

GEOLOGICAL SURVEY CIRCULAR 560



**U.S. Geological Survey
Heavy Metals Program
Progress Report
1966 and 1967**

U.S. Geological Survey Heavy Metals Program Progress Report 1966 and 1967

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United States Department of the Interior
STEWART L. UDALL, *Secretary*



Geological Survey
William T. Pecora, *Director*



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U.S. Geological Survey Heavy Metals Program Progress Report, 1966 and 1967

SUMMARY

The Heavy Metals program was started in April 1966 as a joint effort by the Geological Survey and the Bureau of Mines to stimulate domestic production of a group of metals that are in short supply. These metals are gold, silver, platinum-group metals, mercury, tin, antimony, bismuth, nickel, and tantalum. About 90 percent of program effort during the first year and a half has been on gold because of its international monetary importance. The Geological Survey part of the program has been mainly to identify exploration targets to be further explored and developed by private industry; that of the Bureau of Mines to conduct mining and metallurgical studies of subeconomic mineral deposits, either targets established by the Geological Survey or previously known marginal deposits, in order to make them economic through technological improvements. To attain its objectives in this program, the Geological Survey is conducting a wide variety of field and laboratory studies to increase the knowledge of the geology, geochemistry, and occurrence of the heavy metals on the land and in the marine environment, to improve capabilities for discovering concealed ore deposits, and to develop more accurate and rapid analytical methods for detecting small amounts of gold and other metals.

By December 1967, about 235 employees of the Geological Survey were participating in the program, and more than 100 projects were under way. To provide adequate analytical support for the program, fixed laboratory facilities were greatly expanded and 20 mobile laboratories were assembled. A total of 240,000 chemical and spectrographic analyses had been made by the end of 1967. To supplement studies undertaken within the Geological Survey, research contracts or grants were awarded to 15 universities and one research laboratory.

In the first 21 months of operation, the Heavy Metals program has produced several significant results:

Cortez, Nev.—Identification of an area containing abnormal amounts of gold led to the discovery by private industry of over three million tons of open-pit ore averaging 0.3 ounce gold per ton.

Cripple Creek, Colo.—Samples from an area 3,800 feet long and 500 feet wide average \$2.50 per ton gold and indicate a potentially large low-grade deposit.

Northwestern Wyoming.—Conglomerates in this area contain 6–35 cents in gold per cubic yard of rock, and although these values are low, the volume of rock involved is enormous—50 cubic miles or more—and the possibility of finding higher grade concentrations within the area are good.

Ely, Nev.—Anomalously large amounts of gold, silver, tellurium, and mercury are found in rocks around the copper deposits of the Ely district and point to areas warranting further investigation and exploration.

Northumberland Canyon, Nev.—A large deposit of barite was discovered in east Northumberland Canyon, Nye County, Nev., by geologists assigned to a Heavy Metals project. Exploration by private industry is expected to prove that a major resource is present.

Mercury-vapor detector.—This simple instrument, developed in Geological Survey laboratories, is capable of analyzing 60–100 samples per day for mercury in concentrations as low as 5 parts per billion.

INTRODUCTION

The Heavy Metals program was undertaken in April 1966 as a 5-year open-ended joint effort by the Geological Survey and the Bureau of Mines to increase the output of a group of metals that were being produced from domestic sources in much less than the amounts required by the national economy. These metals include gold, silver, platinum-group metals, antimony, bismuth, mercury, silver, tantalum and tin; nickel was added subsequently. About 90 percent of the program effort during the first 21 months has been on gold because of its international monetary importance.

As wide as possible a range of effort has been brought to bear on the problem of exploration target identification, including geologic mapping, geochemical exploration, ground and airborne geophysical surveys, oceanographic studies, laboratory research on the mineralogy and chemistry of the heavy metals, research on chemical, spectrographic, and radioactivation analytical methods, and broad literature search for any relevant published material.

Results of investigations are published as soon as possible, mostly as circulars but also as maps in one

of the regular map series of the Geological Survey and as chapters in the annual volumes summarizing Geological Survey Research. Nine circulars, three maps, and 18 Geological Survey Research chapters have been published so far.

Available funds were allocated to six broad fields of effort in approximately the following percentages; costs of analytical, administrative, and other general support are distributed proportionately:

	<u>Percent</u>
Lode gold deposits	41
Continental gold placers	17
Marine gold placers	18
Residual gold deposits	4
Metals other than gold	10
Ancillary research	<u>10</u>
	100

ORGANIZATION

In December 1967, some 235 employees of the Geological Survey were participating in the program. About 180 of these were professionals, including 135 geologists, 30 chemists, and 8 geophysicists; more than 40 were hired since inception of the program.

The program is directed by the Office of Economic Geology and is staffed by personnel from 14 units of the Geologic Division, two of which, the Branch of Heavy Metals and the Exploration Unit, were organized specifically for the program. The Water Resources Division also is taking part. Participating units include the following:

Geologic Division

Office of Economic Geology

- Branch of Heavy Metals
- Branch of Exploration Research
- Branch of Organic Fuels
- Branch of Resources Research
- Exploration Unit

Office of Regional Geology

- Branch of Alaska Geology
- Branch of Regional Geophysics

Office of Experimental Geology

- Branch of Experimental Geochemistry and Mineralogy.
- Branch of Field Geochemistry and Petrology
- Branch of Geochemical Census
- Branch of Theoretical Geophysics
- Branch of Analytical Laboratories
- Branch of Isotope Geology

Office of Marine Geology and Hydrology

Water Resources Division

Rocky Mountain Region

In order to supplement the in-house capabilities of the Geological Survey, certain special facilities and

talents of the scientific community have been enlisted through awards of research contracts and grants to 15 universities and one independent research laboratory. Ten contracts totaling \$600,000 were for research in the marine field; most of these programs involve use of oceanographic vessels of the respective institutions for cooperative studies by Geological Survey and university scientists. Eight contracts totaling \$170,000 were for land-based research. Total expenditure for research contracts was \$770,000.

All state geologists have been informed on the program and many have offered valuable suggestions for consideration as field or laboratory projects.

PROJECTS STARTED DURING 1966-67

During the first 21 months of the program, about 108 new projects were started. Most of these were staffed entirely by Geological Survey personnel; nine were staffed by both Geological Survey and contract personnel, and eight by contract personnel only. Included were 80 field projects, 18 combined field-laboratory projects, and 10 laboratory projects. Field projects were carried out on land in 25 states and in the littoral regions of seven states.

Most field projects were in or west of the Rocky Mountains, but several were in north-central states, in the Appalachian region, and on the coasts of the Atlantic and Gulf of Mexico. Several general types of projects have been undertaken:

1. Intensive studies of known heavy metal districts, aimed at obtaining basic information on the occurrence of these metals (15 projects).
2. Studies of larger areas known to contain small and (or) low-grade deposits, aimed at recognizing possible large low-grade resources (37 projects).
3. Studies of broad regions not known to contain deposits of heavy metals but having geologic characteristics favorable for their occurrence, aimed at locating resources heretofore unrecognized because of lack of exposures or inadequacy of methods of detection. Several of these projects are wide-scope investigations of the occurrence and distribution of heavy metals in time and space (28 projects).

Combined laboratory-field projects include studies of abundances of heavy metals in various rock types (7 projects); behavior of heavy metals during weathering, solution, transport, and deposition (5 projects); associations of heavy metals with organic material (3 projects); research on geophysical methods as applied to exploration for heavy metals (2 projects); and research on sulfur isotopes in ore deposits (1 project).

Laboratory projects include research on analysis of rocks, soils, and waters by chemical, spectrographic, spectrophotometric, and radiometric methods; studies of mineral systems involving heavy metals; and research on the platinum metals, the geochemistry of gold, and the crustal abundances of heavy metals.

Research contracts have been awarded to the following institutions for cooperative studies in the marine geology of heavy metals; all the studies but one involve use of oceanographic research vessels:

- University of Alaska—Gulf of Alaska continental shelf.
- Duke University—North Carolina continental shelf.
- Louisiana State University—Gulf Coast studies.
- University of Oregon—Oregon continental shelf.
- Oregon State University—continental margin of southern Oregon and northern California.
- Scripps Institution of Oceanography—Northern California continental shelf.
- University of Southern California—Southern California continental shelf.
- Stanford University—subaerial and subaqueous flow of slurries.
- Texas A&M University—Gulf Coast studies.
- University of Washington—Bering Sea and Washington continental shelf.

For land-based studies, research grants have been awarded to the following institutions:

- University of Alaska—geological and geochemical investigations of the Ester-Cleary mineralized belt, Fairbanks district, Alaska.
- University of Colorado—the use of very low frequency waves in geophysical exploration.
- Colorado School of Mines—adsorption of precious metals by organic deposits.
- Colorado School of Mines—symposium on geochemical exploration.
- Colorado State University—solubilization of trace mineral elements by soil micro-organisms.
- Oregon State University—sulfur isotope investigations, Bingham district, Utah.
- South Dakota School of Mines and Technology—compilation of information on ore deposits in the rocks of the northern Black Hills.
- Tracerlab, Inc.—research and development on a direct-reading field instrument for the detection of selected chemical elements.

ANALYTICAL SUPPORT FOR PROGRAM

At an early stage in planning the Heavy Metals program it became apparent that the analytical capability of the Geological Survey would have to be greatly expanded to handle expeditiously the very large number of rock, soil, and water samples expected as many new projects got under way. In particular, much more rapid services were required to facilitate the day-by-day planning of fieldwork by project geologists. Consequently, fixed laboratory facilities at the Denver, Colo., and Washington, D.C., centers were enlarged and the small fleet of mobile laboratories, first used by the Branch of Exploration Research in its own studies and in support of field parties engaged in Primitive Area evaluations, was increased to 26 vehicles, 15–20 of which have been assigned at various times to Heavy Metals projects. Extensive new laboratory space was

leased at the Table Mountain Research Center of Colorado School of Mines near Golden, Colo.; two fire assay furnaces were installed in Washington, D.C., and a second put in operation at Denver; and about 40 new chemists and technicians were hired, most by the Field Services Section of the Branch of Exploration Research.

During the first 21 months of the program, more than 66,000 analyses for gold, 125,000 analyses for other metals (arsenic, antimony, beryllium, bismuth, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, silver, tantalum, tellurium, tin, tungsten, uranium, and zinc), and 48,000 semiquantitative spectrographic analyses for from 30 to 60 elements each, as well as nearly 800 chemical analyses of the platinum-group metals, were completed, for a total of nearly 240,000 analyses. About 3,500 of these analyses were made under contract with commercial laboratories, the rest were made in laboratories of the Geological Survey.

GEOLOGIC DRILLING

Drilling to obtain geologic information is a valuable aid to the geologist in providing necessary data on the third dimension of a given area. Funding, therefore, was provided to obtain such information, and contracts for diamond core drilling in four areas have been let. These areas are:

1. Iron Canyon, at the south end of Battle Mountain, 10 miles southwest of Battle Mountain, Nev. Drilling began in April 1967 and was continuing at the year's end.
2. Tenabo, on the east side of the Shoshone Range, 30 miles southeast of Battle Mountain, Nev. Drilling started in July 1967 and was still in progress at the year's end.
3. Swales Mountain, in the Independence Mountains, 15 miles north of Carlin, Nev. Drilling began in May 1967 and was finished in September.
4. Squaretown, 11 miles east-northeast of The Forks, Maine. Drilling started in June 1967 and was completed in September.

To facilitate geologic mapping and sampling in the deeply weathered rocks of the Southeastern United States, two truck-mounted auger drills were acquired. Augering has been done at Kershaw, S.C., and at several places on the coastal plain of the Southeastern States.

AIRBORNE GEOPHYSICAL SURVEYS

Various kinds of information may be provided the geologist through use of airborne sensors. These surveys offer rapid and economic coverage of large areas and are particularly valuable to the reconnaissance projects of the Heavy Metals program. Airborne magnetic surveys have been carried out both by the Branch

of Regional Geophysics and under contract by commercial firms. A total of about 41,500 square miles of aeromagnetic surveying has been done, including about 20,000 square miles in western and north-central Nevada; 15,000 square miles in Montana, Idaho, and Washington; 5,000 square miles in southwestern and north-central Colorado; and 1,500 square miles in California. In addition, about 1,200 square miles of combined low-level airborne magnetic, electromagnetic, and radioactivity surveys were flown in California, Maine, and South Carolina. Aeromagnetic maps covering all or parts of about 85 quadrangles in western and north-central Nevada were placed on open-file in 1967.

NEW FACILITIES AND EQUIPMENT

To provide adequate field and laboratory support for the projects initiated under the Heavy Metals program, considerable new equipment was acquired and new laboratory facilities planned.

A new mineralogy laboratory was designed for the Denver Field Center, and construction began in 1967. This laboratory will be completely equipped for mineral studies essential to the program and will include an X-ray diffractometer. New equipment also was acquired for the Washington, D.C., and Beltsville, Md., laboratories.

In addition to equipment for general-use laboratories, considerable new equipment for individual investigators was also purchased. This equipment included petrographic and binocular microscopes and a laser-fired probe for research in spectrography.

In order to increase the capacity for geophysical support of the program, equipment for automatic plotting of aeromagnetic data, for aeromagnetic surveying, and for studies of induced-polarization methods and borehole geophysics was acquired.

Many field projects in the program are in areas distant from living facilities and supplies. To facilitate fieldwork in these remote areas, nine small house trailers were purchased.

