

GEOLOGICAL SURVEY CIRCULAR 622



**U.S. Geological Survey
Heavy Metals Program
Progress Report 1968—
Topical Studies**

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United States Department of the Interior

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U.S. Geological Survey Heavy Metals Program

Progress Report 1968—Topical Studies

INTRODUCTION

Summaries of topical studies carried out in calendar year 1968 as part of the Heavy Metals program are presented in this circular. Background information on the program, summaries of field studies for 1968, and a list of resulting publications appear in U.S. Geological Survey Circular 621.

Abbreviations commonly used are:

ppm = parts per million (1 ppm = 0.0001 percent, or about 0.03 oz per ton; for gold at \$35.00 per oz, 1 ppm equals about \$1.00 per ton)

ppb = parts per billion (1 ppb = 0.0000001 percent)

Analytical data for gold, platinum metals, and silver are usually given in parts per million or parts per billion. Results are frequently 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 detection limit.

STRATIGRAPHY OF THE ROBERTS MOUNTAINS FORMATION

The Roberts Mountains Formation (Silurian) or lithologically similar formations are the principal host rocks for a number of deposits of very fine grained gold in north-central Nevada, including Carlin, Cortez, Bootstrap, and Gold Acres (in part). Most gold particles are <1 micron across, many are <0.01 micron, and the largest are only about 5 microns in largest dimension. Detailed studies at Carlin and Cortez have suggested some sort of stratigraphic control—finely laminated fine-grained black silty and carbonaceous limestone; thus, the regional extent,

stratigraphy, and geochemistry of the Roberts Mountains Formation are of the greatest interest in predicting areas most likely to contain undetected gold deposits.

During 1968 the formation was studied and sampled at about 25 localities over an area that is 200 miles north-south by 50 miles east-west and extends from the Bootstrap mine in Elko County south to Hot Creek in Nye County. These preliminary studies have revealed that limestone similar to that at the Carlin and Cortez mines is the principal rock type in the formation in Eureka, Lander, Nye, and Elko Counties. Each of the spectrographic analyses of about 100 samples for 30 elements shows a nearly uniform trace-element content. (T. E. Mullens, Denver, Colo.)

FLUID-INCLUSION STUDIES

Fluid-inclusion studies are aimed at determining the range of temperature of ore-forming solutions and their salinity, as well as, if possible, their chemical and isotopic composition. Gangue minerals associated with fine gold at the Cortez deposit, Eureka County, Nev., and the Gold Acres deposit, Lander County, Nev., generally contain fluid inclusions too small for studies with the heating and cooling stage, but some measurements and estimates made to date are in the range 150° to 230° C, with salinities equivalent to about 6 weight percent NaCl. Inclusions in vein quartz associated with the Cortez gold deposit homogenize at temperatures between 175° and 230° C, the large spread indicating either that some inclusions are secondary or that trapping from boiling solutions or leakage has occurred; most inclusions are <10 microns across, so filling temperatures cannot be measured directly but are estimated to be low, about 200° C. Inclusions in 11 samples of vein quartz associated with gold ore in the Gold Acres pit homogenize in the range of 150° to 180° C.

Inclusions in quartz from quartz-pyrite-gold veins in quartz monzonite at Mill Creek near Cortez, Nev., indicate a formation temperature of about 250° C; for veins in the adjacent limestone, temperatures are lower, 200° to 225° C. Inclusions in quartz from base-metal veins in and near granitic intrusions at the Gray Eagle, Lander, and other small deposits in the Tenabo district, Nevada, homogenize from as high as 325° C for main ore-stage quartz to 175° C for very late quartz.

Eleven samples of quartz, barite, sphalerite, and calcite from mine dumps in the Silver Cliff district, Custer County, south-central Colorado, have been studied. Some barite apparently was deposited at 250° to 270° C from highly saline solutions (as much as 25 wt percent NaCl). Inclusions in quartz have variable filling ratios and a wide range of salinity, suggesting that they were trapped from a boiling solution; on the assumption that inclusions with the smallest ratio of vapor to liquid were trapped from liquid only, their homogenization temperature of about 200° C gives an estimate of boiling temperature and hence of depth of deposition, probably <500 feet. The salinity of "normal" inclusions in quartz and sphalerite is about 1M in NaCl, similar to that at Creede, Colo.

