
Earth Resources Observation Systems Program.	John M. DeNoyer (703 860-7881)	1925 Newton Sq. East, Reston, VA 22090.
Earth Sciences Applications Program.	Donald R. Nichols (703 860-6961)	720 National Center.
Environmental Impact Analysis	Daniel B. Krinsley (703 860-7455)	760 National Center.
Geography Program	James R. Anderson (703 860-6344)	710 National Center.
Resources and Land Information Program.	J. Ronald Jones (703 860-6717)	750 National Center.
Chief, Administration Division	Edmund J. Grant (703 860-7201)	201 National Center.
Chief, Computer Center Division	Carl E. Diesen (703 860-7106)	801 National Center.
Chief, Conservation Division	Russell G. Wayland (703 860-7524)	600 National Center.
Chief, Geologic Division	Richard P. Sheldon (703 860-6531)	911 National Center.
Chief, Publications Division	Harry D. Wilson, Jr. (703 860-7181)	341 National Center.
Chief, Topographic Division	Robert H. Lyddan (703 860-6231)	516 National Center.
Chief, Water Resources Division	Joseph S. Cragwall, Jr. (703 860-6921).	409 National Center.

PRINCIPAL FIELD OFFICES

Official and (or) office	*Name and telephone number*	*Address*
Assistant Director, Eastern Region	William B. Overstreet (703 860-7414).	109 National Center, 12201 Sunrise Valley Dr., Reston, VA 22092.
Assistant Director, Central Region	Thad G. McLaughlin (303 234-4630).	P.O. Box 25046, Federal Center, Denver, CO 80225.
Assistant Director, Western Region	Joel M. Johanson (415 323-2711)	345 Middlefield Rd., Menlo Park, CA 94025.

SELECTED FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices are not included; list is current as of June 1976. Correspondence to the following offices should be addressed to the Post Office box, if one is given]

COMPUTER CENTER DIVISION

Location	*Official in charge and telephone number*	*Address*
Arizona, Flagstaff 86001	James E. Crawforth (602 774-1312)	601 East Cedar Ave.
California, Menlo Park 94025	James L. Mueller (415 323-2661)	345 Middlefield Rd.
Colorado, Denver 80225	Frederick B. Sower (303 234-5277)	P.O. Box 25046, Federal Center.
Missouri, Rolla 65401	Glenn A. Ridgeway (314 364-6985)	1400 Independence Rd., Stop 817.
South Dakota, Sioux Falls 57198	Ralph J. Thompson (605 594-65555)	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).	P.O. Box 25046, 609 Federal Center; Villa Italia, Wadsworth and Alameda.
Eastern Region:		
Washington, DC 20244	George F. Brown, Regional Conservation Manager (202 254-3137).	Suite 213, 1725 K St., NW.
Gulf of Mexico Outer Continental Shelf Operations:		
Metairie, LA 70011	A. Dewey Acuff, Conservation Manager (504 680-9381).	P.O. Box 7944; 336 Imperial Office Bldg., 3301 North Causeway Blvd.
Western Region:		
Menlo Park, CA 94025	Hillary A. Oden (acting), Regional Conservation Manager (415 323-2108).	345 Middlefield Rd.

AREA AND DISTRICT OFFICES

Location	*Official in charge and telephone number*	*Address*
Alaska Anchorage 99510	Rodney A. Smith, Robert H. McMullin (907 265-4376).	P.O. Box 259; 212 Skyline Bldg., 218 E St.
Arizona, Phoenix 85003	Hall F. Susie (602 261-3766)	Rm. 208, 522 North Central Ave.
California, Los Angeles 90012	Fred J. Shambeck, 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 (415 323-8111, ext. 2874). Henry L. Cullins, Jr. (415 323-7111, ext. 2563). Reid T. Stone (415 323-8111, ext. 2841).	345 Middlefield Rd.
Sacramento 95825	Robert D. Morgan (acting) (916 484-4219).	Rm. W-2231, Federal Bldg., 2800 Cottage Way.
Ventura 93003	Michael F. Reitz (805 648-5131)	Suite 202, 145 N. Brent St.

Location	*Official in charge and telephone number*	*Address*
Colorado, Denver 80225	David V. Haines (acting), John P. Storrs (303 234-4435). Ralph Smith (303 234-5042) Daniel A. Jobin (303 234-4435)	P.O. Box 25046, 602 Federal Center.
Durango 81301	Jerry W. Long (303 247-5144)	P.O. Box 1809; 125 West 10th St.
Grand Junction 81501	Peter A. Rutledge, James W. Hager (303 242-0731).	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 D. Borne (504 863-4033)	P.O. Box 1269.
Lafayette 70501	Elmo G. Hubble, (318 232-6037)	P.O. Box 52289; 239 Bendel Rd.
Lake Charles 70601	Robert H. Darrow (318 478-6440)	P.O. Box 6088, Drew Station.
Metairie 70011	Harry McAndrews (504 680-9341) Donald W. Solanas (504 680-9333). Jake B. Lowenhaupt (504 680-9251).	P.O. Box 7944; 336 Imperial Office Bldg., 3301 North Causeway Blvd.
	Charles B. Mullins (504 680-9301).	P.O. Box 7966.
Mississippi, Jackson 39201	Thomas E. Godfrey (601 969-4405)	505 Unifirst Federal Savings & Loan Bldg.
Missouri, Rolla 65401	C. V. Collins (314 364-8411)	P.O. Box 936; 1400 Independence Rd.
Montana, Billings 59103	Albert F. Czarnowsky, Jim S. Hinds, Virgil L. Pauli (406 245-6711).	P.O. Box 2550; 3 7th St. W.
New Mexico, Artesia 88210	James A. Knauff (505 746-4841)	Drawer U; 105 South 4th St.
Carlsbad 88220	Robert S. Fulton (505 885-6454)	P.O. Box 1716; Federal Bldg., 114 South Halagueno St.
Farmington 87401	J. E. Fassett, Philip T. McGrath (505 325-4572).	P.O. Box 959; Petroleum Club Plaza, 3535 East 30th St.
Hobbs 88240	Arthur R. Brown (505 393-3612)	P.O. Box 1157; 205 North Linam St.
Roswell 88201	Donald M. VanSickle (505 622-1332).	Drawer 1857; Federal Bldg. and U.S. Courthouse, Richardson Ave. at 5th St.
Oklahoma, McAlester 74501	Alexander M. Dinsmore (918 423-5030).	P.O. Box 816; 509 South 3d St.
Oklahoma City 73118	Charley W. Nease (405 231-4806)	Suite 404, 50 Penn Pl.
Tulsa 74135	Edward L. Johnson, Floyd L. Stelzer (918 581-7631).	6136 East 32d Pl.
Oregon, Portland 97208	Jesse L. Colbert, Dick Cramer-Borneman (503 234-3361, ext. 4796).	P.O. Box 2967; Bldg. 100, 1425 NE. Irving St.
Texas, Freeport 77541	Jack C. Sandridge (713 233-2604)	P.O. Box 2006.
Utah, Salt Lake City 84138	Donald C. Alvord (801 524-5643) Edgar Guynn (801 524-5650) Jackson W. Moffit (801 524-5646).	Rm. 8422, 8440, and 8432, Federal Bldg., 125 South State St.
Washington, D.C. 20244	William B. Gazdik (202 343-4587) Harry A. Dupont (202 254-7870) John A. Less (202 254-3137)	Suite 316, 1825 K St., NW. Suite 213, 1725 K St., NW.
Wyoming, Casper 82601	Charles J. Curtis (307 265-5405) Edward Haymaker (307 265-5247) Elmer M. Schell (307 265-5421).	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	George Kinsel (307 864-3477)	P.O. Box 590; Rm. 202, Federal Bldg.

EARTH RESOURCES OBSERVATION SYSTEMS PROGRAM

Location	*Official in charge and telephone number*	*Address*
Mississippi, Bay St. Louis 39521	Frank D. Beatty (acting) (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).	P.O. Box 25046, Federal Center.
Eastern Region: Reston, VA 22092	Eugene H. Roseboom, Jr., Regional Geologist (703 860-6631).	953 National Center, 12201 Sunrise Valley Dr.
Western Region: Menlo Park, CA 94025	David L. Jones, Regional Geologist (415 323-2214).	345 Middlefield Rd.

OFFICES

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage 99501	Thomas P. Miller (907 272-8228) ...	216 Skyline Bldg., 218 E St.
College 99701	Florence R. Weber (907 479-7245) ..	P.O. Box 80586.
Sitka 99501	Willis E. Osbakken (907 747-3332)..	P.O. Box 158.
Arizona, Flagstaff 86001	Michael H. Carr (602 774-1455)	601 East Cedar Ave.
Tucson 85715	Leo E. Davis (602 792-6420)	7290 E. Tanque Verde Rd.
Arkansas, Little Rock 72204	Boyd R. Haley (501 371-1616)	3815 West Roosevelt Rd.
California, Saratoga 95070	Leroy W. Pankratz (408 379-3976) ..	P.O. Box 282.
Connecticut, Middletown 06457	Fred Pessl, Jr. (203 346-5542)	P.O. Box 470.
Florida, Miami 33139	E. A. Shinn (305 672-1784)	Fisher Island Station.
Guam, Agana 96910	Paul M. Hattori (355-5259)	P.O. Box 8001, M.O.V. #3.
Hawaii, Hawaii National Park 96718.	Robert I. Tilling (808 967-7485)	Hawaiian Volcano Observatory.
Kentucky, Lexington 40503	Earle R. Cressman (606 252-2312) ..	2035 Regency Rd.
Massachusetts, Boston 02110	M. H. Pease, Jr. (617 223-7202)	80 Broad St.
Woods Hole 02543	John C. Behrendt (617 437-5800) ...	Quisset Campus, Bldg. 8.
New Mexico, Albuquerque 87115	Jon R. Peterson (505 264-4637)	Albuquerque Seismological Center, Kirtland AFB, East Bldg. 10002.
Pennsylvania, Carnegie 15106	Reginald P. Briggs (412 644-2920) ..	P.O. Box 420.
Puerto Rico, San Juan 00906	James V. A. Trumbull (809 722-1429).	P.O. Box 5917, Puerto de Tierra Station.
South Carolina, Columbia 29208	Lyle D. Benson (803 777-6810)	University of South Carolina.
Tennessee, Knoxville 37902	Robert A. Laurence (615 524-4268)..	301 West Cumberland Ave.
Texas, Corpus Christi 78411	Louis E. Garrison (512 888-3241) ...	P.O. Box 6732; Univ. of Corpus Christi.
Virginia, Corbin 22446	Allen H. Travis (703 371-2564)	Fredericksburg Geomagnetic Center.
Washington, Newport 99156	Leonard E. Kerry (509 447-3195) ...	P.O. Box 56A.
Seattle 98105	Thane H. McCulloh (206 442-1995) ..	Suite 110, 107 NE.45th St.
Spokane 99201	Albert E. Weissenborn (509 456-4677).	West 920 Riverside Ave.
Wyoming, Laramie 82070	J. David Love (307 745-4495)	Box 3007, Univ. Station, Geology Hall, Univ. of Wyoming.

PUBLICATIONS DIVISION

PUBLIC INQUIRIES OFFICES

[Each of the following offices provides over-the-counter sales service for Survey book reports and geologic and topographic maps relating to its geographic area and for selected Survey reports of general interest]

Location	Official in charge and telephone number	Address
Alaska, Anchorage 99501	Margaret I. Erwin (907 277-0577)	Rm. 108, Skyline Bldg., 508 2d Ave.
California, Los Angeles 90012	Lucy E. Birdsall (213 688-2850)	Rm. 7638, Federal Bldg., 300 North Los Angeles St.
San Francisco 94111	Jean V. Molleskog (415 556-5627)	Rm. 504, Custom House, 555 Battery St.
Colorado, Denver 80202	Alice M. Coleman (acting) (303 837-4169).	Rm. 1012, Federal Bldg., 1961 Stout St.
Washington, D.C. 20244	Bruce A. Hubbard (202 343-8073)	Rm. 1028, General Services Bldg., 19th and F Sts., NW.
Texas, Dallas 75202	Jimmie L. Wilkinson (acting) (214 749-3230).	Rm. 1C45, Federal Bldg., 1100 Commerce St.
Utah, Salt Lake City 84138	Wendy R. Hassibe (801 524-5652)	Rm. 8105, Federal Bldg., 125 South State St.
Virginia, Reston 22092	A. Ernestine Jones (703 860-6167)	Rm. 1C402, National Center, 12201 Sunrise Valley Dr.
Washington, Spokane 99201	Eula M. Thune (509 456-2524)	Rm. 678, U.S. Courthouse, West 920 Riverside Ave.

DISTRIBUTION CENTERS

[Survey maps are distributed by mail and over the counter from the following centers]

Location	Official in charge and telephone number	Address
Virginia, Arlington 22202 [1, 2]	John J. Curry (703 557-2781)	1200 South Eads St.
Colorado, Denver 80225 [3]	Dwight F. Canfield (303 234-3832)	Box 25286, Federal Center.
Alaska, Fairbanks 99701 [4]	Natalie A. Cornforth (907 452-1951, ext. 174).	310 First Ave.

TOPOGRAPHIC DIVISION

Location	Official in charge and telephone number	Address
California, Menlo Park 94025	Roy R. Mullen (415 323-2411)	345 Middlefield Rd.
Colorado, Denver 80225	Albert E. Letey (303 234-2351)	P.O. Box 25046, 510 Federal Center.
Missouri, Rolla 65401	A. Carroll McCutchen (314 364-3680).	1400 Independence Rd.
South Dakota, Sioux Falls 57198	Allen H. Watkins (605 594-6123)	EROS Data Center.
Virginia, Reston 22090	Roy E. Fordham (703 471-1711)	1925 Newton Sq. East.
Reston 22092	Peter F. Bermel (703 860-6352)	567 National Center, 12201 Sunrise Valley Dr.

[1] For maps of areas of the Mississippi River (including Minnesota).
[2] Also provides mail and over-the-counter distribution for Survey book reports.
[3] For maps of areas west of the Mississippi River (including Louisiana).
[4] For residents of Alaska.

WATER RESOURCES DIVISION

REGIONAL OFFICES

Location	*Official in charge and telephone number*	*Address*
Northeastern Region: Reston, VA 22092	Joseph T. Callahan, Regional Hydrologist (703 860-6985).	433 National Center, 12201 Sunrise Valley Dr.
Southeastern Region: Atlanta, GA 30309	Leslie B. Laird, Regional Hydrologist (404 526-5395).	Suite 200, 1459 Peachtree St. NE.
Central Region: Denver, CO 80225	Alfred Clebsch, Jr., Regional Hydrologist (303 234-3661).	P.O. Box 25046, 406 Federal Center.
Western Region: Menlo Park, CA 94025	William H. Robinson (acting), Regional Hydrologist (415 323-8111).	345 Middlefield Rd.

DISTRICT OFFICES

Location	*Official in charge and telephone number*	*Address*
Alabama, Tuscaloosa 35486	William J. Powell (205 752-8104)	P.O. Box V; Rm. 202, Oil and Gas Board Bldg., Univ. of Alabama.
Alaska, Anchorage 99501	Harry Hulsing (907 277-5526, 5527).	Skyline Bldg., 218 E St.
Arizona, Tucson 85701	Horace M. Babcock (602 792-6671).	Federal Bldg., 301 W. Congress St.
Arkansas, Little Rock 72201	Richard T. Sniegocki (501 378-5246, 5247).	Rm. 2301, Federal Office Bldg., 700 West Capitol Ave.
California, Menlo Park 94025	Lee R. Peterson (415 323-8111, ext. 2326, 2327, 2465, 2466).	855 Oak Grove Ave.
Colorado, Denver 80225	James E. Biesecker (303 234-5092)	P.O. Box 25046, Federal Center.
Connecticut, Hartford 06101	Frederick H. Ruggles, Jr. (203 244-2528).	P.O. Box 715; Rm. 235, Post Office Bldg., 135 High St.
Delaware	Walter F. White, Jr. (301 661-4664).	See Maryland District Office.
District of Columbia	............do	Do.
Florida, Tallahassee 32303	Clyde S. Conover (904 386-1118)	Suite F-240, 325 John Knox Rd.
Georgia, Doraville 30360	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	E. E. Harris (208 342-2711, ext. 2537).	P.O. Box 036; Rm. 365, Federal Bldg. and U.S. Courthouse, 550 West Fort St.
Illinois, Champaign 61820	Lawrence A. Martens (217 359-3918).	P.O. Box 1026; 605 North Neil St.
Indiana, Indianapolis 46202	James L. Cook (317 269-7101)	1819 North Meridian St.
Iowa, Iowa City 52240	Sulo W. Wiitala (319 338-0581, ext. 521).	P.O. Box 1230; Rm. 269, Federal Bldg.
Kansas, Lawrence 66045	Joseph S. Rosenshein (913 864-4321).	1950 Avenue "A"—Campus West, Univ. of Kansas.
Kentucky, Louisville 40202	P. A. Emery (502 582-5241)	Rm. 572, Federal Bldg., 600 Federal Pl.
Louisiana, Baton Rouge 70806	Albert N. Cameron (504 387-0181, ext. 281).	P.O. Box 66492; 6554 Florida Blvd.
Maine	John A. Baker (617 223-2822)	See Massachusetts District Office.
Maryland, Parkville 21234	Walter F. White, Jr. (301 661-4664).	8809 Satyr Hill Rd.

Location	*Official in charge and telephone number*	*Address*
Massachusetts, Boston 02114	John A. Baker (617 223-2822)	Suite 1001, 150 Causeway St.
Michigan, Okemos 48864	T. Ray Cummings (517 372-1910, ext. 561).	2400 Science Parkway, Red Cedar Research Park.
Minnesota, St. Paul 55101	Charles R. Collier (612 725-7841, 7842).	Rm. 1033, Post Office Bldg.
Mississippi, Jackson 39206	Lamar E. Carroon (601 969-4600)	430 Bounds St.
Missouri, Rolla 65401	Anthony Homyk, Jr. (314 364-1599).	P.O. Box 340; 103 West 10th St.
Montana, Helena 59601	George M. Pike (406 449-5011, ext. 5263).	P.O. Box 1696; Rm. 421, Federal Bldg., 316 North Park Ave.
Nebraska, Lincoln 68508	Kenneth A. MacKichan (402 471-5082).	Rm. 406, Federal Bldg. and U.S. Courthouse, 100 Centennial Mall N.
Nevada, Carson City 89701	John P. Monis (702 882-1388)	Rm. 229, Federal Bldg., 705 North Plaza St.
New Hampshire	John A. Baker (617 223-2822)	See Massachusetts District Office.
New Jersey, Trenton 08607	Harold Meisler (609 599-3511, ext. 212).	P.O. Box 1238; Rm. 420, Federal Bldg., 402 East State St.
New Mexico, Albuquerque 87106	William E. Hale (505 766-2246)	P.O. Box 4369; 2d Floor, 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. 436, Century Sta. Post Office Bldg.
North Dakota, Bismarck 58501	Walter R. Scott (701 255-4011, ext. 227, 228).	P.O. Box 778; Rm. 332, New Federal Bldg., 3d St. and Rosser Ave.
Ohio, Columbus 43212	James F. Blakey (614 469-5553)	975 West 3d Ave.
Oklahoma, Oklahoma City 73102	James H. Irwin (405 231-4256)	Rm. 621, 201 NW. 3d St.
Oregon, Portland 97208	Stanley F. Kapustka (503 234-3361, ext. 4776, 4777, 4778).	P.O. Box 3202; 830 NE. Holladay St.
Pennsylvania, Harrisburg 17108	Norman H. Beamer (717 782-3468)	P.O. Box 1107; 4th Floor, Federal Bldg., 228 Walnut St.
Puerto Rico, San Juan 00934	Ernest D. Cobb (809 783-4660)	P.O. Box 34168; Bldg. 652, Fort Buchanan.
Rhode Island	John A. Baker (617 223-2822)	See Massachusetts District Office.
South Carolina, Columbia 29201	John S. Stallings (803 765-5966)	Suite 200, 2001 Assembly St.
South Dakota, Huron 57350	John E. Powell (605 352-8651, ext. 293, 294).	P.O. Box 1412; Rm. 231, Federal Bldg.
Tennessee, Nashville 37203	Stanley P. Sauer (615 749-5424)	Rm. A-413, Federal Bldg., and U.S. Courthouse.
Texas, Austin 78701	I. Dale Yost (512 397-5766)	Rm. 630, Federal Bldg., 300 East 8th St.
Utah, Salt Lake City 84138	Theodore Arnow (801 524-5663)	Rm. 8002, Federal Bldg., 125 South State St.
Vermont	John A. Baker (617 223-2822)	See Massachusetts District Office.
Virginia, Richmond 23220	William E. Forrest (804 782-2427)	Rm. 304, 200 West Grace St.
Washington, Tacoma 98402	John F. McCall (206 593-6510)	Rm. 300, 1305 Tacoma Ave., South.
West Virginia, Charleston 25301	Vacant (304 343-6181, ext. 310, 311, 339).	Rm. 3303, Federal Bldg. and U.S. Courthouse, 500 Quarrier St., East.
Wisconsin, Madison 53706	W. W. Barnwell (608 262-2488)	Rm. 200, 1815 University Ave.
Wyoming, Cheyenne 82001	Samuel W. West (307 778-2220, ext. 2111).	P.O. Box 2087; 4015 Warren Ave.

OFFICES IN OTHER COUNTRIES

GEOLOGIC DIVISION

Location	*Officer in charge*	*Address*
Brazil, Rio de Janeiro	S. Anthony Stanin	U.S. Geological Survey, USAID/Rio de Janeiro/ENGR, APO New York 09676.

Location	*Officer in charge*	*Address*
Colombia, Bogota	Maurice M. Brock	U.S. Geological Survey, USAID, c/o American Embassy, APO New York 09895.
Indonesia, Bandung	Paul W. Richards	U.S. Geological Survey, c/o American Embassy, USAID/ENGR, APO San Francisco 96356.
Saudi Arabia, Jiddah	Thor H. Kiilsgaard	U.S. Geological Survey, c/o American Embassy, APO New York 09697.
Thailand, Bangkok	Joseph O. Morgan	Office of Agricultural Development, USOM–Thailand, APO San Francisco 96346.

WATER RESOURCES DIVISION

Location	*Officer in charge*	*Address*
Kenya, Nairobi	Neal E. McClymonds	USAID/Nairobi, U.S. Dept. of State, Washington, DC 20521.
New Zealand, Wellington	Ivan K. Barnes	c/o A. J. Ellis, DSIR Chemical Division, Private Bag, Petone, New Zealand.
Yemen, San‘a’	G. Chase Tibbitts, Jr.	U.S. Geological Survey, USAID/San‘a’, Agency for International Development, Washington, DC 20521.

INVESTIGATIONS IN PROGRESS IN THE GEOLOGICAL SURVEY

Investigations in progress during fiscal year 1976 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. 353, for addresses). Inquiries regarding projects for which no address is given in the list of offices should be directed to the appropriate Division of the Geological Survey, Reston, Va. 22092. The lowercase letter after the name of the project leader shows the Division technical responsibility: c, Conservation Division; l, Land Information Analysis; w, Water Resources Division; no letter, Geologic Division.

The projects are classified by principal topic. Most geologic-mapping projects involve special studies of stratigraphy, petrology, geologic structure, or mineral deposits but are listed only under "Geologic Mapping" unless a special topic or commodity is the primary justification for the project. A reader interested in investigations of volcanology, for example, should look under the heading "Geologic Mapping" for projects in areas of volcanic rocks, as well as under the heading "Volcanology." Likewise, most water-resource investigations involve special studies of several aspects of hydrology and geology but are listed only under "Water Resources" unless a special topic—such as floods or sedimentation—is the primary justification for the project.

Areal geologic mapping is subdivided into mapping at scales smaller than 1:62,500 (for example, 1:250,000) and mapping at scales of 1:62,500 or larger (for example, 1:24,000).

Abstracts. *See* Bibliographies and abstracts.
Aluminum:
- Resources of the United States (S. H. Patterson, NC)

Analytical chemistry:
- Activation analysis (J. J. Rowe, NC)
- Analytical methods:
  - Textural automatic image analyzer research (M. B. Sawyer, D)
  - Water chemistry (M. J. Fishman, w, D)
- Analytical services and research (J. I. Dinnin, NC; Claude Huffman, Jr., D; C. O. Ingamells, M)
- Assessment of neutron activation methods (V. J. Janzer, w, D)
- Instrumentation (J. F. Abell, NC)
- Mineral deposits, characteristic analysis (J. M. Botbol, NC)
- Natural organic macromolecules in water (R. L. Wershaw, w, D)
- Organic geochemistry and infrared analysis (I. A. Berger, NC)
- Plant laboratory support (J. J. Connor, D)
- Radioactivation and radiochemistry (H. T. Millard, D)
- Reactor support (G. P. Kraker, Jr., w, D)
- Rock chemical analysis:
  - General (D. R. Norton, D)
  - Rapid (Leonard Shapiro, NC)
- Services (L. B. Riley, D)
- Trace analysis methods, research (F. N. Ward, D)
- Ultratrace analysis (H. T. Millard, D)
- X-ray spectrometer for Viking lander (Priestley Toulmin III, NC)
- *See also* Spectroscopy.

Arctic engineering geology (Rebuen Kachadoorian, M)
Artificial recharge:
- Fort Allen recharge (J. R. Diaz, w, Fort Buchanan, P.R.)

Artificial recharge—Continued
- Nassau County recharge (John Vecchioli, w, Mineola, N.Y.)
- Subsurface storage, waste heat (J. D. Bredehoeft, w, NC)

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)

Borates:
- California (M):
  - Furnace Creek area (J. F. McAllister)
  - Searles Lake area (G. I. Smith)

Chromite. *See* Ferro-alloy metals.
Clays:
- Bentonite, resource evaluation in Rocky Mountain region (C. A. Wolfbauer, D)
- *States:*
- Georgia, kaolin investigations (S. H. Patterson, NC)
- Pennsylvania, ceramic clays, greater Pittsburgh region (B. J. O'Neill, Harrisburg)

Coal:
- Geochemistry of United States coal (V. E. Swanson, D)
- National Coal Resources Data System (M. D. Carter, NC)
- *States:*
- Alaska:
  - Bering River coal field (R. B. Sanders, c, Anchorage)
  - Cape Beaufort-Corwin Bluff coal field (J. E. Callahan, c, Anchorage)
  - Coal sample collection and mapping in Alaska and entry of data into the National Coal Resources Data System (C. N. Conwell, College; M. D. Carter, NC)

Coal—Continued

States—Continued

Alaska—Continued

Kukpowruk River coal field (J. E. Callahan, c, Anchorage)

Nenana (Clyde Wahrhaftig, M)

Utukok River and Kokolik River coal field (J. E. Callahan, c, Anchorage)

Arizona, collection of coal samples for analysis (R. T. Moore, Tucson; V. E. Swanson, D)

Colorado (c, D, except as otherwise noted):

Brook Cliffs coal field (G. D. Fraser)

Buckhorn Lakes quadrangle (R. G. Dickinson)

Citadel Plateau (G. A. Izett)

Collection of coal samples in Colorado (D. K. Murray, V. E. Swanson, D)

Courthouse Mountain quadrangle (R. G. Dickinson)

Danforth Hills area (M. J. Reheis)

Denver basin, Tertiary coal zone (P. E. Soister)

Disappointment Valley, eastern (D. E. Ward, D)

Douglas Creek Arch area (B. E. Barnum)

North Park area (D. J. Madden)

Savery quadrangle (C. S. V. Barclay)

Smizer Gulch and Rough Gulch quadrangles (W. J. Hail, D)

Southwest Colorado (L. J. McGreevy)

Washboard Rock quadrangle (R. G. Dickinson)

Watkins and Watkins SE quadrangles (P. E. Soister)

Yampa coal field (M. E. Brownfield)

Idaho, collection of coal samples in Idaho (C. R. Knowles, Moscow; V. E. Swanson, D)

Illinois, coal sampling, analysis and Coal Data System (H. J. Gluskoter, Urbana; M. D. Carter, NC)

Kentucky (D):

Adams quadrangle (D. E. Ward)

Blaine quadrangle (C. L. Pillmore)

Louisa quadrangle (R. M. Flores)

Richardson quadrangle (P. T. Hayes)

Sitka quadrangle (P. T. Hayes)

Missouri, coal data collection and transfer to the National Coal Resources Data System (C. E. Robertson, Rolla; M. D. Carter, NC)

Montana:

Birney SW quadrangle (S. P. Buck, c, Casper, Wyo.)

Collection of coal samples in Montana (R. E. Matson, Butte; V. E. Swanson, D)

Decker quadrangle (B. E. Law, c, D)

Girard field (M. A. Soule, c, Billings)

Holmes Ranch quadrangle (N. E. Micklich, c, Casper, Wyo.)

Jordan quadrangle (G. D. Mowat, c, Billings)

McCone County lignite (H. C. Taylor, c, Billings)

Monarch quadrangle (B. E. Barnum, c, D)

Pearl School quadrangle (G. L. Galyardt, c, Casper, Wyo.)

Sidney coal field (M. J. Cornevale, c, Billings)

Spring Gulch quadrangle (N. E. Micklich, c, Casper, Wyo.)

Taintor Desert quadrangle (S. P. Buck. c, Casper, Wyo.)

Tongue River Dam quadrangle (Juliana Waring, c, Casper, Wyo.)

Nevada, collection of coal samples in Nevada (J. A. Schilling, Reno; V. E. Swanson, D)

New Mexico:

Alamosa Mesa West quadrangle (D. B. Umshler, c, Roswell)

Collection of coal samples in New Mexico (F. E. Kottlowski, Socorro; V. E. Swanson, D)

Gallup East quadrangle (E. D. Patterson, c, Roswell)

Gallup West quadrangle (J. E. Fassett, c, Farmington)

Manuelito quadrangle (J. E. Fassett, c, Farmington)

Ojo Encino Mesa quadrangle (D. B. Umshler, c, Roswell)

Pueblo Alto Trading Post quadrangle (R. W. Jentgen, c, Farmington)

Samson Lake quadrangle (J. E. Fassett, c, Farmington)

Star Lake quadrangle (J. E. Fassett, c, Farmington)

Tanner Lake quadrangle (D. B. Umshler, c, Roswell)

Twin Butte quadrangle (M. L. Millgate, c, Farmington)

Western Raton field (C. L. Pillmore, D)

North Dakota (c, Billings, Mont., except as otherwise noted):

Adams, Bowman, and Slope Counties lignite resources (R. C. Lewis)

Clark Butte 15-minute quadrangle (G. D. Mowat)

North Almont quadrangle (H. L. Smith, c, D)

West-central North Dakota lignite resources (E. A. Rehbein)

Williston area lignite resources (J. M. Spencer)

Oklahoma (c, Tulsa, except as otherwise noted):

Blocker quadrangle (E. H. Hare, Jr.)

Collection of coal samples in Oklahoma (S. A. Friedman, Norman; V. E. Swanson, D)

Hackett quadrangle (E. H. Hare, Jr.)

Panama quadrangle (E. H. Hare, Jr.)

Spiro quadrangle (E. H. Hare, Jr.)

Pennsylvania (NC, except as otherwise noted):

Collection of coal samples for analysis (W. E. Edmunds, Pennsylvania State Geological Survey, Harrisburg; M. J. Bergin, NC)

Northern anthracite field (M. J. Bergin)

Southern anthracite field (G. H. Wood, Jr.)

Utah (c, D, except as otherwise noted):

Alton coal field (W. E. Bowers)

Basin Canyon quadrangle (Fred Peterson)

Big Hollow Wash quadrangle (Fred Peterson)

Blackburn Canyon quadrangle (Fred Peterson)

Butler Valley quadrangle (W. E. Bowers)

Canaan Peak quadrangle (W. E. Bowers)

Collet Top quadrangle (H. D. Zeller)

East-of-the-Navajo quadrangle (Fred Peterson)

Fourmile Bench quadrangle (W. E. Bowers)

Henry Mountains basin (B. L. Law)

Horse Mountain quadrangle (W. E. Bowers)

Jessen Butte quadrangle (E. M. Schell, c, Casper, Wyo.)

Kaiparowits Plateau area (H. D. Zeller)

Needle Eye Point quadrangle (H. D. Zeller)

Pete's Cove quadrangle (H. D. Zeller)

Ship Mountain Point quadrangle (H. D. Zeller)

Sunset Flat quadrangle (H. D. Zeller)

Coal—Continued

States—Continued

Virginia and West Virginia, Central Appalachian Basin (K. J. Englund, NC)

Washington:

Coal resources of Washington (W. H. Lee, c, M)

Collection of coal samples for analysis (V. E. Livingston, Jr., Olympia; V. E. Swanson, D)

West Virginia:

Formatting coal data for USGS National Coal Resources Data System (M. C. Behling, Morgantown; M. D. Carter, NC)

Louisa quadrangle (C. W. Connor, D)

Wyoming (c, D, except as otherwise noted):

Acme quadrangle (B. E. Law)

Appel Butte quadrangle (G. L. Galyardt)

Bailey Lake quadrangle (M. L. Schroeder)

Beaver Creek Hills quadrangle (E. I. Winger, c, Casper)

Browns Hill quadrangle (C. S. V. Barclay)

Cottonwood Rim quadrangle (C. S. V. Barclay)

Coyote Draw quadrangle (G. L. Galyardt)

Deer Creek quadrangle (D. A. Jobin)

Eagle Rock quadrangle (S. P. Buck, c, Casper)

Fortin Draw quadrangle (B. E. Law)

Four Bar—J Ranch quadrangle (G. L. Galyardt)

Gillette East quadrangle (B. E. Law)

Gillette West quadrangle (B. E. Law)

Greenhill quadrangle (S. P. Buck, c, Casper)

Grieve Reservoir quadrangle (C. S. V. Barclay)

Hanna Basin area (L. F. Blanchard)

Hilight quadrangle (W. J. Purdon, c, Casper)

Hultz Draw quadrangle (E. I. Winger, c, Casper)

Kemmerer area (M. L. Schroeder)

Ketchum Buttes quadrangle (C. S. V. Barclay)

Little Thunder Reservoir quadrangle (G. C. Martin, c, Casper)

Monarch quadrangle (B. E. Barnum)

Moyer Springs quadrangle (B. E. Law)

Neil Butte quadrangle (S. P. Buck, c, Casper)

North Star School NE (S. P. Buck, c, Casper)

North Star School NW (S. P. Buck, c, Casper)

North Star School SW (W. J. Purdon, c, Casper)

North Star School SE (W. J. Purdon, c, Casper)

Oil Mountain quadrangle (G. J. Kerns, c, Casper)

Open A Ranch quadrangle (G. C. Martin, c, Casper)

Oriva quadrangle (B. E. Law)

Pickle Pass quadrangle (M. L. Schroeder)

Piney Canyon NW quadrangle (G. C. Martin, c, Casper)

Piney Canyon SW quadrangle (J. E. Goolsby, c, Casper)

Pleasantdale quadrangle (S. L. Grazis)

Poison Spider quadrangle (G. J. Kerns, c, Casper)

Rawlins coal field (C. S. Barclay)

Reid Canyon (G. J. Kerns, c, Casper)

Reno Junction quadrangle (W. J. Purdon, c, Casper)

Reno Reservoir quadrangle (G. C. Martin, c, Casper)

Rock Springs uplift (P. J. LaPoint)

Rough Creek quadrangle (S. P. Buck, c, Casper)

Saddle Horse Butte quadrangle (S. L. Grazis)

Savery quadrangle (C. S. V. Barclay)

Scaper Reservoir quadrangle (S. L. Grazis)

Coal—Continued

States—Continued

Wyoming—Continued

Sheridan Pass quadrangle (W. L. Rohrer, c, Casper)

Sheridan 2 SW quadrangle (W. L. Rohrer, c, Casper)

Ship Mountain Point quadrangle (H. D. Zeller)

Teckla quadrangle (J. E. Goolsby, c, Casper)

Teckla SW quadrangle (J. E. Goolsby, c, Casper)

The Gap quadrangle (G. L. Galyardt)

The Gap southwest quadrangle (S. L. Grazis)

Tullis quadrangle (C. S. V. Barclay)

Turnercrest NE quadrangle (G. C. Martin, c, Casper)

Weston southwest quadrangle (R. W. Jones, c, Casper)

Construction and terrain problems:

Areal slope stability analysis, San Francisco Bay Region (S. D. Ellen, M)

Electronics instrumentation research for engineering geology (J. B. Bennetti, D)

Engineering geology laboratory (R. A. Farrow, D)

Feasibility of tunneling, Los Angeles (R. F. Yerkes, M)

Fissuring-subsidence research (T. L. Holzer, M)

Geotechnical measurements and services (H. W. Olsen, D)

Reactor hazards research (K. L. Pierce, D)

Reactor site investigations (R. H. Morris, D)

Regional slope-stability studies, California and Colorado (D. H. Radbruch-Hall, M)

Research in rock mechanics (F. T. Lee, D)

Sino-Soviet terrain (L. D. Bonham, l, NC)

Soil engineering research (T. L. Youd, M)

Special intelligence (L. D. Bonham, l, NC)

Volcanic hazards (D. R. Crandell, D)

States:

California (M, except as noted otherwise):

Geologic environmental maps for land-use planning (E. H. Pampeyan)

Geology and slope stability, western Santa Monica Mountains (R. H. Campbell)

Los Angeles County Cooperative (R. H. Campbell)

Pacific Palisades landslide area, Los Angeles (J. T. McGill, D)

Colorado (D):

Coal mine deformation studies, Somerset mining district (C. R. Dunrud)

Engineering geology mapping research, Denver region (H. E. Simpson)

Massachusetts, sea-cliff erosion studies (C. A. Kaye, Boston)

Nevada (D, except as otherwise noted):

Geologic and geomechanical investigations (J. R. Ege)

Seismic engineering program (K. W. King, Las Vegas)

Surface effects of nuclear explosions (R. P. Snyder)

Pennsylvania (Carnegie):

Disturbed ground, Allegheny County (R. P. Briggs)

Greater Pittsburgh region (R. P. Briggs)

Landslides, Allegheny County (R. P. Briggs)

Utah, coal-mine bumps (F. W. Osterwald, D)

See also Urban geology.