PUBLICATIONS

Results of various investigations made under the Heavy Metals program are to be published as quickly as possible. Since inception of the program the following reports have been published:

Map I-471: Distribution of selected accessory minerals in the Osgood Mountains stock, Humboldt County, Nevada, by G. J. Neuberger; published May 1966.

Professional Paper 550-B—Geological Survey Research 1966, Chapter B; published June 1966:

Field determination of nanogram quantities of mercury in soils and rocks, by Margaret Hinkle, K. W. Leong, and F. N. Ward.

Tellurium and mercury in jasperoid samples, by T. G. Lovering, H. W. Lakin, and J. H. McCarthy.

Determination of silver in mineralized rocks by atomic absorption spectrophotometry, by Claude Huffman, Jr., J. D. Mensik, and L. F. Rader.

Professional Paper 550-C—Geological Survey Research 1966, Chapter C; published August 1966:

Metal sorption by northwest Florida humate, by V. E. Swanson, I. C. Frost, L. F. Rader, Jr., and Claude Huffman, Jr.

Distribution of selected metals in the Stockton district, Utah, by W. J. Moore, G. C. Curtin, R. J. Roberts, and E. W. Tooker.

Determination of microquantities of mercury in sulfide ores by Penfield tube-dithizone and semi-quantitative spectrographic methods, by J. I. Dinnin and H. W. Worthing.

Circular 534: Gold geochemical anomaly in the Cortez district, Nevada, by R. L. Erickson, G. H. Van Sickle, H. M. Nakagawa, J. H. McCarthy, Jr., and K. W. Leong; published August 1966.

Circular 535: Distribution of gold, silver, tellurium, and mercury in the Ely mining district, White Pine County, Nevada, by G. B. Gott and J. H. McCarthy, Jr.; published October 1966.

Map GP-561: Aeromagnetic map of parts of the Mother Lode gold and Sierra Foothills corner mining districts, California, and its geologic interpretation, by J. R. Henderson, A. A. Stromquist, and A. Jespersen; published October 1966.

Circular 540: A simple mercury vapor detector for geochemical prospecting, by W. W. Vaughn; published February 1967.

Circular 541: Gold-bearing sedimentary rocks in northwest Wyoming—A preliminary report, by J. C. Antweiler and J. D. Love; published February 1967.

Circular 543: Distribution of gold, tellurium, silver, and mercury in part of the Cripple Creek district, Colorado, by G. B. Gott, J. H. McCarthy, Jr., G. H. Van Sickle, and J. B. McHugh; published April 1967.

Professional Paper 575-B—Geological Survey Research 1967, Chapter B; published May 1967:

Silver and mercury geochemical anomalies in the Comstock, Tonopah, and Silver Reef districts, Nevada-Utah, by H. R. Cornwall, H. W. Lakin, H. M. Nakagawa, and H. K. Stager.

Mineralized veins at Black Mountain, western Seward Peninsula, Alaska, by C. L. Sainsbury and J. C. Hamilton.

Results of some geophysical investigations in the Wood Hills area of northwestern Nevada, by C. J. Zablocki.

Map I-496: Distribution of selected accessory minerals in the Caribou stock, Boulder County, Colorado, by G. J. Neuerburg; published June 1967.

Professional Paper 575-C—Geological Survey Research 1967, Chapter C; published July 1967:

Determination of palladium in the parts-per-billion range in rocks, by F. S. Grimaldi and M. M. Schnepfe.

Circular 555: Bedded barite in east Northumberland Canyon, Nye County, Nevada, by D. R. Shawe, F. G. Poole, and D. A. Brobst; published August 1967.

Circular 544: Determination of gold in geologic materials by solvent extraction and atomic-absorption spectrometry, by Claude Huffman, Jr., J. D. Mensik, and L. B. Riley; published September 1967.

Circular 545: Marine sediment sample preparation for analysis for low concentrations of fine detrital gold, by H. Edward Clifton, Arthur Hubert, and R. Lawrence Phillips; published October 1967.

Professional Paper 575-D—Geological Survey Research 1967, Chapter D; published November 1967.

Age of volcanic activity in the San Juan Mountains, Colorado, by T. A. Steven, H. H. Mehnert, and J. D. Obradovich.

Callaghan window—A newly discovered part of the Roberts thrust, Toiyabe Range, Lander County, Nevada, by J. H. Stewart and A. R. Palmer.

Preliminary report on sulfide and platinum-group minerals in the chromites of the Stillwater Complex, Montana, by N. J. Page and E. D. Jackson.

Bismuth and tin minerals in gold- and silver-bearing sulfide ores, Ohio mining district, Marysvale, Utah, by A. S. Radtke, C. M. Taylor, and J. E. Frost.

A geochemical anomaly of base metals and silver in the southern Santa Rita Mountains, Santa Cruz County, Arizona, by Harald Drewes.

Upper Pleistocene features in the Bering Strait area, by C. L. Sainsbury.

A spectrophotometric method for the determination of traces of platinum and palladium in geologic materials, by C. E. Thompson.

Atomic absorption determination of bismuth in altered rocks, by F. N. Ward and H. M. Nakagawa.

Circular 549: Economic significance of revised age relations of rocks in the Cornucopia mining district, Elko County, Nevada, by R. R. Coats; published December 1967.

FIELD STUDIES ON LAND

Brief descriptions are given of results achieved during the first year and a half of the program. Abbreviations commonly used include:

ppm = parts per million (1 ppm = 0.0001 percent, or about 0.03 oz per ton)

ppb = parts per billion (1 ppb = 0.0000001 percent)
For gold, 1 ppm equals about \$1.00 per ton.

Analytical data for gold, silver, and platinum are usually given in ppm or ppb. Results frequently are reported as "less than" a certain amount, this amount being the limit of detection of the analytical method employed. Such a result means that the element was not detected and, if present at all, occurs only in an amount below the limit of detection.

Alaska

Summary of Alaska field season, 1966.—Because Alaskan logistical problems require planning a year or so in advance of actual geologic fieldwork, only some preliminary studies were made during the first year of the program.

Fairbanks district.—A map showing locations of all lode mines and prospects in the Fairbanks area was compiled, together with a table summarizing data on each deposit.

McGrath area.—Quartzite conglomerates west of Big River, southeast of McGrath, were examined as possible sources of reported placer gold. They proved to be barren, the gold being derived instead from moraine.

Seventy Mile area.—Placer gold along several creeks in the Seventy Mile area of the Yukon River in eastern Alaska appears to be derived from veinlets in bedrock, from mineralized fault zones, or from high-level gravels rather than from Tertiary gravels.

Gold nuggets from the Seventy Mile area have trace-element contents that reflect their mineral associations. Gold from Woodchopper Creek, in which stream sediments contain abundant cassiterite, also contains tin, as well as bismuth, molybdenum, antimony, copper, lead, and zinc.

Seward Peninsula.—A system of tin-bearing veins was discovered at Black Mountain on the Seward Peninsula. The veins are 1,000–5,000 feet long and consist of quartz and fluorite with cassiterite, sulfides of copper, lead, and zinc, and traces of silver and bismuth.

Summary of Alaska field season, 1967.—Projects were carried out in 13 areas of Alaska during the summer of 1967, ranging in type from detailed mapping of mineralized districts to geochemical reconnaissance and in locations from Seward Peninsula to eastern and southeastern Alaska. About 7,500 samples were collected, and most were submitted for gold determination and spectrographic analysis. Analytical data are incomplete as yet, but at least nine projects yielded significant economic results, and in at least six, gold was detected in amounts greater than 0.02 ppm. This work indicates that samples of stream sediment, soil, and spring deposits are all useful in prospecting for gold lodes and placers.

Geophysical studies near Fairbanks—Preliminary tests of magnetic and electrical methods as tools for exploration for gold placers and lode deposits were completed in the Fairbanks district.

Resistivity soundings give a reasonably clear picture of bedrock configuration below gravels despite problems posed by permafrost. At Wiseman, about 200 miles north of Fairbanks, resistivity measurements suggest that bedrock is too deep to reach with present-day dredges.

Efforts to detect narrow gold-quartz and sulfide veins on Cleary Dome north of Fairbanks were made using electromagnetic (EM) and induced-polarization (IP) methods. The veins apparently are too small to detect using EM, but both distribution and attitude of sulfide concentrations were established using IP.

Magnetic profiles failed to reveal any concentrations of magnetite such as might be associated with placer gold.

Reconnaissance studies in southern Brooks Range.—Geochemical sampling in the Chandalar and Wiseman quadrangles in the southern Brooks Range of north-central Alaska revealed a silver anomaly that extends the potential silver-bearing area around a known silver prospect. A gold anomaly was found along the Mikado shear zone 0.5 mile west of the Mikado mine at Chandalar Lake. Sampling of apparently favorable areas in the Table Mountain and Coleen quadrangles along the northeast border of Alaska yielded negative results.

Geologic mapping in Wrangell Mountains.—Geologic mapping of six 15-minute quadrangles in the Wrangell Mountains in south-central Alaska has been completed. These maps will provide a sound base for further study of the heavy metal potential of the region.

Gold in gravel of Kougarak River.—Small amounts of gold have been found in gravels of the Kougarak River in the western part of Seward Peninsula. Seismic profiles near the mouth of the river indicate a buried north-trending channel, possibly indicating a pre-gravel drainage direction. These gravels, formerly thought to be of Tertiary and Pleistocene age, are now believed to be entirely of Pleistocene age.

Gold veins at Nuka Bay.—Several quartz-arsenopyrite veins at Nuka Bay, at the southwest end of Kenai Peninsula, southwestern Alaska, contain as much as 10 ounces of gold per ton. The veins are short and discontinuous, and ore shoots are erratic, but small-scale mining may be feasible.

Arizona

Gold deposits of Gold Basin and Lost Basin.—Study of gold lode and placer deposits of the Gold Basin-Lost Basin area south of Lake Mead in northwestern Arizona has shown that alluvial placers of Pliocene(?) and Quaternary age on the flanks of the Lost Basin Range are the most promising. Small veins of quartz, sulfide minerals, and gold are abundant in Precambrian rocks of the region, and some contain coarse gold, but most are

too small to be of economic interest. Placer deposits derived from Pliocene(?) pediment gravels have formed along arroyos on the east side of the Lost Basin Range over an area of 8–10 square miles. On the west side of the range, some placer deposits in Quaternary alluvial fans are being mined on a small scale. Potential resources may exceed 500 million cubic yards of gravel containing 0.01–0.02 oz gold (\$0.35–\$0.70) per cubic yard. A sampling program is being planned with the U.S. Bureau of Mines.

California

Aeromagnetic map of part of the Mother Lode.—An aeromagnetic map of parts of the Mother Lode gold and Sierra Foothills copper mining districts in Calaveras, Stanislaus, and San Joaquin Counties, together with a geologic interpretation (U.S. Geol. Survey Map GP-561), shows that many of the ore deposits in this region are related to the Bear Mountains and Melones fault zones, which locally are intruded by ultramafic rocks that give rise to magnetic highs. Magnetic evidence suggests a similar buried fault zone 8–9 miles southwest of the Bear Mountains zone. Possible near-surface magnetite- and ilmenite-bearing sands, which elsewhere in the region are known to contain placer gold, also are indicated by the magnetic data.

Aeromagnetic surveys of the Mother Lode-Grass Valley area to the north in the Sierra Nevada have been completed. Some electromagnetic anomalies detected by aerial surveys have been checked on the ground; the conductive units appear to be black slates or phylites and flat-lying volcanic rocks and gravels.

Tertiary gravels, Nevada County.—As an initial stage in the study of Tertiary gold-bearing gravels in the Sierra Nevada, the San Juan Fidge channel in Nevada County was traced for about 15 miles. The sinuous channel is $\frac{1}{4}$ – $1\frac{1}{2}$ miles wide and along its axis is filled with 200–300 feet of gravel. Paleocurrent data show that the ancient river flowed from east to west. Twenty samples were collected for study and analysis. Much gravel was removed from this channel during hydraulic mining prior to 1885, but a large amount remains.

Field tests of six geophysical methods for studying possible gold-bearing Tertiary stream gravels in the Sierra Nevada were made north of Nevada City and are being evaluated. Seismic-refraction methods supplemented by gravity measurements appear to be best for determining bedrock configuration. Resistivity methods provide knowledge of conductive layers and may be able to locate the productive "blue lead" when other methods fail. Magnetic methods are useful if concentrations of magnetite-rich black sands are associated with gold, and induced polarization may detect disseminated sulfides that in placer are associated with gold concentrates. Electromagnetic techniques do not appear promising at this preliminary stage.

Low-level (400 ft above terrain) magnetic, electromagnetic, and radiation profiles were flown across the

San Juan Ridge channel northeast of Nevada City and will be compared with results from earlier ground tests.

Studies and sampling in Klamath Mountains gold region.—Areas around most of the principal gold mines and districts in the Klamath Mountains of northern California and southern Oregon were studied, and zones of shearing and alteration near mines and along roadcuts were sampled. Most samples contained <0.1 ppm gold, but several had as much as 2.1 ppm gold. In particular, samples from the Liberty district near Sawyers Bar contained as much as 2.1 ppm gold in fault zones at known deposits and as much as 0.3 ppm in shear zones half a mile or more from known deposits.

In addition, about 75 samples were collected from basal Cretaceous beds overlying rocks of the Klamath terrane around Redding and Yreka, Calif., and Medford, Oreg. All plutons in the Klamath Mountains of southwest Oregon were sampled for age determination by the potassium-argon method.

Geochemical studies in the Masonic district.—Preliminary results of a geochemical study of the Masonic district in northern Mono County indicate that altered, generally silicified, and locally pyritized volcanic rocks in the center of the district average about 0.1 ppm gold. No significant correlation was found between gold and copper, lead, or silver.