Five samples of late quartz probably post-dating the ore from the Bodie district in Mono County, east-central California, have inclusions showing homogenization temperatures from 225° to 255° C and very low salinities, 0.3 to 1.7 wt percent NaCl. The low salinities indicate that boiling or mixing with meteoric water may have occurred. (J. T. Nash, Menlo Park, Calif.)

ZONING IN EPITHERMAL MINERAL DEPOSITS

The proposition that some epithermal mineral deposits containing manganese oxides, barite, and fluorite may pass downward into sulfide deposits of precious and base metals has been argued persuasively in recent years by D. F. Hewett of the U.S. Geological Survey; some data were presented in Geological Survey Circular 553. A possible example may be the Magnet Cove mine near Walton, Nova Scotia, where a body of silver-bearing sulfide minerals was found recently beneath a large barite deposit.

To test Hewett's ideas, a broad study of epithermal manganese-fluorite-barite deposits in the Western United States was started in 1968, and about 50 areas were visited in Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Washington. Some sampling was done in most areas, and detailed sampling in eight. Some preliminary findings are that barite, fluorite, and manganese oxides form halos around deposits of base and precious metals, no zoning is evident among these three minerals or mineral groups, and all three generally are present in a given area if not in all deposits in that area. Detailed studies are planned in several districts in Colorado, Arizona, and New Mexico. (R. G. Worl, Denver, Colo.)

PLACER DEPOSITS, WESTERN UNITED STATES

A comprehensive study is being made of gold placer deposits in the following Western States: Arizona, New Mexico, Nevada, Utah, Colorado, Wyoming, Montana, Idaho, Washington, Oregon, and California. The purpose of the study is to locate the deposits accurately, to describe their geology and extent, and to compile all pertinent references.

Reports on placer deposits of New Mexico and Arizona are in preparation. Reports on placers of Nevada, Utah, and southern California are planned. These reports will describe most of the placer deposits of the arid to semiarid regions of the United States. The gold-bearing gravels in many areas of the Southwest are found in recent alluvium and on pediments flanking mountain ranges in the Basin and Range province. Difficulties in sampling and mining these "dry placers" have in many instances hampered their development. However, some placer deposits in the Southwest are in high mountains which receive sufficient rainfall to permit development by dredging. Minor placer deposits occur along the major rivers draining the Southwestern States.

The age of most of the placer deposits in the Southwestern United States generally ranges from Pliocene to Holocene, but a few deposits are older. Small amounts of gold were recovered from Paleozoic and Mesozoic conglomerates in the late 1800's, and Eocene gold-bearing gravels

at Goler Canyon in southern California were very productive between 1895 and 1900. Most commonly, the richest deposits are found in gravels which have been continuously deposited for many hundreds of thousands, or even millions, of years. The rich placer deposits at Manhattan in central Nevada are in Pleistocene gravels. The placer deposits in the Moreno River valley in northern New Mexico are in sediments which were continuously deposited from the Pliocene to the present. Many placers in the southwest are in caliche-cemented conglomerates which lie below recent accumulations of barren gravel deposits, but the age of most of these placers is unknown. (M. G. Johnson, Menlo Park, Calif.)

TRACE ELEMENTS IN GOLD

Isotopic composition of lead in placer gold is being studied as a clue to the source of the gold. Comparison of lead from gold in the Little Red Park placer deposit 2 miles northeast of Hahns Peak, Routt County, Colo., with lead from nearby ore deposits of Precambrian and Tertiary age strongly suggests that the placer gold was derived from a Tertiary source. Some uncertainty exists because the amount of uranium in the gold is unknown. (B. R. Doe, M. H. Delevaux, and J. C. Antweiler, Denver, Colo.)

Trace-element content of 23 samples of gold from eastern Alaska and the Kougark River area of Seward Peninsula has been determined. Study of polished sections of all samples revealed

only one inclusion, suggesting that the trace elements are in solution in the gold rather than in grains of other minerals. Lead in placer gold from the Harold Tweet Camp on the Kougark River is somewhat more radiogenic than lead in potassium feldspars of possible source rocks. (B. R. Doe, C. L. Sainsbury, and A. L. Sutton, Denver, Colo.)