Copper:

United States and world resources (D. P. Cox, NC)

States:

Alaska, southwest Brooks Range (I. L. Tailleur, M)

Copper—Continued
States:
Arizona (M):
Jerome and Bagdad districts (C. M. Conway)
Ray porphyry copper (H. M. Cornwall)
California, Shasta districts (C. M. Conway, M)
Maine-New Hampshire, porphyry, with molybdenum (R. G. Schmidt, NC)
Michigan (NC):
Greenland and Rockland quadrangles (J. W. Whitlow)
Michigan copper district (W. S. White)
Crustal studies. *See* Earthquake studies; Geophysics, regional.
Earthquake studies:
Active fault analysis (R. E. Wallace, M)
Automatic earthquake data processing (S. W. Stewart, M)
Comparative elevation studies (R. O. Castle, M)
Computer fault modeling (J. H. Dieterich, M)
Computer operations and maintenance (T. C. Jackson, M)
Crustal strain (J. C. Savage, M)
Crustal studies (ARPA) (Isidore Zietz, NC)
Dynamic soil behavior (A. T. F. Chen, M)
Earth structure studies (J. H. Healy, M)
Earthquake field studies (W. J. Spence, C. J. Langer, J. N. Jordan, M)
Earthquake-induced ground failures (T. L. Youd, M)
Earthquake-induced landslides (E. L. Harp, M)
Earthquake-induced sedimentary structures (J. D. Sims, M)
Earthquake recurrence and history (R. D. Nason, M)
Eastern United States (R. K. McGuire, D)
Experimental liquefaction potential mapping (T. L. Youd, M)
Fault-zone tectonics (J. C. Savage, M)
Fluid injection, laboratory investigations (J. D. Byerlee, Louis Peselnick, M)
Geologic and geotechnical factors in ground-motion analysis (R. C. Wilson, M)
Geologic parameters of seismic source areas (F. A. McKeown, D)
Ground-motion modeling and prediction (W. B. Joyner, M)
Ground-motion studies (R. D. Borcherdt, R. P. Maley, M)
Microearthquake data analysis (W. H. K. Lee, M)
National Earthquake Information Service (A. C. Tarr, D)
National Strong-Motion Instrumentation Network (R. B. Matthiesen, M)
Nicaragua, Central America, technical assistance in establishing center for earthquake hazard reduction (P. L. Ward, M)
Plate-tectonic studies (E. D. Jackson, M)
Precursory phenomena (P. L. Ward, M)
Recurrence intervals along Quaternary faults (K. L. Pierce, D)
Relative activity of multiple fault strands (M. G. Bonilla, M)
Seismic-risk studies (S. T. Algermissen, D)
Seismic-source studies (W. R. Thatcher, M)
Seismic studies for earthquake prediction (C. G. Bufe, M)
Seismicity and Earth structure (J. N. Taggart, D)
Seismicity patterns in time and space (C. G. Bufe, M)
Seismological research observatories (J. R. Peterson, Albuquerque, N. Mex.)
Soil engineering research (T. L. Youd, M)

Earthquake studies—Continued
Stress studies (C. B. Raleigh, M)
Tectonic studies (W. B. Hamilton, D)
Theoretical seismology (A. F. Espinosa, D)
Worldwide Network of Standard Seismographs (J. R. Peterson, Albuquerque, N. Mex.)
States:
Alaska:
Earthquake hazards:
Anchorage (Ernest Dobrovolny, D)
Coastal communities (R. W. Lemke, D)
Juneau (R. D. Miller, D)
Sitka (L. A. Yehle, D)
Southern part (George Plafker, M)
Microearthquake studies (R. A. Page, M)
Turnagain Arm sediments (A. T. Ovenshine, M)
California (M, except as otherwise noted):
Basement rock studies along San Andreas fault (D. C. Ross)
Central California microearthquake studies (C. G. Bufe)
Continental Shelf fault studies (S. C. Wolf)
Depth of bedrock in the San Francisco Bay region (R. M. Hazlewood)
Earthquake hazards:
San Francisco Bay region (E. E. Brabb)
Southern part (D. M. Morton, Los Angeles)
Geodetic strain (W. H. Prescott)
Geophysical studies, San Andreas fault (J. H. Healy)
Measurement of seismic velocities for seismic zonation (J. F. Gibbs, R. D. Borcherdt, T. E. Fumal)
Microearthquake studies:
Central part (J. H. Pfluke)
Southern part (D. P. Hill)
New Melones microearthquake studies (J. C. Roller)
Recency of faulting:
Coastal California Desert (E. H. Pampeyan)
Eastern Mojave Desert (W. J. Carr)
Salton Trough tectonics (R. V. Sharp)
Tectonics:
Central and northern part (W. P. Irwin)
Central San Andreas fault (D. B. Burke, T. W. Dibblee, Jr.)
Southern part (M. M. Clark)
Theory of wave propagation in anelastic media (R. D. Borcherdt)
Colorado, Rangely (C. B. Raleigh, M)
Idaho, active faults, Snake River Plain (S. S. Oriel, D)
Missouri, New Madrid fault-zone geophysics (M. F. Kane, D)
Montana, Yellowstone National Park, microearthquake studies (A. M. Pitt, M)
Nevada, tectonics, west-central (E. B. Ekren, D)
New Mexico, seismotectonic analysis, Rio Grande rift (E. H. Baltz, Jr., D)
South Carolina, microearthquake studies (A. C. Tarr, D)
Washington (M):
Earthquake hazards, Puget Sound region (H. D. Gower, P. D. Snavely, Jr.)
Hanford microearthquake studies (J. H. Pfluke)

Engineering geologic studies. *See* Construction and terrain problems; Urban geology.

Environmental assessment:
- Northern Great Plains, methodological guidebook (B. B. Hanshaw, w, NC)
- Review of environmental impact statements (L. D. Bonham, l, NC)
- South Florida environment (B. F. McPherson, w, Miami)

Environmental geology:
- Colorado, mountain soils of the Front Range urban corridor (K. L. Pierce, D)
- Montana:
  - Butte region (H. W. Smedes, D)
  - Environmental study of the Big Fork-Avon area (I. J. Witkind, D)
  - Land resources, Helena region (R. G. Schmidt, NC; G. D. Robinson, M)
- Pennsylvania (Carnegie):
  - Greater Pittsburgh regional studies (R. P. Briggs)
  - Land-use limitations (R. P. Briggs)
- Utah, Kaiparowits Plateau coal basin (K. A. Sargent, D)
- Wyoming, Gillette area, eastern Powder River basin (W. R. Keefer, D)
- *See also* Construction and terrain problems; Urban geology.

Evapotranspiration:
- Evapotranspiration (F. A. Branson, w, D)
- Evapotranspiration data analyses (T. E. A. van Hylckama, w, Lubbock, Tex.)
- Evapotranspiration theory (O. E. Leppanen, w, Phoenix, Ariz.)
- Mechanics of evaporation (G. E. Koberg, w, D)
- Vegetation ecohydrology (R. M. Turner, w, Tucson, Ariz.)

Extraterrestrial studies:
- Lunar analog studies:
  - Elko craters, Nevada (D. J. Roddy, Flagstaff, Ariz.)
  - Experimental-shock research (E. C. T. Chao, NC)
  - Explosion craters (D. J. Roddy, Flagstaff, Ariz.)
  - Impactite petrology (H. G. Wilshire, M)
  - Lava ridges and rings (C. A. Hodges, M)
  - Lonar Lake, India (D. J. Milton, M)
  - Ries Crater (E. C. T. Chao, NC)
- Lunar data synthesis:
  - Apollo 15-17 photogeology (H. J. Moore, M)
  - Color provinces (L. A. Soderblom, Flagstaff, Ariz.)
  - Imbrium and Serenitatis rim geology (E. W. Wolfe, Flagstaff, Ariz.)
  - Lunar breccia types (E. C. T. Chao, NC)
  - Lunar geochemical mapping (G. A. Swann, Flagstaff, Ariz.)
  - Lunar geologic mapping (D. H. Scott, Flagstaff, Ariz.)
  - Orientale Basin (J. F. McCauley, Flagstaff, Ariz.)
  - Sample petrology and stratigraphy (H. G. Wilshire, M)
  - Scarps and ridges (B. K. Lucchitta, Flagstaff, Ariz.)
  - Synoptic lunar geology (D. E. Wilhelms, M)
- Lunar sample investigations:
  - Chemical and X-ray fluorescence analysis (H. J. Rose, Jr., NC)
  - Glass, magnetic properties (F. E. Sentfle, NC)
  - Impact metamorphism (E. C. T. Chao, NC)
  - Lunar igneous-textured rocks (O. B. James, NC)

Extraterrestrial studies—Continued
- Lunar sample investigations—Continued
  - Major lunar breccia types (E. C. T. Chao, NC)
  - Mass spectrometry (Mitsunobu Tatsumoto, D)
  - Mineralogical analyses (R. B. Finkelman, NC)
  - Oxygen fugacities and crystallization sequence (Motoaki Sato, NC)
  - Petrographic identification (H. G. Wilshire, M)
  - Petrologic studies (Edwin Roedder, NC)
  - Pyroxenes (J. S. Huebner, NC)
- Planetary analog studies:
  - Canyonland development (B. K. Lucchitta, Flagstaff, Ariz.)
  - Internal structure of calderas (K. A. Howard, M)
  - Mass movements (E. C. Morris, Flagstaff, Ariz.)
  - Peruvian coastal desert (J. F. McCauley, Flagstaff, Ariz.)
- Planetary investigations:
  - Eolian processes (J. F. McCauley, Flagstaff, Ariz.)
  - Geologic mapping of Mars (D. H. Scott, J. F. McCauley, Flagstaff, Ariz.)
  - Geologic synthesis of Mars (Harold Masursky, Flagstaff, Ariz.)
  - Image processing studies (L. A. Soderblom, Flagstaff, Ariz.)
  - Mariner Jupiter-Saturn (L. A. Soderblom, Flagstaff, Ariz.)
  - Mariner Venus-Mercury TV (N. J. Trask, NC)
  - Mars mineralogy and chemistry, Viking lander (Priestley Toulmin III, H. J. Rose, Jr., NC)
  - Mars topographic synthesis (S. S. C. Wu, Flagstaff, Ariz.)
  - Planetary cartography (R. M. Batson, Flagstaff, Ariz.)
  - Planetary remote sensing (L. C. Rowan, NC)
  - Radar applications (G. G. Schaber, Flagstaff, Ariz.)
  - Viking mission:
    - Lander (E. C. Morris, Flagstaff, Ariz.)
    - Orbiter TV (M. H. Carr, M)
    - Physical properties of Mars (H. J. Moore, M)
    - Site analysis (Harold Masursky, Flagstaff, Ariz.)

Ferro-alloy metals:
- Chromium resource studies (T. P. Thayer, NC)
- Molybdenum-rhenium resource studies (R. U. King, D)
- Tungsten, North Carolina, Hamme district (J. E. Gair, NC)
- *State:*
- Oregon, John Day area (T. P. Thayer, NC)

Flood 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)
- Maryland (D. H. Carpenter, w, College Park)
- Massachusetts (C. G. Johnson, Jr., w, Boston)
- Virginia (E. M. Miller, w, Richmond)

Flood-hazard mapping:
- United States (G. W. Edelen, w, NC)
- Alabama (J. R. Harkins, w, Tuscaloosa)
- Arkansas (M. S. Hines, w, Little Rock)
- California (J. R. Crippen, w, M)
- Colorado (J. F. McCain, w, D)
- Florida (S. D. Leach, w, Tallahassee)

Flood-hazard mapping—Continued
Connecticut (M. A. Cervione, Jr., w, Hartford)
Georgia (McGlone Price, w, Doraville)
Hawaii (C. J. Ewart, w, Honolulu)
Idaho (W. A. Harenberg, w, Boise)
Illinois (J. D. Camp, w, Champaign)
Indiana (J. B. Swing, w, Indianapolis)
Iowa (O. G. Lara, w, Iowa City)
Kansas (D. B. Richards, w, Lawrence)
Louisiana (A. S. Lowe, w, Baton Rouge)
Maine (R. A. Morrill, w, Augusta)
Massachusetts (S. W. Wandle, Jr., w, Boston)
Michigan (R. L. Knutilla, w, Okemos)
Minnesota (L. C. Guetzkow, w, St. Paul)
Mississippi (K. V. Wilson, w, Jackson)
Missouri (L. D. Hauth, w, Rolla)
Montana (M. V. Johnson, w, Helena)
Nebraska (F. B. Shaffer, w, Lincoln)
Nevada (D. O. Moore, w, Carson City)
New Hampshire (S. W. Wandle, Jr., w, Boston, Mass.)
New Jersey (R. E. Gatton, Jr., w, Trenton)
North Carolina (F. E. Arteaga, w, Raleigh)
North Dakota (O. A. Crosby, w, Bismarck)
Ohio (D. K. Roth, w, Columbus)
Oklahoma (W. B. Mills, w, Oklahoma City)
Oregon (D. D. Harris, w, Portland)
Pennsylvania (L. V. Page, w, Harrisburg)
Puerto Rico (W. J. Haire, w, San Juan)
South Carolina (W. T. Utter, w, Columbia)
Tennessee (C. R. Gamble, w, Nashville)
Texas (J. D. Bohn, w, Austin)
Vermont (S. W. Wandle, Jr., w, Boston, Mass.)
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)
Colorado (R. C. Christensen, w, D)
Connecticut (M. A. Cervione, Jr., w, Hartford)
Florida (S. D. Leach, w, Tallahassee)
Georgia (McGlone Price, w, Doraville)
Illinois (A. W. Noehre, w, Oak Park)
Indiana (D. H. Rapp, w, Indianapolis)
Iowa (A. J. Heinitz, w, Iowa City)
Kansas (D. B. Richards, w, Lawrence)
Louisiana (F. N. Lee, w, Baton Rouge)
Maine (R. M. Morrill, w, Augusta)
Massachusetts (L. A. Swallow, w, Boston)
Michigan (R. L. Knutilla, w, Okemos)
Minnesota (L. C. Guetzkow, w, St. Paul)
Missouri (L. D. Hauth, w, Rolla)
Nebraska (G. G. Jamison, w, Lincoln)
New Jersey (R. D. Schopp, w, Trenton)
New York (R. T. Mycyk, w, Albany)
North Carolina (W. H. Eddins, w, Charlotte)
Ohio (D. K. Roth, w, Columbus)
Oklahoma (T. L. Huntzinger, w, Oklahoma City)
Oregon (D. D. Harris, w, Portland)
Pennsylvania (Andrew Voytik, w, Harrisburg)

Flood-insurance studies—Continued
Puerto Rico (W. J. Haire, w, San Juan)
South Carolina (B. H. Whetstone, w, Columbia)
Texas (J. D. Bohn, w, Austin)
Virginia (D. F. Farrell, w, Marion)
Washington (C. H. Swift, w, Tacoma)
Wisconsin (E. G. Nassar, w, Madison)

Flood investigations:
Countermeasures, scour and erosion (J. C. Brice, w, M)
Documentation of extreme floods (H. H. Barnes, Jr., w, NC)
Model bridge-site report (H. H. Barnes, w, NC)
States:
Alabama, flood, bridge-site studies (C. O. Ming, w, Montgomery)
Arkansas (M. S. Hines, w, Little Rock)
California, Lake-Playa flood study (M. W. Busby, w, Laguna Niguel)
Colorado, flood-plain mapping (J. F. McCain, w, D)
Florida, flood-hazard evaluation, Myakka River (W. R. Murphy, Jr., w, Tampa)
Georgia, Atlanta flood characteristics (H. G. Golden, w, Doraville)
Hawaii, flood gaging (R. H. Nakahara, w, Honolulu)
Idaho (W. A. Harenberg, w, Boise)
Illinois (w, Oak Park, except as otherwise noted):
Flood flows in small basins (G. W. Curtis, w, Champaign)
Flood mapping in northeastern Illinois (A. W. Noehre)
Urban floods in northeastern Illinois (H. E. Allen, Jr.)
Indiana, flood frequency (L. G. Davis, w, Indianapolis)
Iowa (w, Iowa City):
Flood data for selected bridge sites (O. G. Lara)
Flood profiles, statewide (O. G. Lara)
Flood information, Cedar Rapids (O. G. Lara)
Flood information, Linn County (O. G. Lara)
Kentucky, small-area flood hydrology (R. V. Swisshelm, Jr., w, Louisville)
Minnesota, flood-plain studies (L. C. Guetzkow, w, St. Paul)
Mississippi, multiple-bridge hydraulics (B. E. Colson, w, Jackson)
Nebraska, magnitude and frequency of floods (E. W. Beckman, w, Lincoln)
Nevada (w, Carson City):
Environmental study, western Nevada (P. A. Glancy)
Flood investigations (Lynn Harmsen)
New Jersey, flood peaks and flood plains (S. J. Stankowski, w, Trenton)
New Mexico, flood analysis (A. G. Scott, w, Santa Fe)
New York, peak discharge of ungaged streams (Bernard Dunn, w, Albany)
Oklahoma, small watersheds (W. O. Thomas, Jr., w, Oklahoma City)
South Carolina (w, Columbia):
Flood frequency statewide (B. H. Whetstone)
Hydraulic site reports (B. H. Whetstone)
Tennessee (W. J. Randolph, w, Nashville)
Virginia, statewide (E. M. Miller, w, Richmond)
Washington (w, Tacoma):
Flood-inundation mapping (J. H. Bartells)
Chehalis water resources (K. L. Walters)

Flood investigations—Continued
States—Continued
Wisconsin (w, Madison):
Dane County, flood-inundation study (R. C. Grant)
Flood-control effects on Trout Creek (R. S. Grant)
St. Croix scenic river waste study (R. S. Grant)
Wyoming, flood investigations (G. S. Craig, w, Cheyenne)

Fluorspar:
Colorado, Bonanza and Poncha Springs quadrangles (R. E. Van Alstine, NC)
Illinois-Kentucky district, regional structure and ore controls (D. M. Pinckney, D)

Foreign nations, geologic investigations:
Brazil, mineral resources and geologic training (S. A. Stanin, Rio de Janeiro)
Saudi Arabia, crystalline shield, geologic and minerals reconnaissance (T. H. Kiilsgaard, Jiddah)
Spain, marine mineral resources (P. D. Snavely, Jr., M)
Thailand, remote-sensing program (J. O. Morgan, Bangkok)

Foreign nations, hydrologic investigations. *See* Water resources, foreign countries.

Fuels, organic. *See* Coal; Oil shale; Petroleum and natural gas.

Gas, natural. *See* Petroleum and natural gas.

Geochemical distribution of the elements:
Botanical exploration and research (H. L. Cannon, D)
Cambrian and Ordovician rocks, Western United States (A. T. Miesch, D)
Coding and retrieval of geologic data (T. G. Lovering, D)
Data of geochemistry (Michael Fleischer, NC)
Data of rock analyses (Marjorie Hooker, NC)
Data systems (R. V. Mendes, D)
Dispersion of elements in the zone of weathering (R. W. White, D)
Geochemistry of food plants (H. T. Shacklette, D)
Light stable isotopes (J. R. O'Neil, M)
Phosphoria Formation, organic carbon and trace element distribution (E. K. Maughan, D)
Sedimentary rocks, chemical composition (T. P. Hill, D)
Selenium, tellurium, and thallium, geochemical exploration (H. W. Lakin, D)
Statistical geochemistry and petrology (A. T. Miesch, D)
Urban geochemistry (H. A. Tourtelot, D)
States:
California, Sierra Nevada batholith, geochemical study (F. C. W. Dodge, M)
Colorado, Mt. Princeton igneous complex (Priestley Toulmin III, NC)
Pennsylvania, greater Pittsburgh region, environmental geochemistry (R. P. Briggs, Carnegie)

Geochemical prospecting methods:
Application and evaluation of methods of chemical analysis to diverse geochemical environments (J. G. Viets, D)
Application of silver-gold geochemistry to exploration (H. W. Lakin, D)
Botanical exploration and research (H. L. Cannon, D)
Development of effective on-site methods of chemical analysis for geochemical exploration (W. L. Campbell, D)
Elements in organic-rich material (F. N. Ward, D)
Gamma-ray spectrometry (J. A. Pitkin, D)

Geochemical prospecting methods—Continued
Geochemical characterization of metallogenic provinces and mineralized areas (G. J. Neuerburg, D)
Geochemical exploration in glaciated areas (H. V. Alminas, D)
Geochemical exploration research in arctic, alpine, and subalpine regions (J. H. McCarthy, Jr., D)
Geochemical exploration techniques in Alaska (G. C. Curtin, D)
Geochemical exploration techniques in alpine and subalpine environments (G. C. Curtin, D)
Geochemical exploration techniques of the arid environment (M. A. Chaffee, D)
Gold compositional analysis in mineral exploration (J. C. Antweiler, D)
Instrumentation development (R. C. Bigelow, D)
Jasperoid, relations to ore deposits (T. G. Lovering, D)
Lateritic areas, southern Appalachian Mountains (W. R. Griffitts, D)
Mercury, geochemistry (A. P. Pierce, D)
Mineral-exploration methods (G. B. Gott, D)
Mineralogical techniques in geochemical exploration (Theodore Botinelly, D)
New mineral storage and identification program (George Van Trump, Jr., D)
Ore-deposit controls (A. V. Heyl, Jr., D)
Pattern recognition and clustering methods for the graphical analysis of geochemical data (J. B. Fife, D)
Research in methods of spectrographic analysis for geochemical exploration (E. L. Mosier, D)
Sulfides, accessory in igneous rocks (G. J. Neuerberg, D)
Surface and ground water in geochemical exploration (G. A. Nowlan, D)
Volatile elements and compounds in geochemical exploration (M. E. Hinkle, D)
State:
New Mexico, Basin and Range part, geochemical reconnaissance (W. R. Griffitts, D)

Geochemistry, experimental:
Environmental geochemistry, Snake River Plain (R. W. White, D)
Environment of ore deposition (P. B. Barton, Jr., NC)
Experimental mineralogy (R. O. Fournier, M)
Fluid inclusions in minerals (Edwin Roedder, NC)
Fluid zonation in metal deposits (J. T. Nash, M)
Geologic thermometry (J. S. Huebner, NC)
Hydrothermal alteration (J. J. Hemley, NC)
Impact metamorphism (E. C. T. Chao, NC)
Kinetics of igneous processes (H. R. Shaw, NC)
Late-stage magmatic processes (G. T. Faust, NC)
Mineral equilibria, low-temperature (E-an Zen, NC)
Neutron activation (F. E. Senftle, NC)
Oil shale:
Colorado, Utah, and Wyoming (W. E. Dean, Jr., D)
Organic geochemistry (R. E. Miller, D)
Organic geochemistry (J. G. Palacas, D)
Organometallic complexes, geochemistry (Peter Zubovic, NC)
Solution-mineral equilibria (C. L. Christ, M)
Stable isotopes and ore genesis (R. O. Rye, D)

Geochemistry, water:
Chemical constituents in ground water, spatial distribution (William Back, w, NC)

Geochemistry, water—Continued
Chemical reactions at mineral surfaces (J. D. Hem, w, M)
Computer modeling of rock-water interactions (J. L. Haas, Jr., NC)
Elements, distribution in fluvial and brackish environments (V. C. Kennedy, w, M)
Factors determining solute transfer in the unsaturated zone (Jacob Rubin, w, M)
Gases, complexes in water (D. W. Fischer, w, NC)
Geochemistry of geothermal systems (Ivan Barnes, w, M)
Geochemistry of San Francisco Bay waters and sediments (D. H. Peterson, w, M)
Geothermal trace-element reactions (E. A. Jenne, w, M)
Hydrologic applications of quantitative mineralogy (Robert Schoen, w, NC)
Hydrosolic metals and related constituents in natural water, chemistry (J. D. Hem, 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, NC)
Organic geochemistry (R. L. Malcolm, w, D)
Trace-element partitioning (E. A. Jenne, w, M)
See also Quality of water.

Geochemistry and petrology, field studies:
Basalt, genesis (T. L. Wright, NC)
Basin and Range granites (D. E. Lee, D)
Epithermal deposits (R. G. Worl, D)
Geochemical studies in southeastern States (Henry 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)
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 (David Gottfried, NC)
Petrology of the Yellowstone Plateau volcanic field, Wyoming, Idaho, and 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 (George Phair, NC)
Solution transport of heavy metals (G. K. Czamanske, M)
Submarine volcanic rocks, properties (J. G. Moore, M)
Syngenetic ore deposition (C. M. Conway, M)
Tertiary-Laramide intrusives of Colorado (E. J. Young, D)
Thermal waters, origin and characteristics (D. E. White, M)
Trondhjemites, major and minor elements, isotopes (Fred Barker, D)
Ultramafic rocks, petrology of alpine types (R. G. Coleman, M)
Uranium, radon, and helium—gaseous emanation detection (G. M. Reimer, 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:
Alaska (M):
La Perouse layered intrusion (R. A. Loney)
Metasedimentary and metaigneous rocks, southwestern Brooks Range (I. L. Tailleur)
Arizona (M):
Ray program:
Mineral Mountain (T. G. Theodore)
Silicate mineralogy, geochemistry (N. G. Banks)
Stocks (S. C. Creasey)
California:
Kings Canyon National Park (J. G. Moore, M)
Long Valley caldera-Mono Craters volcanic rocks (R. A. Bailey, NC)
Sierra Nevada metamorphism (B. A. Morgan III, NC)
Sierra Nevada xenoliths (J. P. Lockwood, M)
Colorado, petrology of the Mt. Princeton igneous complex (Priestley Toulmin III, NC)
Idaho, Wood River district (W. E. Hall, M)
Missouri (D):
Geochemical survey of rocks (R. J. Ebens)
Geochemical survey of soils (R. R. Tidball)
Geochemical survey of vegetation (J. A. Erdman)
Montana:
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)
South Dakota, Keystone pegmatite area (J. J. Norton, Rapid City)

Geochronological investigations:
Carbon-14 method (Meyer Rubin, NC)
Geochronology, Denver (C. E. Hedge, D)
Geochronology and rock magnetism (G. B. Dalrymple, M)
Geochronology of uranium ores and their host rocks (K. R. Ludig, D)
Igneous rocks and deformational periods (R. W. Kistler, M)
Lead-uranium, lead-thorium, and lead-alpha methods (T. W. Stern, NC)
Magnetic chronology, Colorado Plateau and environs (D. P. Elston, E. M. Shoemaker, Flagstaff, Ariz.)
Quaternary dating techniques, numerical and relative-age (K. L. Pierce, D)
Radioactive-disequilibrium studies (J. N. Rosholt, D)
State:
Alaska, K-Ar dates, southwest Brooks Range (I. L. Tailleur, M; R. B. Forbes, D. L. Turner, Fairbanks)
See also Isotope and nuclear studies.

Geologic mapping:
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

Belt basin study (J. E. Harrison, D)

Columbia River basalt (D. A. Swanson, M)

States:

Alaska (M):

- Ambler River and Baird Mountains quadrangles (I. L. Tailleur)
- Charley River quadrangle (E. E. Brabb)
- Craig quadrangle (G. D. Eberlein, Michael Churkin, Jr.)
- Delong Mountains quadrangle (I. L. Tailleur)
- Geologic map (H. M. Beikman)
- Geology of Alaska (George Gryc)
- Glacier Bay National Monument (D. A. Brew)
- Hughes-Shungnak area (W. W. Patton, Jr.)
- Iliamna quadrangle (R. L. Detterman)
- Juneau and Taku River quadrangles (D. A. Brew)
- Metamorphic facies map (D. A. Brew)
- Natural landmarks investigation (R. L. Detterman)
- St. Lawrence Island (W. W. Patton, Jr.)
- Tracy Arm-Fords Terror (Thundering Fiords) Wilderness Study Area (D. A. Brew)

Arizona (Flagstaff):

- North-central part (D. P. Elston)
- Phoenix 2-degree quadrangle (T. N. V. Karlstrom)
- Shivwits Plateau (Ivo Lucchitta)

Arkansas (B. R. Haley, Little Rock)

California (M):

- Tectonic studies, Great Valley area (J. A. Bartow, D. E. Marchand)
- Environmental maps for land-use planning (E. H. Pampeyan)

Colorado (D):

- Colorado Plateau geologic map (D. D. Haynes)
- Denver 2-degree quadrangle (B. H. Bryant)
- Geologic map (O. L. Tweto)
- Leadville 2-degree quadrangle (O. L. Tweto)
- Montrose 2-degree quadrangle (W. J. Hail, Jr.)
- Pueblo 2-degree quadrangle (G. R. Scott)
- Sterling 2-degree quadrangle (G. R. Scott)

Idaho (D):

- Challis Volcanics (D. H. McIntyre)
- Dubois 2-degree quadrangle (D. L. Schleicher)
- Idaho Falls 2-degree quadrangle (D. L. Schleicher)
- Preston 2-degree quadrangle (S. S. Oriel)
- Snake River Plain, central part, volcanic petrology (H. E. Malde)
- Snake River Plain region, eastern part (S. S. Oriel)

Michigan, Gogebic County (W. C. Prinz, NC)

Montana, White Sulphur Springs 2-degree quadrangle (M. W. Reynolds, D)

Nevada:

- Elko County (R. A. Hope, M)
- Elko County, central (K. B. Ketner, D)
- Elko County, western (R. R. Coats, M)

Geologic mapping—Continued

Map scale smaller than 1:62,500—Continued

States—Continued

Nevada—Continued

- Geologic map (J. H. Stewart, M)
- Lincoln County, Tertiary rocks (G. L. Dixon, D)

New Mexico (D):

- North Church Rock area (A. R. Kirk)
- Sanostee (A. C. Huffman, Jr.)
- Socorro 2-degree quadrangle (G. O. Bachman)
- West half of Santa Fe 2-degree quadrangle (E. H. Baltz, Jr.)

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, Wenatchee 2-degree sheet (R. W. Tabor, R. B. Waitt, Jr., V. A. Frizzell, Jr., M)

Wyoming (D):

- Geologic map (J. D. Love)
- Preston 2-degree quadrangle (S. S. Oriel)

Map scale 1:62,500, and larger:

States and territories:

Alaska:

- Anatuvuk Pass (G. B. Shearer, c, Anchorage)
- Anchorage area (Ernest Dobrovolny, D)
- Bering River coal field (R. B. Sanders, c, Anchorage)
- Cape Beaufort-Corwin Bluffs coal field (J. E. Callahan, c, Anchorage)
- Geology and mineral resources of the Ketchikan quadrangle (H. C. Berg, M)
- Juneau area (R. D. Miller, D)
- Kukpowruk River coal field (J. E. Callahan, c, Anchorage)
- Nelchina area Mesozoic investigations (Arthur Grantz, M)
- Nenana coal investigations (Clyde Wahrhaftig, M)
- Nome area (C. L. Hummel, M)
- Utukok River and Kokolik River coal field (J. E. Callahan, c, Anchorage)

Arizona:

- Bowie zeolite area (L. H. Godwin, c, NC)
- Cummings Mesa quadrangle (Fred Peterson, c, D)
- Garnet Mountain quadrangle (P. M. Blacet, M)
- Hackberry Mountain area (D. P. Elston, Flagstaff)
- Mt. Wrightson quadrangle (H. D. Drewes, D)
- Ray district, porphyry copper (H. R. Cornwall, M)
- Sedona area (D. P. Elston, Flagstaff)
- Western Arizona tectonic studies (Ivo Lucchitta, Flagstaff)

California (M, except as otherwise noted):

- Coast Range, ultramafic rocks (E. H. Bailey)
- Condrey Mountain-Hornbrook quadrangle (P. E. Hotz)
- Geysers-Clear Lake area (R. J. McLaughlin)
- Long Valley caldera (R. A. Bailey, NC)
- Malibu Beach and Topanga quadrangles (R. F. Yerkes)

Geologic mapping—Continued

Map scale 1:62,500 and larger—Continued

States and territories—Continued

California (M, except as otherwise noted)—Continued

- Merced Peak quadrangle (D. L. Peck, NC)
- Northern Coast Ranges (K. F. Fox, Jr.)
- Palo Alto, San Mateo, and Montara Mountain quadrangles (E. H. Pampeyan)
- Peninsular Ranges (V. R. Todd, La Jolla)
- Point Dume and Triunfo Pass quadrangles (R. H. Campbell)
- Regional fault studies (E. J. Helley, D. G. Herd, B. F. Atwater)
- Ryan quadrangle (J. F. McAllister)
- Santa Lucia Range (V. M. Seiders)
- Searles Lake area (G. I. Smith)
- Sierra Nevada batholith (P. C. Bateman)
- Western Santa Monica Mountains (R. H. Campbell)

Colorado (D, except as otherwise noted):

- Aspen 15-minute quadrangle (B. H. Bryant)
- Barcus Creek quadrangle (W. J. Hail)
- Barcus Creek SE quadrangle (W. J. Hail)
- Bonanza quadrangle (R. E. Van Alstine, NC)
- Buckhorn Lakes quadrangle (R. G. Dickinson, c, D)
- Central City area (R. B. Taylor)
- Citadel Plateau (G. A. Izett, c, D)
- Coal mine deformation studies, Somerset mining district (C. R. Dunrud)
- Cochetopa area (J. C. Olson)
- Courthouse Mountain quadrangle (R. G. Dickinson, c, D)
- Denver basin, Tertiary coal zone (P. E. Soister, c, D)
- Denver metropolitan area (R. M. Lindvall)
- Disappointment Valley, geology and coal resource (D. E. Ward)
- Front Range, northeastern part, Fort Collins area (W. A. Braddock)
- Northern Park Range (G. L. Snyder)
- Poncha Springs quadrangle (R. E. Van Alstine, NC)
- Rangely NE quadrangle (B. E. Barnum, c, D)
- Rough Gulch quadrangle (W. J. Hail)
- Savery quadrangle (C. S. V. Barclay, c, D)
- Smizer Gulch quadrangle (W. J. Hail)
- Strasburg SW quadrangle (P. E. Soister, c, D)
- Thornburgh quadrangle (M. J. Reheis, c, D)
- Ward and Gold Hill quadrangles (D. J. Gable)
- 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)

Idaho (D, except as otherwise noted):

- Bayhorse area (S. W. Hobbs)
- Boulder Mountains (C. M. Tschanz)
- Goat Mountain quadrangle (M. H. Staatz)

Idaho (D, except as otherwise noted)—Continued

- Grouse quadrangle (B. A. Skipp)
- Hawley Mountain quadrangle (W. J. Mapel)
- Malad southeast quadrangle (S. S. Oriel)
- Montour quadrangle (H. E. Malde)
- Palisades Dam quadrangle (D. A. Jobin, c, D)
- Patterson quadrangle (E. T. Ruppel)
- Strevell quadrangle (J. F. Smith)
- Upper and Lower Red Rock Lakes quadrangles (I. J. Witkind)
- Wood River district (W. E. Hall, M)
- Yellow Pine quadrangle (B. F. Leonard)

Kentucky, cooperative mapping program (E. R. Cressman, Lexington)

Maine (NC, except as otherwise noted):

- Blue Hill quadrangle (D. B. Stewart)
- Castine quadrangle (D. B. Stewart)
- Orland quadrangle (D. R. Wones)
- Rumford quadrangle (R. H. Moench, D)
- The Forks quadrangle (F. C. Canney, D)

Maryland (NC):

- Delmarva Peninsula (J. P. Owens)
- Howard County (J. B. Roen)
- Northern Coastal Plain (J. P. Minard)
- Western Maryland Piedmont (M. W. Higgins)

Massachusetts (Boston, except as otherwise noted):

- Boston and vicinity (C. A. Kaye)
- Cooperative mapping program (M. H. Pease, Jr.)
- Taconic sequence (E-an Zen, NC)

Michigan, Gogebic Range, western part (R. G. Schmidt, NC)

Montana:

- Bearpaw Mountains, petrology (B. C. Hearn, Jr., NC)
- Birney SW quadrangle (S. P. Buck, c, Casper, Wyo.)
- 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, D)
- Diatremes, Mission River Breaks (B. C. Hearn, Jr., NC)
- Elk Park quadrangle (H. W. Smedes, D)
- Holmes Ranch quadrangle (N. E. Micklich, 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.)
- Spring Gulch quadrangle (N. E. Micklich, c, Casper, Wyo.)
- Taintor Desert quadrangle (S. P. Buck, c, Casper, Wyo.)
- Tongue River Dam quadrangle (Juliana Waring, c, Casper, Wyo.)
- Wickiup Creek quadrangle (H. W. Smedes, D)

Geologic mapping—Continued
Map scale 1:62,500 and larger—Continued
States and territories—Continued
Montana—Continued
Wolf Creek area, petrology (R. G. Schmidt, NC)
Nebraska, McCook 2-degree quadrangle (G. E. Prichard, D)
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)
Midas-Jarbidge area (R. R. Coats, M)
Spruce Mountain 4 quadrangle (G. D. Fraser, c, D)
New Hampshire, cooperative mapping program, surficial (Carl Koteff, Boston, Mass.)
New Mexico:
Acoma area (C. H. Maxwell, D)
Alamosa Mesa West quadrangle (D. B. Umshler, c, Roswell)
Church Rock-Smith Lake (C. T. Pierson, D)
Cretaceous stratigraphy, San Juan basin (E. R. Landis, D)
Gallup East quadrangle (E. D. Patterson, c, Roswell)
Gallup West quadrangle (J. E. Fassett, c, Farmington)
Hillsboro quadrangle (D. C. Hedlund, D)
Iron Mountain (A. V. Heyl, Jr., D)
Manuelito quadrangle (J. E. Fassett, c, Farmington)
Manzano Mountains (D. A. Myers, D)
Ojo Encino Mesa quadrangle (D. B. Umshler, c, Roswell)
Pinos Altos Range (T. L. Finnell, D)
Pueblo Alto Trading Post quadrangle (R. W. Jentgen, c, Farmington)
Raton coal basin, western part (C. L. Pillmore, D)
Samson Lake quadrangle (J. E. Fassett, c, Farmington)
Star Lake quadrangle (J. E. Fassett, c, Farmington)
Tanner Lake quadrangle (D. B. Umshler, c, Roswell)
Twin Butte quadrangle (M. L. Millgate, c, Farmington)
Valles Mountains, petrology (R. L. Smith, NC)
New York (NC):
Pope Mills and Richville quadrangles (C. E. Brown)
Taconic sequence (E-an Zen)
North Carolina, Central Piedmont (A. A. Stromquist, D)
North Dakota:
Clark Butte 15-minute quadrangle (G. D. Mowat, c, Billings, Mont.)
North Almont quadrangle (H. L. Smith, c, D)
Pennsylvania (NC):
Northern anthracite field (M. J. Bergin)
Southern anthracite field (G. H. Wood, Jr.)