Colorado

Alamosa Creek, Conejos and Rio Grande Counties.—An extensive area of hydrothermally altered volcanic and plutonic rocks of intermediate composition along the upper Alamosa Creek 3 miles south of Summitville in the eastern San Juan Mountains locally contains anomalous amounts of lead, copper, molybdenum, and zinc. A presumably late zone of quartz-alunite-pyrophyllite alteration some 2 miles long is superimposed on a more widespread area of quartz-muscovite or illite-kaolinite alteration. The late alteration may be related to intrusive rocks similar to those of the Summitville gold-copper-silver district; if so, ore deposits may be present in the area, perhaps at depth.

Eastern San Juan Mountains.—Reconnaissance geologic study and geochemical sampling has been done in several hydrothermally altered volcanic centers in the eastern San Juan Mountains. Samples are being studied to determine the nature of occurrence of the small amounts of precious metals detected.

The highest gold contents, as much as 50 ppm, are in relatively small bodies of silicified intrusive rocks containing barite, pyrite, and copper sulfides. More extensive altered pyritized zones peripheral to intrusives generally have <0.2 ppm gold. Pyrite from some altered rocks is being analyzed for gold and trace elements to determine whether it is a principal carrier of gold or other elements. Barite from several gold-rich samples also is being analyzed.

Research on stream-sediment sampling, San Juan Mountains.—Stream-sediment samples from 57 localities in the northwestern San Juan Mountains were collected and concentrated by panning as a test of sampling procedures. Most analyzed samples of concentrate weighed about 15 g; large samples were split and analyses made of each split. Three types of areas were sampled: (1) areas not known to have gold deposits; (2) areas known to have some gold veins but few if any prospects or small mines; and (3) areas having numerous veins and productive mines.

Results may be summarized as follows:

1. Agreement among analyses of two or more splits of the same sample was good enough that considerable confidence can be placed in a single analysis of a 15-g sample.
2. One or two samples from a stream are adequate for a preliminary appraisal of the gold potential of a given drainage basin; all samples from apparently barren areas yielded calculated values of 0.000X—0.0000X ppm, nearly all samples from weakly mineralized areas gave calculated values of 0.00X—0.000X ppm, and samples from strongly mineralized areas gave calculated values ranging from 0.X—0.00X ppm.
3. Among samples containing a calculated amount of 0.01 ppm or more, gold was seen in 13 of 15 panned concentrates.

Hahns Peak, Routt County.—At Hahns Peak, geologic mapping shows a steep-dipping breccia pipe in porphyry that intrudes Cretaceous sedimentary rocks. Within the breccia pipe, a lens 150 feet long and 40 feet thick contains about 90 ppm silver, about 0.5 percent lead, and a trace of gold. Analyses of about half of the 400 samples of porphyry and sedimentary rock show that some 8 percent contain >0.1 ppm gold.

Reopening of the Southern Cross adit has permitted additional sampling of the Hahns Peak breccia, exposed in the outer 235 feet of the 1,000-foot adit. Samples to be analyzed for silver and base metals were collected at 25-foot intervals; disseminated pyrite was the only sulfide mineral recognized in the field.

Several hundred samples of soil and stream sediments within a 4–5 mile radius of Hahns Peak also were collected; many panned mineral concentrates contain detectable gold, and other analyses are pending.

Tertiary gold placers in Iron Springs Divide area.—Analysis of heavy mineral concentrates from modern alluvium has outlined an area of high gold content in sand lenses in claystone and siltstone of the Wasatch Formation. The area lies just north of Iron Springs Divide in Moffat County, northwest Colorado, is about 1.5 miles wide and 6 miles long, and trends N. 70° W. The fine grain size and shape of the gold particles suggest hydrologic equilibrium with the enclosing sand; furthermore, gold is most abundant at the base of lenses in the coarsest sediment, and no consistent

correlation has been found between gold content and iron or manganese now being deposited from ground water. Bulk sand samples have as much as 2.5 ppm gold. All evidence indicates that the gold deposits are placers. The association of gold with garnet, monazite, and pebbles of quartz, feldspar, and granitic rocks indicates derivation from Precambrian rocks to the east or north.

Recent placer deposits reworked from those in the Wasatch Formation are 10–50 feet below the surface and therefore only potential areas can be identified without drilling. Modern alluvium along Lay Creek west of Craig was tested by 25 holes drilled with a portable auger. At least three deep low-grade gold-bearing sandy zones were identified. Dredges on the Yampa River below Round Bottom and on Lay Creek above Jackrabbit Spring reportedly will test these placers.

Samples of zeolitic sandstone and shale of Eocene age from 8 localities in Moffat County reported to contain platinum and gold were analyzed by 8 methods in Washington and Denver. On the basis of the most sensitive method for each element, all samples contained <10 ppb gold, <10 ppb platinum, and <2 ppb palladium.

Silver Cliff-Rosita, Custer County.—Manganese oxide veinlets at Silver Cliff, near Westcliffe, contain an average of about 70 oz silver per ton. Inasmuch as these veinlets, 0.5 to 2 inches wide, are fairly abundant over an area of 1,000 by 500 feet, a substantial silver resource may be present.

Altered rocks from vents in the Silver Cliff-Rosita volcanic field are being studied to decipher the relation of manganese-silver-lead-copper mineralization to rock alteration.

Magnetic and gravity surveys at Cripple Creek.—Gravity and ground-magnetic data were obtained at 250 stations in the Cripple Creek district, Teller County. The stations were spaced ¼ mile apart along traverses. Preliminary study of data indicates that magnetic lows generally correlate with known areas of intense alteration. A preliminary Bouguer gravity contour map of the district shows a 10-milligal gravity minimum that conforms to the outline of the Cripple Creek basin. Local gravity minima correspond closely with geochemical anomalies and with altered and mineralized areas. Ground-magnetic and gravity-contour maps have similar configurations.

Aeromagnetic surveys.—About 3,000 traverse miles of aeromagnetic survey was flown in the region between North Park and Central City.

Georgia

Heavy Metals projects in the Southeastern United States are concerned with three major lines of investigation: (1) geological, geochemical, and geophysical studies, principally in areas of known gold deposits, in search of clues to unknown or buried gold deposits; (2) investigation of the behavior of gold during weathering

and sedimentation to establish basic principles concerning the mobility of gold and the mechanisms by which it is transported and deposited, which in turn will enable us to identify favorable geological environments in which to search for new deposits; and (3) study of sedimentary rocks in Triassic basins and along the coastal plain to search for gold that has been eroded from lode deposits in older rocks. Work to date has been done mainly in Georgia and North and South Carolina, which have been the main gold-producing states of the region.

Reconnaissance of Dahlonge gold belt completed.—A reconnaissance study of the Dahlonge gold belt of Georgia and North Carolina was completed. Small amounts of gold can be detected at old mines, and trace amounts, less than 0.25 ppm, are widespread. Most of the ore mined along the belt probably contained less than \$1.00 per ton in gold; however, only a few exposures of ore were found.

Of 478 samples of mica schist, mica gneiss, amphibolite, quartzite, vein quartz, and granite in the southwestern part of the gold belt, 198, or 41 percent, contained detectable gold (limit of detection, 0.02 ppm). Of these, 89 samples contained 0.02–0.04 ppm, 50 contained 0.05–0.1 ppm, 28 contained 0.1–0.49 ppm, and 32 contained 0.5 ppm or more. About 65 percent of the samples were from roadcuts, the rest from the vicinity of an old gold mine. No particular rock type was consistently highest in gold, but mica schist and vein quartz had the highest assays.

Of 37 samples collected at the Calhoun mine, Lumpkin County, only five contained detectable gold. A channel sample across a pillar of the main vein assayed 0.38 ppm gold; quartz stringers contained 0.02 and 0.06 ppm gold; and two samples of soft wet iron hydroxide deposited recently on the walls of a stope and adit contained 0.14 and 2.19 ppm gold, respectively. No gold was found in fresh mica schist and vein quartz near the iron hydroxide.

Maine

Mineral zoning at West Pembroke.—Geologic study and sampling of mineral deposits around West Pembroke, easternmost Maine, have disclosed a well-defined pattern of mineral zoning. The deposits are along small north- or east-trending faults in weakly metamorphosed silicified shale and volcanic rocks of Silurian age. A central zone characterized by intensely altered rocks with copper and some gold is succeeded outward by a zone rich in zinc and then by a peripheral zone of lead, zinc, and silver. Sulfide minerals include chalcopyrite, pyrite, sphalerite, galena, arsenopyrite, and possibly silver sulfarsenides; gangue is quartz, carbonates, and barite. Analyses of large samples from stockpiles at opencuts gave the following results:

Zone	Au (ppm)	Ag (ppm)	Cu (percent)	Pb (percent)	Zn (percent)
Copper-gold	0.05-0.5	3.3-3.7	0.63-0.85	0.003-0.007	0.25-0.43
Zinc	.02	2.5	.1	.005	1.4
Zinc-lead-silver	.02	55	.007	.18	.66

The gold content of some samples from the copper-gold central zone is several ounces per ton.

About 67,000 feet of drill core from the Barrett and Big Hill deposits have been made available by Dolsan Mines, Ltd., for logging and sampling to determine lithologies and metal distribution.

Panned concentrates of beach and stream sediments were collected from 138 localities over an area of 400 square miles in the Pembroke-Calais region. Gold was detected in 21 samples, mostly in amounts ranging from 0.6 to 2.5 ppm; of these, 12 were from an area of only 15 square miles in which the Devonian Perry Sandstone is exposed. This sandstone merits further investigation as a potential source of gold.

Reconnaissance sampling, western Maine.—Samples from 180 localities in western Maine (Rangely, Phillips, and Kennebago quadrangles), comprising metasedimentary rocks, altered and silicified zones, and sulfide veins, were analyzed for gold. A vein of arsenopyrite in gabbro assayed 0.2 ppm gold, and a bed of metasandstone in the Upper Ordovician Nile Brook Formation contained 0.03 ppm gold; in other samples, gold content was below the limit of detection (0.02 ppm). These preliminary results suggest that the stratified rocks of western Maine are not likely sources of gold.

Evaluation of geochemical-geophysical anomaly, Squarctown.—A geochemical and geophysical (electromagnetic) anomaly northeast of The Forks in west-central Maine was tested for evaluation by 10 diamond-drill holes totaling 1,950 feet in length. The anomaly is at least 5,000 feet long. Several zones of disseminated to massive sulfide minerals, mainly nickeliferous and cobaltiferous pyrrhotite with minor chalcopyrite, were cut near the southeast margin of the Moxie gabbro-norite pluton. Preliminary assays show rather low metal content (≤ 1 percent combined metals) but much core remains to be analyzed. Magnetic susceptibility measurements have been completed on the core, and studies of induced polarization are in progress.

Gold prospects along coast.—Suites of samples collected from two old prospects at Deer Isle and Castine along the east side of Penobscot Bay contain from 0.14 to 8 ppm gold. Although both prospects are so situated as to offer little possibility for further development or mining, they do indicate a general area that warrants additional search for gold.

Maryland

Great Falls district.—The gold district near Great Falls, Md., was sampled and more than 400 analyses of vein material, wall rock, and saprolite were made in mobile laboratories. One small unmined vein at Great Falls yielded a sample containing 18 ppm gold, and all vein quartz sampled has more than 0.1 ppm gold.

Massachusetts

Waste quartz-siderite rock from a prospect in northeast Massachusetts contains several ppm gold.

Missouri

Heavy metals in mafic rocks near Ironton.—A geochemical study of platinum-group metals and sulfide minerals in fresh mafic rocks of the Shepherd Mountain intrusive near Ironton, southeast Missouri, has been started.

Montana

Geophysical studies in Wickes district.—Detailed ground-magnetic, gravity-profile, and some AFMAG data have been collected around the Montana Tunnels area in the Wickes district, Jefferson County, north of Butte. The aeromagnetic low previously recognized was confirmed and correlates closely with a geochemical anomaly. Magnetic lows suggestive of altered rock were found across the Minah vein and on the west side of Alta Mountain. Continuity between the Montana Tunnels geochemical anomaly source and the Alta vein to the east was tested by gravity and AFMAG, but nearby powerlines apparently affect AFMAG results.

Soil sampling at Virginia City.—About 900 soil samples, mainly of residual soil on hillsides, have been collected over an area of about 25 square miles around Virginia City, Madison County. Of 87 samples thus far analyzed, 13 show between 0.8 and 1.5 ppm gold. Semi-quantitative spectrographic analyses and gold determinations will be made on all samples.

Mapping of Tertiary basalt overlying gold-bearing Precambrian rocks shows that the prebasalt drainage was similar to the present drainage and that extensive placers are not likely to occur beneath the basalt.

Gold content of Oligocene conglomerate, Jefferson County.—A sample of the basal 6 inches of an Oligocene conglomerate in Jefferson County, west-central Montana, contains about 0.25 ppm gold. A channel sample of the total thickness of conglomerate, about 6 feet, contains only 0.02 ppm. The conglomerate consists of rounded clasts of Cretaceous volcanic rocks in a magnetite-rich sandy matrix.

Ruby River valley, Madison County.—Matrix material concentrated from Tertiary conglomerate in the upper Ruby River valley showed gold in 8 of 15 samples. However, analyses ranged from only 0.02 to 0.1 ppm gold, and the conglomerate layers are thin and lenticular, therefore they appear to have little economic potential.