Isotopic analysis of lead in gold from the Pharmer placer deposit in Alder Gulch, Virginia City district, Montana, shows the lead to be much more radiogenic than lead in composite samples of ore from the Boulder batholith. Moreover, the lead in Alder Gulch gold is more radiogenic than any rock lead in Mesozoic or Cenozoic igneous rocks in the entire Rocky Mountain region; these rocks cannot be the sole source of lead in the gold. (B. R. Doe and K. L. Wier, Denver, Colo.)

The isotopic composition of lead in galena from gold ore at the Carlin mine, Eureka County, Nev., shows it to be the most radiogenic ore lead found to date in Nevada. The isotopic ratios are in the range of those known for lead from the Roberts Mountains Formation, the host rock for Carlin ore, and are higher than those for lead from Cenozoic igneous rocks in Nevada; thus it is likely that some or all of the lead was derived from the Roberts Mountains Formation. (B. R. Doe and M. H. Delevaux, Denver, Colo.)

Isotopic compositions of lead in gold analyzed in 1968 are summarized in the table below (B. R. Doe, Denver, Colo.).

Locality	Collector	Pb ²⁰⁶ : Pb ²⁰⁴	Pb ²⁰⁷ : Pb ²⁰⁴	Pb ²⁰⁸ : Pb ²⁰⁴
Harold Tweet camp, Kougark River, Seward Peninsula, Alaska	C. L. Sainsbury	19.587	15.77	39.21
Fortymile area, east-central Alaska	S. H. B. Clark	19.005	15.83	38.98
Thunder Creek, Talkeetna Mts., Alaska	C. C. Hawley	19.149	15.84	39.41
Little Red Park placer, Hahns Peak, Colo.	J. C. Antweiler	18.131	15.60	37.33
Johnny Tamm placer, Hahns Peak, Colo.	J. C. Antweiler	18.450	15.70	37.52
Pharmer placer, Alder Gulch, Virginia City, Mont.	K. L. Wier	20.685	16.14	43.53
Iron Canyon placer, Battle Mtn., Nev.	T. G. Theodore, B. R. Doe	19.386	15.76	39.23
Carlin mine, Nevada	R. J. Roberts	19.92	16.04	40.10

SOLID-STATE SOLUBILITY OF GOLD IN SULFIDE MINERALS

Quenching experiments and polished-section examination show that 600° and 690°C the solid-state solubility of gold in pyrite, pyrrhotite, and arsenopyrite is <0.1 wt percent; the lower limit is indeterminate. At 690°C, chalcopyrite dissolves between 1.6 and 4.3 wt percent of gold at the sulfur pressure controlled by the pyrite + pyrrhotite buffer. Upon quenching, much of this gold exsolves as blebs about 1 micron across. At 650°C, galena dissolves between 0.1 and 0.5 wt percent of gold in equilibrium with liquid sulfur and a second liquid just on the sulfur-rich side of the galena-gold join. When bismuth is present in equal atomic proportion to gold, the solubility of gold increases to between 1 and 2 wt percent. This increase strongly suggests the substitution of AuBi for 2Pb analogous to the Ag-Bi-S system, and the assignment of the +1 charge to at least some of the gold in solid solution in galena. (P. B. Barton, Jr., Washington, D. C.)

SOLUBILITY OF GOLD IN ORE-FORMING FLUIDS

Measurements of the emf (electromotive force) of the Au-AuCl₄⁻ electrochemical couple are being made to supplement direct measurement of the solubility of gold in aqueous solutions, because of the very low measured solubilities—at or below detection limits of the usual analytical methods of gold—in synthetic ore-forming fluids. At 200°C in a 1N chloride and 0.1N sulfate + bisulfate solution in equilibrium with magnetite + hematite + pyrite, the concentration of dissolved gold is 16 ppb, and of dissolved iron, 4,000 ppm. If all dissolved iron and gold were deposited as auriferous pyrite, the pyrite concentrate would contain about \$2.00 in gold per ton. (J. L. Haas, Washington, D. C.)