Geologic mapping—Continued
Map scale 1:62,500 and larger—Continued
States and territories—Continued
Pennsylvania (NC)—Continued
Wind Gap and adjacent quadrangles (J. B. Epstein)
Puerto Rico (J. M. Aaron, NC)
South Dakota:
Black Hills Precambrian (J. A. Redden, Hill City)
Keystone pegmatite area (J. J. Norton, Rapid City)
Rapid City area (J. M. Cattermole, D)
Texas, Tilden-Loma Alta area (K. A. Dickinson, D)
Utah (c, D, unless otherwise noted):
Basin Canyon quadrangle (Fred Peterson)
Big Hollow Wash quadrangle (Fred Peterson)
Blackburn Canyon quadrangle (Fred Peterson)
Butler Valley quadrangle (W. E. Bowers)
Canaan Peak quadrangle (W. E. Bowers)
Coal mine bumps, Sunnyside mining district (F. W. Osterwald, D)
Collet Top quadrangle (H. D. Zeller)
Confusion Range (R. K. Hose, M)
Crawford Mountains (W. C. Gere, c, M)
East-of-the-Navajo quadrangle (Fred Peterson)
Fourmile Bench quadrangle (W. E. Bowers)
Horse Mountain quadrangle (W. E. Bowers)
Jessen Butte quadrangle (E. M. Schell, c, Casper, Wyo.)
Matlin Mountains (V. R. Todd, M)
Needle Eye Point quadrangle (H. D. Zeller)
Oak City area (D. J. Varnes, D)
Ogden 4 NW quadrangle (R. J. Hite)
Pete's Cove quadrangle (H. D. Zeller)
Salt Lake City and vicinity (Richard VanHorn, D)
Sheeprock Mountains, West Tintic district (H. T. Morris, M)
Ship Mountain Point quadrangle (H. D. Zeller)
Sunset Flat quadrangle (Fred Peterson)
Wah Wah Summit quadrangle (L. F. Hintze, Salt Lake City)
Wasatch Front surficial geology (R. D. Miller, D)
Willard Peak area (M. D. Crittenden, Jr., M)
Virginia (NC):
Culpeper basin (K. Y. Lee)
Delmarva Peninsula (J. P. Owens)
Northern Blue Ridge (G. H. Espenshade)
Rapidan-Rappahannock (Louis Pavlides)
Washington:
Chewelah No. 4 quadrangle (F. K. Miller, M)
Glacier Park area (F. W. Cater, Jr., D)
Northern Okanogan Highlands (C. D. Rinehart, M)
Olympic Peninsula, eastern part (W. M. Cady, D)
Stevens County (R. G. Yates, M)
Togo Mountain quadrangle (R. C. Pearson, D)
Wisconsin, Black River Falls and Hatfield quadrangles (Harry Klemic, NC)
Wyoming (c, D, unless otherwise noted):
Acme quadrangle (B. E. Law)

Geologic mapping—Continued
Map scale 1:62,500 and larger—Continued
States and territories—Continued
Wyoming (c, D, unless otherwise noted)—Continued
Albany and Keystone quadrangles (M. E. McCallum, D)
Alkali Butte quadrangle (M. W. Reynolds, D)
Appel Butte quadrangle (G. L. Galyardt)
Badwater Creek (R. E. Thaden, D)
Bailey Lake quadrangle (M. L. Schroeder)
Beaver Creek Hills quadrangle (E. I. Winger, c, Casper)
Browns Hill quadrangle (C. S. V. Barclay)
Cottonwood Rim quadrangle (C. S. V. Barclay)
Coyote Draw quadrangle (G. L. Galyardt)
Crawford Mountains (W. C. Gere, c, M)
Deer Creek quadrangle (D. A. Jobin)
Devils Tooth quadrangle (W. G. Pierce, M)
Eagle Rock quadrangle (S. P. Buck, c, Casper)
Fortin Draw quadrangle (B. E. Law)
Four Bar—J Ranch quadrangle (G. L. Galyardt)
Greenhill quadrangle (S. P. Buck, c, Casper)
Grieve Reservoir quadrangle (C. S. V. Barclay)
Hilight quadrangle (W. J. Purdon, c, Casper)
Hultz Draw quadrangle (E. I. Winger, c, Casper)
Ketchum Buttes quadrangle (C. S. V. Barclay)
Little Thunder Reservoir quadrangle (G. C. Martin, c, Casper)
Monarch quadrangle (B. E. Barnum)
Moyer Springs quadrangle (B. E. Law)
Neil Butte quadrangle (S. P. Buck, c, Casper)
North Star School NE (S. P. Buck, c, Casper)
North Star School NW (S. P. Buck, c, Casper)
North Star School SW (W. J. Purdon, c, Casper)
North Star School SE (W. J. Purdon, c, Casper)
Oil Mountain quadrangle (G. J. Kerns, c, Casper)
Open A Ranch quadrangle (G. C. Martin, c, Casper)
Oriva quadrangle (B. E. Law)
Pickle Pass quadrangle (M. L. Schroeder)
Pine Creek quadrangle (D. A. Jobin)
Piney Canyon NW quadrangle (G. C. Martin, c, Casper)
Piney Canyon SW quadrangle (J. E. Goolsby, c, Casper)
Pleasantdale quadrangle (S. L. Grazis)
Poison Spider quadrangle (G. J. Kerns, c, Casper)
Reid Canyon quadrangle (G. J. Kerns, c, Casper)
Reno Junction quadrangle (W. J. Purdon, c, Casper)
Reno Reservoir quadrangle (G. C. Martin, c, Casper)
Rough Creek quadrangle (S. P. Buck, c, Casper)
Saddle Horse Butte quadrangle (S. L. Grazis)
Savery quadrangle (C. S. V. Barclay)
Scaper Reservoir quadrangle (S. L. Grazis)
Sheridan Pass quadrangle (W. L. Rohrer, c, Casper)
Ship Mountain Point quadrangle (H. D. Zeller)

Geologic mapping—Continued
Map scale 1:62,500 and larger—Continued
States and territories—Continued
Wyoming (c, D, unless otherwise noted)—Continued
Square Top Butte quadrangle (G. J. Kerns, c, Casper)
Teckla quadrangle (J. E. Goolsby, c, Casper)
Teckla SW quadrangle (J. E. Goolsby, c, Casper)
The Gap quadrangle (G. L. Galyardt)
The Gap southwest quadrangle (S. L. Grazis)
Tullis quadrangle (C. S. V. Barclay)
Turnercrest NE quadrangle (G. C. Martin, c, Casper)
Wapiti quadrangle (W. G. Pierce, M)
Weston southwest quadrangle (R. W. Jones, c, Casper)

Geomagnetism:
External geomagnetic-field variations (W. H. Campbell, D)
Geomagnetic-data analysis (C. O. Stearns, D)
Geomagnetic observatories (J. D. Wood, D)
Geomagnetic secular variation (L. R. Alldredge, D)
Magnetic-field analysis and U.S. charts (E. B. Fabiano, D)
World magnetic charts and analysis (E. B. Fabiano, D)

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)
Quaternary landforms and deposits interpreted from Landsat-1 imagery, Midwest and Great Plains (R. B. Morrison, D)
Stream channelization (J. C. Brice, w, M)
Studies of erosion control (N. J. King, w, M)
States:
Arizona, post-1890 A.D. erosion features interpreted from Landsat-1 imagery (R. B. Morrison, D)
Colorado, mountain soils, regolith (K. L. Pierce, D)
Idaho, surficial geology of eastern Snake River Plain (W. E. Scott, M. D. Hait, Jr., D)
Massachusetts, sea-cliff erosion studies (C. A. Kaye, Boston)
New Mexico, Chaco Canyon National Monument (H. E. Malde, D)
Wyoming (D):
Wind River Mountains, Quaternary geology (G. M. Richmond)
Yellowstone National Park, glacial and postglacial geology (G. M. Richmond)
See also Sedimentology; 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)
Regional studies (Isidore Zietz, 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 (Isidore Zietz, NC)

Geophysics, regional—Continued
- Crust and upper mantle—Continued
  - Aeromagnetic studies of the United States (Isidore Zietz, NC)
  - Analysis of traveltime data (J. C. Roller, M)
  - Seismicity and Earth structure (J. N. Taggart, D)
  - Seismologic studies (J. P. Eaton, M)
- Engineering geophysics (H. D. Ackermann, D)
- Florida Continental Shelf, gravity studies (H. L. Krivoy, NC)
- Gravity surveys:
  - Dona Ana, Otero, Lincoln, Sierra, and Socorro Counties, New Mexico (D. L. Healey, D)
  - Maryland cooperative (D. L. Daniels, NC)
- 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 (Andrew Griscom, M)
- Program and systems development (G. I. Evenden, W. L. Anderson, D)
- Rainier Mesa (J. R. Ege)
- Rocky Mountains, northern (D. L. Peterson, M. D. Kleinkopf, D)
- Southeastern States geophysical studies (Peter Popenoe, NC)
- Southwestern States geophysical studies (D. L. Peterson, NC)
- Ultramafic rocks, geophysical studies, intrusions (G. A. Thompson, M)
- United States, aeromagnetic surveys (E. R. King, NC)
- *States and territories:*
- Alaska, Ambler River and Baird Mountains quadrangles gravity (D. F. Barnes, M)
- California, Sierra Nevada, geophysical studies (H. W. Oliver, M)
- Idaho, Snake River Plain (D. L. Peterson, D)
- Massachusetts, geophysical studies (M. F. Kane, NC)
- Minnesota (NC):
  - Keweenawan rocks, magnetic studies (K. G. Books)
  - Southern part, aeromagnetic survey (E. R. King)
- Nevada, engineering geophysics, Nevada Test Site (R. D. Carroll, D)
- New Mexico, Rio Grande graben (L. E. Cordell, D)
- Pennsylvania, magnetic properties of rocks (Andrew Griscom, M)
- Puerto Rico, seismicity of Puerto Rico (A. C. Tarr, D)

Geophysics, theoretical and experimental:
- Earthquakes, local seismic studies (J. P. Eaton, M)
- Elastic and inelastic properties of Earth materials (Louis Peselnick, M)
- Electrical properties of rocks (R. D. Carroll, D)
- Electrical resistivity studies (A. A. R. Zohdy, D)
- Experimental rock mechanics (C. B. Raleigh, M)
- Gamma-ray spectrometry (J. A. Pitkin, D)
- Geomechanical studies, in-situ stress (J. R. Ege, D)
- Geophysical data, interpretation using electronic computers (R. G. Henderson, NC)
- Ground-motion studies (J. H. Healy, M)
- Infrared and ultraviolet radiation studies (R. M. Moxham, NC)

Geophysics, theoretical and experimental—Continued
- Magnetic and luminescent properties (F. E. Senftle, NC)
- Magnetic Properties Laboratory (M. E. Beck, Jr., Bellingham, Wash.)
- Microwave studies (A. W. England, D)
- Paleomagnetism, Precambrian and Tertiary chronology (D. P. Elston, Flagstaff, Ariz.)
- Remanent magnetization of rocks (C. S. Grommé, M)
- Resistivity interpretation (A. A. R. Zohdy, D)
- Rock behavior at high temperature and pressure (E. C. Robertson, NC)
- Seismicity patterns in time and space (C. G. Bufe, M)
- Stress studies (C. B. Raleigh, M)
- Thermodynamic properties of rocks (R. A. Robie, NC)
- Ultramafic intrusions, geophysical studies (G. A. Thompson, M)
- Volcano geophysics (E. T. Endo, M)
- *States:*
  - California, mass properties of oil-field rocks (L. A. Beyer, M)
  - Nevada (D):
    - Interpretation of geophysical logs, Nevada Test Site (R. D. Carroll)
    - Seismic velocity measuring techniques, Nevada Test Site (R. D. Carroll)
  - Vermont, in-situ stress in a granite quarry (G. E. Brethauer, D)

Geotechnical investigations:
- Coal mine bumps in Utah (F. W. Osterwald, D)
- Coal mine deformation, Somerset, Colorado (C. R. Dunrud, D)
- Engineering geology investigations, Powder River Basin (F. W. Osterwald, D)
- Reston, Va. (S. F. Obermeier, NC)
- Geotechnical measurements and services (H. W. Olsen, D)
- In-situ stress, reactor hazards research (T. C. Nichols, Jr., D)
- Electronics instrumentation research for engineering geology (J. B. Bennetti, Jr., D)
- Miscellaneous landslide investigations (R. W. Fleming, D)
- Open-pit slope stability (F. T. Lee, D)
- Research in rock mechanics (F. T. Lee, D)
- Soil engineering research (T. L. Youd, M)

Geothermal investigations:
- Colorado Plateau, potential field methods (R. R. Wahl, D)
- Electrical and electromagnetic methods in geothermal areas (D. B. Jackson, D)
- Geochemical exploration (M. E. Hinkle, D)
- Geochemical indicators (A. H. Truesdell, M)
- Geochemistry of geopressured systems (Y. K. Kharaka, w, M)
- Geophysical characterization of young silic volcanic centers, eastern Sierran Front (W. F. Isherwood, D)
- Geothermal geophysics (D. R. Mabey, D)
- Geothermal hydrologic reconnaissance (F. H. Olmsted, w, M)
- Geothermal studies (A. H. Lachenbruch, M)
- Heat flow (J. H. Sass, A. H. Lachenbruch, M)
- Oxygen isotopes (J. R. O'Neil, M)
- Physics of geothermal systems (W. H. Diment, M)
- Regional volcanology (R. L. Smith, NC)
- Remote sensing (Kenneth Watson, D)
- Rio Grande geothermal (P. H. Jones, w, Bay St. Louis, Miss.)

Geothermal investigations—Continued
- Rock-water interactions (R. O. Fournier, M)
- Seismic exploration (P. L. Ward, M)
- Statistical characterization of geothermal resources, Basin and Range province (W. F. Isherwood, D)
- Thermal waters (D. E. White, M)
- *States:*
- Alaska, geothermal reconnaissance (T. D. Miller, M)
- Arizona, San Francisco volcanic field (E. W. Wolfe, Flagstaff)
- California:
  - Clear Lake-The Geysers (B. C. Hearn, Jr., NC)
  - Clear Lake-Geysers microearthquake monitoring (C. G. Bufe, M)
  - Geology of Long Valley-Mono basin (R. A. Bailey, NC)
  - H_2S at The Geysers (C. A. Brook, c, M)
  - Imperial Valley geothermal (J. J. French, w, Garden Grove)
  - Imperial Valley microearthquake monitoring (D. P. Hill, M)
  - Long Valley active seismology (D. P. Hill, M)
  - Long Valley hydrology (R. E. Lewis, w, Laguna Niguel)
  - Pre-Tertiary geology of The Geysers-Clear Lake area (R. J. McLaughlin, M)
  - Seismic noise, The Geysers area (H. M. Iyer, M)
  - Simulation model, Raft River basin (W. D. Nichols, w, Sacramento)
- Colorado:
  - Colorado geothermal (M. S. Bedinger, w, D)
  - Geothermal resources (G. L. Galyardt, c, D)
- Hawaii, Kilauea Volcano, potential field methods for subsurface magma mapping (C. J. Zablocki, D)
- Idaho, test drilling, Raft River valley (E. G. Crosthwaite, Boise)
- Montana, geothermal investigations in Montana (R. B. Leonard, w, Helena)
- Nevada, geothermal reconnaissance (R. K. Hose, M)
- Oregon:
  - Geothermal reconnaissance (N. S. MacLeod, M)
  - Hydrologic reconnaissance of geothermal areas (E. A. Sammel, w, M)
  - Newberry Caldera (W. H. Lee, c, M)
- Utah:
  - Geothermal reconnaissance in Utah (F. E. Rush, w, Salt Lake City)
  - Geothermal resources (G. L. Galyardt, c, D)
- West Virginia, eastern Warm Springs (W. A. Hobba, Jr., w, Morgantown)
- Wyoming, Yellowstone thermal areas, geology (L. J. P. Muffler, M)

Glaciology:
- Glaciological research, International Hydrological Decade (M. F. Meier, w, Tacoma, Wash.)
- Ice dynamics (W. J. Campbell, w, Tacoma, Wash.)
- Water, ice, and energy balance of mountain glaciers, and ice physics (M. F. Meier, w, Tacoma, Wash.)
- World Data Center A—Glaciology (M. F. Meier, w, Tacoma, Wash.)
- *State:*
- Alaska (L. R. Mayo, w, Fairbanks)

Gold:
- Composition related to exploration (J. C. Antweiler, D)
- Gold resources of the United States (W. C. Prinz, NC; F. S. Simons, D)
- Great Lakes region (D. A. Seeland, D)
- *States:*
- Alaska, Seward Peninsula, nearshore (D. M. Hopkins, M)
- Arizona, Gold Basin-Lost Basin district (P. M. Blacet, M)
- California, Klamath Mountains (P. E. Hotz, M)
- Montana (D):
  - Confederate Gulch (W. B. Myers)
  - Cooke City quadrangle (J. E. Elliott)
  - Southwestern part, ore deposits (K. L. Wier)
- Nevada (M):
  - Aurora and Bodie districts, Nevada-California (F. J. Kleinhampl)
  - Carlin mine (A. S. Radtke)
  - Comstock district (D. H. Whitebread)
  - Dun Glen quadrangle (D. H. Whitebread)
  - Goldfield district (R. P. Ashley)
- New Mexico, placer deposits (Kenneth Segerstrom, D)
- North Carolina, Gold Hill area (A. A. Stromquist, D)
- Oregon-Washington, nearshore area (P. D. Snavely, Jr., M)
- South Dakota, Keystone area (W. H. Raymond, D)
- Wyoming, northwestern part, conglomerates (J. C. Antweiler, D)
- *See also* Heavy metals.

Ground water-surface water relations:
- Bank storage reconnaissance (W. D. Simons, w, M)
- *States:*
- California:
  - Confined aquifer, San Bernardino (T. J. Durbin, w, Laguna Niguel)
  - Tuolumne gas wells (R. W. Page, w, Sacramento)
- Florida (w, Miami, except as otherwise noted):
  - Biscayne aquifer analog model (E. H. Cordes)
  - Hydrologic base, Dade County (J. E. Hull)
  - Miami Canal infiltration (F. W. Meyer)
  - Well fields, west-central Florida (E. R. Close, w, Tampa)
- Idaho (w, Boise):
  - Hydrology:
    - Island Park-Henrys Lake (R. L. Whitehead)
    - Weiser Basin (H. W. Young)
- Missouri, hydrology of Ozarks Basin (John Skelton, w, Rolla)
- Nebraska, Platte Basin water resources (E. G. Lappala, 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)
- Ohio, Franklin County digital model (R. E. Fidler, w, Columbus)
- Washington, water, Yakima Reservation (R. D. MacNish, w, Tacoma)
- Wisconsin (w, Madison):
  - Hydrology of the Arboretum Marsh (H. L. Young)
  - Hydrology of Cedar Lake (R. S. McLeod)
  - Hydrology of wetlands (R. P. Novitzki)
  - Nederlo Creek hydrology (P. A. Kammerer, Jr.)

Heavy metals:
- Appalachian region:
  - Mineral resources, Connecticut-Massachusetts (J. P. D'Agostino, NC)
  - South-central (A. A. Stromquist, D)
- Hydrogeochemistry and biogeochemistry (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 (Henry Bell III, NC)
- *States:*
- Alaska (M):
  - Gulf of Alaska, nearshore placers (Erk Reimnitz)
  - Hogatza trend (T. P. Miller)
  - Southeastern part (D. A. Brew)
  - Southern Alaska Range (B. L. Reed)
  - Southwestern part (J. M. Hoare)
  - Yukon-Tanana Upland (H. L. Foster)
- Idaho, Washington Peak quadrangle (D. A. Seeland, D)
- Nevada:
  - Aurora and Bodie districts, Nevada-California (F. J. Kleinhampl, M)
  - Basin and Range (D. R. Shawe, D)

Hydraulics, ground water:
- Computer analysis, ground-water problems (S. S. Papadopulos, w, NC)
- Transient phenomena in ground-water flow (C. E. Mongan, w, Boston, Mass.)
- Transport processes in fluid flows (Akio Ogata, w, Honolulu, Hawaii)

Hydraulics, surface flow:
- Dispersion by turbulent flow in open channels (Nobuhiro Yotsukura, w, NC)
- Effect of temperature on winter runoff (W. D. Simons, w, M)
- Time-of-travel studies, New York (L. A. Wagner, w, Albany)
- Unsteady flow and saline intrusions in rivers and estuaries (R. A. Baltzer, w, NC)
- *See also* Hydrologic instrumentation.

Hydrologic-data collection and processing:
- Data file for well records (R. S. McLeod, w, Madison, Wis.)
- Hydrologic probability models (W. H. Kirby, w, NC)
- Runoff cycle simulation (D. R. Dawdy, w, M)
- Store-retrieve hydrologic data (D. E. Vaupel, w, Mineola, N.Y.)
- *See also* Hydrologic instrumentation.

Hydrologic instrumentation:
- Analog model unit (S. M. Longwill, w, NC)
- Drilling techniques (Eugene Shuter, w, D)
- GOES data collection (A. L. Higer, w, Miami, Fla.)
- Instrumentation and environmental studies (G. E. Ghering, w, D)
- Instrumentation research, water (F. C. Koopman, w, Bay St. Louis, Miss.)
- Interagency sedimentation project (J. V. Skinner, w, Minneapolis, Minn.)
- Laboratory research, instruments, water (G. F. Smoot, w, NC)

Hydrologic instrumentation—Continued
- Lake and sea-ice experiment (W. J. Campbell, w, Tacoma, Wash.)
- Optical current meter design (Winchell Smith, w, M)
- Satellite data relay project (R. W. Paulson, w, NC)
- Satellite data relay support (D. M. Preble, w, Bay St. Louis, Miss.)
- Suspended solids sensors (J. V. Skinner, w, Minneapolis, Minn.)
- Susquehanna Landsat–DCS test (J. V. Funt, w, Harrisburg, Pa.)
- Techniques of flood-plain mapping (G. W. Edelen, Jr., w, NC)
- Telemetry evaluation program (J. F. Turner, w, Tampa, Fla.)
- *See also* Hydrologic-data collection and processing.

Hydrology, ground water:
- Alluvial fan deposition (W. E. Price, Jr., w, NC)
- Aquifer systems, theoretical aspects (D. C. Helm, w, Sacramento, Calif.)
- Borehole geophysics (W. S. Keys, w, D)
- Consultation and research (C. V. Theis, w, Albuquerque, N. Mex.)
- Digital modeling, ground-water flow (S. P. Larson, w, NC)
- Geothermal modeling (J. W. Mercer, w, NC)
- Ground-water staff functions (S. W. Lohman, w, D)
- Ground-water tracer studies (R. J. Sun, w, NC)
- Gulf Coast hydrodynamics (P. C. Trescott, w, NC)
- Hydrologic laboratory (F. S. Riley, w, D)
- Hydrology of the Madison aquifer (E. M. Cushing, w, D)
- Hydrology of Wilcox Formation with reference to liquid waste emplacement in the Gulf Coastal Plain (R. H. Wallace, Jr., w, Bay St. Louis, Miss.)
- Impact of mining on aquifers (N. J. King, w, D)
- Imperial geothermal model (R. E. Miller, w, Laguna Niguel, Calif.)
- In-situ stress measurements (J. D. Bredehoeft, w, NC)
- Limestone hydraulic permeability (V. T. Stringfield, w, NC)
- Microbes in ground water (G. G. Ehrlich, w, M)
- Modeling of geothermal systems (M. L. Sorey, w, M)
- Recharge feasibility factors (Jacob Rubin, w, M)
- Regional ground-water-studies coordination (E. M. Cushing, w, NC)
- Role of confining clays (R. G. Wolff, w, NC)
- Tropical carbonate aquifers (William Back, w, NC)
- *States:*
- Alabama, water management, Madison County (W. F. Harris, Jr., w, Huntsville)
- Arizona:
  - Ground water to Colorado River (O. J. Loeltz, w, Yuma)
  - Southern Apache County (T. W. Anderson, w, Flagstaff)
  - Special site studies (H. M. Babcock, w, Tucson)
  - Water supply, Lake Mead area (R. L. Laney, w, Phoenix)
- Arkansas, ground water, lower Mississippi region (J. E. Terry, Jr., w, Little Rock)
- California (w, Laguna Niguel, except as otherwise noted):
  - Cahuilla Indian Reservation water resources (W. R. Moyle, Jr.)
  - Ground-water appraisal, Ocotillo basin (J. A. Skrivan)

Hydrology, ground water—Continued

States—Continued

- California (w, Laguna Niguel, except as otherwise noted)—Continued
  - Ground water, Hollister area (K. S. Muir, w, M)
  - Ground water, Joshua Tree-Yucca Valley (J. J. French)
  - Ground water, Lompoc (R. E. Lewis)
  - Napa County ground water (J. P. Akers, w, M)
  - United States Marine Corps Twentynine Palms (D. H. Schaefer)
  - Updating ground-water information in the Eureka area (M. J. Johnson, w, M)
  - Water resources, Upper Coachella (L. A. Swain)
  - Water resources, Vandenberg AFB (F. W. Giessner)
- Colorado, ground water, Denver basin (R. E. Brogden, w, D)
- Connecticut, Farmington ground-water potential (R. L. Melvin, w, Hartford)
- Florida:
  - Aquifer characteristics in southwest Florida (R. M. Wolansky, w, Tampa)
  - Aquifer maps, Southwest Florida Water Management District (Anthony Buono, w, Tampa)
  - Broward County (C. B. Sherwood, Jr., w, Miami)
  - Dade City ground water (Warren Anderson, w, Winter Park)
  - Deep well injection, Ft. Lauderdale (C. B. Sherwood, Jr., w, Miami)
  - Freshwater in saline aquifers (F. W. Meyer, w, Miami)
  - Geohydrology, citrus irrigation (W. E. Wilson III, w, Tampa)
  - Hydrology of Lake Tsala Apopka (A. T. Rutledge, w, Winter Park)
  - Injecting wastes in saline aquifers (F. W. Meyer, w, Miami)
  - New well fields, Dade County (Howard Klein, w, Miami)
  - Potentiometric maps in Southwest Florida Water Management District (J. W. Stewart, w, Tampa)
  - Sarasota disposal well, phase 1 (Horace Sutcliffe, Jr., w, Sarasota)
  - Storage of storm waters (J. J. Hickey, w, Tampa)
  - Water resources, Everglades (A. L. Higer, w, Miami)
  - Water resources, Lake Worth (L. F. Land, w, Miami)
  - Water resources, St. Lucie County (W. L. Miller, w, Miami)
- Hawaii, Honolulu basal aquifer (R. H. Dale, w, Honolulu)
- Indiana (w, Indianapolis):
  - Ground-water appraisal, Great Lakes basin (W. G. Weist)
  - Ground water near Carmel (D. C. Gillies)
  - Ground water, Upper West Fork of the White River basin (William Meyer)
  - Jennings County fracture trace (William Meyer)
  - Newton County ground water (William Meyer)
- Iowa, hydrology of glaciated carbonate terranes (W. L. Steinhilber, w, Iowa City)
- Kansas:
  - Artificial recharge, western Kansas (J. B. Gillespie, w, Lawrence)

Hydrology, ground water—Continued

States—Continued

- Kansas—Continued
  - Arbuckle Group, southeastern Kansas (K. M. Keene, w, Lawrence)
  - Ford and Hodgeman Counties (E. C. Weakly, w, Garden City)
  - Geohydrologic maps, southwestern Kansas (E. D. Gutentag, w, Garden City)
  - Great Bend prairie (S. W. Fader, w, Lawrence)
  - Greeley and Wichita Counties (S. E. Slagle, w, Garden City)
  - Ground water, Rush County (J. M. McNellis, w, Lawrence)
  - Saline water, Little Arkansas Basin (R. B. Leonard, w, Lawrence)
  - Scott and Lane Counties (E. D. Gutentag, w, Garden City)
  - Water resources, Ness County (E. D. Jenkins, w, Garden City)
- Kentucky (w, Louisville):
  - Lexington urban study (R. J. Faust)
  - Pennyrile Plain potentiometric map (T. W. Lambert)
- Louisiana (w, Baton Rouge):
  - Red River navigation study (T. H. Sanford)
  - Washington Parish ground water (H. L. Case)
- Maine, ground water in southwestern Maine (G. C. Prescott, Jr., w, Augusta)
- Maryland, Maryland Aquifer Studies III (I. J. Kantrowitz, w, Parkville)
- Massachusetts, ground water, Cape Cod and islands (M. H. Frimpter, w, Boston)
- Minnesota (w, St. Paul):
  - Ground water in Minnesota (G. F. Lindholm)
  - Ground water, Souris-Red-Rainy region (H. O. Reeder)
  - Twin Cities tunnel-system hydrology (E. L. Madsen)
- Mississippi, water in Central Delta, Mississippi (G. J. Dalsin, w, Jackson)
- Missouri, water, southeastern Missouri lowlands (E. J. Harvey, w, Rolla)
- Montana (w, Helena, except as noted otherwise):
  - Geohydrologic maps, Madison aquifer (R. D. Feltis, w, Billings)
  - Ground water, Swan-Avon Valleys (K. R. Wilke)
  - Tongue River inflow (R. D. Hutchison)
- Nebraska, test-drilling data collection (C. F. Keech, w, Lincoln)
- Nevada (w, Carson City):
  - Fort McDermitt ground water (J. R. Harrill)
  - Pumping effects on Devil's Hole (J. D. Larson)
  - Storage depletion, Las Vegas (J. R. Harrill)
  - Storage depletion, Pahrump Valley (J. R. Harrill)
- New Jersey (w, Trenton):
  - Digital model, Potomac-Raritan-Magothy (J. E. Luzier)
  - Geohydrology, aquifer system (G. M. Farlekas)
  - Geohydrology, east-central New Jersey (G. M. Farlekas)
  - Mount Laurel-Wenonah Formations (Bronius Nemickas)
  - Pumpage inventory (William Kam)

Hydrology, ground water—Continued
States—Continued
New Mexico (w, Albuquerque, except as otherwise noted):
Effects of development in northwest New Mexico (F. P. Lyford)
Geothermal hydrology, Jemez Mountains (F. W. Trainer)
Hydrologic test sites (F. C. Koopman)
Lower Rio Grande valley (C. A. Wilson)
Navajo Indian Health Service (W. L. Hiss)
Roswell Basin, quantitative (G. E. Welder, w, Roswell)
Sandia-Manzano Mountains (J. B. Cooper)
Water resources, Mimbres Basin (J. S. McLean)
Water resources, Santa Fe (W. A. Mourant)
Water supply, Tijeras Canyon (J. D. Hudson)
New York, buried-channel aquifers, Albany (R. M. Waller, w, Albany)
North Carolina, ground water, Blue Ridge Parkway (M. D. Winner, w, Raleigh)
North Dakota (w, Bismarck, except as otherwise noted):
Ground water, Adams-Bowman Counties (M. G. Croft)
Ground-water availability, Fort Union coal (M. G. Croft)
Ground water, Benson-Pierce Counties (P. G. Randich)
Ground water, Cavalier-Pembina Counties (R. D. Hutchinson, w, Billings, Mont.)
Ground water, Emmons County (C. A. Armstrong)
Ground water, Griggs-Steele Counties (J. S. Downey)
Ground water, McHenry County (P. G. Randich)
Ground water, McIntosh County (R. L. Klausing)
Mining and reclamation, Dunn County (J. S. Downey)
Ohio, Dayton digital model (R. E. Fidler, w, Columbus)
Oklahoma, Ogallala model, Texas County (R. B. Morton, w, Oklahoma City)
Oregon (w, Portland):
Ground water, Clackamas County (A. R. Leonard)
Water resources, lower Santiam (A. R. Leonard)
Pennsylvania (w, Harrisburg, except as otherwise noted):
Geology and ground water, Pike County (L. D. Carswell)
Ground water, central Columbia County (O. B. Lloyd, Jr.)
Hydrology of Gettysburg Formation (C. R. Wood)
Hydrogeology of Great Valley (A. E. Becher)
Water levels and quality monitoring (W. C. Roth)
Rhode Island, ground water, Pawcatuck River basin (H. E. Johnston, w, Providence)
Hydrogeology, Erie County (G. R. Schiner, w, Meadville)
South Carolina (w, Columbia):
Capacity use study (A. L. Zack)
Low country capacity use study (L. R. Hayes)
South Dakota, water resources, Walworth County (Jack Kume, w, Vermillion)
Tennessee, ground-water appraisal, Tennessee region (D. R. Rima, w, Nashville)
Utah (w, Salt Lake City):
Bonneville Salt Flats (G. C. Lines)
Hydrology, Beaver Valley (R. W. Mower)

Hydrology, ground water—Continued
States—Continued
Utah (w, Salt Lake City)—Continued
Navajo Sandstone ground water (R. M. Cordova)
Reconnaissance, Dugway and Government Creeks (J. C. Stephens)
Spanish Valley ground-water model (J. H. Eychaner)
Virginia, Fairfax County urban-area study (R. H. Johnston, w, Fairfax)
Washington (w, Tacoma):
Kitsap Peninsula study (A. J. Hansen, Jr.)
Pullman (R. A. Barker)
Water data for coal mining (F. A. Packard)
West Virginia (w, Charleston):
Guyandotte River study (J. S. Bader)
Water resources, Gauley River basin (G. G. Wyrick)
Wisconsin (w, Madison):
Ground water, Dodge County (R. G. Borman)
Ground-water pollution in dolomite aquifer (M. G. Sherrill)
Wyoming (w, Cheyenne):
Bighorn Basin aquifers (M. E. Cooley)
Paleozoic hydrology, Powder River Basin (W. G. Hodson)

Hydrology, surface-water:
Atchafalaya River Basin model (M. E. Jennings, w, Bay St. Louis, Miss.)
Evaluation of low-flow runoff (W. D. Simons, w, M)
Hydrology defined by rainfall simulation (G. C. Lusby, w, D)
Modeling principles (J. P. Bennett, w, NC)
Water-quality-model development and implementation (R. A. Baltzer, w, NC)
States:
Alabama (w, Tuscaloosa):
Small-stream studies (D. A. Olin)
Travel-time studies (E. R. German)
Alaska, water resources fish sites (G. A. McCoy, w, Anchorage)
Arizona, 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)
Colorado (w, D):
Colorado streamflow statistics (J. F. McCain)
Hydraulics of minimum streamflow (H. E. Petsch, Jr.)
Delaware River master activity (F. T. Schaefer, w, Milford, Pa.)
Florida (w, Tampa, except as otherwise noted):
Hillsborough River basin water supply (J. F. Turner, Jr.)
Hydrograph simulation studies (J. F. Turner, Jr.)
Volusia wetlands delineation (P. W. Bush, w, Winter Park)
Georgia, small-area flood hydrology (H. G. Golden, w, Doraville)
Kansas (w, Lawrence):
Channel geometry (E. R. Hedman)
Flood investigations (H. R. Hejl, Jr.)
Soldier Creek (W. M. Kastner)
Streamflow characteristics (C. V. Burns)

Hydrology, surface-water—Continued
States—Continued
Louisiana (w, Baton Rouge):
Characteristics of streams (M. J. Forbes, Jr.)
Small-stream flood frequency (A. S. Lowe)
Minnesota, bridge site, project reports (L. C. Guetzkow, w, St. Paul)
Mississippi, wetlands hydrology (J. W. Hudson, w, Jackson)
Montana (w, Helena):
Bridge-site investigations (M. V. Johnson)
Peak flow, small drainage areas (M. V. Johnson)
New Jersey (w, Trenton):
Adjusted flow, Delaware River (S. J. Stankowski)
Basin characteristics in New Jersey (S. J. Stankowski)
Low-flow frequency (R. D. Schopp)
Tidal stage (A. A. Vickers)
North Carolina (w, Raleigh):
Channelization effects, Chicod Creek (C. P. Humphreys)
Stream-system modeling (F. E. Arteaga)
Ohio (w, Columbus):
Flood hydrology, small areas (E. E. Webber)
Hydraulics of bridge sites (R. I. Mayo)
Low flow of Ohio streams (R. I. Mayo)
Time-of-travel studies of Ohio streams (A. O. Westfall)
Pennsylvania, flow-routing, Lower Susquehanna Basin (J. T. Armbruster, w, Harrisburg)
South Carolina (w, Columbia):
Data reports, flood forecasting (H. H. Jeffcoat)
Low-flow characteristics (W. M. Bloxham)
South Dakota (w, Huron):
Flood-frequency study (L. D. Becker)
Small-stream flood frequency (L. D. Becker)
Tennessee (w, Nashville, except as otherwise noted):
Memphis urban flood frequency (C. W. Boning, w, Memphis)
Metro urban development alternatives (H. C. Wibben)
Small-stream modeling (H. C. Wibben)
Tennessee bridge scour (W. J. Randolph)
Texas (w, Austin, except as otherwise noted):
Hydrology of small drainage areas (E. E. Schroeder)
Small watersheds (R. D. Hawkinson)
Trinity River time-of-travel studies (R. H. Ollman, w, Fort Worth)
Washington (w, Tacoma):
Anadromous fish hydraulics (C. H. Swift III)
Low flow (P. J. Carpenter)
Nisqually Indian Reservation study (K. L. Walters)
Wisconsin (w, Madison):
Chippewa flowage operation analysis (W. R. Krug)
Flood-frequency study (D. H. Conger)
Low-flow study (W. A. Gebert)
Water-quality control (B. K. Holstrom)
See also Evapotranspiration; Flood investigations; Marine hydrology; Plant ecology; Urbanization, hydrologic effects.

Industrial minerals. *See specific minerals.*

Iron:
Resource studies, United States (Harry Klemic, NC)
States:
Michigan, Gogebic County, western part (R. G. Schmidt, NC)
Wisconsin, Black River Falls (Harry Klemic, NC)

Isotope and nuclear studies:
Instrument development (F. J. Jurceka, D)
Interface of isotope hydrology and hydrogeology (I. J. Winograd, w, NC)
Isotope fractionation (T. B. Coplen II, w, Laguna Niguel, Calif.)
Isotope ratios in rocks and minerals (Irving Friedman, D)
Isotopes in hydrology (C. T. Rightmire, w, NC)
Isotopic hydrology (F. J. Pearson, w, NC)
Lead isotopes and ore deposits (R. E. Zartman, D)
Mass spectrometry and isotopic measurements (J. S. Stacey, D)
Nuclear irradiation (G. M. Bunker, D)
Nuclear reactor facility (G. P. Kraker, Jr., w, D)
Radioisotope dilution (L. P. Greenland, NC)
Stable isotopes and ore genesis (R. O. Rye, D)
Upper mantle studies (Mitsunobu Tatsumoto, D)
See also Geochronological investigations; Geochemistry, water; Radioactive-waste disposal.

Land resources analysis:
Idaho, eastern Snake River Plain region (S. S. Oriel, D)

Land subsidence:
Geothermal subsidence research (B. E. Lofgren, w, Sacramento, Calif.)
Johnson Space Center artificial recharge (Sergio Garza, w, Austin, Tex.)
Land subsidence in the Known Potash Leasing Area of New Mexico (M. L. Millgate, c, Roswell)
Land subsidence studies (B. E. Lofgren, w, Sacramento, Calif.)

Land use and environmental impact:
Central Atlantic Regional Ecological Test Site (CARETS) Project (R. H. Alexander, l, NC)
Comparative urban land use analysis studies (J. R. Wray, l, NC)
Geographic Information Systems software development (W. B. Mitchell, l, NC)
Impact of the oil and gas industry on the Louisiana coast (D. W. Davis, J. L. Place, l, NC)
Land Use Data and Analysis Program and other geographic studies (G. L. Loelkes, R. E. Witmer, l, NC)

Lead, zinc, and silver:
Lead resources of United States (C. S. Bromfield, D)
Zinc resources of United States (Helmuth Wedow, Jr., Knoxville, Tenn.)
States:
Alaska, southwest Brooks Range (I. L. Tailleur, M)
Arizona, Lochiel and Nogales quadrangles (F. S. Simons, D)
Colorado (D):
San Juan Mountains, eastern, reconnaissance (W. N. Sharp)
San Juan Mountains, northwestern (F. S. Fisher)
Illinois-Kentucky district, regional structure and ore controls (D. M. Pinckney, D)

Lead, zinc, and silver—Continued
States—Continued
Nevada (M):
Comstock district (D. H. Whitebread)
Silver Peak Range (R. P. Ashley)
Utah, Park City district (C. S. Bromfield, D)

Limnology:
Colorado lakes reconnaissance (D. A. Wentz, w, D)
Hydrology of lakes (G. C. Bortleson, w, Tacoma, Wash.)
Hydrology of lakes in Wisconsin (R. W. Devaul, w, Madison, Wis.)
Impoundment water quality (D. R. Williams, w, Harrisburg, Pa.)
Interrelations of aquatic ecology and water quality (K. V. Slack, w, M)
Limnological study of Maine lakes (D. J. Cowing, w, Boston, Mass.)
Limnology of selected Ohio lakes (R. L. Tobin, w, Columbus, Ohio)
Oxygen cycle in streams (R. E. Rathbun, w, Bay St. Louis, Miss.)
Quality of water:
Lago Carraizo (Ferdinand Quiñones-Marquez, w, San Juan, P.R.)
Laguna Tortuguero (Ferdinand Quiñones-Marquez, w, San Juan, P.R.)
Relation of ground water to lakes (T. C. Winter, w, D)
Stream health, Chester County, Pa. (B. W. Lium, w, West Chester, Pa.)
Water quality of impoundments (J. L. Barker, w, Harrisburg, Pa.)
See also Quality of water.