Nevada

Geologic and geochemical studies started at Aurora.—Geologic mapping and geochemical sampling have been started in the Aurora district, Mineral County. Gold is in quartz veins in northeast-trending

silicified reefs that cut altered andesites. Preliminary results indicate gold to be in seams of gray chalcedonic quartz. Geologic features of the district and the nearby Bodie district in Mono County, Calif., include collapse breccia, peripheral intrusive rocks, and a central structural dome.

Carlin, Eureka County.—The Carlin gold mine, discovered in 1962 and brought into production in 1965, is the largest new gold mine to be found in the United States since discovery of Goldfield, Nev., in 1902. Reserves were estimated in 1965 to be about 11 million tons of ore averaging 0.32 oz per ton (\$11.00 per ton). Exploration leading to discovery of the mine by Newmont Mining Corp. was guided by earlier work of the Geological Survey.

The Carlin deposit is being studied in cooperation with the company staff. The stratigraphic and structural setting of the deposit, and the mineralogy and chemistry of the gold ore as well as of altered and unaltered country rock are being investigated with the aim of determining the processes by which the deposit formed; such knowledge will be of great value in the search for other similar deposits of very fine grained gold in Nevada and perhaps elsewhere. Study of the minor-element content of the ore has been completed.

The deposit is in the Lynn window of the Roberts Mountains thrust fault, in which rocks of the lower plate are exposed over an area of about 25 square miles. Fieldwork to date suggests that host rocks (Roberts Mountains Formation of Silurian age) are intensely altered; that rock alteration and metallization are closely related; that anomalous amounts of mercury and arsenic are associated with the gold ore; and that ore distribution shows little, if any, detailed relation to the Roberts Mountains thrust fault.

Fallon-Manhattan mineral belt, Churchill and Nye Counties.—The mineral potential of the northwest-trending Fallon-Manhattan belt in Nye and Churchill Counties has been evaluated. Many important ore deposits are along northwesterly-striking faults of pre-Tertiary age. The abundance of mineral deposits in exposed pre-Tertiary rocks suggests that numerous deposits remain to be discovered along other similar faults concealed beneath Tertiary rocks.

A major northwest-trending lineament extending from the Toiyabe Range through the Manhattan district in the Toiyabe Range southeast as far as the Hot Creek and Reveille Ranges in northern Nye County, is marked by faults and alteration in volcanic rocks. Ore deposits at Manhattan are in Paleozoic rocks closely resembling those at Carlin, and similar rocks and ore deposits may be present beneath altered volcanic rocks elsewhere along the lineament. Further geologic mapping and geochemical sampling is planned to test these ideas.

Western Churchill County.—Reconnaissance geochemical sampling in western Churchill County revealed detectable amounts of gold in 27 of 81 samples. Rocks sampled included quartz veins, silicified or otherwise altered volcanic rocks, and altered meta-

morphic rocks. The area has been prospected, but little or no production is recorded. Twenty-five samples contained 0.1–8.74 ppm gold, and two others contained 78 and 93 ppm gold. The mercury content ranges from 0.03 ppm to 300 ppm, and all but two samples contain 0.1 ppm or more. The most promising area is the south part of Fireball Ridge, in the northwest corner of the county; six of the nine highest grade samples were collected here. The highest gold content was in a dike or plug of altered rhyolite cutting metamorphic rocks. This area is to be resampled in detail.

Comstock (Virginia City) district, Storey County.—The bonanza silver-gold district of Comstock is being restudied, in particular the alteration pattern associated with ore deposits along the Comstock fault as a possible clue to concealed deposits. The work is a continuation and amplification of earlier geochemical studies published in Geological Survey Professional Paper 575-B, p. B10-B20, 1967. Geologic, geochemical, and geophysical investigations, aided by X-ray study of many samples show that alunitized rocks resembling those at Virginia City occur along the Comstock fault for several miles to the north.

An induced-polarization anomaly recognized during a preliminary survey along the Comstock fault about 5 miles north of Virginia City, Storey County, was re-surveyed using both induced-polarization and electromagnetic methods, as the original anomaly was difficult to interpret. In addition, an aeromagnetic survey of the entire Virginia City quadrangle was completed. Integration of geologic and geophysical studies is in process.

A magnetometer survey of potential gold-placer ground at the mouth of Sixmile Canyon in the Comstock district was made in cooperation with the U.S. Bureau of Mines.

Cortez, Lander County.—A gold geochemical anomaly discovered near Cortez was announced in August 1966 in Circular 534. As a result, a consortium of mining companies, Cortez Joint Venture, started a drilling and sampling program almost immediately. In June 1967, the Joint Venture announced that approximately three million tons of ore averaging 0.3 oz per ton (\$10.50 per ton) had been discovered, and that metallurgical studies preparatory to design of a concentration plant were under way. The geologic setting of the deposit closely resembles that of the Carlin mine, 60 miles north; the deposit is in the lower plate of the Roberts Mountains thrust fault, which is exposed in the Cortez window over an area of about 20 square miles, the host rock is the Roberts Mountains Formation, and the ore is similar in nature and grade.

Reconnaissance geochemical sampling northeastward for 5 miles from Cortez to the Buckhorn mine revealed several areas of anomalous gold and silver content. Several samples collected along a fault zone in the Buckhorn district contain anomalous amounts of gold, silver, and mercury; some have 10 ppm or more of gold. The samples are of highly altered volcanic

rocks. These findings appreciably extend the area of potential precious metal deposits around the Buckhorn mine. The thickness of basalt flows in the district has been estimated by resistivity soundings, as has the extent of an underlying Tertiary conglomerate.

The age of Caetano Tuff and quartz porphyry dikes associated with the Cortez gold deposit is Oligocene (about 32 million years). Rhyolite east of Cortez and generally believed to cut Pliocene(?) basaltic andesite that is altered and gold-bearing in the Buckhorn district is now known to be of the same age. These new data suggest either that (1) the Buckhorn basalt is older than Pliocene and its mineralization may be related to the same kind of rocks as that at Cortez, or (2) the Buckhorn mineralization is younger than that at Cortez and related to different rocks. Further field study will be done to determine, if possible, the true relative ages of the various rocks.

Chert from the Fourmile Canyon Formation (Silurian) in the upper plate of the Roberts Mountains thrust fault near Cortez contains anomalous amounts of tellurium. Of 31 samples analyzed, three contain >10 ppm tellurium (highest value 20 ppm), 10 contain 1.0-9.9 ppm, 14 contain 0.1-0.9 ppm, and four contain <0.1 ppm. Samples high in tellurium in general also are relatively high in gold, silver, and mercury.

Ely, White Pine County.—A geochemical anomaly discovered in the Ely mining district was announced in Circular 535. Analyses of 1,400 samples show that an area 5 miles long and 3 miles wide, including part of the great copper deposits of Ely, contains anomalous amounts of gold, silver, tellurium, and mercury. Gold content of scattered samples is in the commercial range, and tellurium analyses suggest that a major resource may be present. Although no new company activity has been reported to date, hopefully the gold and tellurium potential will encourage further investigation.

Goldfield, Esmeralda County.—The famous old bonanza gold camp of Goldfield is being restudied in order to learn more about the structural control of the ore deposits and the nature of the alteration associated with them, and thus if possible to establish criteria for exploration in areas of similar geologic setting not known to be mineralized.

More than 2,500 samples were collected, 27 adits totaling 7,500 feet in length were mapped, and geochemical sampling of 100 localities along silicified veins and 90 localities in the Combination-January cuts also was done. Surface mapping of 9 square miles of the district was done utilizing colored aerial photographs. More than 200 samples of altered rock are being studied by microscope and X-ray methods in an attempt to identify alteration types indicative of gold mineralization.

Geochemical maps of the Combination-January mine area showing distribution of eight minor elements have been prepared, and analysis of geochemical data from the oxidized zone in this area has been completed. In order of decreasing correlation coefficient, antimony,

tellurium, silver, zinc, lead, bismuth, arsenic, and mercury show high to moderately high positive correlation with gold, whereas copper, molybdenum, barium, strontium, iron, and manganese show only insignificantly low correlation. Atomic-absorption analyses of 133 samples of unmined near-surface silicified vein material along the Combination vein show 2.4-3.8 ppm gold. These results are high enough to warrant checking of larger samples by fire assay. Quartz-poor altered rocks high in limonite and alunite also are relatively high in gold, whereas quartz-limonite-alunite rocks contain little gold.

Work at Goldfield indicates that rock alteration is similar in both gold-bearing and barren areas, therefore structural interpretations are most important in assessing the potential of the district. Geologic mapping of an additional 10 square miles seems necessary to resolve structural problems.

Iron Canyon, Lander County.—In Iron Canyon just east of Copper Canyon at the south end of Battle Mountain, which is 10 miles southwest of the town of Battle Mountain, geologic mapping and surface indications of mineralization suggested that an environment favorable for ore deposits might exist at shallow depth. To more sharply define a possible exploration target, geologic drilling was begun in April 1967. At the end of December 1967, drill hole 1 had reached a depth of more than 3,900 feet, entirely in Scott Canyon Formation (Lower or Middle Cambrian(?)) in the upper plate of the Roberts Mountains thrust fault. Traces of gold (0.02-0.1 ppm, with one thin interval assaying 0.08-0.5 ppm and another interval of 180 feet having several assays of 0.7-10 ppm) and mercury (as much as 5.4 ppm) were found in the upper 2,600 feet; analyses are not yet available for deeper rocks. Locally, pyrite, marcasite, arsenopyrite, pyrrhotite, chalcopyrite, and sphalerite have been identified.

Drill hole 2 was started in December 1967 and has reached a depth of more than 500 feet.

Shoshone Range, Lander County.—Geological and geochemical studies are being made in the Shoshone Range, particularly in the area between the Gold Acres mine and Tenabo, 30 miles southeast of Battle Mountain. The Gold Acres mine, which has produced about 150,000 ounces of gold, is at the intersection of northeast- and northwest-trending structures, and several other structurally similar areas are being studied in detail. Geochemical surveys have revealed several areas of anomalously high gold and bismuth content. Geochemical maps based on 1,000 samples were prepared to show the distribution of 15 elements, and they reveal several gold-silver anomalies in areas that will be studied further to determine whether their structural settings are favorable. Some geochemical differences between Gold Acres and Tenabo are apparent and may be significant in interpreting geochemical anomalies; at Gold Acres, there is positive correlation between the metal pairs gold-lead, gold-iron,

silver-lead, and silver-tin, whereas at Tenabo positive correlations are shown by gold-silver, gold-bismuth, gold-iron, and silver-copper.

The Gold Acres mine is in the breccia zone of the Roberts Mountains thrust fault, and to determine the position of this favorable structure at depth in the Tenabo area, geologic core drilling began in July 1967. Drill hole 1 was started in chert and argillite of the Devonian Slaven Chert in the upper plate of the Roberts thrust, containing scattered pyrite and pyrrhotite and local veins of galena and sphalerite. The thrust fault was cut at about 3,030 feet and the hole bottomed at about 4,000 feet in the lower plate of the fault. The rocks of the lower plate penetrated by the drill hole consist of about 900 feet of tremolitic limestone (Silurian Roberts Mountains Formation?) overlying 100 feet of argillite of uncertain stratigraphic identity. Core samples are being analyzed. Drill hole 2 was started in December 1967, about 3 miles southeast of hole 1, on an alluvial fan where geophysical data indicate the alluvium to be 200-300 feet thick.

Bleached chert over an area of about 1 square mile near the Gold Acres mine contains anomalous amounts of mercury, zinc, copper, bismuth, arsenic, antimony, and silver. No mines and only a few prospect pits are in the area, which is on the flank of a magnetic anomaly. No gold has been detected, but the elements mercury, arsenic, and antimony are known to be associated with gold elsewhere in north-central Nevada. This association, plus the occurrence at Gold Acres of gold along the Roberts Mountains thrust fault, which underlies the anomaly at an unknown depth, indicates a possible area for further exploration.

Swales Mountain, Elko County.—At Swales Mountain in the Independence Mountains 15 miles north of Carlin, gold, silver, and base metals occur along the axial region of an anticline intruded by quartz porphyry. Both the anticline and intrusive are younger than the Roberts Mountains thrust fault. Geologic mapping of Paleozoic rocks in the Independence Mountains from U.S. Highway 40 north to Pie Creek has been completed, and an evaluation of the mineral potential of the Swales Mountain quadrangle is in preparation.

In order to check complex stratigraphic and structural relations at depth and to test the occurrence of a possibly favorable environment for ore deposits, three geologic core drill holes (totaling 3,956 ft) were completed between May and September 1967. The drill holes revealed that (1) most of the limestone underlying Swales Mountain is Roberts Mountains Formation (Silurian) in the lower plate of the Roberts Mountains thrust fault; (2) mineralization in both upper and lower plate rocks is related to intrusive contacts rather than to stratigraphic or structural horizons; and (3) little leached and bleached limestone similar to that at the Carlin mine is present.

Mapping started in Tuscarora district.—Reconnaissance geologic mapping started recently in the Mt. Blitzen quadrangle northwest of Tuscarora, Elko

County, has revealed extensive areas of hydrothermally altered rocks. Geochemical studies are under way.

Resistivity soundings in north-central Nevada.—Resistivity soundings were made in the Buckhorn area in Eureka County northeast of Cortez, to more clearly define geologic structure; on alluvium at Tenabo, in Lander County, to obtain estimates of depth to bedrock; and at the north end of Battle Mountain, in Humboldt County, to clarify geologic structure. In the latter area, a two-dimensional model of the bedrock surface is being constructed from magnetic and gravity data.