SOLUTION OF GOLD BY PORPHYRY COPPER LEACH SOLUTIONS

Tests of synthetic leach solution approximating the composition of solutions resulting from the commercial leaching of dumps of porphyry copper deposits have shown that the addition of sodium chloride to the solution results in solution of gold in the presence of manganese dioxide. The test solution of ferric sulfate and cupric sulfate (pH 1.5) contained 0.5 wt percent NaCl. Leaf gold was added to two 200-milliliter portions of solution, and 0.5 gram MnO₂ was added to one of

these portions. Air was bubbled through both solutions for 3 days, and the solutions were then filtered. The filtrate of the portion that had been in contact with MnO₂ contained 400 µg (micrograms) of gold, the other portion only 4 µg. (H. W. Lakin, Denver, Colo.)

TRACE ELEMENTS IN SUPERGENE SULFATE MINERALS

Analyses of hand-sorted concentrates of supergene sulfates of copper and iron from underground workings of mines in the Empire district, Colorado, show as much as 11.7 ppm Au, 10 ppm Te, and 0.60 ppm Hg, all well above background amounts for the area. Higher-than-background amounts of manganese, bismuth, cobalt, nickel, and zinc also were detected. The analyses indicate that gold, tellurium, and mercury are mobile in the supergene environment. An attempt will be made to determine the chemical state of the gold in these sulfates and also the Eh-pH conditions in the mine environment. (H. W. Lakin, Denver, Colo.)

STUDIES ON PLATINUM-GROUP MINERALS PLATINUM-GROUP MINERALS FROM GOODNEWS BAY, ALASKA

A new palladium mineral has been found in concentrates from the platinum placer deposits at Goodnews Bay, Alaska. The concentrate was obtained from the Goodnews Bay Mining Co. and furnished by J. B. Mertie, Jr. The chemical formula is Pd₇(Sb,As)₂, and the mineral contains 0 to 3 percent copper. It is the only mineral in the concentrates containing palladium as a major constituent. Mineralogical characteristics were determined by X-ray powder diffraction, quantitative ore microscopy, and electron microprobe analysis. The name mertieite has been proposed for the mineral, in honor of John B. Mertie, Jr.

Qualitative milliprobe X-ray fluorescence analyses of more than 200 grains of platinum-group minerals from Goodnews Bay have been completed. The nonmagnetic fraction of the precious metals consists chiefly of iridium-osmium alloys which contain ruthenium and traces of copper. In addition to a new palladium mineral, these concentrates also contain a few grains of sperrylite (PtAs₂), a mineral not previously reported from this locality. (G. A. Desborough, Denver, Colo.)

Investigations of laurites (Ru,Os,Ir)S₂ from Goodnews Bay have provided quantitative ore

microscopy and chemical composition data for five laurites. These data show variations in composition and reflectivity. The range in composition indicated is as follows, in weight percent: $\text{Ru}_{61}\text{Ir}_{38}$; $\text{Ru}_{53.5}(\text{Ir},\text{Os})_{12.1}\text{S}_{34.4}$; $\text{Ru}_{59.5}(\text{Ir},\text{Os})_{4.5}\text{S}_{36.0}$; $\text{Ru}_{40.5}(\text{Ir},\text{Os})_{28.4}\text{S}_{31.1}$. (G. A. Desborough and B. F. Leonard, Denver, Colo.)

MISCELLANEOUS STUDIES

Mineragraphic and electron microprobe studies of samples of chromite from the Antelope-Pony chromite district in northern Madison County, southwestern Montana, revealed several grains <10 microns across of a platinum-group alloy in which the relative proportion of platinum metals was $\text{Ir} < \text{Ru} < \text{Os} < \text{Pt}$. Analysis of whole rock samples by a fire assay-neutron activation method indicated <1 ppm of combined Ir, Os, and Ru. In addition to the presence of the platinum-group alloys, alloys of iron, nickel, and cobalt are present in trace amounts.

Microprobe analyses of stibiopalladinite (Pd_3Sb) from the discovery locality in the Republic of South Africa indicate that copper is probably an essential constituent; copper content is 1.6 ± 0.2 percent.

Laurite (RuS_2) and OsS_2 have been synthesized in a vacuum by heating the respective sponge metals with pyrite at about 800°C for 15 hours. Pyrrhotite is a reaction product.