Lunar geology. *See* Extraterrestrial studies.

Manganese. *See* Ferro-alloy metals.

Marine geology:
Atlantic Continental Shelf:
Environmental impact of petroleum exploration and production (H. J. Knebel, Woods Hole, Mass.)
Geophysical studies (J. C. Behrendt, Woods Hole, Mass.)
Magnetic chronology (E. M. Shoemaker, D. P. Elston, Flagstaff, Ariz.)
New England coastal zone (R. N. Oldale, Woods Hole, Mass.)
Resources (R. Q. Foote, NC)
Site surveys (W. P. Dillon, Woods Hole, Mass.)
Stratigraphy (J. C. Hathaway, Woods Hole, Mass.)
Stratigraphy and structure (J. S. Schlee, Woods Hole, Mass.)
Caribbean and Gulf of Mexico:
Coastal environments (H. L. Berryhill, Corpus Christi, Tex.)
Estuaries (C. W. Holmes, Corpus Christi, Tex.)
Mississippi delta studies (L. E. Garrison, Corpus Christi, Tex.)
Natural resources and tectonic features (R. G. Martin, Jr., Corpus Christi, Tex.)
Oil migration and diagenesis of sediments (C. W. Holmes, Corpus Christi, Tex.)
Tectonics, Caribbean (J. E. Case, Corpus Christi, Tex.)

Marine geology—Continued
Caribbean and Gulf of Mexico—Continued
Tectonics, Gulf (L. E. Garrison, Corpus Christi, Tex.)
Marine mineral resources, worldwide (F. H. Wang, M)
Outer Continental Basin studies (N. T. Edgar, R. Q. Foote, NC)
Pacific coast sedimentology (H. E. Clifton, M)
Pacific Ocean, biostratigraphy, deep ocean (J. D. Bukry, La Jolla, Calif.)
Pacific reef studies (J. I. Tracey, Jr., NC)
Spain, Spanish Continental Margin (Almeria Province) (P. D. Snavely, Jr., H. G. Greene, H. E. Clifton, W. P. Dillon, J. M. Robb, M)
Volcanic geology, Mariana and Caroline Islands (Gilbert Corwin, NC)
World offshore oil and gas (T. H. McCulloh, Seattle, Wash.)
States and territories:
Alaska (M, except as otherwise noted):
Arctic coastal marine processes (Erk Reimnitz)
Beaufort-Chuckchi Sea Continental Shelf (Arthur Grantz)
Beaufort Sea environment studies (P. W. Barnes)
Bering Sea (D. W. Scholl)
Bering Sea floor, northern (C. H. Nelson)
Coastal environments (A. T. Ovenshine)
Continental Shelf resources (D. M. Hopkins)
Cook Inlet (L. B. Magoon III)
Environmental geologic studies of northern Bering Sea (C. H. Nelson)
Gulf of Alaska (B. F. Molnia)
Seward Peninsula, nearshore (D. M. Hopkins)
Tectonic history (R. E. von Huene, NC)
California (M):
Borderlands, geologic framework (A. E. Roberts)
Borderlands, southern part (G. W. Moore)
Continental Margin. central part (E. A. Silver)
La Jolla marine geology laboratory (G. W. Moore)
Monterey Bay (H. G. Greene)
San Francisco Bay (D. S. McCulloch)
San Francisco Bay, geochemistry of sediments (D. H. Peterson)
Oregon, land-sea transect, Newport (P. D. Snavely, Jr., M)
Oregon-California, black sands (H. E. Clifton, M)
Oregon-Washington, nearshore (P. D. Snavely, Jr., M)
Puerto Rico, cooperative program (J. V. A. Trumbull, Santurce)
Texas, barrier islands (R. E. Hunter, Corpus Christi)

Marine hydrology:
Hydrologic-oceanographic (F. A. Kohout, w, Woods Hole, Mass.)
States and territories:
Maryland, effects of water-quality changes on biota in estuaries (R. L. Cory, w, NC)
North Carolina, flow of Chowan River (C. C. Daniel, w, Raleigh)
Puerto Rico, San Juan lagoons (S. R. Ellis, w, San Juan)
See also Hydrology, surface water; Quality of water; Geochemistry, water; Marine hydrology.

Mercury:
Geochemistry (A. P. Pierce, D)
Mercury deposits and resources (E. H. Bailey, M)
State:
California, Coast Range ultramafic rocks (E. H. Bailey, M)
Meteorites. *See* Extraterrestrial studies.
Mine drainage and hydrology:
Coal mining effects, Grapevine Creek (K. L. Dyer, w, Louisville, Ky.)
Effects of coal mining, Kentucky River (K. L. Dyer, w, Louisville, Ky.)
Metals and buffering in mine stream (W. J. Shampine, w, Indianapolis, Ind.)
Water from coal mines (D. S. Mull, w, Louisville, Ky.)
Mineral and fuel resources—compilations and topical studies:
Arctic mineral-resources investigations (W. P. Brosgé, M)
Basin and Range, geologic studies (F. G. Poole, D)
Colorado Plateau (R. P. Fischer, D)
Information bank, computerized (J. A. Calkins, NC)
Iron resources studies, United States (Harry Klemic, NC)
Lightweight-aggregate resources, United States (A. L. Bush, D)
Metallogenic maps, United States (P. W. Guild, NC)
Mineral-deposit controls, central States (A. V. Heyl, Jr., D)
Mineral-resource surveys:
Minerals for energy production (L. F. Rooney, NC)
Northern Wisconsin (C. E. Dutton, Madison)
Primitive and Wilderness Areas:
Bob Marshall Wilderness Area, Montana (R. L. Earhart, D)
Chama-South San Juan Study Area, Colorado (M. R. Brock, D)
Charles M. Russell Wildlife Range (C. A. Wolfbauer, D)
Charles Sheldon Antelope Range and Sheldon National Antelope Refuge (R. C. Greene, M)
Cougar Lakes-Mt. Aix Study Area, Washington (G. C. Simmons, D)
Flint Creek Range Study Area, Montana (G. E. Ericksen, NC)
Gros Ventre Wilderness Study Area, Wyoming (F. S. Simons, D)
Hells Canyon, Oregon-Idaho (G. C. Simmons, D)
Indian Peaks Area, Colorado (R. C. Pearson, D)
John Muir Wilderness, California (N. K. Huber, M)
Maroon Bells-Snowmass Wilderness Area, Colorado (V. L. Freeman, D)
Mill Creek, Peters Mountain, and Mountain Lake Study Areas, Virginia (F. G. Lesure, NC)
Minarets Wilderness Area and adjacent study area, California (N. K. Huber, M)
Mount Shasta Wilderness Study Area, California (R. L. Christiansen, M)
Ramseys Draft Study Area, Virginia, and Dolly Sods Wilderness, West Virginia (F. G. Lesure, NC)
Rawah Wilderness Area and nearby study areas, Colorado (R. C. Pearson, D)
Rock River Canyon Wilderness, Michigan (J. W. Whitlow, NC)
Sheep Mountain and Cucamonga Wilderness, California (J. G. Evans, M)

Mineral and fuel resources—compilations and topical studies —Continued
Mineral-resource surveys—Continued
Primitive and Wilderness Areas—Continued
Sheep Mountain, Wyoming (R. S. Houston, D)
Strawberry Mountain Study Area, Oregon (T. P. Thayer, NC)
Sturgeon River Gorge Wilderness, Michigan (W. F. Cannon, NC)
Superstition Wilderness, Arizona (D. W. Peterson, D)
Washakie Wilderness, Wyoming (J. C. Antweiler, D)
Southeastern United States (R. A. Laurence, Knoxville, Tenn.)
Nonmetallic deposits, mineralogy (B. M. Madsen, M)
Oil and gas resources:
Central and northern California Continental Shelf (C. W. Spencer, D)
Petroleum potential of southern California borderland appraised (C. W. Spencer, D)
Peat resources, northeastern States (C. C. Cameron, NC)
Resource analysis, economics of mineral resources (J. H. DeYoung, Jr., NC)
Wilderness Program:
Geochemical services (D. J. Grimes, D)
Geophysical services (M. F. Kane, D)
States:
Alaska (M, except as otherwise noted):
Mineral resources of Alaska (E. H. Cobb)
Southwestern Brooks Range (I. L. Tailleur)
Colorado, Summitville district, alteration study (R. E. Van Loenen, D)
Michigan, base and precious metals in Archean greenstones (W. C. Prinz, NC)
Nevada, igneous rocks and related ore deposits (M. L. Silberman, M)
Utah, mineral-resource maps (L. S. Hilpert, Salt Lake City)
See also specific minerals or fuels.
Mineralogy and crystallography, experimental:
Crystal chemistry (Malcolm Ross, NC)
Crystal structure, sulfides (H. T. Evans, Jr., NC)
Electrochemistry of minerals (Motoaki Sato, NC)
Mineralogical crystal chemistry (J. R. Clark, M)
Mineralogic services and research (R. C. Erd, M)
Mineralogy of heavy metals (F. A. Hildebrand, D)
Planetary mineralogical studies (Priestley Toulmin III, NC)
Research on ore minerals (B. F. Leonard, D)
See also Geochemistry, experimental.
Minor elements:
Geochemistry (George Phair, NC)
Niobium:
Colorado, Wet Mountains (R. L. Parker, D)
Niobium and tantalum, distribution in igneous rocks (David Gottfried, NC)
Phosphoria Formation, stratigraphy and resources (R. A. Gulbrandsen, M)
Nonpegmatic lithium resources (J. D. Vine, D)
Rare-earth elements, resources and geochemistry (J. W. Adams, D)
Trace-analysis methods, research (F. N. Ward, D)

Model studies, geologic and geophysical:
- Computer modeling of rock-water interactions (J. L. Haas, Jr., NC)
- Computer modeling, tectonic deformation (J. H. Dieterich, M)

Model studies, hydrologic:
- Alluvial fan deposition (W. E. Price, w, NC)
- Digital model, aquifer system (A. F. Robertson, w, Tampa, Fla.)
- Ground-water hydrology, strip mining areas (D. D. Knochenmus, w, Columbus, Ohio)
- Hydrodynamics of a tidal estuary (R. T. Cheng, w, M)
- Linear models (T. N. Keefer, w, Bay St. Louis, Miss.)
- Miocene aquifer study (E. T. Baker, Jr., w, Austin, Tex.)
- Numerical simulation (V. C. Lai, w, NC)
- Operation models, surface-water systems (M. E. Jennings, w, Bay St. Louis, Miss.)
- Physical modeling (V. R. Schneider, w, Bay St. Louis, Miss.)
- Runoff simulation (P. H. Carrigan, w, NC)
- Streamflow models (P. R. Jordan, w, Lawrence, Kans.)
- Surface-water-quality modeling (S. M. Zand-Yazdani, w, M)
- Systems Analysis Laboratory (N. C. Matalas, w, NC)
- Transport in ground water (L. F. Konikow, w, D)
- Water-quality modeling (D. B. Grove, w, D)
- Watershed modeling (J. F. Turner, w, Tampa, Fla.)
- *States:*
- California, Salinas ground-water model (T. J. Durbin, w, M)
- Colorado, Rocky Mountain Arsenal DIMP contamination (S. G. Robson, w, D)
- Florida:
  - Impact phosphate mining, Mid-Peace (W. E. Wilson, w, Tampa)
  - Loxahatchee River basin model (G. W. Hill, w, Miami)
- Indiana, Logansport ground-water study (D. C. Gillies, w, Indianapolis)
- New Jersey, Englishtown Formation (W. D. Nichols, w, Trenton)
- New York, Tioughnioga River ground water (R. M. Waller, w, Albany)
- Pennsylvania, flow simulation, Juniata River basin (J. T. Armbruster, w, Harrisburg)
- Tennessee, Memphis ground-water model (J. V. Brahana, w, Nashville)
- Washington, Columbia River basalt model (J. V. Tracy, w, Tacoma)
- Wyoming, hydrology of Sweetwater Basin (W. B. Borchert, w, Cheyenne)

Molybdenum. *See* Ferro-alloy metals.

Moon studies. *See* Extraterrestrial studies.

Nickel. *See* Ferro-alloy metals.

Nuclear explosions, geology:
- Engineering geophysics, Neveda Test Site (R. D. Carroll, D)
- Environmental effects (P. P. Orkild, D)
- Geologic investigations:
  - Computer-stored physical properties data (J. R. Ege, D)
  - Nevada Test Site:

Nuclear explosions, geology—Continued
    - Nevada, Test Site (P. P. Orkild, D)
    - Northern Yucca Flat and Pahute Mesa (W. D. Quinlivan, D)
    - Pahute Mesa and central and southern Yucca Flat (G. L. Dixon, D)
- Geomechanical investigations, Nevada Test Site (J. R. Ege, D)

Nuclear explosions, hydrology:
- Hydrology in nuclear-explosive underground engineering (J. E. Weir, Jr., w, D)
- Hydrology of Amchitka Island Test Site, Alaska (D. D. Gonzalez, w, D)
- Hydrology of Central Nevada Test Site (G. A. Dinwiddie, w, D)
- Hydrology of Nevada Test Site (W. W. Dudley, Jr., w, D)

Oil shale:
- Experimental mining, Piceance Creek basin, Rio Blanco County, Colorado (R. P. Snyder, D)
- Geochemistry, Colorado, Utah, and Wyoming (W. E. Dean, Jr., D)
- Organic geochemistry (R. E. Miller, D)
- Oil shale and associated minerals (J. L. Renner, c, D)
- Petrology (J. R. Dyni, D)
- *States:*
- Alaska, Anatuvuk Pass(G. B. Shearer, c, Anchorage)
- Colorado (D):
  - East-central Piceance Creek basin (R. B. O'Sullivan)
  - Lower Yellow Creek area (W. J. Hall)
  - Piceance Creek basin (J. R. Donnell)
- Utah (W. B. Cashion, Jr., D)
- Wyoming-Colorado, Eocene rocks (H. W. Roehler, D)

Paleobotany, systematic:
- Diatom studies (G. W. Andrews, NC)
- Floras:
  - Cenozoic, Pacific Northwest (J. A. Wolfe, M)
  - Cenozoic, Western United States and Alaska (J. A. Wolfe, M)
  - Devonian (J. M. Schopf, Columbus, Ohio)
  - Paleozoic (S. H. Mamay, NC)
- Fossil wood and general paleobotany (R. A. Scott, D)
- Plant microfossils:
  - Cenozoic (E. B. Leopold, D)
  - Mesozoic (R. H. Tschudy, D)
  - Paleozoic (R. M. Kosanke, D)

Paleoecology:
- Faunas, Late Pleistocene, Pacific coast (W. O. Addicott, M)
- Foraminifera, ecology (M. R. Todd, NC)
- Ostracodes, Recent, North Atlantic (J. E. Hazel, NC)
- Paleoenvironmental studies, Miocene, Atlantic Coastal Plain (T. G. Gibson, NC)
- Pollen, Recent distribution studies (E. B. Leopold, D)
- *Tempskya*, Southwestern United States (C. B. Read, Albuquerque, N. Mex.)
- Vertebrate faunas, Ryukyu Islands, biogeography (F. C. Whitmore, Jr., NC)

Paleontology, invertebrate, systematic:
- Brachiopods:
  - Carboniferous (Mackenzie Gordon, Jr., NC)
  - Ordovician (R. B. Neuman, NC; R. J. Ross, Jr., D)
  - Permian (R. E. Grant, NC)
  - Upper Paleozoic (J. T. Dutro, Jr., NC)

Paleontology, invertebrate, systematic—Continued
- Bryozoans:
  - Ordovician (O. L. Karklins, NC)
- Cephalopods:
  - Cretaceous (D. L. Jones, M)
  - Jurassic (R. W. Imlay, NC)
  - Upper Cretaceous (W. A. Cobban, D)
  - Upper Paleozoic (Mackenzie Gordon, Jr., NC)
- Chitinozoans, Lower Paleozoic (J. M. Schopf, Columbus, Ohio)
- Conodonts, Devonian and Mississippian (C. A. Sandberg, D)
- Corals, rugose:
  - Mississippian (W. J. Sando, NC)
  - Silurian-Devonian (W. A. Oliver, Jr., NC)
- Foraminifera:
  - Fusuline and orbitoline (R. C. Douglass, NC)
  - Cenozoic (M. R. Todd, NC)
  - Cenozoic, California and Alaska (P. J. Smith, M)
  - Mississippian (B. A. Skipp, D)
  - Recent, Atlantic shelf (T. G. Gibson, NC)
- Gastropods:
  - Mesozoic (N. F. Sohl, NC)
  - Miocene-Pliocene, Atlantic coast (T. G. Gibson, NC)
  - Paleozoic (E. L. Yochelson, NC)
- Graptolites, Ordovician-Silurian (R. J. Ross, Jr., D)
- Mollusks, Cenozoic, Pacific coast (W. A. Addicott, M)
- Ostracodes:
  - Lower Paleozoic (J. M. Berdan, NC)
  - Upper Cretaceous and Tertiary (J. E. Hazel, NC)
  - Upper Paleozoic (I. G. Sohn, NC)
- Pelecypods:
  - Inoceramids (D. L. Jones, M)
  - Jurassic (R. W. Imlay, NC)
  - Paleozoic (John Pojeta, Jr., NC)
  - Triassic (N. J. Silberling, M)
- Trilobites, Ordovician (R. J. Ross, Jr., D)

Paleontology, stratigraphic:
- Cenozoic:
  - Coastal plains, Atlantic and Gulf (Druid Wilson, NC)
  - Diatoms, Great Plains, nonmarine (G. W. Andrews, NC)
  - Foraminifera, smaller, Pacific Ocean and islands (M. R. Todd, NC)
  - Mollusks:
    - Atlantic coast, Miocene (T. G. Gibson, NC)
    - Pacific coast, Miocene (W. O. Addicott, M)
  - Pollen and spores, Kentucky (R. H. Tschudy, D)
  - Vertebrates:
    - Pleistocene (G. E. Lewis, D)
    - Atlantic coast (F. C. Whitmore, Jr., NC)
    - Pacific coast (C. A. Repenning, M)
    - Panama Canal Zone (F. C. Whitmore, Jr., NC)
- Mesozoic:
  - Pacific coast and Alaska (D. L. Jones, M)
  - Cretaceous:
    - Alaska (D. L. Jones, M)
    - Foraminifera:
      - Alaska (H. R. Bergquist, NC)
      - Atlantic and Gulf Coastal Plains (H. R. Bergquist, NC)
      - Pacific coast (R. L. Pierce, M)
    - Gulf Coast and Caribbean (N. F. Sohl, NC)
    - Molluscan faunas, Caribbean (N. F. Sohl, NC)

Paleontology, stratigraphic—Continued
- Mesozoic—Continued
  - Cretaceous—Continued
    - Western interior United States (W. A. Cobban, D)
  - Jurassic, North America (R. W. Imlay, NC)
  - Triassic, marine faunas and stratigraphy (N. J. Silberling, M)
- Paleozoic:
  - Devonian and Mississippian conodonts, Western United States (C. A. Sandberg, D)
  - Fusuline Foraminifera, Nevada (R. C. Douglass, NC)
  - Mississippian biostratigraphy, Alaska (A. K. Armstrong, M)
  - Onesquethaw Stage (Devonian), stratigraphy and rugose corals (W. A. Oliver, NC)
  - Paleobotany and coal studies, Antarctica (J. M. Schopf, Columbus, Ohio)
  - Palynology of cores from Naval Petroleum Reserve No. 4 (R. A. Scott, D)
  - Subsurface rocks, Florida (J. M. Berdan, NC)
  - Ordovician:
    - Bryozoans, Kentucky (O. L. Karklins, NC)
    - Stratigraphy and brachiopods, Eastern United States (R. B. Neuman, NC)
    - Western United States (R. J. Ross, Jr., D)
  - Silurian-Devonian:
    - Corals, northeast United States (W. A. Oliver, Jr., NC)
    - Upper Silurian-Lower Devonian, Eastern United States (J. M. Berdan, NC)
  - Mississippian:
    - Stratigraphy and brachiopods, northern Rocky Mountains and Alaska (J. T. Dutro, Jr., NC)
    - Stratigraphy and corals, northern Rocky Mountains (W. J. Sando, NC)
  - Pennsylvanian:
    - Fusulinidae:
      - Alaska (R. C. Douglass, NC)
      - North-central Texas (D. A. Myers, D)
    - Spores and pollen, Kentucky (R. M. Kosanke, D)
  - Permian:
    - Floras, Southwestern United States (S. H. Mamay, NC)
    - Stratigraphy and brachiopods:
      - Alaska (R. E. Grant, NC)
      - Southwestern United States (R. E. Grant, NC)
  - Upper Paleozoic, Western States (Mackenzie Gordon, Jr., NC)

Paleontology, vertebrate, systematic:
- Artiodactyls, primitive (F. C. Whitmore, Jr., NC)
- Pinnipedia (C. A. Repenning, M)
- Pleistocene fauna, Big Bone Lick, Ky. (F. C. Whitmore, Jr., NC)
- Tritylodonts, American (G. E. Lewis, D)

Paleotectonic maps. *See* Regional studies and compilations.

Petroleum and natural gas:
- Automatic data processing system for field and reservoir estimates (K. A. Yenne, c, Los Angeles, Calif.)
- Methods of recovery (F. W. Stead, D)
- Oil and gas map, North America (W. W. Mallory, D)

Petroleum and natural gas—Continued
Oil and gas resource appraisal methodology and procedures (B. M. Miller, D)
Organic geochemistry (J. G. Palacas, D)
Origin, migration, and accumulation of petroleum (L. C. Price, D)
Petroleum prospecting with helium detector (A. A. Roberts, D)
Rocky Mountain States, seismic detection of stratigraphic traps (R. T. Ryder, D)
Western United States:
Devonian and Mississippian (C. A. Sandberg, D)
Devonian and Mississippian flysch source-rock studies (F. G. Poole, D)
Properties of reservoir rocks (R. F. Mast, D)
Source rocks of Permian age (E. K. Maughan, D)
Williston basin, Wyoming, Montana, North Dakota, South Dakota (C. A. Sandberg, D)
World petroleum-resource evaluation (A. B. Coury, D)
States:
Alaska (M):
Cook Inlet (L. B. Magoon III)
North Slope, petroleum geology (R. D. Carter)
California (M, except as otherwise noted):
Carpenteria and Hondo-Santa Ynez fields reserves, OCS (D. G. Griggs, c, Los Angeles)
Eastern Los Angeles basin (T. H. McCulloh, Seattle, Wash.)
Salinas Valley (D. L. Durham)
Southern San Joaquin Valley, subsurface geology (J. C. Maher)
Colorado (c, D, except as otherwise noted):
Citadel Plateau (G. A. Izett)
Denver Basin, Tertiary coal zone and associated strata (P. A. Soister)
Grand Junction 2-degree quadrangle (W. B. Cashion, D)
Savery quadrangle (C. S. V. Barclay)
Montana:
Bearpaw Mountains area (B. C. Hearn, Jr., NC)
Decker quadrangle (B. E. Law, c, D)
New Mexico, San Juan basin (E. R. Landis, D)
Utah (c, D, except as otherwise noted):
Canaan Peak quadrangle (W. E. Bowers)
Collet Top quadrangle (H. D. Zeller)
Grand Junction 2-degree quadrangle (W. B. Cashion, D)
Wyoming:
Browns Hill quadrangle (C. S. V. Barclay, c, D)
Lander area phosphate reserve (W. L. Rohrer, c, D)
Oil Mountain quadrangle (G. J. Kerns, c, Casper)
Poison Spider quadrangle (G. J. Kerns, c, Casper)
Reid Canyon quadrangle (G. J. Kerns, c, Casper)
Savery quadrangle (C. S. V. Barclay, c, D)
Square Top Butte quadrangle (W. H. Laraway, c, Casper)
Stratigraphy, Frontier Formation, northeastern Wyoming (E. A. Merewether, D)

Petrology. *See* Geochemistry and petrology, field studies.

Phosphate:
Phosphoria Formation, stratigraphy and resources (R. A. Gulbrandsen, M)

Phosphate—Continued
Southeastern United States, phosphate resources (J. B. Cathcart, D)
States:
Alaska, Anatuvuk Pass (R. B. Sanders, c, Anchorage)
Florida, land-pebble phosphate deposits (J. B. Cathcart, D)
Idaho:
Palisades Dam quadrangle (D. A. Jobin, c, D)
Phosphate resources (Peter Oberlindacher, c, M)
Montana, Melrose phosphate field (G. D. Fraser, c, D)
Nevada:
Phosphate resources (E. A. Johnson, c, M)
Spruce Mountain 4 quadrangle (G. D. Fraser, c, D)
Utah:
Crawford Mountains (W. C. Gere, c, M)
Ogden 4 NW quadrangle (R. J. Hite, c, D)
Wyoming (c, D, except as otherwise noted):
Alpine quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Bull Creek quadrangle (M. L. Schroeder)
Camp Davis quadrangle (M. L. Schroeder)
Crawford Mountains phosphate deposits (W. C. Gere, c, M)
Pickle Pass quadrangle (D. A. Jobin)
Pine Creek quadrangle (D. A. Jobin)

Plant ecology:
Vegetation and hydrology (R. S. Sigafoos, w, NC)
Periodic plant-growth phenomena and hydrology (R. L. Phipps, w, NC)
See also Evapotranspiration; Geochronological investigations; Limnology.

Platinum:
Mineralogy and occurrence (G. A. Desborough, D)
States:
Montana, Stillwater complex (N. J Page, M)
Wyoming, Medicine Bow Mountains (M. E. McCallum, Fort Collins, Colo.)

Potash:
Arizona, Patagonia area (J. A. Crowley, c, M)
California, potash resources (J. A. Crowley, c, M)
Colorado and Utah, Paradox basin (O. B. Raup, D)
Nevada, alunite (J. A. Crowley, c, M)
New Mexico:
Carlsbad, potash and other saline deposits (C. L. Jones, M)
Southeastern, distribution map of potash deposits (P. C. Aguilar, R. J. Cheeseman, E. T. Sandell, c, Roswell)

Primitive areas. *See under* Mineral and fuel resources—compilations and topical studies, mineral-resource surveys.

Public and industrial water supplies. *See* Quality of water; Water resources.

Quality of water:
Bedload samplers (D. W. Hubbell, w, D)
Chemistry of New Zealand waters (I. K. Barnes, w, M)
Development of biological methods (B. W. Lium, w, Atlanta, Ga.)
Environmental impact statement, Youngs Creek Mine, Montana (C. W. Lane, w, D)
Geochemical kinetics studies (H. C. Claassen, w, D)
Geochemistry, Western coal region (G. L. Feder, w, D)
Heat transfer (H. E. Jobson, w, Bay St. Louis, Miss.)

Quality of water—Continued
Identification of organics in water (M. C. Goldberg, w, D)
Methods coordination (M. W. Skougstad, w, D)
Modeling mineral-water reactions (L. N. Plummer, w, NC)
Natural water quality (D. A. Rickert, w, Portland, Oreg.)
Organics in oil-shale residues (J. A. Leenheer, w, D)
Pesticide monitoring network (R. J. Pickering, w, NC)
Radioanalytical methods (L. L. Thatcher, w, D)
Radiochemical network (R. J. Pickering, w, NC)
Stream temperature patterns (E. J. Pluhowski, w, NC)
Thermal pollution (G. E. Harbeck, Jr., w, D)
Toxic substances in aquatic ecosystems (H. V. Leland, w, M)
Trace-element availability in sediments (E. A. Jenne, w, M)
Transport in ground water (L. F. Konikow, w, D)
Water-quality-data evaluation (W. H. Doyle, Jr., w, Salt Lake City, Utah)
States:
Alabama (w, Tuscaloosa):
Water problems in coal-mine areas (A. L. Knight)
Water resources in oil fields (W. J. Powell)
Arkansas, waste-assimilation capacity (C. T. Bryant, w, Little Rock)
California:
Ground-water quality, Barstow (J. L. Hughes, w, Laguna Niguel)
Hydrology, Sagehen Creek (R. G. Simpson, w, Sacramento)
Nitrate and nitrogen isotope study (J. M. Klein, w, Laguna Niguel)
Quality of water, California streams (G. A. Irwin, w, M)
Santa Maria water quality (J. L. Hughes, w, Laguna Niguel)
Thermograph network evaluation (J. T. Limerinos, w, M)
Colorado (w, D):
Effects of feedlots on ground water (S. G. Robson)
Effects of sludge on ground water (S. G. Robson)
Yampa Valley ground-water reconnaissance (W. E. Hofstra)
Florida:
Contaminants, Broward County (B. G. Waller, w, Miami)
Deep-well waste injection (C. A. Pascale, w, Tallahassee)
Environmental studes, statewide (D. A. Goolsby, w, Tallahassee)
Florida barge canal water quality (A. G. Lamonds, Jr., w, Winter Park)
Injection wells, Santa Rosa County (C. A. Pascale, w, Tallahassee)
Lakes Faith, Hope, and Charity (A. G. Lamonds, Jr., w, Winter Park)
Storm water quality, south Florida (H. C. Mattraw, Jr., w, Miami)
Subsurface waste storage (G. L. Faulkner, w, Tallahassee)
Water quality, Broward County (C. B. Sherwood, Jr., w, Miami)

Quality of water—Continued
States—Continued
Florida—Continued
Water quality, South New River Channel (B. G. Waller, w, Miami)
Hawaii, surface-water-quality monitoring network (J. S. Yee, w, Honolulu)
Illinois (w, Champaign):
Mine drainage in Illinois (L. G. Toler)
Quality-of-water monitoring, Fulton County (L. G. Toler)
Indiana (w, Indianapolis):
Landfill monitoring, Marion County (J. R. Marie)
Stream temperature study (W. J. Shampine)
Watershed water quality (M. A. Ayers)
Kansas (w, Lawrence):
Saline discharge, Smoky Hill River (J. B. Gillespie)
South Fork, Ninnescah River basin (A. M. Diaz)
Kentucky, effects of coal mining, Kentucky River (K. L. Dyer, w, Louisville)
Louisiana (w, Baton Rouge):
Pollution capacity of streams (D. E. Everett)
Quality of lower Mississippi River (F. C. Wells)
Water quality, Atchafalaya Basin (F. C. Wells)
Nebraska, ground-water quality (R. A. Engberg, w, Lincoln)
Nevada (w, Carson City):
Ground-water conditions, gasoline contamination (J. R. Harrill)
Ground-water contamination by explosives wastes (A. S. Van Denburgh)
Pond seepage, Weed Heights (J. R. Harrill)
Topical quality of water studies, Nevada (J. P. Monis)
New Hampshire, eutrophication, Lake Winnisquam (W. D. Silvey, w, Concord)
New Jersey (w, Trenton):
Channel geometry, New Jersey streams (E. A. Pustay)
Waste-water reclamation (William Kam)
New Mexico, Malaga Bend evaluation (C. C. Cranston, w, Carlsbad)
New York (w, Albany):
Biology of landfill leaching (T. A. Ehlke)
Public water supply, New York State (D. F. Farrell)
Transport of heavy metals at Waterford (J. T. Turk)
North Dakota, mining effects, Gascoyne area (M. G. Croft, w, Bismarck)
Ohio, acid-mine-drainage characterization (C. G. Angelo, w, Columbus)
Oregon (w, Portland):
GOES water-data system (G. L. Gallino)
Portland water-quality study (S. W. McKenzie)
Pennsylvania (w, Harrisburg):
Anthracite mine discharge (D. J. Growitz)
Ground-water quality in Pennsylvania (C. W. Poth)
Lakes, eastern Pennsylvania (J. L. Barker)
Water quality in Tioga River basin (J. R. Ward)
South Carolina, Savannah River plant (D. I. Cahal, w, Columbia)
Tennessee, burial-ground studies at Oak Ridge National Laboratory (D. A. Webster, w, Knoxville)

Quality of water—Continued
States—Continued
Texas, Colorado River salinity (Jack Rawson, w, Austin)
Utah (w, Salt Lake City):
Reconnaissance of Utah coal fields (K. M. Waddell)
Surface-water quality, Dirty Devil River basin (J. C. Mundorff)
Virginia, quality of ground waters (S. M. Rogers, w, Richmond)
Washington, waste effects, coastal waters (W. L. Haushild, w, Tacoma)
Wisconsin (w, Madison):
Irrigation and ground-water quality (S. M. Hindall)
Nederlo Creek biota (P. A. Kammerer, Jr.)
Stream reaeration (R. S. Grant)
Wyoming, North Platte reservoirs (S. J. Rucker IV, w, Cheyenne)
See also Geochemistry; Hydrologic instrumentation; Hydrology, surface water; Limnology; Marine hydrology; Sedimentology; Water resources.

Quicksilver. *See* Mercury.

Radioactive materials, transport in water. *See* Geochemistry, water.

Radioactive-waste disposal:
Hydrology of nuclear landfill (A. D. Randall, w, Albany, N.Y.)
Hydrology of salt domes (R. L. Hosman, w, Baton Rouge, La.)
National Overview Atlas (J. P. Ohl, D)
Pierre Shale (G. W. Shurr, D)
Radioactive byproducts in salt (J. W. Mercer, w, Albuquerque, N. Mex.)
Radioactive-waste burial (George DeBuchananne, w, NC)
Radioactive-waste-burial study (J. M. Cahill, w, Columbia, S.C.)
Radiohydrology technical coordination (George DeBuchananne, w, NC)
Waste-disposal sites (S. S. Papadopulos, w, NC)
States:
Idaho, National Reactor Testing Station, hydrology of subsurface waste disposal (J. T. Barraclough, w, Idaho Falls)
Kentucky, Maxey Flats investigation (H. H. Zehner, w, Louisville)
Nevada, Nevada Test Site (D. L. Hoover, D)
New Mexico (D):
Eddy and Lea Counties, exploratory drilling (C. L. Jones)
Southeastern, waste emplacement (C. L. Jones)
Utah (D):
Paradox Basin (L. M. Gard)
Salt Valley anticline (L. M. Gard)
See also Geochemistry, water.

Rare-earth metals. *See* Minor elements.

Regional studies and compilations, large areas of the United States:
Basement rock map (R. W. Bayley, M)
Paleotectonic map folios:
Devonian System (E. G. Sable, D)
Mississippian System (L. C. Craig, D)
Pennsylvanian System (E. D. McKee, D)
Volcanic rocks of the Appalachians (D. W. Rankin, NC)

Remote sensing:
Geologic applications:
Airborne and satellite research:
Aeromagnetic studies (M. F. Kane, D)
Development of an automatic analog earthquake processor (J. P. Eaton, M)
Electromagnetic research (F. C. Frischknecht, D)
Fraunhofer line discriminator studies (R. D. Watson, D)
Gamma radioactivity studies (J. A. Pitkin, D)
Geochemical plant stress (F. C. Canney, D)
Geothermal resources (Kenneth Watson, D)
Infrared surveillance of volcanoes (J. D. Friedman, D)
Interpretation studies (R. H. Henderson, NC)
Linear features of the conterminous United States (W. D. Carter, l, NC)
National aeromagnetic survey (J. R. Henderson, D)
Remote sensing geophysics (Kenneth Watson, D)
Satellite magnetometry (R. D. Regan, NC)
Surficial and thematic mapping (T. N. V. Karlstrom, Flagstaff, Ariz.)
Terrain mapping from Skylab data (H. W. Smedes, D)
Urban geologic studies (T. W. Offield, D)
Volcanic gas monitoring (Motoaki Sato, NC)
High-resolution film recording system (George Harris, l, Sioux Falls, S. Dak.)
Landsat-1 experiments:
CARETS, a prototype regional environmental information system (R. H. Alexander, l, NC)
Computer mapping of terrain using multispectral data, Yellowstone National Park (H. W. Smedes, D)
Effects of the atmosphere on multispectral mapping of rock type by computer, Cripple Creek-Canon City, Colo. (H. W. Smedes, D)
Evaluation of Great Plains area (R. B. Morrison, D)
Experimental digital enhancement of Landsat images and CCT's (George Harris, l, Sioux Falls, S. Dak.)
Geologic mapping, South America (W. D. Carter, l, NC)
Investigations of the Basin and Range-Colorado Plateau boundary, Arizona (D. P. Elston, Ivo Lucchitta, Flagstaff, Ariz.)
Iron-absorption band analysis for the discrimination of iron-rich zones (L. C. Rowan, NC)
Landsat imagery and DCS to relate water depth to observed area of inundation of coastal marshes (G. A. Thorley, W. Herke, l, NC)
Monitoring changing geologic features, Texas Gulf Coast (R. B. Hunter, Corpus Christi, Tex.)
Morphology, provenance, and movement of desert and seas in Africa, Asia, and Australia (E. D. McKee, D)

Remote sensing—Continued

Geologic applications—Continued

Landsat-1 experiments—Continued

North-central Arizona Test Site (D. P. Elston, Flagstaff, Ariz.)

Post-1890 A.D. episode erosion, Arizona Regional Ecological Test Site (R. B. Morrison, D)

Prototype volcano surveillance network (J. P. Eaton, M)

Remote sensing of permafrost and geologic hazards in Alaska (O. J. Ferrians, Jr., M)

Structural, volcanic, glaciologic, and vegetation mapping, Iceland (R. S. Williams, Jr., l, NC)

Studies of the inner shelf and coastal sedimentation environment of the Beaufort Sea (Erk Reimnitz, M)

Study of multispectral imagery, northwestern Saudi Arabia (A. J. Bodenlos, NC)

Suspended particulate matter in nearshore surface waters, northeast Pacific Ocean and the Hawaiian Islands (P. R. Carlson, M)

Thermal surveillance of active volcanoes (J. D. Friedman, NC)

Landsat-2 experiments, mineral-resource inventory and exploration, Andes Mountains (W. D. Carter, l, NC)

Monitoring weather parameters for the High Plains Cooperative Program with Landsat DCS (G. A. Thorley, A. M. Kahn, l, NC)

Skylab/EREP studies:

Evaluation of Great Plains area (R. B. Morrison, D)

Marine and coastal processes on the Puerto Rico-Virgin Islands Platform (J. V. A. Trumbull, Santurce, P.R.)

Remote sensing geophysics (Kenneth Watson, D)

Urban and regional land-use analysis—CARETS and census cities experiment (R. H. Alexander, l, NC)

Skylab/visual observations:

Desert sand seas (E. D. McKee, D; C. S. Breed, Flagstaff, Ariz.)

Volcanologic features (J. D. Friedman, D)

Targeting of mineral-exploration effort (J. V. Taranik, l, Sioux Falls, S. Dak.)

Time-lapse satellite data for monitoring dynamic hydrologic phenomena (Morris Deutsch, S. Serebreny, l, NC)

Hydrologic applications:

Arctic Ice Dynamics Joint Experiment (H. E. Skibitzke, w, Prescott, Ariz.)