Isotopic composition of lead in gold from Nevada.—The isotopic composition of lead in a placer concentrate from the Battle Mountain area, Lander County, is very similar to that of lead from galena in various lead-silver prospects elsewhere in north-central Nevada. The isotopic data suggest a relationship between lead-silver mineralization and Tertiary igneous activity.

Isotopic analysis of lead in bulk gold ore from Cortez, in Lander County, shows the ratio Pb^{206}/Pb^{204} to be higher than for lead from any galena in north-central Nevada thus far analyzed. Lead from unaltered host rock (Roberts Mountains Formation) will be analyzed to determine whether the lead in Cortez ore might have been concentrated from the host rock rather than introduced with the gold.

New Hampshire

Iron Mountain deposit.—The Iron Mountain iron-beryllium deposit, at Bartlett in east-central New Hampshire, consists of magnetite cut by veins of galena, sphalerite, quartz, fluorite, and the complex beryllium silicate danalite. These veins contain 90 ppm silver and 0.06 ppm gold. Because the magnetite contains 0.03 percent tin, other magnetite deposits in New England will be checked for their tin content.

Preliminary sampling at the Milar mine.—The Milar mine in northeastern New Hampshire is a massive pyrite-chalcopyrite deposit in schist; the ore commonly has yielded a few dollars per ton in gold. However, one sample collected at the mine contained 70 ppm gold. Additional analyses are being made.

Geologic mapping and sediment sampling in New Hampshire and Maine.—Detailed stream-sediment sampling and geologic mapping of selected areas in eastern New Hampshire and southwestern Maine, including the central part of the Ossipee Lake quadrangle in New Hampshire, have been completed.

Heavy metals in White Mountains.—Galena from lead ores in small deposits along the north-trending White Mountains ring-dike belt, New Hampshire and Maine, contains 0.03-5 percent silver, more than 1 percent bismuth, and as much as 0.01 percent tin. Further analytical data will be forthcoming.

New Mexico

Mogollon-Monticello area, Sierra and Catron Counties.—Altered areas along faults in volcanic rocks between Mogollon and Monticello in west-central New Mexico contain anomalous amounts of cadmium, manganese, beryllium, tellurium, niobium, and zinc. The anomalous areas are as much as 2 miles wide. These areas may represent halos over buried ore deposits in Paleozoic limestone which is a host rock for ore deposits in the Magdalena district to the northeast. Most of the post-volcanic ores in the area contain appreciable amounts of gold and silver. The region has been little prospected. Further work is necessary to locate possible exploration targets.

New York

Gold content of Shawangunk Conglomerate.—Two samples of basal pyritic Shawangunk Conglomerate (Silurian) in southern New York contain 0.1 and 0.3 ppm gold. This conglomerate extends over many square miles, and has been sampled extensively in New Jersey and Pennsylvania also.

North Carolina

Geochemical studies near Taylorsville.—Visible gold was found in heavy mineral concentrates from 27 of 114 localities sampled near Taylorsville in western North Carolina. A small unworked placer deposit may offer a clue to the location of a concealed lode deposit, but further study and perhaps geologic drilling will be needed to evaluate the potential of the area.

Copper and gold anomalies in central North Carolina.—Preliminary analytical results show several areas of anomalously high copper and gold content in Rowan, Davidson, and Randolph Counties in central North Carolina. Areas containing 80–600 ppm copper are in the Silver Hill-Gold Hill shear zone and in the shear zone of the Laughlin, Ward, and Cid prospects; in the latter area, several samples contain as much as 2–8 ppm gold. The most favorable host rock is rhyolite, rhyodacite, and mudstone of the Ordovician Cid Formation.

A lens of gabbro about 2 miles long and 700 feet wide lies within the Silver Hill-Gold Hill shear zone. The east contact zone of the gabbro with tuffaceous mudstone has anomalous amounts of copper (80–400 ppm) across a width of 400 feet. Further sampling has been done to locate possible extensions of this mineralized zone or other zones of similar trend.

Gold in younger sedimentary rocks.—More than 300 samples were collected from Coastal Plain and Triassic sedimentary rocks in North and South Carolina and Georgia. As much as 2 ppm of gold was found in Triassic rocks, and up to 1 ppm of gold was found in Coastal Plain rocks. Several copper anomalies, having as much as 500 ppm of copper, also were discovered in Triassic rocks.

Gold-niobium-tin placer, western North Carolina.—Heavy-mineral concentrates panned along a small stream-placer deposit northwest of Morganton in west-central North Carolina contain 2–5 percent niobium, 0.5–0.7 percent tin, and visible gold. The area is in the Brevard fault zone, and other samples from the zone also show anomalously high content of Nb and Sn. The niobium and tin minerals are believed to have been derived from pegmatites; however, further study is needed to evaluate the area as a possible source of these elements.

South Carolina

Haile-Brewer-Lamar belt.—This area in north-central South Carolina contains several gold prospects and mines, one of which, the Haile, was the largest gold mine in the Southeastern United States. All of these mines appear to be in the same stratigraphic unit, and work at the Lamar mine showed that although only quartz veins have been mined, wall rocks may also be gold bearing.

A new discovery along this belt, the De Kalb prospect, near Kershaw, S. C., was brought to the attention of the Geological Survey by Henry S. Johnson, State Geologist of South Carolina. A cooperative program with the Bureau of Mines was undertaken to study and sample this prospect. More than 500 trench and auger samples were collected from the B soil horizon; most contain between 0.1 and 1.0 ppm gold. Samples taken in roadcuts across the strike of the rocks showed that most of the gold is concentrated in a 1,200-foot stratigraphic interval. Results were as follows:

<u>Feet</u>	<u>Average ppm</u>
0–1,900	0.06
1,900–3,100	.27
3,100–3,600	.06

Samples collected at depths of ½ inch, 8 inches–3 feet, and 3–6 feet below the surface at the prospect suggest that gold is concentrated at or near the surface, probably by removal of soil and saprolite by sheet wash. A small amount of gold is being produced using a "Gold Saver" machine.

The Haile-Brewer belt is believed to be offset from its continuation, the De Kalb-Lamar-McCormick belt, along a fault with an estimated left lateral displacement of 4 miles. Both widely spaced and detailed sampling across the Haile-Brewer trend failed to find any extension of a molybdenum anomaly at the Haile mine.

McCormick County.—Ground magnetometer studies by the Geological Survey of South Carolina at the Jennings mine near McCormick, in conjunction with geologic mapping and geochemical sampling by the U.S. Geological Survey, show that silicic to intermediate

gold- and copper-bearing pyroclastic rocks extend at least 1.6 miles along the strike and are 25–75 feet thick. The rocks average about 0.03 ppm gold, and no high assays have been reported to date. Geochemical sampling traverses along roads and streams have completed the preliminary geologic study of the county. Analytical work and airborne geophysical studies remain to be done.

South Dakota

Black Hills, Lawrence and Pennington Counties.—Detailed geologic mapping of about 50 square miles of Precambrian rocks in the Black Hills has yielded a tentative stratigraphy of the rocks containing the great Homestake gold deposits. Knowledge of this stratigraphy will permit recognition and exploration of the Homestake Formation, the ore-bearing unit at the Homestake mine, in areas of favorable structure. Tertiary intrusions in the Precambrian rocks are mineralized locally, and metallization in the contiguous Precambrian rocks seems to increase toward the intrusives; however, the problem of whether the mineralization is entirely Tertiary or is both Precambrian and Tertiary is unsolved.

Under a research contract the South Dakota School of Mines and Technology compiled geologic data on all mineral deposits in the northern Black Hills. Study of joint patterns and orientation of ore bodies in Paleozoic rocks in the Galena, Squaw Creek, Ruby Basin, and Bald Mountain mining districts suggests that ore deposition is controlled by northeasterly trending structures that do not reflect the northerly trend of the underlying Precambrian rocks.

Systematic geochemical sampling was done in an area of 6 square miles in the Galena district; sampling was on a ¼-mile grid, at 20-foot intervals along several lines, and at 6-foot intervals across two Paleozoic sections. Copper, lead, and zinc were determined in all samples; any sample showing a high concentration of one or more of these metals also was analyzed for silver, and some for gold. High zinc analyses (to 1,500 ppm) are reported from several Cambrian and Ordovician beds and high lead (to 15,000 ppm or 1.5 percent) from the lower two of these beds, together with minor amounts of copper (to 600 ppm). Silver (as much as 150 ppm) is found only in samples of high lead content. Lead, zinc, and silver are virtually absent from Precambrian rocks, but copper is present in amounts as high as 1,200 ppm in Precambrian graphitic schist.

Utah

Heavy mineral content of Cretaceous and Tertiary conglomerates, northeast of Salt Lake City.—Panned heavy-mineral concentrates from 75 samples of Cretaceous and Tertiary conglomerates, and of stream sediment derived from them, along Echo Canyon and Lost Creek northeast of Salt Lake City, are sparse and contain very little gold. Concentrates from 35-pound samples average only about 2 g, as compared with

50–100 g obtained from the same size samples of gold-bearing Paleocene Pinyon Conglomerate in northwest Wyoming.

Wyoming

New Rambler mine, Albany County.—Preliminary analyses by wet chemical methods of 36 samples from the vicinity of the New Rambler mine in the Medicine Bow Mountains showed 0.2–20 ppm of the platinum metals. Twenty samples of dump material averaged 1 ppm. Most of the metal appears to be palladium. Analyses of five of these samples were checked by three methods. Results of these check analyses are as follows:

Method	Average of 5 samples (ppm)
Tellurium extraction colorimetric	2.3
Electrolysis (spectrographic)	2.1
Fire assay (spectrographic)	4.0

The average ratio of palladium to platinum in these analyses is about 5:1. The dump contains about half a million tons of broken rock, and the mine therefore may represent an appreciable palladium resource.

Atlantic City district.—Residual soil over gold-bearing quartz veins in the Atlantic City district contains as much as 80 ppm arsenic, but the average is only 15 ppm and there is no detectable arsenic (10 ppm) in soils above many veins. Thus, geochemical sampling in the area involving only arsenic would not be entirely successful in locating hidden veins. Soil over some apparently unmineralized Precambrian graywacke also contains more than the background amounts of arsenic. Of 50 samples of graywacke at these localities, 8 contain 0.1 ppm or more of gold.

Jackson Hole and vicinity, Teton County.—A description of gold-bearing conglomerates in Jackson Hole was published in Circular 541 in February 1967. In summary, analyses of 1,200 samples and 750 panned concentrates of quartzite conglomerates from seven formations of Late Cretaceous to Miocene age at 53 localities show the average gold content to range from 35 to 222 ppb. Alluvium derived from these rocks averages 103 ppb. The most thoroughly sampled formations, Upper Cretaceous Harebell Formation and Paleocene Pinyon Conglomerate, contain 65 ppb and 86 ppb respectively, or about 11 cents and 14 cents per cubic yard. New discoveries of quartzite conglomerate in the upper Green River basin, along upper Pilgrim Creek northeast of Jackson Lake, and in some headwaters of the Hoback River indicate that the previous estimate of 50 cubic miles of potential gold-bearing conglomerate is considerably too low.

Pinyon Conglomerate in the southern part of its outcrop area appears to have appreciably more gold than in the northern part. About 30 samples from a section nearly 1,000 feet thick near Burnt Mountain in the southern area average 120 ppb gold, whereas similar sections in the northern area may average only 5 ppb.

Gold and magnetite are closely associated inplacer deposits along streams in the region. To test the idea that magnetite might be a guide to gold, magnetometer traverses were made along Pacific Creek, Buffalo Fork, and the Gros Ventre River and its tributaries. Encouraging results were obtained along the Pacific Creek and Buffalo Fork drainages, and this work was followed by resistivity soundings to determine the thickness of the placers. Magnetic contour maps of placer areas show some correspondence between gold content and magnetic intensity on the basis of 134 gold analyses; however, the correspondence is not considered reliable because of the small number of samples. Magnetic field data are effective in delineating concentrations of heavy minerals. No correlation was found between gold values and magnetic susceptibility on one hand, or between magnetic susceptibility and in-place magnetic intensity on the other.

Correlation of Upper Cretaceous and Paleocene rocks in Jackson Hole and the Bighorn Basin, using heavy mineral suites, is being studied. Preliminary examination of suites from paired samples from 25 localities suggests that the association tourmaline-zircon is characteristic of the Upper Cretaceous Harebell Formation in the Gros Ventre River basin; green-brown hornblende-garnet is typical of conglomerates of both the Harebell and the Pinyon Conglomerate; and garnet-zircon-tourmaline is distinctive of rocks of the Bighorn Basin.

Platinum in placer deposits of Teton and Park Counties.—Platinum was found in sluice concentrates of heavy minerals from two localities in northwestern Wyoming. Analytical results are as follows:

Locality	Platinum (ppb)	Palladium (ppb)
Crandall Creek	120	37
Pacific Creek: magnetic fraction	45	6
nonmagnetic fraction	29	< 4

Crandall Creek drains an area of Tertiary volcanic rocks east of Yellowstone Park; Pacific Creek drains a large area of Pinyon Conglomerate and Harebell Formation south of the Park. A similar sluice concentrate of gravel along the Gros Ventre River and also derived from Pinyon Conglomerate contained <10 ppb platinum and <4 ppb palladium.

MARINE INVESTIGATIONS

Marine investigations under the Heavy Metals program were initiated on the west coast of the United States and in Alaska. Because marine studies require contracting for use of oceanographic research vessels well in advance of actual work, only a modest start was achieved during 1966. Contracts with 10 universities were awarded in 1966-67, and thus enabled a comprehensive marine program to get under way in 1967.