Eight samples of drill core from the mafic Shepherd Mountain intrusion near Pilot Knob, Mo., were analyzed for platinum, palladium, and rhodium by fire assay and quantitative spectroscopy. Results for all samples were: platinum <0.010 ppm, palladium <0.004 ppm, and rhodium <0.005 ppm. (G. A. Desborough, Denver, Colo.)

An iron-bearing variety of laurite (RuS_2) has been found in chromitite from the I_3 -zone in the Mountain View area of the Stillwater Complex in southcentral Montana. A platinum-iron alloy containing a little nickel and palladium and traces of iridium and osmium has been identified in the H-zone in the same area, where it is associated with copper-nickel-iron sulfide and pentlandite in chromitite. (N. J. Page, Menlo Park, Calif.)

PLATINUM CONTENT OF ULTRAMAFIC ROCKS

Ultramafic rocks of the alpine type from several localities have been analyzed for platinum, palladium, and rhodium, and the results, in parts per billion, are as follows:

Locality	Rock type	Pt	Pd	Rh
Red Mountain, California-----	Peridotite-----	<10	Tr.	<5
Red Mountain, California-----	Dunite-----	<10	<4	<5
Red Mountain, California-----	Chromite-----	32-40	8-12	9-10
Butler Estate chromite mine, California-----	Chromitite-----	<10	<4	<5
Cypress Island, Washington-----	Dunite-----	<10	<4	<5
Twin Sisters, Washington-----	Dunite-----	<10	<4	<5
Josephine ultramafic, Oregon-----	Laterite-----	36	13	5

These results suggest that (1) platinum-group metals are associated with chromite concentrations in alpine-type ultramafic rocks and (2) these metals are concentrated by weathering in laterites. (N. J. Page, Menlo Park, Calif.)

ABUNDANCE OF GOLD IN METEORITES, ROCKS, AND MINERALS

Data compiled on the abundance of gold in meteorites and in the earth's crust were reported in Geological Survey Circular 603. Meteorites contain from 0.0003 to 8.74 ppm Au, mainly in the iron-rich phases, and estimates of abundance in the earth's crust range from 0.001 to 0.006 ppm. Circular 610 on the gold content of rocks and Circular 612 on gold in minerals and the composition of native gold were published early in 1969. (R. S. Jones, Washington, D.C.)

GOLD CONTENT OF NATIVE SULFUR FROM CYPRUS

A sample of native sulfur from acid sulfate gossan on cupriferous pyrite deposits on the island of Cyprus contains 8,200 ppm Au. The sample was collected by the late Prof. C. F. Davidson and labeled "Devil's Mud." The gold particles are 10 to 100 microns across and the smaller ones show poorly formed crystal faces. The larger particles are rounded, resembling framboidal pyrite which many geologists believe to be of bacterial origin. (H. A. Tourtelot, Denver, Col.)

GOLD CONTENT OF DEER ANTLERS

The gold content of nine samples of deer antlers has been determined by neutron activation analysis to range from 0.7 to 5.5 ppb.

FINE-GRAINED GOLD IN SLUICE OVERFLOW

Studies of overflow material from a placer sluicing operation near Livengood, 50 miles northwest of Fairbanks, Alaska, have shown that a substantial amount of fine-grained gold is not being recovered by normal sluicing techniques. The

size range of the gold particles in the sample studied was about as follows:

<i>Millimeter</i>	<i>Percent</i>
>0.35 -----	10
.2-.35 -----	40
.061-.2 -----	40
<.061 -----	10

Under conditions of operation at the time the sample was collected, the loss of gold is estimated to be around 0.5 oz per minute, and total loss between sluice cleanups may be 30 to 40 oz.

These findings may have considerable economic significance, because it is unlikely that all such losses could be detected even by careful panning methods; about 35 percent of the gold is <0.150 mm in diameter, which was the smallest size recovered by panning done by the placer operator, and about 15 percent is <0.100 mm in diameter, which is about the limit for recovery even by very careful panning. (H. A. Tourtelot, Denver, Colo.)