Arizona Test Site (H. H. Schumann, w, Phoenix)

Basin precipitation from satellite data (Morris Deutsch, P. A. Davis, l, NC)

Delineation of shallow glacial drift aquifers in eastern South Dakota (Morris Deutsch, P. Rahn, l, NC)

Remote sensing—Continued

Hydrologic applications—Continued

Detection of oil on marine waters using Landsat data (Morris Deutsch, l, NC)

Flood and flood-plain analysis (J. V. Taranik, l, Sioux Falls, S. Dak.)

GOES, Juniata basin, Pennsylvania (C. D. Kauffman, Jr., w, Harrisburg, Pa.)

Image-map atlas of the Lake Ontario basin (Morris Deutsch, A. Falconer, l, NC)

Landsat, south Florida (A. L. Higer, w, Miami, Fla.)

Landsat data for ground-water exploration (Morris Deutsch, l, NC)

Microwave remote sensing (G. K. Moore, w, Bay St. Louis, Miss.)

Optical enhancement of Landsat imagery for hydrogeological appraisal, north Yemen (Morris Deutsch, l, NC)

Polar-ice remote sensing (W. J. Campbell, w, Tacoma, Wash.)

Remote sensing of Elephant Butte-Fort Quitman Project (G. A. Thorley, D. Mach, l, NC)

Remote sensing techniques (E. J. Pluhowski, w, NC)

Remote sensing, wetlands (V. P. Carter, w, NC)

States:

Arizona, snowcover mapping (H. H. Schumann, w, Phoenix)

Connecticut, Connecticut River estuary (F. H. Ruggles, Jr., w, Hartford)

Land-resources applications:

Agricultural inventory demonstration project (W. H. Anderson, l, Sioux Falls, S. Dak.)

Applications of Landsat imagery to land systems mapping, Australia (C. J. Robinove, l, NC)

Colorado River natural resources and land-use data acquisition (G. A. Thorley, R. L. Hansen, l, NC)

Forest defoliation mapping and damage assessment (W. G. Rohde, l, Sioux Falls, S. Datk.)

Forest land classification and assessment of forest succession (W. G. Rohde, l, Sioux Falls, S. Dak.)

Impact of strip mining on range resources and wildlife habitat (D. M. Carneggie, l, Sioux Falls, S. Dak.)

Investigation of remote sensing techniques to assess agricultural drainage (G. A. Thorley, W. A. Lidester, l, NC)

Landsat imagery for aiding objectives of the IFYGL (Morris Deutsch, A. Falconer, l, NC)

Landsat imagery for archaeological resource inventory and management potential in Chaco Canyon National Monument, New Mexico (G. A. Thorley, T. R. Lyons, l, NC)

Repetitive satellite imagery for the delineation and monitoring of State/Federal Recreation Research Management Zones (G. A. Thorley, B. J. Niemann, Jr., l, NC)

South Dakota Cooperative Land Use Demonstration Project (D. R. Hood, l, Sioux Falls, S. Dak.)

Remote sensing—Continued

Land-resources applications—Continued

Spatial importance of open space and recreational facilities in urban environments (G. A. Thorley, W. H. Key, l, NC)

Reservoirs. *See* Evapotranspiration; Sedimentology.

Resources and land investigations:

Colville Indian Reservation case study on land-use planning (E. T. Smith, l, NC)

Council of State Governments:

Federal/State communication of data needs (J. T. O'Connor, l, NC)

Data and information product evaluation (J. T. O'Connor, l, NC)

Designation of critical environmental areas (E. A. Imhoff, l, NC)

Directory to sources of natural sciences information, U.S. Department of the Interior (E. T. Smith, l, NC)

Directory to U.S. Geological Survey program activities in coastal areas, 1974–75 (P. A. Marcus, l, NC)

Environmental modeling case study, Campbell County, Wyoming (E. T. Smith, l, NC)

Environmental planning and Western coal development (E. T. Smith, l, NC)

Methodology for siting onshore facilities associated with OCS development in the New England region (W. W. Doyel, l, NC)

Mined-area reclamation and related land-use planning (E. A. Imhoff, l, NC)

National Environmental Indicators report (E. T. Smith, l, NC)

Regional workshops related to RALI-funded methodological guidebooks (J. R. Jones, l, NC)

South Florida environment (T. J. Buchanan, w, Miami)

State land inventory systems (Olaf Kays, l, NC)

Rhenium. *See* Minor elements; Ferro-alloy metals.

Saline minerals:

Mineralogy (B. M. Madsen, M)

States:

Colorado and Utah, Paradox Basin (O. B. Raup, D)

New Mexico, Carlsbad potash and other saline deposits (C. L. Jones, M)

Wyoming, Sweetwater County, Green River Formation (W. C. Culbertson, D)

Saltwater intrusion. *See* Marine hydrology; Quality of water.

Sedimentology:

Arctic fluvial processes, landforms (K. M. Scott, w, Laguna Niguel, Calif.)

Bedload-transport research (W. W. Emmett, w, Boise, Idaho)

Channel morphology (L. B. Leopold, w, Berkeley, Calif.)

Coon Creek morphology (S. W. Trimble, w, NC)

Estimation of sediment yield (P. R. Jordan, w, Lawrence, Kans.)

Estuarine intertidal environments (J. L. Glenn, w, D)

Measurement of sediment-laden flows (H. H. Barnes, w, NC)

Nemadji River sediment study (S. M. Hindall, w, Madison, Wis.)

Petrology Laboratory (L. G. Schultz, D)

Sediment characteristics (L. M. Nelson, w, Tacoma, Wash.)

Sediment-hillside morphology (G. P. Williams, w, D)

Sedimentology—Continued

Sediment movement in rivers (R. H. Meade, Jr., w, D)

Sediment transport phenomena (D. W. Hubbell, w, D)

Transport processes (C. F. Nordin, w, D)

States:

Alaska, coastal environments (A. T. Ovenshine, M)

California (w, M):

San Francisco Bay, circulation (T. J. Conomos)

Santa Margarita reservoir sediment (J. M. Knott)

Sediment, Feather River (George Porterfield)

Idaho, Snake and Clearwater Rivers, sediment (W. W. Emmett, w, Boise)

Kansas (w, Lawrence):

Sediment and geometry of channels (W. R. Osterkamp)

Sediment, Arkansas River (W. R. Osterkamp)

Kentucky, sediment yields (W. F. Curtis, w, Pikesville)

Louisiana, sediment in Lake Verret basin (L. D. Fayard, w, Baton Rouge)

Minnesota, red clay sediment and quality-of-water evaluation (E. G. Giacomini, w, St. Paul)

Pennsylvania (w, Harrisburg):

Highway erosion-control measures (L. A. Reed)

Predicting sediment flow (L. A. Reed)

Study of cobble bed streams (J. R. Ritter)

Tennessee, coal-mining study, New River (R. S. Parker, w, Nashville)

See also Geochemistry, water; Geochronological investigations; Hydraulics, surface flow; Hydrologic data collection and processing; Stratigraphy and sedimentation; Urbanization, hydrologic effects.

Selenium. *See* Minor elements.

Silver. *See* Heavy metals; Lead, zinc, and silver.

Soil moisture:

Effects of grazing exclusion (G. C. Lusby, w, D)

Effects of vegetation changes (G. C. Lusby, w, D)

Infiltration and drainage (Jacob Rubin, w, M)

See also Evapotranspiration.

Spectroscopy:

Mobile spectrographic laboratory (D. J. Grimes, D)

Spectrographic analytical services and research (A. W. Helz, NC; A. T. Myers, D; Harry Bastron, M)

X-ray spectroscopy (H. J. Rose, Jr., NC; Harry Bastron, M)

Stratigraphy and sedimentation:

Antler flysch, Western United States (F. G. Poole, D)

East coast Continental Shelf and margin (R. H. Meade, Jr., Woods Hole, Mass.)

Indian Trail Formation, abandonment of name (G. L. Dixon, D)

Louisiana Continental Shelf (H. L. Berryhill, Jr., Corpus Christi, Tex.)

Middle and late Tertiary history, Northern Rocky Mountains and Great Plains (N. M. Denson, D)

Pennsylvanian System stratotype section (G. H. Wood, Jr., NC)

Permian, Western United States (E. K. Maughan, D)

Phosphoria Formation, stratigraphy and resources (R. A. Gulbrandsen, M)

Rocky Mountains and Great Basin, Devonian and Mississippian conodont biostratigraphy (C. A. Sandberg, D)

Sedimentary structures, model studies (E. D. McKee, D)

Stratigraphy and sedimentation—Continued
Williston basin, Wyoming, Montana, North Dakota, South Dakota (C. A. Sandberg, D)

States:
Alaska, Cretaceous (D. L. Jones, M)
Arizona:
Hermit and Supai Formations (E. D. McKee, D)
Magnetic chronology, Colorado Plateau and environs (D. P. Elston, E. M. Shoemaker, Flagstaff)
Arizona-New Mexico, paleomagnetic correlation, Colorado Plateau (J. D. Strobell, Flagstaff, Ariz.)
California, southern San Joaquin Valley, subsurface geology (J. C. Maher, M)
Colorado, Jurassic stratigraphy (G. N. Pipiringos, D)
Florida-Alabama, stratigraphy (J. A. Miller, w, Raleigh, N.C.)
Montana, Ruby Range, Paleozoic rocks (E. T. Ruppel, D)
Nebraska, central Nebraska basin (G. E. Prichard, D)
New Mexico, western and adjacent areas, Cretaceous stratigraphy (E. R. Landis, D)
Oregon-California (M):
Black sands (H. E. Clifton)
Hydrologic investigations, black sands (P. D. Snavely, Jr.)
Utah, Promontory Point (R. B. Morrison, D)
Wyoming (D):
Lamont-Baroil area (M. W. Reynolds)
South-central part, Jurassic stratigraphy (G. N. Pipiringos)
See also Paleontology, stratigraphic; *specific areas under* Geologic mapping.

Structural geology and tectonics:
Contemporary coastal deformation (R. O. Castle, M)
East-trending lineaments, central Nevada (G. L. Dixon, D)
Rock behavior at high temperature and pressure (E. C. Robertson, NC)
Structural studies, basin and range (F. G. Poole, D)
Tectonics of southeast Arizona (Harold Drewes, D)
Transcurrent fault analysis, western Great Basin, Nevada-California (R. E. Anderson, D)
See also specific areas under Geologic mapping.

Talc:
New York, Pope Mills and Richville quadrangles (C. E. Brown, NC)

Tantalum. *See* Minor elements.

Thorium:
Analytical support (C. M. Bunker, D)
Investigations of thorium in igneous rocks (M. H. Staatz, D)
States:
Colorado (D):
Cochetopa area (J. C. Olson)
Thorium resources appraisal, Wet Mountains (T. J. Armbrustmacher)
Wyoming, Bear Lodge Mountains (M. H. Staatz, D)

Tungsten. *See* Ferro-alloy metals.

Uranium:
Basin analysis of uranium-bearing Jurassic rocks of Colorado Plateau, Arizona, Utah, Colorado, New Mexico (Fred Peterson, D)
Colorado Plateau tabular deposits, Colorado, New Mexico, Arizona, Utah (R. A. Brooks, D)

Uranium—Continued
Exploration techniques:
Geochemical techniques (R. A. Cadigan, D)
Geochemical techniques of halo uranium (J. K. Otton, D)
Morrison Formation (L. C. Craig, D)
Ore-forming processes (H. C. Granger, D)
Organic chemistry of uranium, Wyoming, Colorado, New Mexico, Utah, Texas (J. S. Leventhal, D)
Paleomagnetism applied to uranium exploration (R. L. Reynolds, D)
Precambrian sedimentary and metasedimentary rocks (F. A. Hills, D)
Radium and other isotopic disintegration products in springs and subsurface water (R. A. Cadigan, J. K. Felmlee, D)
Resources of radioactive minerals (A. P. Butler, Jr., D)
Resources of United States and world (W. I. Finch, D)
Roll-type deposits, Wyoming, Texas (E. N. Harshman, D)
Southern High Plains (W. I. Finch, D)
United States:
Eastern:
Appalachian Basin, Paleozoic rocks (A. F. Jacob, D)
Basin analysis as related to uranium potential in Triassic sedimentary rocks (C. E. Turner, D)
Uranium vein deposits (R. I. Grauch, D)
Southwestern, basin analysis related to uranium potential in Permian rocks (J. A. Campbell, D)
Western, relation of diagenesis and uranium deposits (M. B. Goldhaber, D)
Uranium daughter products in modern decaying plant remains, in soils, and in stream sediments (K. J. Wenrich-Verbeek, D)
Uranium potential of Basin and Range province, Arizona, Nevada, Utah (J. E. Peterson, D)
Uranium in streams as an exploration technique (K. J. Wenrich-Verbeek, D)
Volcanic source rocks (R. A. Zielinski, D)
States:
Arizona (R. E. Thaden, D)
Colorado (D):
Cochetopa Creek uranium-thorium area (J. C. Olson)
Marshall Pass uranium (J. C. Olson)
Schwartzwalder mine (E. J. Young)
Uranium-bearing Triassic rocks (R. D. Lupe)
New Mexico (D):
Acoma area (C. H. Maxwell)
Church Rock-Smith Lake (C. T. Pierson)
North Church Rock (A. R. Kirk)
San Juan Basin uranium (M. W. Green)
Sanostee (A. C. Huffman, Jr.)
Texas:
Coastal Plain, geophysical and geological studies (D. H. Eargle, Austin)
Tilden-Loma Alta area (K. A. Dickinson, D)
Uranium disequilibrium studies (F. E. Senftle, NC)
Utah, Green River mining district (H. H. Doelling, Utah Geological and Mineralogical Survey, Salt Lake City)
Utah-Colorado (D):
Moab quadrangle (A. P. Butler, Jr.)
Uinta and Piceance Creek basins (L. C. Craig)

Uranium—Continued

States—Continued

Wyoming (D):

- Badwater Creek (R. E. Thaden)
- Crooks Peak quadrangle (L. J. Schmitt, Jr.)
- Granite as a source rock of uranium (J. S. Stuckless, D)
- Northeastern Great Divide Basin (L. J. Schmitt, Jr.)
- Powder River Basin (E. S. Santos)
- Sagebrush Park quadrangle (L. J. Schmitt, Jr.)
- Stratigraphic analysis of Tertiary uranium basins of Wyoming (D. A. Seeland)
- Stratigraphic analysis of western interior Cretaceous uranium basins (H. W. Dodge, Jr.)

Urban geology:

Alaska (D):

- Anchorage area (Ernest Dobrovolny)
- Juneau area (R. D. Miller)
- Sitka area (L. A. Yehle)
- Small coastal communities (R. W. Lemke)

Arizona, Phoenix-Tucson region resources (T. G. Theodore, M)

California (M, except as otherwise noted):

- Coastal geologic processes (K. R. Lajoie)
- Earth science planning applications (W. J. Kockelman)
- Flatlands materials and their land-use significance (E. J. Helley)
- Geologic factors in open space (R. M. Gulliver)
- Hillside materials and their land-use significance (C. M. Wentworth, Jr.)
- Malibu Beach and Topanga quadrangles (R. F. Yerkes)
- Point Dume and Triunfo Pass quadrangles (R. H. Campbell)
- Quaternary framework for earthquake studies, Los Angeles Basin (J. C. Tinsley III)
- Regional slope stability (T. H. Nilsen)
- San Francisco Bay region, environment and resources planning study:
  - Bedrock geology (M. C. Blake)
  - Marine geology (D. S. McCulloch)
  - Open space (C. S. Danielson)
  - San Andreas fault, basement studies (D. C. Ross)
  - San Andreas fault, basin studies (J. A. Bartow)
  - San Andreas fault, regional framework (E. E. Brabb)
  - San Andreas fault, tectonic framework (R. D. Brown)
  - San Mateo County cooperative (H. D. Gower)
  - Sargent-Berrocal fault zone (R. J. McLaughlin, D. H. Sorg)
  - Seismicity and ground motion (W. B. Joyner)
- Southern:
  - Eastern part (D. M. Morton, Riverside)
  - Western part (R. F. Yerkes)

Colorado (D):

- Denver-Front Range urban corridor, remote sensing (T. W. Offield)
- Denver metropolitan area (R. M. Lindvall)

Urban geology—Continued

States—Continued

Colorado (D)—Continued

- Denver mountain soils (regolith), Front Range urban corridor (K. L. Pierce, P. W. Schmidt)
- Denver urban area, regional geochemistry (H. A. Tourtelot)
- Denver urban area study:
  - Geologic map, Boulder-Ft. Collins-Greeley area (R. B. Colton)
  - Geologic map, greater Denver area (D. E. Trimble)
  - Geologic map, Colorado Springs-Castle Rock area (W. R. Hansen)
  - Land-use classification, Colorado Front Range urban corridor (W. R. Hansen, L. B. Driscoll, D)
- Engineering geology mapping research, Denver region (H. E. Simpson)
- Terrain mapping from Skylab data (H. W. Smedes)

Connecticut (Middletown):

- Connecticut Valley urban area study:
  - Distribution of clay deposits (Fred Pessl, Jr.)
  - Depth to bedrock (Fred Pessl, Jr.)

Maryland, Baltimore-Washington urban area study (J. T. Hack, NC)

Massachusetts, Boston and vicinity (C. A. Kaye, Boston)

Minnesota, studies for tunneling construction, Minneapolis-St. Paul (R. F. Norvitch, w, St. Paul)

Montana, geology for planning, Helena region (R. G. Schmidt, NC)

New Mexico, geology of urban development (H. E. Malde, D)

Pennsylvania:

- Allegheny Group coal-zone outcrop, Armstrong, Beaver, and Butler Counties (K. O. Bushnell, Slippery Rock)
- Areas of subsidence due to coal mining (K. O. Bushnell, Slippery Rock)
- Coal-mining features, Allegheny County (W. E. Davies, NC)
- Impact of maps on municipal governments, Allegheny County (R. P. Briggs, Carnegie)
- Jointing in Pennsylvania rocks, central greater Pittsburgh region (W. R. Kohl, Carnegie)
- Land use affected by landsliding (R. P. Briggs, Carnegie)
- Large-scale linear features, southwestern Pennsylvania (R. P. Briggs, Carnegie)
- Pittsburgh coal bed outcrop (K. O. Bushnell, Slippery Rock)
- Rock types, Allegheny County (W. R. Kohl, Pittsburgh)
- Surface subsidence due to underground coal mining, Armstrong, Beaver, and Butler Counties (K. O. Bushnell, Slippery Rock)
- Susceptibility to landsliding, Allegheny County (J. S. Pomeroy, NC)
- Susceptibility to landsliding, Beaver, Butler, and Washington Counties (J. S. Pomeroy, NC)
- Upper Freeport coal bed outcrop (K. O. Bushnell, Slippery Rock)

Urban geology—Continued
States—Continued
Pennsylvania—Continued
Greater Pittsburgh regional studies (R. P. Briggs, Carnegie)
Limitations of land, Allegheny County (R. P. Briggs, Carnegie)
South Dakota, Rapid City area (J.M. Cattermole, D)
Utah, Salt Lake City and vicinity (Richard VanHorn, D)
Virginia, geohydrologic mapping of Fairfax County (A. J. Froelich, NC)
Urban hydrology:
Geohydrology, urban planning (H. G. O'Connor, w, Lawrence, Kans.)
Puget Sound urban area studies (B. L. Foxworthy, w, Tacoma, Wash.)
Urban area reconnaissance (W. E. Hale, w, Albuquerque, N. Mex.)
Urban runoff networks (H. H. Barnes, Jr., w, NC)
Urban sedimentology (H. P. Guy, w, NC)
States and territories:
Alabama, Jefferson County floodway evaluation (A. L. Knight, w, Tuscaloosa)
Arizona, Tucson-Phoenix urban area pilot study (E. S. Davidson, w, Tucson)
California:
Morphology, San Francisquito (J. R. Crippen, w, M)
Perris Valley (M. W. Busby, w, Laguna Niguel)
Poway Valley (J. A. Skrivan, w, Laguna Niguel)
San Francisco Bay area, urbanization (R. D. Brown, Jr., w, M)
Colorado:
Climatological atlases, Colorado Front Range urban corridor (W. R. Hansen, D)
Distribution and thickness of mountain soils (K. L. Pierce, D)
Flood frequency, urban areas (L. G. Ducret, Jr., w, D)
Front Range urban corridor (M. S. Bedinger, w, D)
Storm runoff quality, Denver (J. C. Briggs, w, D)
Connecticut:
Connecticut Valley urban area study (Fred Pessl, Jr., Middletown)
Connecticut Valley urban pilot study (R. L. Melvin, w, Hartford)
Drainage areas (Fred Pessl, Jr., Middletown)
Florida:
Bay Lake (A. L. Putnam, w, Winter Park)
Tampa Bay region (G. E. Seaburn, w, Tampa)
Hawaii, hydrology, sediment in Mauna Loa (C. J. Ewart, w, Honolulu)
Illinois, quality-of-water monitoring, Bloomington-Normal (B. J. Prugh, Jr., w, Champaign)
Iowa, flow models, Walnut Creek (O. G. Lara, w, Iowa City)
Kansas, urban runoff, Wichita (D. B. Richards, w, Lawrence)
Kentucky (w, Louisville):
Hydraulics of bridge sites (C. H. Hannum)
Water use and availability (D. C. Griffin)
Mississippi, bridge-site investigations (K. V. Wilson, w, Jackson)

Urban hydrology—Continued
States and territories—Continued
Missouri, stream hydrology, St. Louis (T. W. Alexander, w, Rolla)
North Carolina, urban hydrology, Charlotte (W. H. Eddins, w, Raleigh)
Ohio (P. W. Anttila, w, Columbus)
Oklahoma, urban hydrology, Enid (W. B. Mills, w, Oklahoma City)
Oregon, Portland rainfall-runoff study (Antonius Laenen, w, Portland)
Pennsylvania:
Availability of hydrologic data, greater Pittsburgh region (R. M. Beall, w, Carnegie)
Extreme-streamflow statistics, greater Pittsburgh region (M. B. Coll, Jr., w, Pittsburgh)
Philadelphia (T. G. Ross, w, Harrisburg)
Runoff, upper Ohio River Basin (R. M. Beall, w, Carnegie)
Storm-water measurements (T. G. Ross, w, Harrisburg)
Streamflow experience graphs, southwestern Pennsylvania (R. M. Beall, w, Carnegie)
Puerto Rico, Rio Piedras (Fernando Gomez-Gomez, w, San Juan)
South Carolina, hydraulic-site reports (B. H. Whetstone, w, Columbia)
Texas:
Austin (M. L. Maderak, w, Austin)
Dallas County urban study (B. B. Hampton, w, Fort Worth)
Dallas urban study (B. B. Hampton, w, Fort Worth)
Fort Worth urban study (R. M. Slade, Jr., w, Fort Worth)
Houston urban study (S. L. Johnson, w, Houston)
San Antonio urban study (R. D. Steger, w, San Antonio)
Urbanization, hydrologic effects:
Effect on flood flow, Charlotte area, North Carolina (W. H. Eddins, w, Raleigh. N.C.)
Vegetation:
Elements in organic-rich material (F. N. Ward, D)
See also Plant ecology.
Volcanic-terrane hydrology. *See* Artificial recharge.
Volcanology:
Cascade volcanoes, geodimeter studies (D. A. Swanson, M)
Cauldron and ash-flow studies (R. L. Smith, NC)
Columbia River basalt (D. A. Swanson, M)
Regional volcanology (R. L. Smith, NC)
Volcanic-ash chronology (R. E. Wilcox, D)
Volcanic hazards (D. R. Crandell, D)
States:
Arizona, San Francisco volcanic field (J. F. McCauley, M)
Hawaii (M, except as otherwise noted):
Hawaiian Volcano Observatory (R. I. Tilling, Hawaii National Park)
Seismic studies (P. L. Ward)
Submarine volcanic rocks (J. G. Moore)
Idaho (D):
Central Snake River Plain, volcanic petrology (H. E. Malde)

Volcanology—Continued
States—Continued
Idaho (D)—Continued
Eastern Snake River Plain region (P. L. Williams, H. J. Prostka)
Snake River basalt (P. L. Williams, H. J. Prostka)
Montana, Wolf Creek area, petrology (R. G. Schmidt, NC)
New Mexico, Valles Mountains, petrology (R. L. Smith, NC)
Wyoming, deposition of volcanic ash in the Mowry Shale and Frontier Formation (G. P. Eaton, D)

Water resources:
Central Region field coordination (J. L. Poole, w, D)
CENTO working group on hydrogeology (J. R. Jones, w, NC)
Chattahoochee intensive river quality (R. N. Cherry, w, Atlanta, Ga.)
Columbia-North Pacific ground water (B. L. Foxworthy, w, Tacoma, Wash.)
Comprehensive studies, Pacific Northwest (L. E. Newcomb, w, M)
Dams, weirs, and flumes (H. J. Tracy, w, Atlanta, Ga.)
Data coordination, acquisition, and storage:
NAWDEX Project (S. M. Lang, w, NC)
Water Data Coordination (R. H. Langford, w, NC)
East Triassic waste-disposal study (G. L. Bain, w, Raleigh, N.C.)
Effects of vegetation changes (G. C. Lusby, w, D)
Environmental impact analyses support (G. H. Davis, w, NC)
Environmental impact statement, Idaho phosphate (W. J. Schneider, w, Pocatello, Idaho)
Evaluation of land treatment (R. F. Hadley, w, D)
Foreign countries:
Brazil, surface water, national program (D. C. Perkins, w, Rio de Janeiro)
Canada, gas pipeline (V. K. Berwick, w, Anchorage, Alaska)
India, ground-water investigations in states of Madhya Pradesh, Gujarat, Maharashtra, and Mysore (J. R. Jones, w, NC)
Kenya, range water resources (N. E. McClymonds, w, Nairobi)
Nepal, hydrogeology of Terai region (G. C. Tibbitts, Jr., w, Katmandu)
Saudi Arabia, sources of Riyadh water supply (J. R. Jones, w, NC)
Yemen, water and mineral survey, north Yemen (J. R. Jones, w, NC)
General hydrologic research (R. L. Nace, w, Raleigh, N.C.)
Ground-water appraisal, New England region (Allen Sinnott, w, Trenton, N.J.)
Ground water, Missouri Basin (O. J. Taylor, w, D)
Infiltration and drainage (Jacob Rubin, w, M)
Intensive river quality assessment (D. A. Rickert, w, Portland, Oreg.)
Intermediate-depth drilling (L. C. Dutcher, w, M)
Madison Limestone plan of study (E. M. Cushing, w, D)
Modeling principles (J. P. Bennett, w, NC)
Network design (M. E. Moss, w, NC)
Northeastern Region field coordination (J. W. Geurin, w, NC)

Water resources—Continued
Northwest water-resources data center (N. A. Kallio, w, Portland, Oreg.)
Powell arid lands centennial (R. F. Hadley, w, D)
Quality-of-water accounting network (R. J. Pickering, w, NC)
Rating extensions (K. L. Wahl, w, NC)
Rehabilitation potential, energy lands (L. M. Shown, w, D)
Reservoir bank storage study (T. H. Thompson, w, M)
Southeastern Region field coordination (M. D. Hale, w, Atlanta, Ga.)
Subsurface waste emplacement potential (P. M. Brown, w, Raleigh, N.C.)
Water-resource activities (J. R. Carter, w, D)
Waterway treaty engineering studies (J. A. Bettendorf, w, NC)
Western Region field coordination (G. L. Bodhaine, w, M)
States and territories:
Alabama (w, Montgomery, except as noted otherwise):
Cretaceous aquifer simulation (R. A. Gardner)
Drainage areas (C. O. Ming)
Geology and hydrology along highway locations and rest areas (J. C. Scott)
Low flows of Alabama streams (W. J. Powell, E. C. Hayes, w, Tuscaloosa)
Plans, reports, and information (W. J. Powell, w, Tuscalooosa)
Alaska (w, Anchorage, except as noted otherwise):
Alaska water assessment (G. O. Balding)
Alaskan gas pipeline environmental impact statement (A. J. Feulner)
Arctic resources (J. M. Childers)
Coal resources study (A. J. Feulner)
Hydrology:
Anchorage area (Chester Zenone)
Hydrologic environment of the trans-Alaska pipeline system (TAPS) (J. M. Childers)
Hydrologic studies for Alaskan Air Command (R. J. Madison)
Municipal water supply (G. S. Anderson)
North Star project (G. L. Nelson, w, Fairbanks)
TAPS construction hydrology (C. E. Sloan)
Arizona:
Black Mesa hydrologic study (R. M. Myrick, w, Tucson)
Black Mesa monitoring program (G. W. Levings, w, Flagstaff)
Channel loss study (T. W. Anderson, w, Phoenix)
Coconino Sandstone water budget, Navajo County (L. J. Mann, w, Flagstaff)
Copper Basin study (B. W. Thomsen, w, Phoenix)
Ground-water appraisal, Lower Colorado River (E. S. Davidson, w, Tucson)
National eutrophication survey (E. B. Hodges, w, Tucson)
Sedona ground-water availability (G. W. Levings, w, Flagstaff)
Arkansas (w, Little Rock):
Bayou Bartholomew systems study (M. E. Broom)
Cache River aquifer-stream system (M. E. Broom)
Characteristics of streams (M. S. Hines)

Water resources—Continued
States and territories—Continued
Arkansas (w, Little Rock)—Continued
Investigations and hydrologic information (R. T. Sniegocki)
National eutrophication survey (M. S. Hines)
Time-of-travel study (T. E. Lamb)
California (w, M, except as noted otherwise):
Antelope Valley ground-water model (T. J. Durbin, w, Laguna Niguel)
Ground water:
Antelope Valley area (F. W. Geissner, w, Laguna Niguel)
City of Modesto, ground-water planning (R. W. Page, Sacramento)
Death Valley (F. W. Giessner, w, Laguna Niguel)
Geohydrology, Round Valley (K. S. Muir)
Indian Wells Valley (J. H. Koehler, w, Laguna Niguel)
Joshua Tree (F. W. Giessner, w, Laguna Niguel)
Madera area, ground-water model (W. D. Nichols, w, Sacramento)
Redlands nitrate study (L. A. Eccles, w, Laguna Niguel)
Sacramento Valley (R. M. Bloyd, Jr., w, Sacramento)
Santa Barbara-San Luis Obispo (F. W. Giessner, w, Laguna Niguel)
Santa Cruz (K. S. Muir)
South California (W. R. Moyle, Jr., w, Laguna Niguel)
Withdrawals, statewide (H. T. Mitten, w, Sacramento)
Indian reservations (J. W. Wark)
Quality of water:
Ground-water quality, Suisun Bay (Chabot Kilburn)
Lakes and reservoirs (R. C. Averett)
Trace-metals control, Sacramento (R. F. Ferreira, w, Sacramento)
Surface water:
Floods, small drainage areas (A. O. Waananen)
National eutrophication survey (J. R. Crippen)
Sediment, Redwoods National Park (J. M. Knott)
Urbanization, Santa Clara County (J. M. Knott)
Colorado (w, D, except as noted otherwise):
Coal rehabilitation (W. E. Hofstra)
Evaporation, Colorado lakes (D. B. Adams)
Ground water:
Aquifer testing (J. B. Weeks)
Geophysical logging (J. B. Weeks)
High Plains of Colorado (W. E. Hofstra)
Potentiometric surface mapping (J. B. Weeks)
Recharge, Bijou Creek (W. E. Hofstra)
Southern Ute lands (R. E. Brogden)
Southwestern Colorado (R. E. Brogden)
U.S. Bureau of Mines prototype mine (J. B. Weeks)
Hydrology:
Arkansas River basin (R. L. Livingston, w, Pueblo)

Water resources—Continued
States and territories—Continued
Colorado (w, D, except as noted otherwise)—Continued
Hydrology—Continued
El Paso County (R. L. Livingston, w, Pueblo)
Parachute-Roan Creek Basin (G. H. Leavesley)
San Luis Valley (O. J. Taylor, w, Pueblo)
South Platte River basin, Henderson to State line (R. T. Hurr)
National eutrophication survey (H. E. Petsch, Jr.)
Quality of water:
Boulder County (D. C. Hall)
Geochemical investigations (S. G. Robson)
Hydrology of Jefferson County (D. C. Hall)
Sediment yield, Piceance Basin (V. C. Norman)
Water-quality monitor network (J. E. Biesecker)
West slope aquifers (R. E. Brogden)
Spring hydraulics (J. B. Weeks)
Water resources, Park-Teller County (K. E. Goddard, w, Pueblo)
Yampa River Basin assessment (T. D. Steele)
Connecticut (w, Hartford):
Hydrogeology, south-central Connecticut (R. L. Melvin)
Part 7, Upper Connecticut River basin (R. B. Ryder)
Part 8, Quinnipiac River basin (D. L. Mazzaferro)
Part 9, Farmington River basin (H. R. Anderson)
Part 10, lower Connecticut River basin (L. A. Weiss)
Short-term studies (F. H. Ruggles, Jr.)
Delaware, aquifer-model studies (R. H. Johnston, w, Dover)
Florida:
Bridge-site studies (W. C. Bridges, w, Tallahassee)
Broward County (C. B. Sherwood, Jr., w, Miami)
Ground water:
Aquifer mapping, south Florida (Howard Klein, w, Miami)
Coastal springs (W. C. Sinclair, w, Miami)
Hallandale area (H. W. Bearden, w, Miami)
Hollywood area (H. W. Bearden, w, Miami)
Hydrogeology, middle Peace basin (W. E. Wilson III, w, Tampa)
Hydrology, Cocoa well field (J. B. Holly, w, Winter Park)
Hydrology, Manatee County (D. P. Brown, w, Sarasota)
Hydrology, Sarasota County (Horace Sutcliffe, Jr., w, Sarasota)
Ochlockonee River basin investigation (C. A. Pascale, w, Tallahassee)
Palm Beach County flatlands (L. F. Land, w, Miami)
Peace and Alafia River basins (A. F. Robertson, w, Tampa)
Potentiometric St. Petersburg-Tampa (C. B. Hutchinson, w, Tampa)
Recharge, Orange County (P. W. Bush, w, Winter Park)
Saltwater intrusion, Fernandina (R. W. Fairchild, w, Jacksonville)
Sand-gravel aquifer, Pensacola (Henry Trapp, w, Tallahassee)

Water resources—Continued

States and territories—Continued

Florida—Continued

Ground water—Continued

Santa Fe River basin (J. D. Hunn, w, Tallahassee)

Sewage effluent disposal, irrigation (L. J. Slack, w, Tallahassee)

Shallow aquifer, Brevard County (J. M. Frazee, Jr., w, Winter Park)

Shallow aquifers, Alafia and Peace (C. B. Hutchison, w, Tampa)

Technical assistance, Hillsborough County (J. W. Stewart, w, Tampa)

Technical assistance, south Florida (Howard Klein, w, Miami)

Urban hydrology, Englewood area (Horace Sutcliffe, Jr., w, Sarasota)

Verna well field (Horace Sutcliffe, Jr., w, Sarasota)

Water resources, Duval-Nassau (G. W. Leve, w, Jacksonville)

Water resources, Martin County (R. A. Miller, w, Miami)

Water resources, Tequesta (L. F. Land, w, Miami)

Water-supply potential, Green Swamp (H. F. Grubb, w, Winter Park)

Hydrogeologic maps, Seminole County (W. D. Wood, w, Winter Park)

Hydrologic suitability study (L. V. Causey, w, Jacksonville)

Hydrology, Volusia County (P. W. Bush, w, Winter Park)

Lee County (D. H. Boggess, w, Ft. Myers)

Mapping, Green Swamp (B. F. McPherson, w, Miami)

Palm Beach County (L. F. Land, w, Miami)

Quality of water:

Estuarine hydrology, Tampa Bay (C. R. Goodwin, w, Tampa)

Landfill and water quality (J. E. Hull, w, Miami)

Solid waste, Hillsborough County (Mario Fernandez, Jr., w, Tampa)

Solid waste, St. Petersburg (Mario Fernandez, Jr., w, Tampa)

Subsurface disposal, Pinellas (J. J. Hickey, w, Tampa)

Technical assistance, Department of Pollution Control (D. A. Goolsby, w, Tallahassee)

Riviera Beach investigations (L. F. Land, w, Miami)

Special studies, statewide (C. S. Conover, w, Tallahasseee)

Surface water:

Hydrology study, Fakahatchee Strand (L. J. Swayze, w, Miami)

Lakes in southwest Florida (R. C. Reichenbaugh, w, Tampa)

Manasota technical assistance (Horace Sutcliffe, Jr., w, Sarasota)

Technical assistance:

Northwest Florida Water Management District (W. B. Mann, w, Tallahassee)

Suwanee River Water Management District (J. C. Rosenau, w, Tallahassee)

Technical support, ground water (A. F. Robertson, w, Tampa)

Tri-county investigation (C. B. Bentley, w, Jacksonville)

Waccasassa Basin hydrology (G. F. Taylor, w, Winter Park)

Water atlas (S. D. Leach, w, Tallahassee)

Water resources, Hendry County (T. M. Missimer, w, Miami)

Water resources of Orange County (C. H. Tibbals, w, Winter Park)

Western Collier County (H. J. McCoy, w, Miami)

Georgia (w, Doraville, except as noted otherwise):

Cretaceous (R. C. Vorhis)

Information system (J. R. George)

Northwest Georgia geology and water (C. W. Cressler, w, Calhoun)

Valdosta hydrology (R. E. Krause)

Hawaii (w, Honolulu):

Data management, Guam (C. J. Huxel, Jr.)

Kauai water resources survey (R. J. Burt)

Regional study (B. L. Jones)

Topical studies (F. T. Hidaka)

Idaho (w, Boise):

Flow in Silver Creek, Idaho (J. A. Moreland)

Kootenai Board—WWT (H. K. Hall)

National eutrophication survey (W. A. Harenberg)

Illinois, water-quality appraisal (L. G. Toler, w, Champaign)

Indiana (w, Indianapolis):

Ground water near Ft. Wayne (Michael Planert)

Maumee River Basin level B (Michael Planert)

Streamflow summaries (R. G. Horner)

Time-of-travel regionalization (S. E. Eikenberry)

Iowa (w, Iowa City):

Bedrock mapping (R. E. Hansen)

Cambrian-Ordovician aquifer (W. L. Steinhilber)

Low flow, Iowa streams (O. G. Lara)

National eutrophication survey (I. L. Burmeister)

Sediment data (J. R. Schuetz)

South-central (J. W. Cagle, Jr.)