Alaska

Nome area, Seward Peninsula.—A 2-month cruise of the U.S. Bureau of Mines drilling ship "Virginia City"

was finished in early September 1967. Some 50 holes were drilled during a cooperative Bureau-Survey program within a distance of 10 miles from Nome to investigate the stratigraphic and geomorphic distribution of gold; the deepest hole was 240 feet, and many were more than 100 feet deep. In addition, 500 miles of continuous seismic profiling was done using the tug "Yamhill" of the U.S. Army Corps of Engineers. About 120 bottom grab samples were collected, and surface and bottom currents measured at each drilling site.

Low but perhaps economic concentrations of gold were found over a large area. Surface sediments have a higher gold content than the average for a total sedimentary section; the highest offshore concentration was found in bottom sediments off a modern beach having a relatively high gold content. Gold concentrations were not found on bedrock but do occur in offshore glacial drift that had been reworked by streams during times of low sea level.

Onshore work included study of raised terraces and beaches. Similar onshore work also was done on St. Lawrence Island in the Bering Sea. Systems of submerged beach ridges at depths of 25-30 feet in southern Kotzebue Sound are indicated by new bathymetric data.

Seward Peninsula and St. Lawrence Island.—Under a research contract, R/V "Thompson" of the University of Washington has completed sampling for heavy metals, acoustical profiling, and measurements of magnetic field between Seward Peninsula and St. Lawrence Island, western Alaska.

Gulf of Alaska.—A 14-day cruise in the northeastern Gulf of Alaska between Yakutat and Cape Spencer was made by the University of Alaska's R/V "Acona" as part of a U.S. Geological Survey-University of Alaska research contract. During the voyage, 1,085 miles of continuous seismic reflection profiles was made and 131 sediment samples were collected.

Seismic records from the continental shelf of the northeastern part of the Gulf of Alaska between Yakutat and Cross Sound at the north end of Chichagof Island are being interpreted. Upper strata of the shelf are deformed, mainly along trends parallel to the coast but, in the area west of Yakutat Bay, also along north-east trends. The courses of Yakutat and Aisek Sea Valleys are controlled partly by tectonic features and partly by a bank of sediments deposited on the shelf during glaciation.

Southeastern Alaska.—More than 100 core and grab samples have been collected offshore from potential gold-bearing areas near Ketchikan, Helm Bay, Wrangell, and Sitka in southeastern Alaska. All samples have been processed and will be analyzed for heavy metals.

Bering Sea.—More than 300 bottom samples from the Bering Sea collected by scientists of the University of Washington have been analyzed and preliminary results are encouraging. About half the samples contain 0.1 ppm (\$0.10 per ton) or more of gold and many contain

nearly 1 ppm (\$0.05 per ton) of silver. Further extensive sampling was done during the summer of 1967.

California

Sediment sampling of streams, southern California.—Sediments at the mouths of streams at 57 localities in southern California between Point Conception, west of Santa Barbara, and the Mexican border have been sampled. Although the heavy metal content appears to be very small, the identification of tracer minerals or mineral suites may aid in locating offshore concentrations. Sampling continues along the coast from Point Conception north to the Santa Ynez River and also on Santa Catalina, Santa Rosa, and Santa Cruz Islands. This work is being done under a research contract with the University of Southern California.

Acoustic seismic profiling, San Francisco Bay.—Stratigraphic control of bottom sediments in deeper water parts of San Francisco and San Pablo Bays has been obtained by running about 400 miles of continuous acoustic sampling profiles. This reconnaissance survey will indicate areas requiring more detailed coverage and will aid in selection of sample sites.

Northern California continental shelf.—During a 40-day cruise of the R/V "Oconostota" under a research contract with Scripps Institution of Oceanography, 3,700 kilometers (2,300 miles) of intersecting acoustic reflection profiles was run across the continental shelf between the coast of northern California and the Mendocino fracture zone. In addition, 125 bottom samples were collected.

California and Oregon

Offshore studies.—R/V "Polaris" made a 38-day cruise along the coast of southwestern Oregon. This vessel, formerly operated under charter from the University of California, was acquired by the Geological Survey in May 1967. Subbottom acoustical profiles were obtained across potential heavy metals-bearing sands between Coos Bay and the Rogue River and samples were collected in the same area.

Acoustic profiling along 170 miles of lines between Crescent City, Calif., and the delta of the Klamath River showed that Recent sediment in the area is 0-200 feet thick. Filled Pleistocene river channels, the modern delta of the Klamath River, and Pleistocene faults account for the range in thickness. Samples of Recent sediment were collected for heavy metals analysis.

Gold contents significantly higher than background were detected in black sands off the coast of Oregon and in sediments off California that may be on Mesozoic basement or that may have been reworked from outcrops of a folded Pliocene unconformity during lower stands of sea level. The Oregon black sands were located by acoustical profiling and reconnaissance sampling and are offshore from beach sands containing significant amounts of gold.

Gold in beach sands.—More than 1,000 samples of terrace, beach, and nearshore sands from southern Oregon and northern California have been analyzed for gold. Reproducible results can be obtained by analyzing the fraction finer than 100 mesh and having a specific gravity greater than 3.2; analyses of splits of raw samples were not reproducible.

A mobile sedimentology laboratory, supported by a mobile analytical laboratory, was used in the field at Bandon, Oreg., to concentrate heavy minerals in sediment samples prior to chemical analysis. The sensitivity of these analyses thus was greatly increased. A marine heavy metals sedimentology laboratory recently established at Menlo Park, Calif., is being utilized in preparing additional samples from these areas.

Oregon

Gold on continental shelf, southern Oregon.—Anomalous high concentrations of fine gold were found in surface sediments on the continental shelf off southern Oregon by the Department of Oceanography of Oregon State University operating under a research contract with the Geological Survey. The gold is associated with heavy minerals tentatively believed to be on submerged beaches of late Pleistocene age. Promising areas were resampled using box and piston corers. About 235 samples were collected by the research vessels "Cripple Creek" and "Yaquina". In addition, about 565 nautical miles of acoustical subbottom profiling and 145 miles of magnetometer traverse was run. Sea-bottom photographs were taken at 22 localities.

Each area of relatively high gold content is associated with a concentration of heavy minerals and marked by a positive magnetic anomaly that suggests a considerable concentration of magnetic black sands beneath the surface sediments. The gold content is low, generally <0.03 ppm, but may reflect a larger concentration at depth; this possibility can be tested only by drilling.

Oregon and Washington

Heavy metals studies along coast.—Terrace and beach sands, Tertiary sediments, and a granodiorite intrusion on the coast of northwest Washington were sampled, and coastal terrace and beach deposits near Newport, west-central Oregon, previously shown to contain anomalous amounts of gold, were resampled.

Washington

Studies on continental shelf.—Reconnaissance acoustical subbottom profiling and sampling in nearshore areas of the continental shelf off the coast of Washington were done during an 8-day cruise by R/V "Oceanear" of the University of Washington under a research contract. Local thick deposits of Recent sediments that may be sources of heavy metals were recognized. Systematic sampling will be done after interpretation of records has been completed.

As part of the study of the mineral potential of the continental shelf, 200 samples were collected by the R/V "Oceaneer" between the mouth of the Columbia River and Cape Flattery. These samples were collected along subbottom acoustical profile tracks run earlier.

Test of vibratory corer.—A vibratory coring device developed by Ocean Science and Engineering Corp. was tested by the R/V "Oceaneer" on the continental shelf near the mouth of the Columbia River. Testing was done in collaboration with personnel from the University of Washington and the U.S. Bureau of Mines. Cores of well-compacted fine sand as much as 2 meters long were obtained with little disturbance of sedimentary structures. Samples will be analyzed for heavy metals.

Gulf of Mexico

During a cruise of nearly 3,000 miles in the Gulf of Mexico, Texas A&M University recorded continuous acoustical profiles and collected samples from 60 localities. The work was done under a research contract.

TOPICAL STUDIES

Heavy Metals in Organic-Rich Rocks

The frequently reported occurrence of heavy metals, including gold, in organic-rich rocks such as black shale and coal was the basis for starting a systematic program of sampling and analysis of these rocks from all parts of the United States. More than 700 samples have been analyzed to date, and considerable research carried out on the nature of the association of organic material and metals and on the analytical problems involved in detecting small amounts of gold and other metals in the presence of abundant organic material. The gold content of these rocks, on the basis of work done to date, appears to be very low, and in only a few was any detected with certainty. They do not at this time seem to be likely sources for gold, but many more rocks, particularly those of Alaska, remain to be studied.

Gold Content of Coal, Peat, and Associated Rocks

Four hundred samples of coal and associated rocks from Colorado, Wyoming, Utah, and Idaho contain <0.020 ppm gold. Some uncertainty still exists regarding the detection of small amounts of gold in carbonaceous rocks by routine analytical methods, but it seems likely that coals of the Rocky Mountain region are consistently low in gold. Even coals previously reported to contain substantial amounts of gold have proved to be barren. For instance, coal, coke, and carbonaceous shale from the Cambria coal field near Newcastle, Wyo., were analyzed for gold on both a "dry sample" and "ashed sample" basis; all samples contained less than 0.1 ppm. This is the field from which ash from coal and coke was reported by Stone (U.S. Geological Survey Bull. 499, 1912) to contain as much as \$10 in gold per ton.

However, some western coals do contain small amounts of gold. Gold was detected in samples of coal from the Kemmerer, Wyo., and Wales, Utah, coal fields, and these samples were analyzed repeatedly for gold, but analyses are nonreproducible. To test the idea that gold in these coals may be particulate rather than adsorbed in organic material, several fractions were prepared and studied microscopically; no gold was found. The fractions will be analyzed for gold.

Twelve samples of peat, muck, and driftwood from streams and wet areas near the Front Range mineral belt in Colorado were analyzed for gold on a dry sample basis. Muck from Elk Park and peat from Rudolphs Bog contained 0.3 ppm gold; driftwood from Clear Creek and soft peat from Caribou Peat Bog contained 0.2 ppm. All other samples had less than 0.1 ppm.

Samples of ash, fly ash, and waste products from coal-washing plants have been requested from 38 coal-producing companies in the Western States. These samples will be analyzed for gold and other elements.

More than 900 samples of coals collected over a period of several years from the Appalachian and central interior areas will be analyzed for gold.

Gold Content of Black Shales

Chattanooga Shale (Devonian and Mississippian).—The gold content of 214 samples of Chattanooga Shale and stratigraphic equivalents as determined by the cyanide-atomic absorption method, is <0.020 ppm. Checks on 15 samples by fire assay and atomic absorption confirmed these results. Silver content ranges from <0.2 to 4.5 ppm, and mercury from <0.02 to 1.5 ppm.

Neither silver nor mercury content shows any regional variation. Mercury appears to be closely associated with organic material, whereas silver content apparently is independent of organic content.

Analyses of 44 other samples of Chattanooga Shale from a drill hole in western Kentucky show <0.020 ppm gold, 0.2–1.0 ppm silver, and <0.020–0.3 ppm mercury, results very similar to earlier analyses.

Carbondale Formation (Pennsylvanian).—Seven samples of black shale above No. 6 coal bed in the Carbondale Formation of Daviess County, Ky., were analyzed. All contain <0.02 ppm gold.

Hermosa Formation (Pennsylvanian).—One sample of black shale from the Paradox Member of the Hermosa Formation contained 0.2 ppm gold.

Pierre Shale (Upper Cretaceous).—Analysis of 26 samples of the Sharon Springs Member of the Pierre Shale by the cyanide leach-atomic absorption method showed all samples to contain 0.020 ppm gold. One sample from the lower part of the Sharon Springs Member from northwest Kansas contained 0.2 ppm gold.

Metal-rich Cretaceous Asphaltic Sandstone near Durango, Colo.

Lenses of radioactive black "asphaltic" material in the Cretaceous Dakota Sandstone near Durango, Colo., are enriched in gold (as much as 0.16 ppm) as well as in thorium, titanium, and other elements. The metal-rich asphaltic material may be a form of thucholite.

Gold in Marine Sediments

The gold content of three marine samples has been determined by neutron activation. Results are:

Manganese nodules, Blake Plateau (composite sample), 0.2 ppb
Phosphorite, Blake Plateau (composite sample), 7.2 ppb
Metal-rich sediment, Red Sea, 130 ppb

The last figure is of particular interest inasmuch as these Red Sea sediments have already been reported to contain 0.9 percent copper, 2.6 percent zinc, 0.1 percent lead, 0.008 percent silver, and 0.002 percent tin.

Gold Content of Batholithic Rocks

Gold content of 8 samples from each of 3 batholiths was determined by neutron activation analysis. Results are as follows:

Southern California batholith, 0.2-4 ppb
Sierra Nevada batholith, 0.3-10 ppb
Boulder batholith, 0.4-3.3 ppb

Fossil Placer Deposits

Studies of ancient deposits of sand and gravel formed in environments similar to those of modern placers were started early in the program with the hope that some might contain gold deposits similar to those of the Witwatersrand in the Republic of South Africa. Work on sandstones and conglomerates in several western and midwestern states has been unsuccessful to date, but will continue as only a small part of the potential gold-bearing strata has been examined.

Precambrian and Paleozoic rocks

Great Lakes region.—Preliminary sampling and paleocurrent measurements were done in upper Precambrian and Cambrian clastic rocks in Minnesota, Wisconsin, Michigan, and New York, and in Devonian, Mississippian, and Pennsylvanian clastic rocks in Michigan, Ohio, Pennsylvania, and New York.

Selected samples from 22 localities were fire assayed for gold. Five of the 22 samples contained 0.027-0.050 ppm, the rest less than 0.025 ppm, the limit of detection of the analytical method. Samples with detectable gold were separated into light and heavy fractions and submitted for analysis, in order to test whether samples of these rocks can be effectively preconcentrated. Heavy minerals concentrated from pyritic conglomerates of the Precambrian Fond du Lac Sandstone contain 2.1 ppm gold. Inasmuch as the whole rock contained only 0.050 ppm gold, and the concentration ratio is only about 9, the heavy concentrate

contains about five times as much as gold as would be expected; presumably the whole rock sample was not representative because of its relatively small size and the possible coarse nature of the gold.

Northwestern United States.—Samples of selected conglomerates of the Precambrian Belt Series from 11 localities in southwest Montana assayed less than 0.02 ppm gold. It seems likely therefore that conglomerates in this area of Belt rocks cannot be considered as potential sources of gold.

Of about 300 samples of quartzite from central Elko County, Nev., that were analyzed for gold, only one contained as much as 0.1 ppm.

Southwestern United States.—Of 70 samples of Precambrian and lower Paleozoic conglomerates collected during a reconnaissance study of possible fossil placers in central Arizona, only one contained more than 0.02 ppm gold, the limit of detection. A boulder conglomerate from the upper Precambrian Scanlan Conglomerate in the northern Sierra Ancha of Gila County had 0.1 ppm gold. However, the matrix of this conglomerate has small quartz-lined vugs possibly indicative of hydrothermal activity, therefore the gold may not be of detrital origin.

Quartzitic conglomerate from the basal conglomerate of the Precambrian Pahrump Group was sampled at eight localities between the Panamint and Kingston Ranges in southeastern California. These samples are to be analyzed for gold.

Conglomerates of the younger Precambrian Uncompahgre Formation in the San Juan Mountains, Colo., contain less than 0.1 ppm gold. Samples were taken from a basal conglomerate 3-8 feet thick and from 8 conglomerate lenses in a section of quartzite and slate 8,000 feet thick.

No gold was detected in four splits of heavy minerals concentrated from a 170-pound sample of Precambrian Vallecito Conglomerate from Vallecito Canyon on the south flank of the San Juan Mountains in southwest Colorado. Detection limits ranged from 0.3 to 0.02 ppm. The heavy mineral content of the conglomerate is very low.

Four samples of Precambrian conglomerate from the Las Tablas quadrangle west of Taos, N. Mex., contained less than 0.1 ppm gold. A heavy mineral concentrate from one sample also had less than 0.1 ppm.

Conglomerate beds in the Precambrian Ortega Quartzite in the Picuris Range near Pilar, Taos County, N. Mex., contain 0.05 ppm or less of gold.

Mesozoic Rocks

Analysis of 53 samples of black sands of Late Cretaceous age from the Rocky Mountain region reveals that only nine contain detectable gold (limit of detection, 0.1 ppm); the highest gold content is 0.3 ppm. Several samples earlier reported to contain as much as

1 ppm gold were reanalyzed and no gold was detected. Fossil magnetite-bearing placers near Choteau, northwest of Great Falls, Mont., have been traced into areas with several hundred feet of overburden using a ground magnetometer. Beds with anomalies of as much as 20,000 gammas yield anomalies of up to 10,000 gammas where covered by an estimated 200 feet of overburden.

Samples from two previously unstudied black sand deposits on the east flank of Teapot Dome, Natrona County, Wyo., are being analyzed for gold and rutile, and also spectrographically. The deposits are 1 and 1.5 miles long, respectively. A third deposit in Elbert County, Colo., about 1 mile long and 200 feet wide, was mapped and partly sampled.

Black sand deposits at Salt Creek, Wyo., and at the Long Shot deposit on the Kaiparowitz Plateau in Utah were sampled intensively. Of 83 samples from Salt Creek, only 8 contained 0.1 ppm or more gold, with a maximum of 0.45 ppm. At Long Shot, gold was detected in only 14 of 66 samples, the maximum being 0.03 ppm.

Black sandstone beds were studied and sampled in Montana, near Escalante, Utah, and near Page, Ariz. The Utah and Arizona rocks are twice as radioactive as others in the Rocky Mountains.

Mercury as a Possible Indicator of Uranium on the Colorado Plateau

Nearly 900 samples of sandstone and siltstone from the Colorado Plateau were analyzed for mercury. The number of sandstone samples from the Triassic Chinle Formation containing >1 ppm mercury is 10 times higher near known uranium deposits than would be expected, assuming random distribution. Similarly, the number of siltstone samples is 7-8 times higher. Although caution must be used in areas of tectonism or hydrothermal mineralization, both of which tend to have rocks of high mercury content, these results suggest the use of mercury as an indicator of uranium.

Stream Transport of Lead Particles

An experiment designed to test the mode of transport and deposition of heavy particles by a stream was started in March, and the first results were obtained in September, at the end of the spring and summer runoff. One thousand pounds of lead particles more than 0.18 mm in diameter and coated with fluorescent paint were dumped into the Trinity River, a tributary of the Klamath River in northwestern California. The particles had high roundness but low sphericity and thus a lower settling velocity than spheres of equivalent diameter. By mid-September, only a few particles had moved as much as 700 feet downstream, but many had moved as much as 200 feet. Further field checks will be made next year.

If the lead particles (sp gr 11.4) are deposited in about the same places as gold (sp gr 15-19), then gold concentrations might be located by searching for the more easily detected concentrations of fluorescent lead. This idea is also to be checked in the field.

Concentration of Gold in Particle Size Fraction

Studies of gold placer deposits along streams in northern California and on beaches of California and Oregon indicate that gold is concentrated in the size fraction 62-125 microns (0.062-0.125 mm). This finding suggests appropriate screening of sand and gravel samples as a useful prospecting technique that might yield gold concentrates in other areas where gold is too fine grained to be concentrated effectively with the gold pan.

Fluvial Geochemistry of Gold and Silver

Work accomplished during the first year of this research project being carried out by personnel of the Water Resources Division included: construction of a mineral separation and concentration facility to determine distribution of gold in various size fractions of stream sediments; development of methods for detecting minute quantities of gold and silver in waters, involving for gold, collection by mercurous chloride or anion exchange, dissolution of collected gold, and analysis by atomic absorption, and for silver, collection by an ion exchange crystal (AMP) and an anion exchange resin; progress toward solving the problem of adsorption of traces of gold and silver onto container walls; and a preliminary review of the literature on geochemistry of gold and silver.

Behavior of Gold in Weathering Environments

A principal finding to date has been that gold is mobilized in the zone of weathering and is coprecipitated with secondary iron oxides. The amount of gold thus mobilized may be appreciable, as much as 1,000 times background.

At Kershaw, S. C., in a warm, humid region of deep weathering, the gold content of iron-rich weathered granite and of iron-stained leached sericite schist is an order of magnitude greater than that of the parent rock.

Nine composite samples of secondary iron accumulations at mines in the Kershaw, S. C., and Dahlonega, Ga., areas contain from 0.020 to 1.7 ppm gold. Four samples of concretions or hardpan contained between 0.5 and 1.7 ppm, appreciably more than vein quartz in the same areas. These data indicate appreciable mobilization of gold during weathering as well as fixation of gold during accretion of iron hydroxide nodules. Iron concretions thus appear to be valuable prospecting guides, and particulate iron minerals may be principal sites of gold concentration in fine-grained detrital sediments.

At Hahns Peak, Colo., in a cool region of moderate rainfall, four samples of iron-stained weathered porphyry gruss contained 0.26–0.44 ppm gold in the hydrofluoric acid-soluble portions. A fifth sample of iron-encrusted porphyry at a seep near a gold prospect contained 5.3 ppm gold in the acid-soluble part.

Gold in all these samples probably was derived from nearby sources, as possibilities of dilution and precipitation increase with distance from source.

Study of heavy-mineral concentrates from samples in a vertical section extending from topsoil to quartz vein at the Van Cluse mine in Orange County west of Fredericksburg, Va., shows that: (1) gold is most abundant in saprolitic vein quartz; (2) gold particles are most numerous, though smallest, in topsoil; and (3) gold is least abundant in the lowest lateritic horizon. In this weathering environment (semitropical with dense vegetation and moderate rainfall), gold appears to dissolve easily in the phreatic ground-water oxidation zone where associated with sulfide-bearing bedrock. Thus much gold enters colloidal or chemical solution and is either precipitated before reaching streams or is deposited with the clay or silt fractions of stream sediments.

Fine-grained sodium-rich red and black Triassic shales from Connecticut, New Jersey, and Pennsylvania were sampled as examples of rocks that might be expected to have a higher than average gold content: they were derived from gold-bearing source rocks and deposited in closed basins; they are unusually alkaline; and they contain detritus of iron-enriched soil in which gold might have been concentrated. Preliminary analyses show no significant gold content, but more analyses remain to be made and further sampling will be done.

Studies of Sulfide and Telluride Mineral Systems

The solubility of gold in galena, pyrrhotite, and pyrite is being determined. Solubility is very low in both galena and pyrrhotite, <0.1 mol percent at 450°C in galena (possibly more at 700°C), and <0.01 mol percent at 700°C in pyrrhotite. Solubility in pyrite is uncertain yet because of slow reaction rates.

The activity of tellurium in nickel telluride is being measured preliminary to studies of the stabilities of precious-metal tellurides and the mechanism of separation of tellurium, selenium, and sulfur in nature.

Investigations of the systems Fe-As-S, Fe-Sb-S, and Fe-Bi-S continue as a necessary base from which to study possible enhancement of gold solubility in sulfides by group V elements.

Solution Chemistry of Gold at High Temperatures and Pressures

Study of the solubility of gold in various solutions at high temperatures and pressures was started in 1967. Results so far indicate that gold is only very slightly soluble in ammoniacal and sulfate-rich solutions at temperatures up to about 200°C, suggesting little or no complexing of Au⁺ under these conditions.

Research on analytical methods for detecting trace amounts of gold has been done in Geological Survey laboratories for several years, but in anticipation of a greatly increased work load from the Heavy Metals program, this research has been expanded and several new approaches to developing accurate, rapid, simple, and economical methods have been utilized. Although problems remain to be solved, suitable methods were devised to analyze large numbers of samples on a routine basis, both in fixed laboratories and in the newly constructed mobile laboratories. Present research is on fluorescent, atomic absorption, fire assay, and neutron activation methods (or combinations of these) for determination of trace or background amounts of gold.

An ultimate procedure for determining background amounts of gold, using fire assay concentration followed by the rhodamine-B-HAuCl₄ fluorescence method, is being studied. The rhodamine-B fluorescence method has a sensitivity of about 3 ppb gold. Tests using radio-gold indicate that fire-assay concentration is very effective in recovering submicrogram amounts of gold; in four tests using 0.1 microgram of gold and three tests using 0.5 microgram, recovery ranged from 97.0 to 99.0 percent. Recovery of gold varied only slightly with the amount of silver added, which ranged from 2 to 20 milligrams. The behavior of submicrogram amounts of gold in the rhodamine-B method has been checked using Au¹⁹⁸ as a radiochemical tracer; no gold losses due to adsorption or reduction occur during cyanide decomposition and filtration. Gold dissolution is faster and simpler with sodium cyanide and sodium peroxide than with the cyanide-oxygen mixture formerly used.

A radioactivation analysis method for determining background amounts of gold is being developed. The method involves irradiation of 0.5 g of sample for 4 hours in a neutron flux of 5×10^{12} n/cm²/sec., solution and selective precipitation of gold, and gamma counting. The 3 sigma limit of detection for the method is about 0.05 ppb gold. Present capacity for this type of analysis is 30 samples per month.

A combined fire assay-neutron activation method is being studied as a simpler and more rapid technique for determining background amounts of gold than pure activation. Results so far are similar to those achieved by activation analysis alone but are not sufficiently precise. Most of the variation in results is due to variable blanks; reagent blanks tested for gold contain 15–36 nanograms (10⁻⁹ g) of gold, so that the 3 sigma detection limit for the method is about 0.5 ppb gold for a 15-g sample. By using a purified flux and pure alumina crucibles, the accuracy of the method for determining gold in 15-g samples of rocks is improved to nearly that attainable by pure neutron activation on 0.5-g samples. In four runs of Standard Rock W-1, values obtained by the combined method were 4.0, 3.2, 3.4, and 3.9 ppb, with an average of 3.6 ± 0.4 ppb, as compared to values in six runs by neutron activation of 2.9, 3.2, 4.2, 3.8, 3.8, and 2.8 ppb, with an average of 3.4 ± 0.6 ppb.

A comparison of the classical gravimetric fire assay with a fire assay-atomic absorption method has been made on 13 samples of gold ore from the Witwatersrand, South Africa. The two methods showed very close agreement on ore containing from 75 to 440 ppm gold. For 11 samples, the maximum difference in results was 5 ppm. The two highest grade samples showed differences of 10 ppm and 25 ppm.

Research on Analysis of Gold in Heavy Mineral Concentrates

Fire assays of successive splits of heavy mineral concentrates show that all of a concentrate sample should be analyzed if meaningful results are to be obtained. Analysis of 2-6 splits of 6 entire samples in the grain size range 60-80 mesh, consisting mainly of either zircon and garnet or of magnetite, showed that in general no single analysis gives a reliable value for gold content, particularly in samples containing 1 ppm or less of gold.

Research on Determination of Trace Elements in Placer Gold

A solution-spectrochemical method was developed to determine the trace-element content of detrital gold. Samples weighing 5-10 mg are needed. Limits of detection are similar to those of the standard 6-step semiquantitative spectrographic method, but accuracy is better.