Water resources, east-central Iowa (K. D. Wahl)

Kansas (w, Lawrence, except as noted otherwise):

Kansas-Oklahoma Arkansas River Commission (E. R. Hedman)

Miscellaneous investigations (H. G. O'Connor)

National eutrophication survey (M. L. Thompson)

Numerical modeling (J. C. Halepaska)

Saline ground-water resources of Kansas (K. M. Keene)

Report processing (H. E. McGovern)

Saline water from Permian rocks (D. R. Albin)

Water supply in droughts (F. C. Foley)

Kentucky (w, Louisville):

Covington-Lexington-Louisville triangle (D. S. Mull)

Ground water, Ohio River valley (P. D. Ryder)

Water resources—Continued

States and territories—Continued

Kentucky (w, Louisville)—Continued
- London-Corbin area (R. W. Davis)
- Somerset hydrology (R. W. Davis)

Louisiana (w, Baton Rouge):
- Baton Rouge area (C. D. Whiteman, Jr.)
- New Orleans area (D. C. Dial)
- Ground water:
  - Gramercy area (G. T. Cardwell)
  - Kisatchie Forest area (J. E. Rogers)
  - Terrace aquifer, central Louisiana (T. H. Sanford)
- Reports on special topics (M. F. Cook)
- Site studies (R. L. Hosman)
- Southwestern part (D. J. Nyman)
- Surface water:
  - Flood hydraulics and hydrology (B. L. Neely, Jr.)
  - Velocity of Louisiana streams (A. J. Calandro)
- Tangipahoa-Tchefuncte River basins (D. J. Nyman)

Maryland (w, Parkville, except as noted otherwise):
- Baltimore-Washington urban hydrology (W. F. White)
- Geohydrologic studies, Carroll County (E. G. Otton)
- Ground-water resources-urbanization, Hartford County (L. J. Nutter)
- Low-flow studies in Maryland (W. J. Herb)
- Special studies, ground water (C. G. Richardson)
- Trap efficiency, Rock Creek (T. H. Yorke, Jr., College Park)

Massachusetts (w, Boston):
- Coastal southeastern Massachusetts, Wareham to Seekonk (G. D. Tasker)
- Connecticut River lowlands (E. H. Walker)
- Deicing chemicals, ground water (L. G. Toler)
- Nashua River basin (R. A. Brackley)
- Northeastern coastal basins (F. B. Gay)
- Northeastern river basins (R. A. Brackley)
- Public inquiries (J. A. Baker)

Michigan (w, Okemos, except as noted otherwise):
- Erosion in St. Joseph Basin (T. R. Cummings)
- Geohydrology, environmental planning (F. R. Twenter)
- Ground-water models, Muskegon County (W. B. Fleck)
- Ground water, West Upper Peninsula (C. J. Doonan, w, Escanaba)

Minnesota (w, St. Paul):
- Evaluation, quality-of-water data for management (S. P. Larson)
- Ground water in Park Rapids area (J. O. Helgesen)
- Impact of copper-nickel mining (P. G. Olcott)
- Twin Cities level B study (C. R. Collier)
- Upper Mississippi and Souris-Red-Rainy (V. J. Latkovich)
- Water budget, Shagawa Lake (D. W. Ericson)

Mississippi (w, Jackson):
- Ground water:
  - Aquifer maps for Mississippi (E. H. Boswell)
  - Ground-water use (J. A. Callahan)
  - Hydrology, Tennessee-Tombigbee (J. D. Shell)
  - Southern delta (J. M. Bettandorff)
  - Water, subcoastal Mississippi (J. V. Brahana)

Water resources—Continued

States and territories—Continued

Mississippi (w, Jackson)—Continued
- Waste assimilation (J. K. Arthur)
- Water use (J. A. Callahan)

Missouri (w, Rolla):
- Ground-water resources—Springfield area (L. F. Emmett)
- National eutrophication survey (John Skelton)
- Water quality, scenic riverways (J. H. Barks)

Montana (w, Helena, except as noted otherwise):
- Ground water:
  - Central Powder River valley (W. R. Miller, w, Billings)
  - Clark Fork basin (A. J. Boettcher)
  - Fort Belknap (R. D. Feltis)
  - Fort Union Formation (W. B. Hopkins, w, Billings)
  - Hydrology, lower flathead (A. J. Boettcher)
  - Madison Group (W. R. Miller, w, Billings)
  - Mined lands reclamation (W. R. Hotchkiss)
  - Northern Judith basin (R. D. Feltis, w, Billings)
  - Quality of water near Libby (A. J. Boettcher)
  - "Saline seeps" (R. G. McMurtrey)
  - Southern Powder River valley (W. R. Miller, w, Billings)
  - Special investigations (D. L. Coffin)
  - Water availability, Madison (W. R. Miller, w, Billings)
  - Water supplies for national parks, monuments, and recreation areas (D. L. Coffin)
- Mining effects, shallow water (R. S. Roberts)
- National eutrophication survey (R. R. Shields)

Nebraska (w, Lincoln):
- Ground-water use, Blue River basin (E. K. Steele, Jr.)
- Hydrogeology of southwest Nebraska (E. G. Lappala)
- Movement of nitrogen into aquifers (L. R. Petri)
- National eutrophication survey (G. G. Jamison)
- Seward County (M. J. Ellis)
- Time-of-travel data (L. R. Petri)
- Water in the Loup River basin (R. Bentall)

Nevada (w, Carson City):
- Aquifers in the Fallon area (P. A. Glancy)
- National eutrophication survey (D. O. Moore)
- Smith Valley (F. E. Rush)
- Statewide reconnaissance (F. E. Rush)
- Topical studies (J. P. Monis)
- Water supply, Cold Spring Valley (A. S. Van Denburgh)
- Water supply, mining districts (H. A. Shamberger)

New Hampshire, ground-water reconnaissance, river basins (J. E. Cotton, w, Concord)

New Jersey (w, Trenton):
- Automatic processing of ground-water data (William Kam)
- Base-flow studies (E. G. Miller)
- Camden County, geology and ground-water resources (G. M. Farlekas)
- Miscellaneous Federal work (Harold Meisler)
- Problem river studies (J. C. Schornick, Jr.)

Water resources—Continued
States and territories—Continued
New Jersey (w, Trenton)—Continued
Quantification non-point pollution (J. C. Schornick, Jr.)
Short-term studies (Harold Meisler)
Test drill geophysical logging (J. E. Luzier)
Time-of-travel study (E. A. Pustay)
Water resources, Wharton Trace (William Kam)
New Mexico (w, Albuquerque):
Bureau of Indian Affairs water-supply investigations (F. P. Lyford)
Cimarron Basin analysis (P. L. Soule)
Coal-lease areas, northwest New Mexico (Kim Ong)
Ground water:
Capitan Reef (W. L. Hiss)
Gallup ground-water exploration (W. L. Hiss)
Harding County (F. D. Trauger)
Miscellaneous activities, State Engineer (W. A. Mourant)
White Sands Missile Range, water levels and pumpage (H. D. Hudson)
Surface water:
National eutrophication survey (L. P. Denis)
Pojoaque River analyses (L. J. Reiland)
New Mexico data bank (P. L. Soule)
Rio Grande Commission (P. L. Soule)
New York (w, Mineola, except as noted otherwise):
Basin recharge with sewage effluent (R. C. Prill)
Column-basin studies (M. S. Garber)
Hydrogeology of southeast Nassau County (H. F. H. Ku)
Hydrologic modeling (R. T. Getzen)
Long Island water quality (S. E. Ragone)
Management modeling (G. E. Kimmel)
Nassau County, ground-water system study (Chabot Kilburn)
Short-term studies (R. J. Dingman, w, Albany)
Suffolk County, hydrologic conditions (H. M. Jensen)
Suffolk County, water-quality observation well program (Julian Soren)
Supplemental recharge by storm basins (D. A. Aronson)
Water resources, South Fork, Long Island (Bronius Nemickas)
North Carolina (w, Raleigh):
Ground water:
Automatic data processing program (C. C. Daniel)
Blue Ridge Parkway (M. D. Winner)
Wilson County (M. D. Winner)
Hydrology of Albermarle-Pamlico area (C. C. Daniel)
North Carolina water atlas (G. L. Giese)
Public water supplies (T. M. Robison)
Surface water:
Hydrology of estuaries (H. B. Wilder)
Requests for data (H. G. Hinson)
North Dakota (w, Bismarck, except as noted otherwise):
Ground water:
Billings-Golden Valley Slope (M. G. Croft)
Dickey-Lamoure (J. S. Downey)
Dunn County (R. L. Klausing)
Grant and Sioux Counties (P. G. Randich)
Hydrologic changes due to mining (O. A. Crosby)

Water resources—Continued
States and territories—Continued
North Dakota (w, Bismarck, except as noted otherwise)—Continued
Ground water—Continued
Morton County (P. G. Randich)
Ramsey County (R. D. Hutchinson, w, Grand Forks)
Ransom-Sargent (C. A. Armstrong)
Special investigations (Q. F. Paulson)
National eutrophication survey (O. A. Crosby)
Ohio, water inventory, hydrologic studies (D. D. Knockhenmus, w, Columbus)
Oklahoma (w, Oklahoma City):
Ground water:
Antlers Sand (D. L. Hart, Jr.)
Vamoosa Formation (J. J. D'Lugosz)
National eutrophication survey (W. B. Mills)
Requests, special investigations (J. H. Irwin)
Oregon (w, Portland):
Ground water:
Coos Bay, dune aquifers (J. H. Robison)
Drain-Yoncalla area (J. H. Robison)
Lincoln County coast (F. J. Frank)
Near Winston (D. D. Harris)
Newberg area (A. R. Leonard)
Surface water:
National eutrophication survey (Antonius Laenen)
Oregon lakes and reservoirs (R. B. Sanderson)
Umatilla Reservation water (J. B. Gonthier)
Pennsylvania (w, Harrisburg, except as otherwise noted):
Geohydrology of Berks County (C. R. Wood)
Geology and ground-water resources of Monroe County (L. D. Carswell, w, Philadelphia)
Ground water:
Chester County (L. J. McGreevy, w, West Chester)
Cumberland Valley (A. E. Becher)
Ground-water resources of the Williamsport area (O. B. Lloyd)
Pilot study, greater Pittsburgh (R. M. Beall, w, Pittsburgh)
Quality of water:
Highway construction effects on streams (J. F. Truhlar, Jr.)
Sediment from highway construction (L. A. Reed)
Streamflow characteristics (L. V. Page)
Western Pennsylvania (G. R. Schiner)
Puerto Rico (w, San Juan):
Contingent requests (E. D. Cobb)
Ground water, North Coast model (J. E. Heisel)
Hydrologic systems modeling (M. A. Lopez)
Quality of water, hydrologic effects of copper mining (L. J. Mansue)
Surface water, floods investigation program (W. J. Haire)
South Carolina (w, Columbia):
Cooper River re-diversion (C. A. Spiers)
Reconnaissance of estuaries (F. A. Johnson)
Short-term planning studies (W. M. Bloxham)

Water resources—Continued
States and territories—Continued
South Dakota (w, Huron, except as noted otherwise):
Cheyenne and Standing Rock Indian Reservations (L. W. Howells)
Clark County (L. J. Hamilton)
Deuel and Hamlin Counties (Jack Kume, w, Vermillion)
Douglas and Charles Mix Counties (Jack Kume, w, Vermillion)
Ground water, Hand and Hyde Counties (N. C. Koch)
McPherson, Edmunds, and Faulk Counties (L. J. Hamilton)
National eutrophication survey (O. J. Larimer)
Tennessee (w, Nashville, except as noted otherwise):
Flow characteristics (R. L. Gold)
Hydrogeology of linear features (D. R. Rima)
Memphis area (J. H. Criner, Jr.)
Terrace-deposits study (W. S. Parks, w, Memphis)
Water for Murfreesboro (D. R. Rima)
Texas:
Ground water:
Artificial recharge research (E. P. Weeks, w, Lubbock)
El Paso (W. R. Meyer, w, El Paso)
Galveston County continuing quantitative studies (R. K. Gabrysch, w, Houston)
Houston (R. K. Gabrysch, w, Houston)
Model study, Chicot and Evangeline aquifer (D. G. Jorgensen, w, Houston)
Orange County (G. D. McAdoo, w, Houston)
Rio Grande environmental study (J. S. Gates, w, El Paso)
Salt encroachment at Houston (D. G. Jorgensen, w, Houston)
San Antonio (R. D. Reeves, w, San Antonio)
Hydrologic investigations:
Drainage-area determinations (P. H. Holland, w, Austin)
Limestone hydrology study (R. W. Maclay, w, San Antonio)
National eutrophication survey (L. G. Stearns, w, Austin)
Quality of water, bays and estuaries (D. C. Hahl, w, Austin)
Trust territory, water-resource information (D. A. Davis, w, Honolulu, Hawaii)
Utah (w, Salt Lake City, except as otherwise noted):
Environmental impacts (Donald Price)
Ground water:
Cedar City and Parawon (L. J. Bjorklund, w, Cedar City)
Oil-shale hydrology (F. K. Fields)
Statewide ground-water conditions (J. C. Stephens)
Navajo Sandstone, southeastern Utah (J. W. Hood)
Program enhancement (Theodore Arnow)
Quality of water:
Flaming Gorge Reservoir (E. L. Bolke)
Surface water:
Canal-loss studies (R. W. Cruff)
Inflow to Great Salt Lake (J. C. Mundorff)
Mined lands rehabilitation (G. W. Sandberg, w, Cedar City)

Water resources—Continued
States and territories—Continued
Utah (w, Salt Lake City, except as otherwise noted)—Continued
Surface water—Continued
National eutrophication survey (R. W. Cruff)
Vermont (w, Montpelier):
Ground water:
Barre-Montpelier area (A. L. Hodges, Jr.)
Mad River area (A. L. Hodges, Jr.)
Upper Winooski Basin (A. L. Hodges, Jr.)
White River junction (A. L. Hodges, Jr.)
Virginia (w, Richmond, except as noted otherwise):
Coastal plain studies (H. T. Hopkins)
Ground water:
Geohydrologic data (R. L. Wait)
Hydrology of Prince William Forest (G. A. Brown)
South of James River (O. J. Cosner)
Hydrologic monitoring, Fairfax (E. H. Mohler, Jr., w, Fairfax)
Service work (R. L. Wait)
Surface water, project planning and public inquiries (R. L. Wait)
Washington (w, Tacoma):
Ground water:
Long Beach (J. V. Tracy)
Special hydrologic problems (B. L. Foxworthy)
Spokane Basin water resources (H. H. Tanaka)
Swinomish (K. L. Walters)
Test drilling (K. L. Walters)
Model simulation for water management (R. D. MacNish)
National eutrophication survey (P. J. Carpenter)
Real-time data collection (R. R. Adsit)
Surface-water network reevaluation (W. L. Haushild)
Tulalip water resources (B. W. Drost)
West Virginia (w, Charleston, except as otherwise noted):
Coal River study (J. S. Bader)
Elk River basin study (G. R. Tarver)
Quantitative mine-water studies (G. G. Wyrick)
Salt water in State (J. B. Foster)
Small drainage areas (G. S. Runner)
Studies for unforeseen needs (G. G. Wyrick)
Wisconsin (w, Madison):
Ground water:
Columbia County (C. A. Harr)
St. Croix County (R. G. Borman)
Washington-Ozaukee Counties (H. L. Young)
Low flow of small streams (S. J. Field)
Quality of water:
Ground-water-quality monitoring (C. A. Harr)
Menomonee River sediment study (E. R. Zuehls)
Pine River basin (P. A. Kammerer, Jr.)
Washington County sediment study (S. M. Hindall)
Surface water:
Drainage areas (B. K. Holstrom)
Recreation reservoirs (B. K. Holstrom)
Water resources of Wisconsin (R. D. Cotter)
Wyoming (w, Cheyenne):
Arikaree Formation, Lusk (M. A. Crist)
Effluent monitor, national parks (E. R. Cox)

Water resources—Continued
States and territories—Continued
Wyoming (w, Cheyenne)—Continued
Green River Basin water supply (H. W. Lowham)
Hanna Basin water resources (K. D. Peter)
National eutrophication survey (K. G. Polinoski)
Stream loss to Madison Limestone (F. C. Boner)
Water resources, Powder River Basin (M. E. Lowry)
Water use:
United States, water use in 1975 (C. R. Murray, w, NC)
States:
Florida, water-use statewide (S. D. Leach, w, Tallahassee)
Hawaii, water-use data (R. H. Nakahara, w, Honolulu)
Louisiana, water use, 1975 (G. C. Cardwell, w, Baton Rouge)
Washington, water use (G. G. Parker, w, Tacoma)
Waterpower classification:
Alaska (c, Portland, Oreg.):
Barrier Glacier and its effect on Chakachamna Lake potential powersite (J. B. Dugwyler, Jr.)
Chakachatna River, review of withdrawals (J. B. Dugwyler, Jr.)
California (c, Sacramento):
Owens River Basin, George Creek to Olancha Creek, review of withdrawals (R. D. Morgan)
Owens River Basin, Westside tributaries, review of withdrawals (R. D. Morgan)
Colorado, Dolores River Basin, review of withdrawals (Ralph Smith, c, D)
Oregon (c, Portland):
Clackamas River Basin, review of withdrawals (L. O. Moe)
Waterpower classification—Continued
Oregon (c, Portland)—Continued
Coquille River Basin, review of withdrawals (S. R. Osborne)
Nestucca River Basin, review of withdrawals, (K. J. St. Mary)
North Umpqua River, review of withdrawals (K. J. St. Mary)
South Umpqua River, review of withdrawals (L. D. Moe)
Washington (c, Portland, Oreg.):
Blanca Lake and Troublesome Creek pumped-storage site, Skykomish River (J. B. Dugwyler, Jr.)
Columbia River, vicinity of developed Wells Project, review of withdrawals (J. B. Dugwyler, Jr.)
Wood Plateau-Coyote Creek and John Day pool pumped-storage site, Columbia River (J. B. Dugwyler, Jr.)
Wyoming (c, D):
Shoshone River, review of withdrawals (G. A. Lutz)
Wind River Basin, review of withdrawals (Ralph Smith)
Wilderness Program. *See* Primitive and Wilderness Areas *under* Mineral and fuel resources—compilations and topical studies, mineral-resource surveys.
Zeolites:
Arizona, Bowie area (L. H. Godwin, c, NC)
Southeastern California, Oregon, and Arizona (R. A. Sheppard, D)
Zinc. *See* Lead, zinc, and silver.

SUBJECT INDEX

Page

A

Aerotriangulation, topographic applications 310
Age determinations. *See* Geochronology, Geochronometry, Methods and techniques, *as well as under individual States.*
Alabama:
  Cooperators 346
  Land-use and land-cover mapping 288
  USGS office 358
Alaska:
  Artificial recharge 199
  Benthic invertebrates 214
  Bouguer gravity map 82
  Channels:
    Channel erosion surveys 128
    Floods 247
  Chromite 11
  Cooperators 346
  Earthquake studies 228
  Faulting 88, 229
  Geochemical anomalies, Willow Creek mining district 11
  Geologic hazards 237
  Geologic investigations, results of 82
  Geologic map 82
  Glacier Bay National Monument study 87
  Gold 5
  Granitic rocks 89
  Gravity surveys in ice-covered areas 164
  Ground water 128
  Hydrocarbons 149
  Marine geology 148
  Mercury 150
  Metamorphic facies map 96
  Mineral Resource Assessment Program 10
  Mineral-resource investigations 23
  Mineralization 12
  Natural gas 28
  Oilspill risk analysis, Gulf of Alaska OCS 128
  Pack ice 151
  Paleontology 195
  Petroleum 29
  Plate tectonics 85
  Platinum 6, 7
  Plutonic rocks 85
  Remote sensing, Arctic Slope icings 277
  Resource assessment, western Gulf of Alaska 149
  Sedimentation, Portage 86
  Seismic network 231
  Stratigraphy 82, 83, 85
  Structural geology 84, 86, 148
  Subsidence 255
  Tectonics 150
  Trans-Alaska pipeline corridor:
    Hydrologic impacts of construction 249
    Quality of water 214
  Uranium and thorium 35
  USGS offices 354, 356, 357, 358
Alaska—Continued
  Volcanism 89
  Volcano studies 40, 170
  Water availability, lower Ship Creek basin 127
  Water resources, coalfield areas 128
  Water-supply problems, Prudhoe Bay 128
  Wilderness studies 88
Algeria, Landsat training 318
American Samoa, rainfall and runoff 129
Antarctica:
  Geoceiver operations 317, 318
  Geochronometry 184
  Mapping 318
  Marine geology 148
  McMurdo Sound IMW map 314
  Satellite image maps 278
  True geographic South Pole 317
  USGS investigations 306, 307, 317
Antimony 219
Apollo missions. *See* Astrogeology.
Appalachian Highlands and coastal plains, results of geologic investigations 58
Aquifer studies 100, 101, 103, 105, 108, 110, 112, 114, 115, 120, 121, 123, 124, 125, 179, 198, 199, 202, 207, 244
Arizona:
  Chronostratigraphy 75
  Cooperators 346
  Copper 18
  Evapotranspiration 210
  Flood maps 247, 248
  Geology and mineral resources, Tucson 2° quadrangle 14
  Ore deposits:
    Source and structural control 2
    Tectonic control 72
  Plutonism 77
  Satellite image map, Phoenix 1° × 2° quadrangle 279
  Sedimentary rocks 158
  Structural geology, Grand Canyon region 75
  Structure and volcanism, Cenozoic 75
  Subsidence 256
  Urban-area study, Phoenix and Tucson 282, 288
  USGS offices 354, 356, 358
  Volcanism 41
Arizona-California, tectonics 75
Arkansas:
  Cooperators 346
  Geologic map 95
  USGS offices 356, 358
Armalcolite 262
Arsenic 219
Artificial recharge 117, 199, 200, 302
  See also Aquifer studies, Ground water, *as well as under individual States.*
Astrogeology:
  Lunar studies:
    Basalts 165, 166
    Basins and craters 258
Astrogeology—Continued
  Lunar studies—Continued
    Breccias, petrology 262
    Ilmenites, lunar and terrestrial 168
    Isotopic systematics 265
    Lunar samples, chemistry 265
    Metamorphic rocks, petrology and mineralogy 263
    Mineralogical and chemical studies 264
    Reference system 280
    Structure 260
    Technical results 261
    Volcanic units 259
  Mariner missions, Jupiter and Saturn 257
  Mars:
    Channels, age of 257
    Topographic mapping 258
    Viking landing sites, assessment of 257
    Volcanoes, age of 257
  Mercury:
    History, early 257
    Topographic mapping 258
  Planetary geology, comparative 257
  Results of investigations 257
  Terrestrial analog and experimental studies:
    Ilmenites, terrestrial and lunar 168
    Impact craters, terrestrial 261
    Photogrammetric techniques 262
    Volcanic features 262
Atlantic coast:
  Hydrology 152
  Marine geology 141
Atlantic Ocean:
  Baltimore Canyon Trough, sand waves 142
  Falkland Plateau, Cretaceous foraminifers 194
  Mid-Atlantic Ridge:
    Chemistry and mineralogy of basalts 175
    Basalt differentiation 166
    Coccoliths in igneous crust 152
Australia:
  Land-systems mapping, Landsat data 269
  Geochronometry 184

B

Base metals 1
  See also metal names.
Basin and Range region, results of geologic investigations 72
Bauxite 8
Bentonite 47
Beaufort Sea 151
Bering Sea 149, 150
Bolivia, engineering geology 299
Brazil:
  Hydrology 300
  Structural geology 300
  USGS office 359
Brines 48

Page

C

California:
- Benthic invertebrates 130
- Boron content in spring water, geothermal significance 42
- Cooperators 346
- Coso Hot Springs 43
- Diagenetic studies 177
- Earthquake occurrences in San Francisco, history 223
- Earthquake studies 226, 230, 231, 232
- Earthquakes:
  - Hollister, 1974 227
  - Imperial Valley, 1973–75 224
  - Oroville, 1975 223, 233
  - San Bernardino Mountains, 1975 225
  - San Fernando, 1971 233
- Evaporation, San Diego Aqueduct 205
- Faulting 80, 224, 227, 229, 230, 240
- Geochronology 77, 79, 80, 176
- Geologic hazards, California continental borderland 146
- Geothermal resources 41, 42
- Ground motion, result of nuclear events 233
- Ground water 129, 130, 137, 220
- Heat flow 42
- Land-use change map, San Francisco 282
- Landslides 236, 241
- Limnology 213
- Mineral-resource information, desert lands 15
- Paleogeography 183
- Phosphorite 8
- Plant ecology, Lassen Volcanic National Park 216
- Quality of water 130
- San Andreas fault 80, 227
- San Francisco Bay:
  - Estuarine hydrology 153
  - Sediment transport and dynamics 190
- San Francisco Bay Region Environment and Resources Planning Study:
  - Earth-science information in land-use planning 285
  - Evaluations 285
  - Flood-prone areas and land-use planning 284
  - Land-capability assessment, new approach 285
- Soil engineering 237
- Structural geology 78, 79, 80, 146
- Subsidence 255
- Surface water 208
- Thermal infrared anomalies 275
- Urban-area study, San Francisco 282
- USGS offices 353, 354, 356, 357, 358
- Volcanic rocks 157, 171, 173
- Volcano studies 171

California-Nevada, geochronology 79

Caribbean Sea 144, 281

Cenozoic studies 193

Central African Republic, Bangui magnetic anomaly 298

Central America, porosity preservation in reefs 33

Central Atlantic Regional Ecological Test Site Project 288

Central Laboratories System 138

Central region and Great Plains, results of geologic investigations 64

Channels:
- Erosion surveys 128
- Floods 247

Page

Channels—Continued
- Geometry 204
- Hydraulics, open channels 203
- Scour 191
- Tidal 148

Chemistry, analytical 219

Chemical analyses:
- Precipitation, chemical quality 249
- Water, determination of trace elements 19

Chemical resources 46

Chromite 11

Chronostratigraphy 75

Chukchi Sea 150

Circum-Pacific Map Project 299

Coal:
- Aquifers 121
- Chemical data 24
- Clinker deposits, Powder River coal basin environmental impact statement 291
- Element determination in coal 219
- Exploration 26
- Geochemical survey, Western coal regions 252
- Geochemistry, laboratory investigations of 25
- Geophysical investigations 25
- Hydrology of coal lands 118
- Magnetic surveys, use in coal exploration 165
- Resource data, computerization of 24
- Resource development model 22
- Resources 27, 28
- Surface mining 202, 239
  - *See also under individual States.*

Coastal hydrology, results of investigations 152

"Coastal Zone Mapping Handbook" 314

Colombia:
- Gold 300
- USGS office 360

Colorado:
- Artificial recharge 117
- Coal, Mesaverde Group 28
- Cooperators 347
- Erosion 239
- Evaporation, Denver water-supply reservoirs 211
- Flood studies 246, 248
- Fluorspar 8
- Fossils, impact of highway construction 291
- Geochronology 1
- Geohydrology 119
- Geologic hazards, urban areas 237
- Geologic map 95
- Green River Formation, discovery of unnamed tongue 34
- Ground water 116, 117, 118, 119
- Hydrology 116, 118
- Igneous rocks 68
- Land-use map, Jefferson County 241
- Mineralization model 1
- Molybdenum and copper deposits 13
- Oil-shale region:
  - Clinker zones 34
  - Hydrology 118, 119
  - Plant ecology 216
  - Resources 34, 35
  - Sediment yields 189
  - Vertical electrical soundings 162
- Potash 9
- Quality of water 206, 207
- Rock mechanics 238

Page

Colorado—Continued
- Slope failures 239
- Storm-runoff management, Denver Federal Center 118
- Structural geology 34
- Sulfide 3
- Surface coal mining, effects on shallow aquifers 202
- Thorium 38
- Uranium 36
- Urban-area study, Denver 287
- USGS offices 353, 354, 355, 356, 357, 358
- Waste disposal 119, 250
- Water management, South Platte River valley 117
- Water resources, El Paso County 118

Colorado-New Mexico, oil from fracture shale 31

Colorado-Utah:
- Landslide maps 235
- Quality of water 206
- Structural geology 71

Colorado-Wyoming, diamonds in kimberlite diatremes 10

Computer technology:
- Chemical data-acquisition system 220
- Computer-Oriented Microform facility 322
- CRIB 22
- Geographic Names Information System 316
- GEOTHERM 46
- GIPSY 46
- GIRAS 289
- GRASP 22
- Hydrologic data-handling techniques 218
- National Coal Resources Information System 316
- NCRDS 24
- Oil and Gas Data Bank 22
- RASS 22
- Surface-water processes, computer programs 205
- USGS facilities 321, 322
- Waste migration, subsurface, computer simulation of 245
- Water-data storage system 134

Connecticut:
- Aeroradioactivity and geology 58
- Cooperators 347
- Geochemical survey, Hartford 1°×2° quadrangle 14
- Glacial geology 50
- Intrusive rocks 56
- Metamorphism 57
- Satellite image map, Hartford 1°×2° quadrangle 279
- Sediments, maximum saturated thickness 100
- Structural geology 55
- Surficial geology 49
- Urban-area study, New Haven 282
- USGS offices 356, 358

Conodont thermometer 197

Continental margin:
- Energy studies 29
- Northern United States, structural and geophysical studies 141
- Southern United States, structure 142

Copper 13, 16, 18, 104, 184, 302

Craters:
- Lunar 258
- Impact craters, terrestrial 261

Crystal chemistry, results of mineralogic studies 166

Page

D

Delaware:
- Aquifer studies ---------- 100
- Cooperators ---------- 347
- USGS office ---------- 358

Delaware-Maryland, remote sensing of basin characteristics ---------- 205
District of Columbia:
- Cooperators ---------- 347
- Land-use change, map ---------- 282
- Urban-area study ---------- 282, 288
- USGS offices ---------- 353, 354, 355, 357, 358

E

Earth Resources Observation Systems (EROS) program ---------- 267, 326
"Earthquake Data Report" ---------- 293
"Earthquake Information Bulletin" ---------- 324, 325
Earthquake studies:
- Crustal strain studies ---------- 226
- Geologic studies ---------- 228
- Geothermal areas ---------- 188
- Ground motion ---------- 231
- Hazard studies ---------- 229, 230, 231
- Mechanics and prediction studies ---------- 222, 228
- Seismic risk studies ---------- 234
- Seismicity and Earth structure ---------- 222
- Seismological observatories, world-wide network ---------- 293
- Sounds ---------- 224
- Theoretical and laboratory studies ---------- 225
  - *See also under individual States.*

"Earthquakes in the United States" ---------- 324
Economic geology:
- Mineral resources, potential ---------- 16
- Minor metals, distribution in magnetite and ilmenite ---------- 8
- Potash ---------- 9, 305
- Uranium, lead, and tin in silver-lead-gold veins ---------- 4
  - *See also specific elements, as well as under individual States.*

Ecuador, volcano study ---------- 293
Energy Mineral Rehabilitation Inventory and Analysis program ---------- 25
- *See also under individual States.*

Energy studies:
- Coal conversion, water use ---------- 136
- Energy-related minerals ---------- 23
- Nuclear energy ---------- 35, 135, 136
- Outer Continental Margin ---------- 29

Engineering geology:
- Reservoir site studies ---------- 299
- Results of investigations ---------- 234
- Slope stability ---------- 234
  - *See also under individual States.*

Environmental geochemistry ---------- 252, 253, 254
Environmental geology ---------- 142, 239, 241, 242, 269
Environmental impact:
- Environmental Impact Analysis program ---------- 290
- Results of investigations ---------- 284

Estuarine hydrology, results of investigations ---------- 152
Evaporation ---------- 210

F

Far East. *See individual countries.*
Fault mapping ---------- 231
Faulting ---------- 31, 54, 55, 56, 62, 63, 73, 80, 81, 88, 90, 224, 227, 229, 230, 231, 240
- *See also under individual States.*

Ferrous metals ---------- 7
- *See also metal names.*

Floods:
- Frequency studies ---------- 246
- Mapping ---------- 247, 248, 249
- National Program for Managing Flood Losses ---------- 249
- Outstanding ---------- 245
- Remote-sensing analysis, Red River Valley flood ---------- 268
- USGS studies ---------- 245
  - *See also under individual States.*

Florida:
- Aquifer studies ---------- 110, 112
- Artificial recharge ---------- 199
- Canal infiltration, Miami Springs-Hialeah area ---------- 210
- Cooperators ---------- 347
- Freshwater-saltwater interface ---------- 110
- Geohydrology ---------- 112
- Ground water ---------- 110, 111, 250
- Hydrology ---------- 109, 111
- Land-use and land-cover mapping ---------- 288
- Land-use map overlays ---------- 314
- Paleontology ---------- 194
- Peats, freshwater ---------- 24
- Quality of water ---------- 109
- Remote-sensing studies:
  - Everglades ---------- 276
  - Green Swamp ---------- 277
- Saline-water intrusion ---------- 110, 111
- Satellite image maps ---------- 279
- Surface water ---------- 112
- USGS offices ---------- 356, 358
- Waste disposal ---------- 111, 201
- Water resources ---------- 109, 111
- Wells ---------- 110

Fluid inclusions ---------- 184
Fluorite ---------- 48
Fluorspar ---------- 8
Fuels, mineral, results of investigations ---------- 1
- *See also* Coal, Energy studies, Petroleum, *as well as under individual States.*

G

Geochemical investigations:
- Areal studies ---------- 18
- Exploration tools ---------- 20
- Instrumentation ---------- 19
- Methodology ---------- 19, 20
- Sample media ---------- 21
- Topical studies ---------- 20

Geochemical resource technology, results of investigations ---------- 18
Geochemistry:
- Elements:
  - Concentrations in plant ash ---------- 254
  - Transfer during basalt weathering ---------- 253
- Environmental ---------- 252, 253, 254
- Hydrothermal experiments ---------- 166
- Isotope and nuclear ---------- 182
- Landscapes ---------- 253
- Lunar basalts, origins ---------- 166
- Minerals:
  - Diffusion and growth rates ---------- 165
  - Thermodynamic properties ---------- 165
- Organic ---------- 29
- Pollution, chemical ---------- 253

Geochemistry—Continued
- Statistical ---------- 181
- Water and sediments:
  - Diagenetic studies ---------- 177
  - Experimental kinetics ---------- 180
  - Geologic controls on water chemistry ---------- 179
  - Mineral alteration ---------- 178
  - Mineral-equilibrium studies ---------- 180
  - Trace elements ---------- 180

Geochronology ---------- 1, 2, 66, 67, 77, 79, 80, 81, 157, 176, 184, 196, 300, 302
Geochronometry ---------- 178, 184, 185
Geohydrology ---------- 101, 112, 116, 119, 121, 286
Geologic maps ---------- 90
- *See also under individual States.*

Geologic principles, processes, and techniques, results of investigations ---------- 157
Geology, results of regional investigations ---------- 49
Geomagnetism ---------- 157, 158, 159, 160, 162
Geophysical investigations:
- Aeroradioactivity ---------- 58
- Anomalies, aeromagnetic, gravity, and magnetic ---------- 164
- Borehole geophysical studies, equipment ---------- 217
- Digital data, maps ---------- 165
- Geomagnetic variometer array ---------- 162
- Geothermal exploration, geophysical instrumentation and techniques ---------- 162, 188
- Gravity studies:
  - Inversion ---------- 163
  - Mapping as mineral-exploration aid ---------- 20
  - Terrain correction ---------- 163
- Magnetic surveys, use in coal exploration ---------- 165
- Mineral target areas, definition of ---------- 301
- Remote sensing, active and passive microwave techniques ---------- 272
- Resistivity and water content, relationship ---------- 162
- Schlumberger resistivity soundings ---------- 162
- Uranium exploration, electromagnetic methods ---------- 162
  - *See also* Methods and techniques, *as well as under individual States.*

Geophysical resource technology, results of investigations ---------- 18
Geophysical techniques, applied ---------- 161
Geophysics, experimental ---------- 157
Georgia:
- Aquifer studies ---------- 112
- Cooperators ---------- 348
- Faulting ---------- 62
- Ground water ---------- 202
- Land-use and land-cover mapping ---------- 288
- Land-use map overlays ---------- 314
- Satellite image map ---------- 279
- Subsidence ---------- 255
- USGS offices ---------- 358

Georgia-South Carolina, paleontology ---------- 193
Geothermal studies:
- Boron in spring water, geothermal significance ---------- 42
- Earthquakes in geothermal areas ---------- 188
- Geophysical techniques ---------- 162
- Geothermal systems ---------- 185
- Heat flow ---------- 42, 44
- Remote-sensing investigations ---------- 272
- Resources ---------- 39, 41, 42, 43, 45

Page

Geothermal studies—Continued
Subsidence in geothermal areas 256
Thermal infrared scanning 274
Thermal springs 202
See also Heat flow, Hot springs, *as well as under individual States.*
Germany:
Earth-science information exchange 297
Ries Crater, investigations 261
Glacial geology 50, 51, 70
See also under individual States.
Glaciology 192
Gold 5, 183, 184, 220, 300, 304
Great Britain:
Geochronology 196
Remote sensing, archaeological sites 270
Ground water. *See* Water, ground, *as well as under* Aquifer studies, Artificial recharge, *individual States.*
Ground water and surface water, relationship 209
"Ground-Water Levels of the United States" 323
Guam, USGS office 356
Guatemala, earthquakes 225, 293
Gulf coast, marine geology 144

H

Hawaii:
Bauxite resource estimates 8
Cooperators 348
Earthquake studies 225, 231
Geomagnetism 158
Gravity change, Kilauea Volcano 163
Remote sensing, application to forest succession 267
Self-potential anomaly, Kaoiki fault zone 163
USGS offices 356, 358
Volcanic rocks 158
Volcano studies 168, 169, 170
Hazard assessment, applications of geology and hydrology to 222
Heat flow 42, 44
Hot springs 43
Hydrologic principles, processes, and techniques, results of investigations 157
Hydrologic unit maps, by State 133, 323
Hydrology:
Coal lands 118
Ground water 197
Heat flow 44
Instruments and techniques 217
Land-cover types, relation to hydrology 114
Surface water 203
Vegetation as a hydrologic indicator 210
See also Water, ground, Water, quality, Water, surface, *as well as under individual States.*

I

Iceland:
Basalts, lead isotope composition 182
Remote sensing:
Lava diversion 270
Vatnajökull, Landsat image map 270

Idaho:
Bedload transport 190
Cooperators 348
Environmental geology 241
Faulting 229
Flood investigations 246
Geochronology 2
Geothermal resources 43
Ground water and surface water, relationship 210
Magnetotelluric study, Snake River-Yellowstone region 161
Ore deposits and ring fractures 2
Phosphate 291
Schlumberger resistivity soundings, Upper Raft River Valley 162
Stability studies, Snake River Canyon 287
Stratigraphy 70
Structural geology 71, 73
Thorium 39
Uranium, selenium, and tin in silver-lead-gold veins 4
USGS offices 355, 358
Volcanic rocks 173
Waste disposal, radioactive and chemical 244
Water resources 130, 131
Idaho-Montana:
Geochemical study, Coeur d'Alene district 18
Land-use maps, Centennial Mountains 241
Mineral deposits, relation to thrust faults 67
Stratigraphy, Belt Supergroup 69
Structural geology, Centennial Mountains 71
Idaho-Washington, Pullman-Moscow basin, simulation of hydrology of primary basalt aquifer 199
Igneous rocks 16, 67, 68, 76, 90
See also under individual States.
Illinois:
Cooperators 348
Quality of water 215, 250
USGS office 358
Illinois-Wisconsin, reaeration coefficients in Rock River 108
India, Lonar Crater investigations 261
Indian lands, mineral assessment of 17
Indiana:
Cooperators 348
Ground water 101
Landfills, leachate movement 101
Surface water 251
USGS office 358
Indonesia:
USGS office 360
Volcanic rocks 300
Infrared imagery:
Geologic applications, thermal infrared images 274
Geothermal exploration reconnaissance 274
International cooperation:
Disaster response 292
International commissions and representations 298
Scientific and technical cooperation 297
Technical assistance and participant training 293
International Hydrological Program 138
Iowa:
Cooperators 348
Urban-area study, Cedar Rapids 282
USGS office 358

Isotope geochemistry 182
Isotopes:
Stable 183
Tracer studies 182

J

"Journal of Research of the U.S. Geological Survey" 324, 325

K

Kansas:
Cooperators 348
Flood mapping 248
Ground water 120, 137
Land-use and land-cover mapping 288
Subsurface mapping 210
Surface water 205
USGS office 358
Kentucky:
Cooperators 348
Geologic mapping 64
Ground water 112
Paleogeography 65
Paleontology 197
Palynology 197
Radioactive-waste storage site 243
Tectonics 64
USGS offices 356, 358
Kenya:
Ground water 301
USGS office 360
Known Coal Leasing Areas 155
Known Geologic Structures 154
Known Geothermal Resources Areas 154

L

Land subsidence. *See* Subsidence.
Land-Use Data and Analysis Program 287
Land-use studies:
Computer mapping system 240
Earth-science information in land-use planning 285
Land-capability assessment, new approach 285
Land-use change, maps 282
Land-use and land-cover mapping program 287
Mapping project 301
Remote sensing in land-use inventory 268, 271
Results of investigations 284
See also under individual States.
Landsat. *See* Remote sensing.
Landslides:
Slope and foundation stability 286
Susceptible areas 235
U-shaped valley, new topographic form 241
See also Engineering geology, Soil engineering, *as well as under individual States.*
Lead 3, 14
Light metals 8
See also metal names.
Lignite 124
Limnology 104, 209, 211, 212, 213, 214
See also under Water, surface, *as well as under individual States.*
Lithium 46, 47, 164
Lopoliths 5

Page

Louisiana:
Aquifer studies 120
Cooperators 348
Ground water 120
Oil and gas industry, economic impact on Coastal Plain area 290
Quality of water 120, 121
Runoff and suspended-sediment yield 120
USGS offices 354, 355, 358
Lunar investigations. *See* Astrogeology.