Research on Analysis of the Platinum Group Metals

The platinum group of metals (platinum, palladium, rhodium, iridium, osmium, and ruthenium) presents particularly difficult problems of analysis for trace amounts. Research on these problems, started some time ago, has been greatly intensified as a result of the need to develop an accurate, rapid, and economical method of analysis before any field studies of the occurrence of these metals could profitably be undertaken. This research has been successful in that a reliable method is now available for determining platinum and palladium; however, it is lengthy and complicated, and further research will be directed toward simplification of techniques and increasing the analytical capacity of the laboratories.

The method for the simultaneous determination of platinum and palladium with a detection limit of 10 ppb of either metal in a 10-g sample involves the following steps:

1. Solution of sample.
2. Concentration of platinum metals (platinum, palladium, rhodium, some iridium) and gold by coprecipitation with tellurium.
3. Separation of gold and tellurium by extraction from 4N HCl into methyl isobutyl ketone.
4. Separation of platinum and palladium by extraction as diethyldithiocarbamates into chloroform.
5. Separation of palladium by extraction of palladium-a-furildioxime into chloroform.

6. Determination of palladium and platinum spectrophotometrically.

In this sequential method, gold and rhodium can also be determined in their respective fractions.

The problem of low recovery of platinum and palladium in the presence of rhodium and iridium remains unsolved. In absence of rhodium and iridium, recovery of palladium averages 96 percent and of platinum, 90 percent, whereas when rhodium and iridium are present recovery is only about 73 percent. Apparently, aqua regia fails to dissolve completely the refractory palladium-platinum-rhodium-iridium alloys produced during the tellurium precipitation step for concentrating the platinum metals. Palladium loss is not attributable to adsorption on any insoluble material at any stage. Studies on solution of platinum-metal concentrates continue.

Research also has been done and continues on other methods for platinum group analysis:

Experimental determinations of platinum and palladium by fire assay followed by spectrographic analysis on samples containing known amounts of these metals gives good recovery of both metals when silver and gold are used together as collectors. When gold alone is used, better recovery is obtained on palladium than on platinum at high concentrations and the reverse at low concentrations, but in general recovery is poorer than when both gold and silver are used.

Radiotracers of platinum and palladium were used to measure recovery of these metals by fire assay at low concentrations using both gold and silver as collectors. Recoveries ranged from 90 percent in the silver bead using 2 micrograms of platinum to 97 percent in the gold bead using 50 micrograms of palladium. Losses were largely to the cupel and were almost negligible in slag.

Determination of platinum and palladium in high-silver ore from the dump of the Copper Hill mine at La Plata, Colo., by the fire assay-spectrographic method gave excellent reproducibility, even when solution of the fire assay bead in aqua regia produced considerable white precipitate (silver chloride); the precipitate is relatively free of either platinum or palladium. Platinum content was 0.36-0.43 ppm and palladium content 0.37-0.45 ppm in three analyses.

Results of other studies of fire assay methods to concentrate the platinum metals, using both gold and silver as collectors, show that:

1. Very large amounts of osmium appear to be lost through volatilization.
2. Appreciable amounts of osmium and ruthenium are lost to the slag.
3. Large amounts of osmium, ruthenium, and iridium are lost to the cupel.

Experiments with a silver oxide matrix for spectrographic determination of platinum showed that volatilization was complete in 130 seconds using a 70-30 argon-oxygen atmosphere, whereas it was incomplete after 5 minutes in air. Detection limits were:

	<u>ppm</u>
Platinum	1
Palladium	1
Rhodium	1
Ruthenium	1
Iridium	10
Osmium	100
Gold	.1

In an improved version of the fire assay-spectrographic method, gold is used as a collector for the platinum metals, and the bead is burned in an atmosphere of 70 percent argon-30 percent oxygen. Detection limits for a 20-g sample are:

	<u>ppb</u>
Platinum	2-4
Palladium	.5-1
Rhodium	4

Detection limits are set by the purity of the fire assay flux and hopefully will be reduced by use of purified flux. The method is simple enough to permit limited reconnaissance studies.

A combined fire assay concentration-radioactivation method for determining palladium and platinum in rocks is being studied; preliminary concentration would permit simpler and faster radiochemical processing. Silver is used as a collector in the fire assay in order to avoid the high radioactivity produced by irradiation of gold. The silver bead from fire assay and cupellation is irradiated for 7 hours in a reactor, after which platinum and palladium are isolated chemically for counting.

Solution detection limits by atomic absorption using air-acetylene flame were determined for platinum (1 ppm), palladium (0.3 ppm), and rhodium (0.1 ppm). Detectabilities were not improved by using a very hot nitrous oxide flame.

The Wickers method for separating platinum from the other platinum metals on the macro scale does not seem to be effective on the microgram scale. The method depends on the high stability of the chloroplatinate ion as compared to the chloro-ions of other platinum metals, which can be precipitated as hydrated oxides by hydrolysis at pH = 6.

A catalytic method for the determination of osmium and ruthenium, based on catalysis of the reduction of Ce(IV) by As(III), is being investigated. The reaction time between two definite concentrations of Ce(IV) is inversely proportional to the concentration of osmium or ruthenium during the early part of the reaction.

Research in Spectrography and Spectrophotometry

Glass reference standards to aid in spectrographic determination of 45 elements, including all the heavy metals, are being prepared by the Corning Glass Works for use by the Analytical Laboratories and Exploration Research Branches. Five batches of 200 pounds each will be prepared, containing concentrations of <0.5, 0.5, 5, 50, and 500 ppm, respectively, of all 45 elements. The glass matrix will simulate the composition of a silicate rock. Grinding to about 200 mesh will be done by Coors Porcelain Co. in high-purity alumina-lined mills.

Investigation of seven matrices for the spectrochemical determination of some heavy metals in both air and argon-oxygen atmospheres has shown that GeO₂ in argon-oxygen appears to be the most useful; detection limits are <10 ppm for platinum, <80 ppm for iridium, and 1 ppm for gold, silver, and the other platinum metals.

More than 25 elements have been tested for sensitivity of detection by atomic fluorescence. The method is highly sensitive for silver (1 ppb). Palladium and bismuth have detection limits of 1 ppm, but sensitivities are poor for platinum and the other platinum metals.

Investigation of atomic absorption spectrophotometry for analysis of trace amounts of bismuth has shown that the method is accurate and rapid in the range 10 to 400 ppm. The technique is useful in scanning the large numbers of samples collected during geochemical prospecting.

Miscellaneous Research

Gold and platinum content of U.S. Geological Survey standard rocks.—The gold content and platinum content of eight U.S. Geological Survey standard rocks have been determined by the most accurate methods now available. Gold was determined by radioactivation analysis (at least four determinations on each rock), and platinum metals (platinum, palladium, and rhodium) by a combined fire assay-spectrochemical solution method. Results are as follows; all values are in parts per billion:

<u>Rock No.</u>	<u>Type</u>	<u>Gold</u>	<u>Palladium</u>	<u>Platinum</u>	<u>Rhodium</u>
G-1	Granite	2.6 ± 0.4	<4	<10	<5
W-1	Basalt	3.5 ± .6	14, 14	16, 22	<5
G-2	Granite	.8 ± .1	<4	<10	<5
GSP-1	Granodiorite	1.2 ± .5	<4	<10	<5
AGV-1	Andesite	.5 ± .3	<4	<10	<5
BCR-1	Basalt	.6 ± .2	<4	<10	<5
PCC-1	Peridotite	.7 ± .2	7, 7	15, 15	<5
DTS-1	Dunite	.7 ± .2	<4	11, <10	<5

Nineteen determinations of the gold content of Standard Rock G-2 have now been made. Of these analyses, 17 are between 0.6 and 1.0 ppb, the other two analyses gave 2.0 ppb.

Vein quartz in stream gravels as a prospecting tool.—Analyses of vein quartz collected in situ from gold mines and also from stream gravel presumably derived from outcrops at the same mines gave comparable results in two areas—Dahlonega, Ga. (4 mines), and Kershaw, S. C. (4 mines). None of the samples contained visible gold. Analysis of stream gravel material appears therefore to be a potentially useful prospecting tool in the Southeastern United States.

Geology and geochemistry of manganese.—A comprehensive study of manganese deposits in the Southwestern United States as indicators of possible occurrence of silver and base metal deposits at depth was made and results, including suggestions for a number of exploration targets, will be published in 1968.

Economic geology of platinum.—A comprehensive report on the economic geology of the platinum metals was completed and will be published in 1968. The report includes a general discussion of the geology of platinum and descriptions of all the major platinum deposits of the world.

Hydraulic equivalences of placer minerals.—A report on the hydraulic equivalence of grains of quartz, magnetite, silver, and gold, and on settling velocities of spheres and flakes of gold in water, bromoform (density 2.89) and methylene iodide (density 3.325) was prepared for distribution to workers in the program.

Geobotanical prospecting for gold.—A restudy of Equisetum samples from mineralized areas in the United States shows the maximum gold content to be only 0.4 ppm. Higher values reported many years ago are believed to have been caused by contaminated assay equipment.

Field detectors for heavy metals.—A gamma-ray spectrometer system designed for airborne use has been mounted in a van and tested in the Shoshone, Toiyabe, Tuscarora, and Cortez Mountains in central Nevada. Traverses were made over areas of altered and mineralized rock in order to evaluate the response of the system to surficial concentrations of potassium, uranium, and thorium. Results may be summarized as follows:

1. In Buckhorn mine area, gold-silver mineralization in basaltic andesites is associated with significant radioactive anomalies caused by potassium and uranium.
2. In the Cortez district, kaolinitic alteration in chert results in reduced radioactivity owing to depletion of potassium. During this work a uranium anomaly was discovered in altered chert along a fault.
3. Both sericitic (potassium addition) and kaolinitic (potassium depletion) alteration are associated

with gold deposits in chert in the Tenaho district of the Shoshone Range, and potassium anomalies are therefore difficult to interpret. Further work is required to evaluate the data.

4. Both potassium and uranium anomalies were found at the Carlin mine in the Tuscarora Mountains. Additional work is planned.

The principal conclusions are that significant patterns of radioelement variation are associated with hydrothermally altered and mineralized rocks, and that radioactivity measurements may be useful in exploring for deposits of nonradioactive minerals. Detailed geologic information is necessary for meaningful interpretation of the radioactivity data, particularly because of the opposing effects of sericitization and kaolinization on the magnitude of potassium anomalies.

The neutron activation heavy-metal detector, Mark III, is completed, and preliminary testing was done at a site in the gold district of Dahlonega, Ga. The equipment performed well under rugged conditions. Several minor modifications were made and testing will continue.

Work also is progressing on a field detector for gold and silver using X-ray fluorescence. Despite some problems involving back-scatter of initial X-rays, results to date are encouraging.

Use of wool as collector of gold.—Experiments have shown that wool is an effective collector of gold in solution. Radiotracer studies have shown complete retention of gold from a 1.5 M HCl solution containing 5 ppb gold. Gold also is concentrated quantitatively from tapwater solutions containing 0.05, 0.5, and 5 ppb gold. The gold content of commercial grade wool being used was determined by three methods. All gave the same result, 30 ppb gold. The gold content of unprocessed wool is not known as yet.

In addition to gold, bismuth, antimony, and silver are adsorbed from 1 M HCl. Other metals, including copper, zinc, cobalt, iron, and manganese, are not. Work continues on the problem of analyzing gold collected on wool. Sodium contained in the wool interferes with neutron irradiation measurements because of the similarity of its radioactive emission spectrum to that of gold.

Testing of "Gold Saver" heavy mineral concentrator.—The portable heavy-mineral concentrator known commercially as "Gold Saver" has been thoroughly tested in the Denver Heavy Metals Laboratory and modified for more efficient operation. Modifications were necessary because, although recovery of gold in the +200 mesh size was complete, recovery in the -200 +400 size range was only 36 percent, and in the -400 mesh size, only 2.4 percent. The machine will facilitate concentration in the field of large samples of auriferous conglomerate from northwest Wyoming and thus help to provide much more reliable information on such factors as gold content and particle size.

Compilations on Geology and Geochemistry of Gold

1. A comprehensive bibliography on the geology and geochemistry of gold is in preparation.
2. A 73-page preliminary bibliography on the geology of gold deposits of the world was distributed to project geologists.
3. A 70-page summary report on the occurrence of gold in igneous, sedimentary, and metamorphic rocks was prepared for use of workers in the program.
4. A 6-page bibliography on prospecting for placer deposits by magnetic methods was distributed to geologists who are studying areas where such deposits might occur.

Data storage and retrieval.—An interim system for storing and retrieving data resulting from the Heavy Metals program has been developed pending completion of a comprehensive system. The interim sys-

tem can be entered automatically into the final system. Specifications for the system have been transmitted to the Computer Center Division and programming has begun. The system has been designated RASS (Rock analysis storage system).

Standard sample for gold.—A homogeneous gold standard was prepared and is now available for inter-laboratory standardization. The standard was made using 120 pounds of gold-bearing quartz from the Great Falls gold mine, Maryland. Analyses of ten 15-g samples of the homogenized standard by the fire assay-atomic absorption method ranged from 1.8 to 2.2 ppm, with an average of 2 ppm and a standard deviation of 0.16 ppm. Analyses of seven 10-g samples by the cyanide leach-fluorimetric method ranged from 1.9 to 2.3 ppm with an average of 2.2 ppm and a standard deviation of 0.14 ppm.