M

Magmatic processes 176
Maine:
Cooperators 348
Faulting 56
Stratigraphy 53
USGS office 358
Mapping standards, USGS 309
Marine geology:
Alaska-Antarctica 148
Atlantic coast 141
Gulf coast and Caribbean Sea 144
Manganese nodules, resource investigations 151
Pacific coast 146
Results of investigations 141
Submarine canyons, sediment processes 142
Unstable sediments, Mississippi Delta 144
See also under specific body of water.
Mariner missions. *See* Astrogeology.
Mars. *See* Astrogeology.
Maryland:
Aquifer studies 101
Cooperators 349
Environmental geology 242
Erosion and sedimentation 135
Geohydrology 101
Geophysical investigations 60
Ground water 101
Structural geology 60
Urban-area study, Baltimore-Washington, D.C., area 287
USGS office 358
Massachusetts:
Aquifer studies 101
Cooperators 349
Environmental study of Cape Cod via Landsat imagery 269
Faulting 54, 55
Flood-frequency studies 246
Glacial geology 50
Ground water 102
Hebron Formation 53
Intrusive rocks 56
Metamorphic rocks 53
Metamorphism 57
Quaternary geology 143
Stratigraphy 51, 52, 53, 54, 144
Tills 49
Urban-area study, Boston 282
USGS offices 356, 359
Water resources, Nantucket Island 144
Mercury (planet). *See* Astrogeology.
Mercury 4, 35, 150
Mesozoic studies 193
Metamorphism 57, 176, 177
Methods and techniques:
Analytical methods 219
Artificial substrate samplers, comparative evaluations 215

Page

Methods and techniques—Continued
Atomic absorption technique for determining constituents in coal 219
Borehole gamma spectrometry, stripping technique 244
Diversity index, use in water-quality studies 215
Einstein method, revised modified 190
Electromagnetic modeling and inversion 186
Emission spectroscopy 219
Factor analysis, interpretation of airborne radiometric data 274
Fraunhofer line discriminator, airborne sensing of water contamination 278
Gas chromatograph, measurement of dissolved gases in water samples 220
Geophysical techniques, applied 161
Gravity inversion, iterative three-dimensional program 163
Hydration-rind dating 178
Hydrologic techniques 217
Induction logs, use in ground-water investigations 113
Luminescence remote sensing 20
Microwave techniques, active and passive, use in remote-sensing geophysics 272
Neutron-activation analysis, application to analysis of water 220
Petroleum resource appraisal method 22
Schlumberger resistivity soundings 162
Six-step semiquantitative method 20
Stream traveltime, equations for estimating 204
Transmission electron microscopy, use in lunar sample investigations 264
Uranium exploration:
Borehole geophysics 39
Electromagnetic methods 162
Germanium spectrometer system 165
X rays:
Carbonate to noncarbonate ratios, determination 179
Diffraction, lunar sample investigations 264
Spectrography 219
See also Chemical analyses.
Mexico:
Copper 18
Hydrology 298
Land-use mapping project 301
Mapping along international boundary 318
Mineral target areas 301
Michigan:
Amasa uplift 66
Cooperators 349
Erosion 102
Flood of April 1975, Lansing 245
Geochronology 66
Metal potential 16
Geomorphology 65
Ground water 102
Iron resources 8
Magnetic measurements, Keweenawan rocks 158
Urban-area study, Pontiac 282
USGS office 359
Volcanic rocks 66

Page

Mineral Assessment Program 14
Mineral deposits:
Gravity mapping, exploration aid 20
Isotope studies 183, 184
Lead and zinc 3
Remote sensing, use in exploration 267
Thrust faults, relation to deposits 67
See also mineral names, as well as under individual States.
Mineral lands, classification and evaluation 154
Mineral leasing, supervision 155
Mineral resources:
Analysis, results of 22
Assessment of areas 10
Data bases 22
Economic potential 16
Investigations 23
Mineral-exploration modeling study 23
Model studies 22
Wilderness Act, related investigations 12
See also mineral names, as well as under individual States.
Mineral resources and mineral fuels, results of investigations 1
Mineralogy:
Basalts, Mid-Atlantic Ridge 175
Crystal structure analysis 166, 167
Ilmenites, lunar and terrestrial 168
Iron-titanium oxides 306
Mineral alteration 37, 178, 179
Mineralization model 1
Minor-element variations 175
New mineral, Southwest Africa 168
Pyroxene studies 167
Results of investigations 175
Volcanic rocks 175
Minerals Discovery Loan Program 17
Mining activities 202, 236, 239, 284
See also Coal, Economic geology, *and other mineral names, as well as under individual States.*
Minnesota:
Aquifer studies 103
Cooperators 349
Flood studies 246, 248, 249
Geologic hazards, urban areas 237
Ground water 103, 104
Limnology 104
Paleontology 193
Quality of water 104
Surface water 104
USGS office 359
Water resources 103
Minnesota-North Dakota, remote sensing, analysis of Red River Valley flood 268
Mississippi:
Cooperators 349
Dewatering, Tennessee-Tombigbee Waterway 112
Lead-zinc deposits 3
USGS offices 355, 356, 359
Missouri:
Cooperators 349
Ground water 201
Ores 3
Surface water 250
USGS offices 354, 355, 357, 359
Vegetation as hydrologic indicator 210

Page

Molybdenum ... 13
Montana:
Coal aquifers ... 121
Cooperators ... 349
Copper ... 16, 19
Earthquake hazards, relation to faulting ... 230
EMRIA program ... 25
Faulting ... 230
Geohydrology ... 121
Geophysical studies ... 164
Geothermal reconnaissance ... 43
Ground water ... 121, 122
Quality of water ... 207
Silver ... 16
Stratigraphy ... 69, 70
Uranium and thorium ... 12
USGS offices ... 355, 359
Volcanic rocks ... 173
Volcanism ... 68
Wells ... 121
Montana-North Dakota, quality of water ... 206
Montana-Wyoming, coal resources ... 27

N

National Cartographic Information Center ... 316, 326
National Environmental Overview maps 95
National Stream Quality Accounting Network ... 133, 137
National Technical Information Service 326
National Water Data Exchange ... 133
Natural remanent magnetization ... 157
Near East. *See individual countries.*
Nebraska:
Bedrock geology, map ... 67
Cooperators ... 349
Flood-frequency regions ... 122
Ground water ... 122, 137
USGS office ... 359
Nepal, ground water ... 301
Nevada:
Chemistry of water, southern Nevada aquifer ... 179
Cooperators ... 349
Earthquake hazards, relation to faulting ... 230
Economic geology ... 16
Faulting ... 73, 230
Flood of July 1975, Las Vegas Valley ... 245
Geochronology ... 77
Geologic map ... 95
Gold ... 183
Ground water ... 131
Heat flow ... 44
Hydrologic conditions and hazards, Washoe Lake area ... 131
Lithium ... 46
Mercury and uranium mineralization ... 4
Metal leakage ... 14
Mineral deposits, stable isotope studies ... 183, 184
Oil resources ... 32
Plutons ... 76
Sediment transport, Lake Tahoe ... 189
Sedimentation, lacustrine ... 30
Stratigraphy ... 73, 74
Structural geology ... 74
Tholeiites ... 76
USGS office ... 359
Nevada-Utah, igneous rocks ... 76
New England, results of geologic investigations ... 49

Page

New Hampshire:
Cooperators ... 349
Faulting ... 55
Glacial geology ... 50, 51
Intrusive rocks ... 56
Stratigraphy ... 52
USGS office ... 359
New Jersey:
Aquifer studies ... 105
Cooperators ... 349
Flood of July 1975, Mercer County ... 245
USGS office ... 359
Volcanic rocks ... 174
New Mexico:
Anomaly enhancement ... 19
Channel scour ... 191
Cooperators ... 349
Evaporation ... 211
Geochronology ... 77
Geochronometry ... 185
Ground water ... 123
Heavy minerals ... 18
Igneous rocks ... 16
Palynology ... 195
Thermal springs ... 44
Uranium ... 35
USGS offices ... 355, 356, 359
Volcanic rocks ... 68
New Mexico-Texas:
Ground-water movement and natural recharge ... 201
Quality of water ... 206
New York:
Aeromagnetic survey ... 58
Artificial recharge ... 200
Cooperators ... 350
Ground water ... 105
Heavy metals and PCB, Hudson River ... 249
Stratigraphy ... 106
USGS office ... 359
Waste disposal ... 106, 243, 251
New Zealand, USGS office ... 360
Nicaragua, earthquake of 1972, follow-up investigation ... 292
Nickel ... 104
Niger, hydrological investigations ... 301
Nonmetallic minerals ... 8
See also mineral names.
North America, metallogenic map ... 95
North Carolina:
Cooperators ... 350
Diagenetic studies ... 177
Peat resources ... 10
Surface water ... 113
Thermal loading, Hyco Lake ... 211
USGS office ... 359
North Carolina-Virginia, remote-sensor mapping, Great Dismal Swamp ... 278
North Dakota:
Aquifer studies ... 123, 124
Cooperators ... 350
Ground water ... 123, 209
Lignite ... 124
USGS office ... 359
Nuclear energy. *See* Energy studies.
Nuclear geochemistry ... 182

O

Office of Water-Data Coordination ... 132
Ohio:
Cooperators ... 350
Landslides ... 235
Potamology ... 209
Quality of water ... 251
USGS office ... 359

Page

Oil and gas resources:
Data Bank ... 22
Economic impact of industry on coastal areas ... 290
Eolian reservoirs ... 28
Faulting, relation to ... 31
Fracture shale, oil source ... 31
Lease sales, OCS ... 155
Natural gas ... 28, 32
Oil resources ... 32
United States ... 31
See also under individual States.
Oil shale ... 35, 206
See also under individual States.
Oilspills ... 128
Oklahoma:
Cooperators ... 350
USGS offices ... 355, 359
Oman, pillow lavas ... 175
Open-file reports ... 324
Ore ... 2, 3, 5, 7, 20, 72, 182, 184
Oregon:
Cooperators ... 350
Diagenetic studies ... 178
Geochronology ... 81
Geologic map ... 95
Geothermal resources ... 45
Ground water ... 131
Heat flow ... 44
Limnology ... 212
Platinum ... 15
Quality of water ... 131, 137
Sediment transport, Tillamook Estuary ... 190
USGS offices ... 355, 359
Orthophoto products ... 312
Outer Continental Shelf:
Georges Bank, environmental conditions ... 142
Lease sales for oil and gas ... 155
Oilspill risk analysis ... 128
South Texas shelf, sediment patterns 145

P

Pacific coast:
Hydrology ... 153
Marine geology ... 146
Results of geologic investigations ... 77
Pacific Ocean:
Diagenetic studies ... 178
Hawaiian-Emperor bend, age ... 184
Monterey Fan, sedimentation and erosion ... 147
Strait of Juan de Fuca and Pacific Continental Shelf, tectonic framework ... 147
Pakistan, Salinity Control and Reclamation Projects ... 302
Palau Islands, structural geology ... 301
Paleogeography ... 183
Paleomagnetism ... 62, 157
Paleontology ... 193, 194, 195, 196, 197
See also under individual States.
Paleotectonic maps ... 96
Paleozoic studies ... 195
Palynology ... 195, 197
Pan American Institute of Geography and History ... 298, 320
Pennsylvania:
Cooperators ... 350
Greater Pittsburgh region studies:
Bedrock maps, Allegheny County ... 284

Page

Pennsylvania—Continued
  Greater Pittsburgh region studies—Continued
    Coal-mining activity, maps and reports ---- 284
    Land-use maps ---- 282
    Landslide susceptibility, maps and reports ---- 284
  Ground water ---- 106
  Land-use and land-cover mapping ---- 288
  Limnology ---- 106, 213
  Lithium ---- 47
  Low-flow frequency characteristics ---- 204
  Remote sensing:
    Forest defoliation ---- 269
    Geologic features ---- 269
  Slope stability ---- 242
  Trout populations, Sacony Creek ---- 106
  USGS offices ---- 356, 359
Peru, earthquake of October 3, 1974 ---- 302
Petroleum:
  Exploration problems, application of chalk diagenesis ---- 33
  Hydrocarbons ---- 30
  Permian Phosphoria black shales, organic geochemistry and thermal maturation ---- 29
  Remote sensing of petroleum accumulations ---- 32
  Resource appraisal method ---- 22
Petrology, results of investigations ---- 165, 181
Petrophysics ---- 161
Phosphate ---- 9, 13, 291
Phosphorite ---- 8
Photogrammetric techniques ---- 262, 310
Photoimage mapping ---- 311
Plant ecology ---- 215, 216
  See also under individual States.
Plate tectonics ---- 85
Platinum ---- 6, 7, 15
Plutonic rocks ---- 76, 77, 78, 85, 176
  See also under individual States.
Poland, base metals and mining hydrology ---- 298
Pollution ---- 108, 249, 253
Potamology ---- 209, 210, 211
  See also Water, surface, *as well as under individual States.*
Potash ---- 9, 305
Precious metals ---- 4
  See also metal names.
"Preliminary Determination of Epicenters" ---- 293, 324
Publications program, USGS:
  How to obtain publications:
    By mail ---- 325
    Over the counter ---- 325
  Products ---- 323
  Publications issued ---- 324
  See also specific titles or designations.
Puerto Rico:
  Cooperators ---- 352
  Faulting ---- 90
  Igneous rocks ---- 90
  Limnology ---- 214
  Sediments, Puerto Rican shelves ---- 146
  Serpentinite ---- 89
  USGS offices ---- 356, 359

Q

Q-mode factor analysis, application to geochemistry and petrology ---- 181
Qatar, artificial recharge ---- 302
"Quality of Surface Waters of the United States" ---- 323
Quality of water. *See* Water, quality, *as well as under individual States.*

R

Rare metals ---- 4
  See also metal names.
Remote sensing:
  Agricultural drainage ---- 271
  Archaeological sites ---- 270
  Basin characteristics from satellite imagery ---- 205
  Cartographic studies, applications to ---- 278
  Cloud-formation monitoring ---- 271
  Digital image processing ---- 280
  Electromagnetic radiation, interaction with geologically important materials ---- 272
  EROS program ---- 267
  Forest succession, applications to ---- 267
  Geologic studies, applications to ---- 272
  Geographic studies, applications to ---- 282
  Geothermal systems, microwave studies of surficial anomalies ---- 272
  Hydrologic data transmission via satellite ---- 218
  Hydrologic studies, applications to ---- 276
  Land-use maps ---- 282
  Landsat:
    Altered rocks, mapping ---- 272
    Cover-type classification ---- 277
    Data-user facilities ---- 281
    Environmental study of Cape Cod ---- 269
    Flashing experiment ---- 317
    Flood analysis ---- 268
    Follow-on missions ---- 282
    Forest defoliation ---- 270
    Icecap mapping ---- 270
    Icings, Arctic Slope ---- 277
    Image processing ---- 311
    Imagery resolution, improvement of ---- 281
    Land-use mapping project ---- 301
    Land-systems mapping ---- 269
    Land-use inventories ---- 268, 271
    Land-use and land-cover mapping ---- 287
    Mine inventorying ---- 271
    Mineral target areas, definition of ---- 301
    Range- and water-management problems ---- 302
    Small-scale images ---- 275
    Structure mapping ---- 273, 300
    Uranium exploration ---- 39
    Water depths in Florida Everglades ---- 276
  Lava diversion, applications to ---- 270
  Lineament map of United States ---- 267
  Luminescence remote sensing ---- 20
  Magnetic anomalies, satellite studies ---- 160
  Microwave techniques, active and passive ---- 272
  Mineralization targeting ---- 267
  Petroleum accumulations, remote sensing of ---- 32
  Radiometric data, airborne ---- 274
  Resource mapping, applications to ---- 271
  Results of investigations ---- 267
  Satellite-Data Relay Project ---- 276
  Satellite image maps ---- 278
Remote sensing—Continued
  Sea-ice studies ---- 218
  Skylab:
    Cover-type classification ---- 277
    Earth Resource Experiment Package ---- 279
    S–192 data, discrimination of geologic materials ---- 275
    Thematic mapping ---- 280
    Volcanic landforms and eruption clouds, images ---- 276
  Snow-cover measurement ---- 276, 277
  Volcanic rocks ---- 273, 275
  Water contamination ---- 278
  Wetlands classification and mapping ---- 278
    See also Infrared imagery, *as well as under individual States.*
Rhode Island:
  Cooperators ---- 351
  Floods, magnitudes and frequency on streams ---- 247
  Ground water ---- 107
  Quaternary features, Rhode Island Sound ---- 143
  USGS office ---- 359
Rock mechanics ---- 237, 238
Rocky Mountains, results of geologic investigations ---- 67

S

Saline water ---- 110, 111, 152
San Andreas fault ---- 80, 227
Saudi Arabia:
  Agricultural development ---- 305
  Copper-zinc deposit ---- 302
  Geochronology ---- 302
  Gold, Mahd adh Dhahab mine ---- 304
  Ground water ---- 305
  Mapping activities ---- 318
  Red Sea continental margin ---- 304
  Sulfide ---- 303
  USGS office ---- 360
  Water resources ---- 305
  Water supply, alternative sources for Riyadh ---- 305
  Work Agreement, extension of ---- 294
Sea-ice studies ---- 151, 218
Sediment transport ---- 189, 190
  See also under individual States.
Sedimentary rocks ---- 9, 158
  See also under individual States.
Sedimentation ---- 30, 86, 100, 135, 142, 144, 145, 146, 147
  See also under individual States.
Sedimentology ---- 120, 145, 189, 217
  See also under individual States.
Seismic studies ---- 64, 222, 231, 232, 234
  See also Earthquake studies, *as well as under individual States.*
Selenium ---- 4, 219
Silver ---- 5, 16, 184, 220
Skylab. *See* Remote sensing.
Soil engineering ---- 237
South America, resource mapping in Andes Mountains, remote-sensing applications ---- 271
South Carolina:
  Aquifer contamination ---- 114
  Cooperators ---- 351
  Ground water ---- 113

Page

South Carolina—Continued
Mines, Landsat inventory 271
Paleomagnetism 62
Paleontology 193
Saltwater intrusion, Intracoastal Waterway 152
Seismic studies 64, 231
Stratigraphy 63, 64
USGS offices 356, 359
Volcanic rocks 174
South Dakota:
Aquifer studies 124, 125
Cooperators 351
Land-use inventory, Landsat data 268
Paleontology 193
USGS offices 354, 356, 357, 359
Spain, marine geology information acquisition program 297
State map indexes 314
Stratigraphy 51, 52, 53, 54, 58, 59, 61, 63, 64, 69, 70, 73, 74, 82, 83, 85, 106, 144
See also under individual States.
Structural geology 55, 59, 60, 61, 71, 73, 74, 75, 78, 79. 80, 81, 84, 86, 146, 148, 300, 301, 304, 307
See also under individual States.
Subsidence 238, 254, 255, 256
See also under individual States.
Sulfide 3, 303, 306
Surface water. *See* Water, surface, Limnology, Potamology, *as well as under individual States.*
Surface water and ground water, relationship 209
"Surface-Water Supply of the United States" 323
Surveying, field 308

T

Tennessee:
Cooperators 351
Ground-water movement and natural recharge 201
Hydrocarbons 30
Land-cover types, relation to hydrology 114
Rainfall-runoff model application 135
USGS offices 356, 359
Waste disposal, radioactive 244
Wetlands classification and mapping, remote sensing 278
Texas:
Aquifer studies 125
Artificial recharge 200
Cooperators 351
Ground water 125
Mineral alteration, Edwards aquifer 178
Paleochannels 39
Plant ecology 216
Structural geology 63
Subsidence 255
Suspended sediment, Corpus Christi Bay 145
Trace-metal levels, Corpus Christi Bay biota 145
USGS offices 355, 356, 357, 359
Thailand, USGS office 360
Thailand and Laos, potash 305
Thallium 48
Thermal springs 202
Tholeiites 76
Thorium 12, 35, 38, 39
Tin 4

Page

Topographic surveys and mapping:
Aerotriangulation 310
Camera calibration 310
Cartography, automated 314
Equipment 309, 311, 312, 314, 315
Geodetic data 308
Images:
Correlation 310
Processing 311
Quality 311
International activities 317
Map design 313
Mapping standards 309
Orthophoto products 312
Photogrammetric techniques 310
State index maps, redesign of 314
Surveying systems, automated 308
Training and tours 320
Transpiration 210
Tungsten 4

U

United States:
Active faults, map 240
Appalachian Mountains:
Late Precambrian triple junctions 59
Thermal springs 202
Appalachian Plateau, new topographic form 241
Atlantic Coastal Plain, stratigraphic correlation in and between depositional basins 63
Eastern:
Fault movement 62
Geothermal resources 45
Volcanic rocks 174
Geothermal resources, assessment of 39
Great Basin, volcanism and mineralization 72
Great Plains, water quality of Upper Cretaceous aquifers 207
Lineament map 267
Mineral Assessment Program 14
Mississippi Embayment, remote-sensor analysis 273
New England, Connecticut Valley Urban Area Project 286
Oil and gas resources 31
Paleotectonic maps:
Mississippian System 96
Pennsylvanian System 96
Sierra Nevada:
Geochronometry 185
Pluton depths 78
Souris-Red-Rainy region, ground-water resources and development 104
Upper Chesapeake Bay, satellite image map 279
Uranium 35, 37
Western:
Geochemical survey of coal regions 252
Late Paleozoic Eurasian bryozoans 196
Satellite image maps 279
Subsidence-associated ground fractures 238
Volcanic rocks 171
Uranium 4, 9, 12, 35, 36, 37, 38, 39, 162, 165, 175
Urban-area studies 282, 286, 287, 288
See also under individual States.

Page

Urban geology:
Connecticut Valley Urban Area Project 286
Geologic hazards 236, 237
See also Subsidence.
Urban hydrology:
Connecticut Valley Urban Area Project 286
Runoff, quality in urban areas 250
USGS program 134
Utah:
Coal 28
Cooperators 351
Earthquake hazards, relation to faulting 230
EMRIA program 26
Faulting 230
Geochemical survey, Sheeprock Range 18
Igneous rocks and hydrothermal minerals, age 67
Lead 14
Lithium 47
Mercury 35
Paleontology 195, 196
Petroleum potential 33
Rock mechanics 237, 238
Uranium 36
USGS offices 355, 357, 359
Volcanic rocks 174
Volcanism 45
Utah-Montana, paleontology 197
Utah-Nevada, metalliferous Mississippian siltstone 4

V

Vermont:
Cooperators 351
Glacial geology 51
Rock mechanics 238
USGS office 359
Viking mission. *See* Astrogeology.
Virginia:
Coal 27
Cooperators 351
Faulting 63
Geohydrology 286
Heavy minerals 17
Landslides 236
Lithology 62
Mineral alteration 179
Sedimentary rocks 9
Stratigraphy 59, 61
Structural geology 59, 60, 61
USGS offices 353, 356, 357, 358, 359
Volcanism 41, 45, 66, 67, 68, 72, 75, 89, 157, 158, 171, 173, 174, 175, 176, 300, 307
See also Volcano studies, *as well as under individual States.*
Volcano studies 40, 168, 169, 170, 171, 225, 293
See also Volcanism, *as well as under individual States.*

W

Washington:
Cooperators 351
Earthquake hazards, relation to faulting 230
Faulting 81, 230
Geophyscial investigations 164
Glaciology 192
Ground water 132
Hydrology, estuarine 148
Magnetostratigraphy 81

Page

Washington—Continued
pH modeling 153
Streamflows, relation to steelhead trout spawning 205
Strontium isotope composition, Yakima Basalt 182
Structural geology 81
Surface water 132
Uranium 38
Urban-area study, Puget Sound area 287
USGS offices 356, 357, 359
Volcano studies 170, 171
Washington, D.C. *See* District of Columbia.
Waste disposal 106, 111, 119, 135, 199, 201, 242, 243, 244, 245, 250, 251
See also Water, quality, *as well as under individual States.*
Water, chemical, physical, and biological characteristics 206
Water, ground:
Hydrology, results of investigations 197
Lakes, interaction with ground water 209
Madison Limestone, model 115
Miscellaneous studies 201
Missouri River region, summary appraisal 116
Model calibration 199
Surface water, relationship with ground water 209
See also Aquifer studies, Artificial recharge, *as well as under individual States.*
Water, quality:
Diversity index, use in water-quality studies 215
Geophysical logs, use in extending data 206
Highway deicing chemicals, relation to water quality 250
Iron bacteria, influence on pyrite oxidation in soils 208
Measuring equipment 217
Modeling 208
Oil-shale retorting, effect on water quality 206
Results of investigations 249
Runoff, quality in urban areas 250
Water in sediments, effects of geopressure on quality 179
See also under individual States.
Water resources:
Central region 114
Northeastern region 99
Southeastern region 108
USGS investigations 97
Western region 126
See also Water, ground, Water, quality, Water, surface, *as well as under individual States.*
Water, surface:
Basin characteristics from satellite imagery 205
Computer programs, surface-water processes 205
Flow-routing models 203
Ground water, relationship with surface water 209
Hydrology, results of investigations 203
Open-channel hydraulics 203
Stream traveltime, equations for estimating 204
Streamflow prediction 205
Waterpower classification 155
Wells 110, 121
West Virginia:
Coal drilling, exploratory 26
Cooperators 351
Hydrology, Coal River basin 107
Land-use and land-cover mapping 288
Natural gas 32
Stratigraphy 58
USGS office 359
Wetlands, classification and mapping 278, 314
Wisconsin:
Aquifer studies 108
Cooperators 351
Flood studies 107, 108
Ground water 107, 108
Hydrology, Nevin Fish Hatchery wetland 108
Low-flow estimation, Flambeau River 107
Plant ecology 216
Quality of water 107
Sulfide 3
USGS office 359
Wyoming:
Alluvium, resistivity measurements 126, 202
Borehole geophysical study, Powder River basin 126
Bouguer gravity map, Powder River basin 126
Coal 27, 291
Cooperators 352
EMRIA program 26
Geochronometry 184
Geologic hazards, urban areas 236, 237
Geologic map 96
Geomorphism 72
Glacial geology 70
Ground water 202
Igneous rocks 68
Landslides, relation to mining activity 236
Magmatic processes, Bighorn Mountains 176
Mineral-resource investigations 23
Oil and gas evaluation, relation to faulting 31
Petroleum, stratigraphic traps 31, 33
Phosphate 13
Platinum 7
Porosity variation, Tensleep Sandstone 30
Rock mechanics 238
Structural geology 71
Tidal gravity, measurements at Yellowstone caldera 227
Uranium 36, 37
USGS offices 355, 356, 359
Volcanic rocks 173

X

X-ray techniques. *See* Methods and techniques.

Y

Yemen Arab Republic:
Geologic investigations 306
Ground water 306
USGS office 360

Z

Zinc 3, 302

INVESTIGATOR INDEX

Page

A

Abbott, W. H 193
Ackerman, D. J 123
Ackermann, H. D 64, 231
Adams, D. B 211
Adinolfi, F. G 49
Adkison, W. L 28
Ahlbrandt, T. S 28
Aki, K 223
Aldridge, B. N 247, 248
Alexander, C. C 168
Alexander, R. H 288
Algermissen, S. T 234
Alldredge, L. R 159
Allen, R. V 170
Allmendinger, R. W 55
Alminas, H. V 19, 21
Altschuler, Z. S 24
Anderson, B. M 253
Anderson, F. J 291
Anderson, G. S 199
Anderson, L. A 163, 168, 169
Anderson, R. C 33
Anderson, T. W 210
Anderson, W. L 186
Andreasen, G. E 304
Andregg, C. H 318
Andrews, D. J 231
Andrews, G. W 193
Angelo, C. G 251
Angsuwathana, P 295
Anna, L. O 123
Annell, C. S 174
Antweiler, J. C 220
Arihood, L. D 101
Armbruster, J. T 203, 204
Armbrustmacher T. J 38
Armstrong, C. A 123, 124
Armstrong, F. C 298
Arnal, R. E 146
Arndt, H. H 26
Aronson, D. A 200
Arteaga, F. E 113
Aruscavage, P 219
Asaro, F 76
Ashenden, D. D 55
Ashley, R. P 77, 273
Attanasi, E. D 136
Atwater, B. F 230
Averett, R. C 127, 130, 215
Ayers, M. A 251

Page

B

Babcock, H. M 301
Babcock, J. W 171
Back, W 179, 180, 298
Bader, J. S 107
Baedecker, P. A 265
Bailey, E. H 294
Bailey, R. A 157
Bakun, W. H 228
Balch, A. H 25, 33
Bancroft, W. L 276
Banks, N. G 77
Barclay, C. S. V 27
Barger, K. E 231
Barker, F 174, 176
Barker, J. L 106, 213
Barker, R. A 199
Barks, J. H 250
Barnes, D. F 82, 163
Barnes, H. H., Jr 139
Barnes, I 179
Barnes, P. W 151
Barnum, B. E 28
Barosh, P. J 53
Barraclough, J. T 245
Barrett, P. J 307
Barton, P. B., Jr 1
Batchelder, J. N 70, 184
Bateman, P. C 4, 299
Bates, D. E. B 197
Bath, G. D 74
Batson, R. M 262
Bauer, D. P 205
Beach, D. K 146
Beam, H. W 271
Bearden, H. W 109
Beaven, T. R 110
Beckman, E. W 122
Bedinger, M. S 198
Beeson, M. H 170
Behrendt, J. C 141
Bell, H., III 62
Belt, K 318
Bennett, R. H 145
Bentley, C. B 112
Bentley, R. D 81
Berdan, J. M 196
Berg, H. C 12
Bergmann, J. M 135
Berman, S 265
Berryhill, H. L., Jr 145
Bethke, P. M 1
Biddle, K. T 28
Bigelow, R. C 19, 278
Billings, R. H 135, 217
Bingham, D. L 118
Bird, K. J 29
Bird, M. L 7, 8
Bischoff, J. L 152
Bisdorf, R. J 162
Blacet, P. M 14
Black, D. F. B 64
Blair, M. L 284
Blake, M. C., Jr 77
Blanchard, D. P 263
Blanchard, L. F 27
Blank, H. R 304
Blean, K. M 87
Boehl, J. R 161
Boettcher, A. J 121
Bohannon, R. G 46
Bonhommet, N 170
Bonilla, M. G 230
Boning, C. W 135, 246
Booker, R. E 218
Books, K. G 62, 66, 158
Booth, J. S 145

Page

Borcherdt, R. D 231, 232
Bortleson, G. C 127, 212
Boschert, R. G 317
Bostick, F. X 161
Botbol, J. M 22, 23
Bothner, M. H 142, 203
Botinelly, T 13
Botsford, M. L 165
Boucher, G 151
Boudette, E. L 52, 53, 55
Bowden, T. D 16
Bowen, R. W 22
Bowman, H. R 76
Boyce, J, M 257, 259, 260
Boyles, J. M 239
Boynton, G. R 25
Brabb, E. A 240
Bradbury, J. P 193
Braddy, D 263
Branson, F. A 215
Bredehoeft, J. D 139, 198
Breger, I. A 25
Bressler, S. L 158
Brethauer, G. C 238
Brett, P. R 265
Brew, D. A 87, 88, 89, 96
Briggs, R. P 284
Britton, L. J 130
Brock, M. R 13, 240
Brogden, R. E 116, 117, 118
Bromfield, C. S 14, 66
Brookins, D. G 53, 56
Brosgé, W. P 84
Broussard, W. L 103
Brown, C. E 58
Brown, D. P 111
Brown, G. F 294, 304, 305
Brown, R. F 255
Bruns, T. R 148
Bryan, W. B 175
Bryant, B. H 68
Bryant, W. R 145
Buck, S. P 27
Bucknam, R. C 230
Bufe, C. G 223, 224, 228
Bukry, J. D 146, 152
Bunker, C. M 38
Burchett, R. R 66
Burford, R. O 227
Burkham, D. E 190
Burnham, W. L 127
Bush, W. V 95
Butler, H. M 222
Butman, B 142
Buzzanell, P. J 289
Bybell, L 194
Byerlee, J. D 187, 226
Byers, F. M., Jr 41, 73

C

Cacchione, D. A 142
Cady, J. W 163
Cahill, J. M 243
Cain, J. C 160
Caire, L. F 18
Calandro, A. J 205
Calkins, J. A 22
Callahan, J. T 305
Callender, E 178
Cameron, C. C 10
Campbell, D. L 162, 231
Campbell, J. A 37
Campbell, R. H 236
Campbell, W. J 127, 218, 219
Cannon, W. F 8, 65
Cargill, S. M 24
Carlson R. R. 7

Page

Carlson, C 87, 88, 89
Carlson, J. E 95
Carneggie, D. M 291, 294
Carothers, W. W 179
Carr, M. H 257
Carr, W. J 75
Carrara, P. E 239
Carrigan, P. H., Jr 302
Carroll, R. D 162
Carter, L. D 82
Carter, M. D 24
Carter, V. P 278
Carter, W. D 267, 271, 293, 299
Case, J. E 299
Cassand, J 142
Castle, R. O 224, 231
Cathcart, J. B 9, 294
Cathrall, J. B 14, 18
Chaffee, M. A 18
Chandler, J. C 25
Chao, E. C. T 261, 262
Chao, T. T 19, 20, 21
Chapman, R. M 5, 84, 85
Charm, W. B 34
Chemlik, F. B 149
Chen, A. T. F 161
Cheng, R. T 213
Chernosky, J. V 165
Chiang, S. H 136
Childers, J. M 128, 247
Chidester, A. H 298
Chisholm, J. L 107
Chleborad, A. F 236
Christensen, C. M 124
Christensen, R. C 248
Christian, R. P 265
Christiansen, A. C 96
Christiansen, R. L 171
Christie, J. M 161
Christopher, R. A 64, 194
Churkin, M., Jr 89
Claassen, H. C 180
Clague, D. A 184
Clardy, B. F 95
Clark, A. L 299
Clark, M. M 172, 224
Clarke, J. W 61
Clarke, S. H., Jr 146
Claypool, G. E 29, 30
Click, D. E 140
Clifton, H. E 148
Clough, A 87
Coakley, J. M 224, 225
Coates, D. A 72
Coats, R. R 76
Cobb, E. H 12, 23
Cobban, W. A 31
Coe, R. S 158, 167
Coffin, D. L 121
Coker, A. E 114, 276, 277
Colby, B. R 190
Cole, W. S 301
Coleman, J. M 144
Coleman, R. G 175, 304
Coleman, S. L 24
Colman, S. M 127, 176
Colton, R. B 234
Connor, J. J 253
Conomos, T. J 153
Cook, H. E 29
Cooley, E. F 7, 14
Coonrad, W. L 170, 195
Coplen, T. B., II 220
Cordes, E. H 218, 276
Cornwall, H. R 2, 14
Corwin, G 301
Cory, R. L 139
Counts, H. B 255

	Page
Coury, A. B	31
Cousteau, J	281
Cox, E. R	203
Coyle, J. M	241
Cragwall, J. S., Jr	138, 139
Craig, L. C	36, 96
Crandell, D. R	171
Crawford, T. J	62
Crawley, M. E	200
Creasey, S. C	14, 77
Crenshaw, G. L	14
Cressler, C. W	62
Criner, J. H., Jr	201
Croft, M. G	115, 123, 207
Crosby, O. A	124
Crosthwaite, E. G	43
Culbertson, J. K	140
Culbertson, W. C	27
Cummings, T. R	102
Curet, A. F	90
Curtis, G. W	246
Curtiss, D. A	131, 212
Czamanske, G. K	6, 168

D

D'Agostino, J. P	14
Dalrymple, G. B	79, 170, 176, 184, 185
Dalziel, M	32, 189
Damon, P. E	41, 69
Daniel, C. C., III	113
Daniels, D. L	60
Daniels, J. J	39
Davidian, J	135
Davies, W. E	235, 241, 284
Davis, D. W	290
Davis, G. H	139, 255
Davis, J. R.	46
Davis, L. G	100
Davis, R. K	128
Dawdy, D. R	127, 135, 190
deForest, A. V	49
Dean, W. T	197
Dearborn, L. L	128
Deike, R. G	178, 179
Delaney, D. F	102
Delevaux, M. H	303
Demas, C. R	121
Denson, N. M	27
Denton, E. H	20
Desborough G. A	34, 35
Detterman, R. L	11, 86
Deutsch, M	268
Dewey, J. W	222
DeYoung, J. H., Jr	23
Dial, A. L., Jr	259
Dial, D. C	120
Diaz, J. M	260
Dibblee, T. W., Jr	80
Dickerman, D. C	107
Dickey, D. D	75
Dickinson, K. A	39
Dieterich, J. H	225, 226
Dillon, W. P	142
Diment, W. H	40, 42, 43
Dingler, J. R	191
Dixon, G. L	74
Dixon, H. R	58
Dobrovolny, E	237
Dodge, F. C. W	4
Dodge, H. W., Jr	23
Doe, B. R	3, 182, 303
Doerge, T. A	7
Dolan, R	289
Dolton, G. L	31
Domenico, J. A	306
Donnell, J. R	35
Donnelly, J. M	41, 42
Donovan, T. J	33
Dorrzapf, A	219
Douglass, R. C	197
Dover, J. H	27
Downey, J. S	124
Downing, R. A	179
Downs, S. C	107
Doyle, P. F	128
Drake, A. A., Jr	60
Drake, D. E	143
Dreeszen, V. H	66
Drew, L. J	22
Drewes, H. D	72
Druffel, L. A	217
Dube, A	261
Duffield, W. A	172
Dunlap, W. A	145
Dunrud, C. R	238
Dupré, W. R	150
Durbin, T. J	129, 199
Durum, W. M	208
Dutro, J. T., Jr	84, 85
Duval, J. S	274
Dwornik, E. J	265
Dysart, J. E	112

E

Earhart, R. L	16
Eaton, G. P	20, 163, 164
Eaton, J. P	224
Ebaugh, W. F	236
Ebens, R. J	252
Eberlein, G. D	89
Eccles, L. A	127
Edson, G. M	27
Eggers, D. E	244
Eggler, D. H	10
Ehrlich, G. G	208
Ekren, E. B	73
Ege, J. R	238
Ehlke, T. A	251
Eikenberry, S. E	100, 204, 251
Einstein, H. A	190
Eittreim, S	150
Elassal, A. A	163
El Goresy, A	261
Ellen, S. D	79, 241
Ellersieck, I. F	86
Elliot, J. E	12
Elliott, D. H	184
Ellis, M. Y	317
Ellis, W. L	238
Ellsworth, W. L	188
Elsheimer, H. N	219
Elston, D. P	158
Embree, G. F	229
Emery, P. A	220
Emmett, L. F	202
Emmett, W. W	190, 217, 291
Emmons, P. J	117
Endo, E. T	168
Engberg, R. A	122
Engdahl, E. R	223
England, A. W	164, 272
Englund, K. J	26
Epstein, A. G	74, 197
Epstein, J. B	95
Erd, R. C	168
Erdman, J. A	252, 254
Erickson, A. J., Jr	66
Ericson, D. W	103, 104
Espenshade, G. H	62
Espinosa, A. F	302
Espos, L. F	219
Evans, H. T., Jr	167
Evans, J. G	300
Evans, J. R	188
Evans, W. E.	205, 277

F

Fabbi, B. P	219
Fabiano, E. B	159
Fahey, R. J	55
Fahl, C. B	192
Fail, J. P	142
Fairchild, R. W	111
Fairer, G. M	238
Farlekas, F. M	105
Farrow, R. A	237, 291
Faulkner, G. L	201
Faust, C. R	186
Faust, G. T	174
Fayard, L. D	120
Feder, G. L	206, 209
Felsheim, P. E	103
Feltis, R. D	121
Fernandez, M., Jr	250
Ferreira, R. F	130, 215
Ficke, J. F	137, 138
Ficklin, W. H	19, 21
Field, M. E	146
Field, M. T	52, 54, 56
Field, S. J	108
Finkelman, R. B	171, 265
Firek, F	145
Fischer, F. G	225
Fisher, D. W	207
Fitterman, D. V	162
Fitzpatrick, K. A	288
Flanigan, V. J	162
Fleck, R. J	184, 302, 304
Fleck, W. B	102
Fleming, R. W	235
Flippo, H. N., Jr	249
Folger, D. W	142, 144
Foose, M. P	58, 66
Forbes, R. B	185
Force, E. R	17
Ford, A. B	88, 89, 306, 307
Forester, E	194
Foster, H. C	12
Foster, H. L	7
Fouch, T. D	30, 32
Fournier, R. O	185
Fox, J. E	30
Fox, K. F., Jr	78
Frank, D. G	170, 171
Frank, F. J	131
Frederiksen, N. O	64, 194
Freethey, G. W	127
Fretwell, M. O	132, 171
Frey, M	183
Frickel, D. G	190, 216
Friedman, I	19, 20, 48, 176, 177, 230
Friedman, J. D	274, 275, 276
Frost, L. R., Jr	250
Fryberger, S. G	28
Fuis, G. S	225
Fuller, F. J	318
Fuller, R. H	177, 213, 252
Fullerton, D. S	72
Fumal, T. E	232

G

Gabrysch, R. K	255
Galanis, S. P., Jr	44
Gallagher, D. B	283, 291
Gardiner, L. R	263
Garrigues, R. S	28
Garrison, L. E	144
Garrison, R. E	299
Gaskill, D. L	13

Page

Gates, J. S ... 125
Gatson, K. W ... 317
Gawarecki, S. J ... 294, 299
Gawthrop, W. H ... 229
Gay, F. B ... 102
Gazin, C. L ... 30
Geraci, P. J ... 17
Gettings, M ... 304
Gibbons, M. A ... 234
Gibbs, J. F ... 232
Giese, G. L ... 211
Giles, T. F ... 116
Gillespie, J. B ... 210
Giusti, E. V ... 136
Glancy, P. A ... 127, 131, 189, 245
Glanzman, R. K ... 47
Gleason, J. D ... 177
Glenn, J. L ... 190
Glick, E. E ... 95
Gloersen, P ... 218
Glysson, G. D ... 127
Godson, R. H ... 165
Godsy, E. M ... 208
Goff, F. E ... 41, 42, 79
Gogel, A. J ... 210
Gohn, G. S ... 63
Goldhaber, M. B ... 177
Goldsmith, R ... 58
Golightly, D. W ... 219
Gore, R. Z ... 55, 56
Gott, G. B ... 18
Gottfried, D ... 174
Gough, L. P ... 253, 291
Gower, H. D ... 230, 240
Granger, H. C ... 298
Grant, R. S ... 108
Grantz, A ... 150
Graser, W. F ... 317
Grauch, R. I ... 37
Green, A. W., Jr ... 159, 160
Green, M. W ... 35
Greene, H. G ... 146, 297
Greene, R. C ... 14
Greenland, L. P ... 219
Griffitts, W. R ... 18
Grimes, D. J ... 19
Griscom, A ... 45, 163
Grolier, M. J ... 306
Grommé, C. S ... 157, 158
Grossling, B. F ... 293
Grove, D. B ... 199, 208
Grow, J. A ... 141
Grybeck, D ... 87, 88
Gude, A. J., III ... 48
Guetzkow, L. C ... 246, 248, 249
Guild, P. W ... 95, 298, 299
Gulbrandsen, R. A ... 48, 291
Guswa, J. H ... 101
Gutentag, E. D ... 120, 137
Gutschick, R. C ... 33

H

Hackett, O. M ... 138, 139
Hackman, R. J ... 241
Hadley, D. G ... 304
Hadley, D. M ... 224
Hadley, R. F ... 239
Haeni, F. P ... 100
Haffty, J ... 6, 15
Hahn, S. S ... 214
Hail, W. J ... 34
Haire, W. J ... 110, 249
Hait, M. H., Jr ... 229
Haley, B. R ... 95
Hall, C. A., Jr ... 229, 240
Hall, D. C ... 206, 250
Hall, S. A ... 304

Page

Halley, R. B ... 34
Hamilton, L. J ... 124
Hamilton, M. S ... 22
Hampton, J. N ... 270
Hanks, T. C ... 223, 233
Hanna, W. F ... 173
Hansen, W. R ... 71
Hanshaw, B. B ... 180, 298
Harbaugh, A. W ... 106
Harden, D. R ... 127
Harding, S. T ... 233
Hardyman, R. F ... 73
Harenberg, W. A ... 130, 131, 246
Hargadine, G. D ... 210
Harlow, D ... 293
Harms, T. F ... 254
Harmsen, L ... 127, 245
Harp, E. L ... 232
Harrill, J. R ... 131
Harris, L. D ... 30
Harrison, J. E ... 69
Harsh, P. W ... 224
Harvey, E. J ... 210
Hasbrouck, W. P ... 165
Haskin, L. A ... 263
Hassemer, J. R ... 18
Hatch, J. R ... 24, 25
Hatcher, P. G ... 143
Hathaway, J. C ... 203
Haushild, W. L ... 153
Have, M. R ... 104
Hawkinson, R. O ... 137
Hayes, L. R ... 114
Hayes, P. T ... 26
Hays, W. W ... 233
Hazel, J. E ... 194
Hazlewood, R. M ... 232
Head, W. J ... 126, 202
Head, W. S ... 33
Healy, J. H ... 228
Hearn, B. C., Jr ... 41, 42
Hedel, C. W ... 230
Hedge, C. E ... 68, 300
Hedlund, D. C ... 16, 77
Hedman, E. R ... 204
Heidel, S. G ... 208
Heiken, G ... 276
Heindl, L. A ... 138
Helgesen, J. O ... 103
Helley, E. J ... 230
Helm, D. C ... 255
Helz, A. W ... 220
Hem, J. D ... 180, 208
Hembree, C. H ... 190
Hemingway, B. S ... 165
Hemley, J. J ... 177
Hemphill, W. R ... 19, 278
Hendricks, T. A ... 31
Herb, W. J ... 135
Herd, D. G ... 230
Hereford, R ... 76
Hernandez, J ... 237
Heropoulos, C ... 219
Herter, C. A., Jr ... 138
Hettinger, R. D., Jr ... 27
Heyl, A. V ... 5
Henry, T. W ... 58
Hepburn, J. C ... 53
Hess, A. E ... 218, 244
Hessed, G. R ... 147
Hickey, J. J ... 111
Higer, A. L ... 114, 276, 277
Higgins, B. B ... 63, 174
Higgins, M. W ... 60
Hilde, T. W. C ... 295
Hill, D. P ... 224, 225
Hill, G. W ... 145
Hillhouse, J. W ... 157

Page

Hillier, D. E ... 117
Himmelberg, G. R ... 306
Hindall, S. M ... 107, 217
Hinely, J. A ... 317
Hines, W. G ... 137
Hinkle, M. E ... 19
Hintze, L. F ... 196
Hirst, T. J ... 145
Hiss, W. L ... 123, 201, 206
Hitchcock, T ... 188
Hite, R. J ... 9, 305
Hoare, J. M ... 86, 170, 195
Hobba, W. A., Jr ... 45, 202
Hobbs, S. W ... 70
Hockley, J. J ... 184
Hodges, C. A ... 262, 275
Hoerle, R. C ... 194
Hoerle, S. E ... 194
Hoffman, R. J ... 130
Hoggan, R. D ... 229
Hoggatt, W. C ... 80
Holcomb, G. L ... 222
Holcomb, R. T ... 169
Hollyday, E. F ... 114, 205
Holm, R. F ... 41
Holmes, C. W ... 145
Holt, H. E ... 76
Holzer, T. L ... 238
Holzle, A. F ... 299
Hood, D. R ... 268
Hoose, S. N ... 237
Hoover, D. B ... 162
Hoover, D. L ... 231
Hopkins, D. M ... 84, 149
Horton, J. C ... 318
Hotchkiss, W. R ... 121
Hotz, P. E ... 78
Houston, R. S ... 68
Howard, K. A ... 240
Howell, D. G ... 146
Howell, J. I ... 150
Howells, L. W ... 125
Hu, C. L ... 76
Hubbard, H. A ... 9, 66
Hudson, J. H ... 34
Hudson, T. L ... 86, 88, 195
Huebner, J. S ... 165, 264
Hughes, J. L ... 130
Hull J. E ... 110, 135, 199
Hult, M ... 103
Hummel, C. L ... 5
Hunn, J. D ... 109
Hunt, G. R ... 272
Hunter, R. E ... 191
Hunter, R. N ... 222
Hunziker, J. C ... 183
Hurr, R. T ... 117
Hussey, A. M., II ... 53
Hutcheon, I. D ... 263
Hutchinson, C. B ... 110, 111
Hutchinson, E. C ... 116
Hutt, C. R ... 222
Hyde, J. H ... 171

I

Ibrahim, M. M ... 306
Irwin, W. P ... 77, 299
Isherwood, W. F ... 164
Iwatsubo, R. T ... 127
Iyer, H. M ... 188
Izett, G. A ... 197

J

Jachens, R. C ... 163
Jackson, D. B ... 43
Jackson, E. D ... 231

	Page
Jackson, R. O	304
Jacob, A. F	35
Jaffe, H. W	167
James, I. C., II	136
James, O. B	262
Jamieson, I. M	42
Janda, R. J	127
Jarrett, R. D	118, 246
Jenkins, E. D	120
Jenne, E. A	127, 150
Jenner, C. B	289
Jennings, M. E	205
Jensen, R. G	245
Jobson, H. E	205
Johnson, A. I	139
Johnson, B. R	87, 88
Johnson, C. E	224
Johnson, C. G	246, 247
Johnson, C. J	253
Johnson, D. A	233
Johnson, F. A	152
Johnson, G. R	269, 272
Johnson, K. G	249
Johnson, M. G	15
Johnson, M. S	213
Johnson, R. C	34
Johnson, R. W., Jr	64
Johnston, H. E	107
Johnston, M. J. S	228
Johnston, R. H	100
Jones, B. F	178
Jones, J. R	301
Jones, R. W	27
Jordan, C. F	29
Jordan, J. N	298
Jordan, P. R	205
Jordan, R	262
Julian, B. R	222
Junger, A	146

K

Kachadoorian, R	86
Kammerer, J. C	139
Kanizay, S. P	72
Kapinos, F. P	139
Kapple, G. W	118, 127
Kaplan, I. R	263
Karklins, O. L	196
Karlstrom, T. N. V	76, 299
Katzer, T. L	127, 131, 245
Kauffman, E. G	195
Kay, L	231
Keefer, D. K	232
Keefer T. N	203
Keefer, W. R	31
Keighin, C. W	35
Keil, K	263
Keith, J. R	253
Keith, T. E. C	12
Keller, G. H	143
Keller, G. R	64
Kelley, J. S	28
Kennedy, V. C	208
Kepferle, R. C	65
Kerbs, L	118
Kernodle, D. R	214, 249
Kerridge, J. F	263
Ketner, K. B	196
Keys, W. S	217, 243
Kharaka, Y. K	179
Kibler, J. D	238
Kilpatrick, F. A	140
Kilty, K. T	126, 202
Kimble, A. L	87
Kimmel, G. E	106
Kindsvater, C. E	140
King, C.-Y	228
King, E. R	66
King, K. W	233
King, N. J	121
Kinoshita, W. T	173
Kirby, S. H	161, 167
Kirkemo, H	294
Kirsten, T	263
Kistler, R. W	183
Klein, H	110
Klein, I. E	299
Klein, J. M	118
Kleinhampl, F. J	196
Kleinkopf, M. D	164, 301
Klemic, H	8
Klepper, M. R	69
Klitgord, K. D	141
Knebel, H. J	142
Knutilla, R. L	245
Kockelman, W. J	284
Kohl, W. R	284
Kohout, F. A	102, 144, 203
Konikow, L. F	116
Konnert, J. A	167
Kosanke, R. M	197
Kosiur D. R	180
Koslowski, W	126
Koszalka, E. J	106
Koteff, C	49, 50
Kowalik, W. S	269
Koyanagi, R. Y	168, 188
Krasnow, M. R	25
Krause, R. E	202
Krimmel, R. M	170
Krinsley, D. B	294
Krug, W. R	107
Krushensky, R. D	89, 90
Ku, H. F. H	105
Kuberry, R. W	159
Kuellmer, F. J	77
Kulp, K. P	106
Kume, J	125
Kuntz, M. A	173
Kuo, J. T	163
Kvenvolden, K. A	147

L

Lachenbruch, A. H	40, 44, 226
Ladd, H. S	301
LaFleur, R. G	243
Lahr, K. M	223, 224, 225, 231
Lai, C	204
Lajoie, K. R	231
Lambert, P. W	30
Land, L. F	111
Landis, E. R	25, 26
Laney, R. L	256
Lang, S. M	139
Langbein, W. B	139
Langer, W. H	51
Langford, R. H	139
Lanphere, M. A	1, 77, 79, 184, 185
Lappala, E. G	122
Lara, O. G	300
Larsen, B. R	150
Larson, R. R	171
Larson, S. P	198
Lassman, A. V	257
Lauer, D. T	301
Leahy, P. P	100
Leake, S. A	112
Learned, R. E	21
Leavesley, G. H	118, 119
LeBlanc, D. R	101
Lee, D. E.	76
Lee, F. T	236, 237, 238
Lee, K. W	127
Lee, M. W	33
Lee, R. W	207
Lee, W. H. K	223
Lee, K. Y	59
Lee-Moreno, J. L	18
Leenheer, J. A	206, 209
Lehrman, N. J	38
Leinz, R. W	19
Leland, H. V	213, 215
Lennartz, F. E	31
Leo, G. W	56, 300
Leonard, B. F	2
Leonard, R. B	43
Leopold, L. B	190, 204
Lepper, C. M	25
Lescelius, R. H	188
Lester, F. W	223
Leve, G. W	110
Lewis, J. E	291
Lewis, J. E., Jr	289
Lewis, R. E	187
Lichty, R. W	135
Lidz, B. H	34
Ligon, D. T., Jr	25
Limerinos, J. T	284
Lind, C. J	180
Linden, E. C	206
Lindholm, G. F	103, 104
Lindskov, K. L	204
Lindvall, R. M	291
Ling, C. H	219
Lins, H. F., Jr	289
Lipin, B. R	166
Lipman, P. W	45, 168, 175
Lium, B. W	215
Livingston, R. K	118, 203
Lobmeyer, D. H	137
Lockner, D. A	187
Lockwood, J. P	168, 169
Lofgren, B. E	255, 256
Long, C. L	162
Love, J. D	31, 70, 71, 96
Lucchitta, B. K	259, 261, 267
Lucchitta, I	75, 235
Ludington, S. D	166
Ludwig, K. R	184
Lupe, R. D	36
Luzier, J. E	105

M

Mabarak, C. D	10
MacCary, L. M	217
Mack, F. K	101
Maclay, R. W	125
MacLeod, N. S	45, 81, 147
Maddock, T., III	136, 139, 204
Madole, R. F	239
Madsen, E. L	237
Magner, J. E	238
Magoon, L. B., III	149
Main, R. J	159
Major, T. J	118
Malahoff, A	142
Malde, H. E	191, 239
Mallory, W. W	31
Malone, S. D	170, 171
Mamet, B	70
Mankinen, E. A	157, 158
Marcus, L. G	291
Mari, K	263
Marincovich, L. N	195
Mariner, R. H	42, 186
Mark, R. K	76
Marlow, M. S	150
Marsh, B. D	298
Marshall, B. V	40
Martens, C. S	177
Martien, R. F	120

Page

Martin, G. C 27
Marvin, R. F 2, 68, 74, 77, 144, 300
Mast, R. F 30
Masters, C. D 299
Masursky, H 257
Matalas, N. C 136
Matson, N. A., Jr 199
Matsuoka, I 129
Mattraw, H. C., Jr 134
Maughan, E. K 29
Mavko, B. B 225
May, F. E 64, 194
Mayfield, C. H 84
Mayo, L. R 192
Mays, R. E 219
McCain, J. F 118, 246
McCallum, M. E 7, 10
McCauley, J. F 259
McClymonds, N. E 301
McCoy, H. J 109, 110
McCulloch, D. S 190
McDonald, M. G 102
McEwen, R. B 295
McGinty, H. K 288
McGreevy, L. J 106
McGrew, L. W 68
McGuire, R. K 234
McKay, D. S 276
McKay, E. J 25
McKee, E. D 75, 96
McKee, E. H 41, 45, 72, 76, 77, 81
McKelvey, V. E 138
McKenzie, S. W 135, 137
McLane, J. E 171
McLaughlin, R. J 41, 79
McLaughlin, T. J 294, 305
McLean, D. W 194
McLean, H 146
McLean, J. S 211
McMurtery, R. G 121
McNeal, J. M 252
McQueen, I. S 215
McQuivey, R. S 205
Meckel, J. P 247
Medlin, A. L 24
Medlin, J. H 24
Meeder, J 194
Mehnert, H. H 1, 45, 66, 77
Meier, A. L 46, 47
Meier, M. F 276, 277
Meissner, C. R., Jr 27
Melvin, R. L 100
Mercer, J. W 186
Merewether, E. A 31
Merkel, R. H 126
Merritt, V. M 77
Meyer, C. E 78
Meyer, E. L 136
Meyer, F. W 199, 201
M'Gonigle, J. W 90
Middelburg, R. F., Jr 130, 213
Miesch, A. T 181
Milazzo, V. A 283
Millard, H. T., Jr 174, 175
Miller, B. M 31
Miller, C. D 171, 293
Miller, C. H 291
Miller, D. R 238
Miller, F. K 80
Miller, J. B 245
Miller, R. E 142
Miller, R. F 215
Miller, R. L 179
Miller, T. L 135
Miller, T. P 35, 40, 85
Miller, W. L 110, 210
Miller, W. R 21, 116

Page

Mills, L. R 111
Milton, D. J 240, 261
Minard, J. P 63
Minges, D. R 117
Minkin, J. A 263
Mitchell, W. D 246
Mitten, H. T 137
Mixon, R. B 61, 63
Mjachkin, V. I 226
Monkhouse, R. A 179
Moore, H. J., II 260, 261
Moore, J. G 175, 270
Moore, R. B 41
Moore, W. J 76
Moosburner, O 248
Morain, S. A 295
Moreland, J. A 210
Morgan, B. A 177
Morgan, J. O 295, 299
Morris, F. O 107
Morris, H. T 174
Mortensen, C. E 228
Morton, D. M 181, 236
Mosier, E. L 220
Moss, M. E 139
Mowinckel, P. K 224
Moxham, R. H 171
Mrose, M. E 173
Muehlberger, W. R 240
Muffler, L. J. P 40
Mull, C. G 84
Muller, D. C 162
Mullineaux, D. R 293
Mundorff, M. J 302
Munroe, R. J 44
Murata, K. J 177
Murray, C. R 135, 136, 139
Myers, W. B 5

N

Nace, R. L 139
Naeser, C. W 69, 80, 185, 196
Nash, J. T 38
Nason, R. D 223
Nathenson, M 40
Nauman, J. W 214
Ndombi, J 157
Neff, R. J 318
Neiman, H. G 4
Nellis, D. A 49, 52
Nelson, D. O 183
Nelson, G. L 128
Nelson, H 150
Nelson, S. W 11
Nemickas, B 106
Neuerburg, G. J 13
Neuman, R. B 197, 299
Newell, W. L 63
Newman, K. R 28
Newman, W. S 106
Nichols, T. C., Jr 236, 238
Nieter, W 106
Nishi, J. M 220
Nixon, R. C 318
Nkomo, I. T 38
Noble, R. L 33
Nolan, K. M 127
Nord, G. L., Jr 167, 264
Nordstrom, D. K 127
Norman, V. W 189
Normark, W. R 147
Norvitch, R. F 104
Novitzki, R. P 108, 216
Nowlan, G. A 21
Nunes, P. D 265
Nuss, N. W 30

Page

Nutt, C. J 87, 88, 89
Nutter, L. J 101

O

Oaksford, E. T 200
Obermeier, S. F 236
Obradovich, J. D 1, 68, 230, 300
O'Connor, B 62
O'Donnell, J. E 43
Offield, T. W 39, 273, 300
Ogilbee, W 137
O'Hara, C. J 143
Ohlmacher, G. C 241
Olcott, P. G 103, 104
Oldale, R. N 143
O'Leary, D. W 274, 301
O'Leary, R. M 11
Olhoeft, G. R 160
Oliver, H. W 78
Olmsted, F. H 44
Olson, A. B 241
Olson, A. C 24
Olson, J. C 36
O'Neil, J. R 183
Onstott, T. C 41
Oriel, S. S. 73, 196
Orkild, P. P 74
Ormiston, A. R 85
Osmonson, L. M 27
Osterkamp, W. R 204
Osterwald, F. W 72, 237
Otlet, R. L 179
Otton, E. G 101
Outcalt, S. I 289
Ovenshine, A. T 86
Overstreet, W. C 20, 306

P

Pabst, M. E 120
Page, N. J 15, 299
Page, R. A 231
Pak, H 143
Panderson, D 276
Papadopulos, S. S 40, 305
Papp, C. S. E 254
Park, J. W., Jr 318
Parkhurst, D. L 180, 181
Pascale, C. A 201
Patrick, L. D 127
Patterson, S. H 8
Patton, P. C 190
Patton, W. W., Jr 5, 84, 85
Paulson, R. W 276
Pavlides, L 61
Pearl, J. E 147
Pearson, F. J., Jr 178, 179, 180
Pease, M. H., Jr 49, 52, 53, 55
Pease, R. W 289
Peck, D. L 40, 173
Peck, J. H 53, 55
Peek, C. O 248
Pendleton, A. F 140
Penley, R. D 118
Peper, J. D 50, 54
Perkins, D. M 234
Perry, W. J., Jr 32
Person, W. J 222
Peruzzi, D 283
Peselnick, L 187, 226
Pessagno, E. A 79
Pessel, G. H 84
Pessl, F., Jr 51
Peterman, Z. E 66, 183
Peterson, D. H 153
Peterson, D. M 241
Peterson, D. W 168, 169

	Page
Peterson, J. L	116
Peterson, J. R	222
Petri, L. R	122
Petrov, O. M	84
Petsch, H. E., Jr	248
Pettijohn, R. A	101
Pfeiffer, L	318
Philbin, P. W	25
Phillips, R. L	148
Philpott, B.' C	76
Pickering, R. J	138
Pierce, K. L	176, 230, 241
Pierce, W. G	71
Pierson, C. T	35
Pilkey, O. H	146
Pillinger, C. T	263
Pinder, G. F	186, 198
Pipiringos, G. N	34
Pitman, J. K	35
Pitt, A. M	188
Pitt, W. A. J., Jr	201
Place, J. L	290
Plafker, G	148, 195, 229, 240
Planert, M	101
Plouff, D	163
Pluhowski, E. J	205, 289
Plummer, L. N	180, 181
Pogorski, L. A	32
Pohn, H. A	273, 274, 275
Poland, J. F	139
Pollard, D. D	187
Pollard, L. D	112
Polski, W	195
Pomeroy, J. S	49, 242, 284
Poole, F. G	4, 30, 32, 74
Poore, R. Z	194
Post, A. S	170, 192
Powers, P. S	238
Powers, R. B	31
Preble, D. M	276
Prescott, W. H	227
Presser, T. S	179
Prichard, G. E	66
Prill, R. C	200
Prinz, W. C	16
Prostka, H. J	71, 73
Prowell, D. C	62, 240
Prudic, D. E	243
Prugh, B. J., Jr	250
Prych, E. A	153
Puente, C	125
Putnam, W. C	172
Pyle, T. E	180

Q

Quiñones-Márquez, F	214
Quirt, S. G	32

R

Radbruch-Hall, D	234
Radtke, A. S	183
Ragland, T. M	295
Rahn, P	180
Raines, G. L	301
Raleigh, C. B	223
Ralph, E. K	270
Ramp, L	15
Ramseier, R. O	218
Randall, A. D	302
Randall, J. P	318
Randich, P. G	124
Rankin, D. W	59
Rapp, J. B	147, 179
Rataj, J	87
Rathbun, R. E	220
Ratté, J. C	68
Raymond, W. H	3
Redder, G. D	147
Reed, B. L	11, 182
Reed, E. C	66
Reed, J. C., Jr	174
Reed, J. E	198
Reed, V. S	258
Reed, W. E	289
Reeder, H. O	104
Regan, R. D	160, 298
Reichenbaugh, R. C	209
Reid, G. O	241
Reimer, G. M	19
Reimnitz, E	151
Rein, R. D	30
Reinemund, J. A	299
Reiser, H. N	84
Renner, J. L	40
Rettig, S. L	179
Rettman, P. L	125
Reynolds, M. W	69
Reynolds, R. L	37
Rice, D. D	32
Richards, A. F	145
Richmond, G. M	70
Rickert, D. A	137
Rickley, S. E	217
Ridgley, J. L	68
Rightmire, C. T	180
Rima, D. R	121
Rinehart, C. D	81
Rinehart, W. A	234
Ritter, J. J	293
Roberts, A. A	20, 32, 188
Roberts, A. E	8
Roberts, H. H	144
Roberts, R. J	303
Roberts, R. S	207
Robertson, E. C	226
Robertson, J. B	245
Robie, R. A	165
Robinove, C. J	269
Robins, C. M	318
Robinson, G. R., Jr	55, 56
Robinson, P	51, 167
Robson, S. G	119, 207
Rodis, H. G	111
Roedder, E	1, 3, 264
Roen, J. B	242
Roeske, R. H	247
Rogers, A. M	233
Rogers, R. H	276
Rohde, W. G	267, 269
Rohret, D. H	188
Rooney, L. F	23
Rose, H. J., Jr	265
Rose, M. A	137
Rosenbauer, B. J	152
Rosenblum, S	20
Rosenlund, G. C	34
Ross, D. C	80
Ross, D. S	281
Ross, M	167, 264
Ross, R. J., Jr	196
Rowan, L. C	273, 299
Rowe, G. T	142
Rowe, J. J	56
Rowley, P. D	45
Rubin, D. M	190
Rubin, M	180, 298
Ruppel, E. T	66
Rush, F. E	131
Rusky, F	25
Russell, P. C	42
Russell, S. L	55
Ryder, P. D	111
Ryder, R. T	31, 33
Rye, R. O	1, 183
Rymer, M. J	228
Rytuba, J. J	4

S

Sable, E. G	31, 149
Sallenger, A. H., Jr	191
Sammel, E. A	44
Sandberg, C. A	33
Sando, W. J	197
Sanzolone, R. F	20, 21
Sarna-Wojcicki, A. M	230
Sass, J. H	40, 42, 44
Sato, M	170, 171, 264
Sauer, V. B	203
Saulnier, G. J., Jr	119, 207
Saunders, C	146
Savage, J. C	227
Savage, N. M	89
Savage, W. Z	236, 238
Savina, M. A	241
Schaber, G. G	257, 260, 267
Schafer, F. J	262
Schaffer, J. P	76
Schilling, J. G	182
Schlee, J. S	141
Schleicher, D. L	70
Schmidt, D. L	304
Schmidt, R. G	66, 230
Schmitt, L. J., Jr	37
Schnabel, R. W	298
Schneider, D. L	318
Schneider, J. J	111
Schneider, P. A., Jr	117
Schneider, V. R	217
Schneidermann, N	146
Schnepfe, M. M	265
Scholl, D. W	149
Scholle, P. A	33
Schoonmaker, J. W., Jr	317
Schopp, R. D	245
Schultz, D. M	142
Schumann, H. H	277
Schwarz, L. J	56, 174
Schwarzman, E. C	78
Schweinfurth, S. P	26
Scott, A. G	191
Scott, D. H	259, 260
Scott, G. R	291
Scott, J. H	39
Scott, R. A	195
Scott, W. E	241
Scrivani, E. P	153
Scully, D. R	128
Sebetich, M. J	208
Seekins, L. C	223
Seeland, D. A	36
Seeley, J. L	219
Seiders, V. M	61
Seitz, H. R	130, 131
Sena, J	217
Senftle, F. E	25, 165, 168, 252
Severson, R. C	252, 253, 291
Shacklette, H. T	253
Shafiqullah, M	41
Sharp, R. V	224, 230
Shaw, H. R	40, 231
Shaw, V. E	35
Shawe, D. R	16
Shawe, F. R	239
Shearman, J. O	205
Shedlock, R. J	178
Sheffer, H. W	271
Sheppard, R. A	48
Sheridan, D. M	3
Sherrill, M. G	108
Sherwood, C. B., Jr	109, 134

Page

Shideler, G. L 145
Shinn, E. A 34
Shorthill, R. W 260
Shown, L. M 190
Shride, A. F 53
Shroba, R. R 237
Shulters, M. V 212
Shultz, D. J 220
Sieber, C. R 204
Siems, D. F 14
Sigafoos, R. S 216
Signor, D. C 200
Sikonia, W. G 193, 205
Silberman, M. L 11, 72, 149
Silva, L. R 231
Simirenko, M. S 223
Simmons, C. E 113
Simon, F. O 4
Simons, F. S 13
Simpson, S. L 274
Sims, J. D 228, 299
Sims, P. K 3, 66
Singer, D. A 22
Sisler, F. D 252
Skelton, J 210
Skinner, J. V 217
Skipp, B. A 68, 70, 196, 235
Slack, J. R 128
Slack, K. V 214, 215
Sliter, W. V 194
Sloan, C. E 249, 277
Sloto, R. A 106
Small, T. A 125
Smalley, W. C 179
Smedes, H. W 173
Smith, B. D 164
Smith, C. C 194
Smith, C. L 46
Smith, C. W 302
Smith, D 205
Smith, D. B 162, 179
Smith, G. I 48, 172, 299
Smith, J. F 196
Smith, R. A 128, 149
Smith, R. E 178
Smith, R. L 40
Smith, R. M 15
Smith, W. H 161
Smith, W. K 236
Smoot, G. F 135, 140, 217
Smyth, J. R 167
Snavely, P. D., Jr 147, 230
Snider, J. L 120
Sobolev, G. A 226
Soderblom, L. A 257, 259
Sohl, N. F 194
Sorensen, J. E 317
Sorey, M. L 44, 186
Sorg, D. H 150
Sossipatrova, G. P 70
Southward, R. B 318
Spangle, W. E 284
Spence, W. J 222
Spieth, M. A 227
Staatz, M. H 35, 39
Stager, H. K 15
Stankowski, S. J 245
Stanley, W. D 125, 161
Stearns, C. D 160
Steele, E. K., Jr 137
Steele, T. D 302
Steen-McIntyre, V. C 178
Stephens, D. W 205, 220
Stern, T. W 185
Stevens, M 295
Stevens, T. A 1
Stewart, D. B 263
Stewart, J. H 72, 74, 76, 95

Page

Stewart, R. M 187, 228
Stewart, S. W 222, 223
Still, J 87
Stone, B. D 49, 50
Stone, C. G 95
Stone, J. R 49
Stoneman, E. A 318
Stoner, J. D 121
Stricker, G. D 26
Stuckless, J. S 38
Subitzky, S 284
Suhayda, J. N 144
Sulam, D. J 105
Sullivan, J. K 218
Summers, R. S 187
Sun, R. J 244
Sun, S. S 182
Sutter, J. F 184
Sutton, R. L 76
Swallow, L. A 245
Swanson, D. A 81, 164, 170, 182
Swanson, J. R 46
Swanson, V. E 24
Swayze, L. J 110, 276
Swift, C. H., III 205
Swolfs, H. S 238
Szabo, B. J 185

T

Tabor, R. W 79
Tailleur, I. L 84
Takasaki, K. J 127
Tangborn, W. V 192, 205
Tanner, A. B 25
Taranik, J. V 268
Tarr, A. C 231, 299
Tasker, G. D 246
Tatsumoto, M 182, 265
Taylor, G. C., Jr 139
Taylor, J. C 146
Taylor, O. J 116
Taylor, R. E 40
Taylor, T. A 243
Terbeek, C. L 251
Terman, M. J 299
Terry, G. R 238
Thatcher, L. L 220
Thatcher, W. R 227
Thayer, T. P 7
Theodore, T. G 14, 77
Thomas, C. P 219, 220
Thomas, D. M 139
Thompson, C. L 263
Thompson, J. M 42
Thomsen, H. L 31
Thorpe, A. N 168
Thorstenson, D. C 180, 181, 208
Tibbitts, G. C., Jr 306
Tidball, R. R 252, 253
Tilley, L. J 214
Tilling, R. I 68, 158, 168, 169
Tobin, R. L 211
Todd, V. R 80, 196
Toimil, L. J 151
Toler, L. G 112, 252
Tourtelot, E. B 47
Tourtelot, H. A 47
Towle, J. N 162
Townsend, T. E 39, 165
Trabant, D. C 192
Trainer, F. W 44
Trapp, H., Jr 110
Trask, N. J 257
Trautmann, C. H 241
Trautwein, C. M 267
Trescott, P. C 105, 110, 198
Truesdell, A. H 185

Page

Trumbull, J. V. A 146
Tschanz, C. M 2
Tschudy, R. H 70, 195
Tuchek, C. T 14
Tucker, R 54
Turk, J. T 249
Turner, R. L 19
Turner-Peterson, C. E 36
Twenter, F. R 102
Tweto, O. L 95
Tyler, T. F 27, 191

U

Ulrich, G. E 41
Unger, J. D 225
Unruh, D. M 265
Urban, T. C 40, 42, 43, 44

V

Valentine, P. C 194
Van Alstine, R. E 8
Van Driel, J. N 286
van Hylckama, T. E. A 216
Vanlier, K. E 112
Varnes, D. J 234
Varnes, K. L 31
Vecchioli, J 302
Vedder, J. G 146
Velnich, A. J 245
Verbeek, E. R 63
Vickers, J 270
Viets, J. G 20
Vine, J. D 47
Visher, F. N 202
Vlash, D. F 49
Volckmann, R. P 90
von Huene, R. E 149, 297

W

Waananen, A. O 284
Wagner, H. C 229
Wahl, R. R 164
Wahrhaftig, C 86
Waitt, R. B., Jr 81
Walker, E. H 102, 203
Walker, G. W 95
Wallace, C. A 69
Wallace, R. E 230, 240
Wallace, R. H., Jr 40
Waller, B. G 109, 110
Wandle, S. W., Jr 246
Wang, F. H 299
Ward, P. E 305
Warrick, R. E 232
Washarakitti, S 295
Watkins, J. A 260
Watson, D. E 161
Watson, K 274
Watson, R. D 19, 20, 33, 278
Watts, K. C 18
Watts, R. D 164
Weaver, C. S 188
Weber, F. R 12
Webster, W. J 218
Weeks, J. B 119
Weeks, J. D 187
Weeks, W. F 218
Weiblen, P. W 264
Weidie, A. E 180
Weiss, E. J 209
Welder, F. A 119
Wells, F. C 121
Welsch, E. P 19
Wenrich-Verbeek, K. J 21
Wentworth, C. M., Jr 241

	Page
Wesselman, J. B	40
Westfall, A. O	204
Whelan, T	145
Whipple, E. R	209
White, A. F	180
White, D. E	4, 40
White, R. W	253, 254
Whitebread, D. H	73
Whitehead, R. L	130
Whitesides, D. V	112
Whitfield, M. S., Jr	121
Whitlow, J. W	17
Whitney, O. T	150
Wier, K. E	61
Wigley, T. M. L	180, 181
Wilcox, R. E	171
Wilheit, T. T	218
Wilhelms, D. E	258
Wilke, K. R	122
Willey, L. M	179, 186
Williams, D. L	40
Williams, D. R	213
Williams, E. J	229
Williams, G. P	204
Williams, K. M	230
Williams, N. F	95
Williams, R. S., Jr	269, 270
Williams, V. S	72
Wilson, D	194
Wilson, L. A	197
Wilson, R. F	318
Wilson, R. P	247
Wilson, R. T	127
Wilson, W. E., III	110
Winkler, K. W	187
Winner, M. D., Jr	113
Winograd, I. J	179
Winter, T. C	209
Witkind, I. J	71, 240, 241
Wobus, R. A	68
Wolf, R. J	103
Wolfbauer, C. A	47
Wolfe, E. W	41, 258
Wollenberg, H. A	44
Woo, C. C	152
Wood, J. D	159
Wood, M. D	227
Wood, W. W	200
Woodward, M. B	95
Wright, T. L	81, 164, 166, 183
Wu, S. S. C	261, 262
Wynn, J. C	164

Y

	Page
Yerkes, R. F	230
Yorke, T. H., Jr	135
Yotsukura, N	203
Youd, T. L	237
Youger, J	211
Young, H. W	131
Yount, J. C	230

Z

	Page
Zablocki, C. J	158, 168, 169
Zachry, D. L	95
Zack, A. L	113
Zand, S. M	215
Zarinski, K	37
Zartman, R. E	174, 182
Zehner, H. H	243
Zeller, H. D	28
Zen, C. S	24
Zen, E	57, 70, 165
Zielinski, R. A	175
Zietz, I	58, 76, 164
Zohdy, A. A. R	162