TRANSPORT OF GOLD PARTICLES ALONG SNAKE RIVER, WYO. AND IDAHO

The mass of gold particles within a given size range decreases progressively downstream along the Snake River for more than 400 miles below the outcrops of auriferous conglomerates in Jackson Hole. For instance, in northern Jackson Hole, particles approximately 0.125 mm in diameter average about 10 μ g in weight, whereas near Twin Falls, Idaho, particles of the same diameter weigh only half as much. The striking correlation between weight of particles of a certain range of diameter and distance from source is useful in suggesting transport direction from the source of gold in the conglomerates. The data indicate that discrete gold particles can and do travel great distances despite their high specific gravity. (J. C. Antweiler and D. A. Lindsey, Denver, Colo.)

FLUVIAL TRANSPORT OF HEAVY MINERALS

Fluvial transport of heavy minerals is being studied experimentally at Colorado State University, Fort Collins, Colo., by scientists of the U.S. Geological Survey. The study deals with the hydraulic environments in which heavy minerals are transported and deposited and with the formation of placer deposits.

Fall velocity of gold flakes and other heavy minerals has been measured in newly constructed fall columns. The concept of hydraulic equivalence of minerals is being thoroughly investigated, and the transportation, deposition, and re-entrainment of minerals under different conditions of waterflow are being studied in two flumes. Minerals used in the hydraulic experiments include quartz, garnet, monazite, magnetite, lead, and gold; some minerals are dyed to facilitate recognition. In addition to the experimental work, transport rates of various heavy minerals have been measured under natural conditions in some irrigation channels in New Mexico. Results of the work during 1968 are to be published in 1969 in a series of papers in "Geological Survey Research 1969" and in technical journals.

A literature search aimed at gaining quantitative data on gold placers—including dimensions of gold particles, size distribution of the enclosing sediments, and discharge and slope of stream—indicated that only limited data are available and that field studies, including observations at operating placer mines, will be necessary to obtain adequate information. (R. S. McQuivey, Fort Collins, Colo.)

FLUVIAL TRANSPORT OF GOLD AND SILVER

The fluvial transport of gold and silver is being investigated at the Denver Federal Center. The project is concerned with the mode of transport of these and other metals in streams—in bedload, suspension, and solution—and possible applications to geochemical exploration. To date most work has been done on analytical methods for measuring the very low concentrations of silver and gold in natural waters. Some of the problems involved in analyzing for these small amounts, on the order of a few micrograms per liter (1 μ g/l is 1 ppb), are described in two articles in "Geological Survey Research 1968," chapter D. In summary, it has been found that adsorption of silver on the walls of polyethylene containers can be reduced to about 1 percent of the silver present if the water sample is acidified to a pH of 1 with either hydrochloric or nitric acid. Desorption can also be effected in several days by similar acidification. Adsorption of gold may be greatly decreased by (1) acidification to pH 1 with hydrochloric acid and addition of 5 to 50 mg/l (milligrams per liter) of bromine, (2) acidification with hydrochloric acid to

1N without bromine, and (3) acidification with nitric acid to 2N or 3N. Adsorption is also much reduced by adding 50 mg/l of bromine to water of pH 6. On the other hand, acidification to pH 2 or 3 with hydrochloric or acetic acid, or to pH 1 with nitric acid, increases gold adsorption.

Water samples from six gold-producing districts (Iron Springs Divide and Hahns Peak in northwest Colorado, Central City and Empire in central Colorado, Cripple Creek west of Colorado Springs, Colo., and Encampment in south-central Wyoming) have been analyzed; their gold content ranges from 13 to 58 $\mu\text{g/l}$. (T. T. Chao, Denver, Colo.)

SUBAQUEOUS FLOW OF SLURRIES

The subaqueous flow of slurries is being studied to gain an understanding of the transport and deposition of heavy minerals by turbidity currents. Investigations are being done at Stanford University, Stanford, Calif., under a research contract.

Experiments are being carried out in a tank $8 \times 8 \times 4$ feet deep and in a 20-foot flume with glass sides and a tiltable bottom. A conveyor-belt machine with controllable speed and variable slope also is being used to study velocity and mechanical properties of slurry flow in a channel. The nature of transformation from submarine slump or debris flow into turbidity currents is being studied in the flume, and particle sorting is being studied in the conveyor belt. (P. D. Snively, Menlo Park, Calif.)

GOLD, OTHER TRACE ELEMENTS, AND HEAVY MINERALS IN SEDIMENTARY ROCKS HEAVY METALS, ATLANTIC COASTAL PLAIN AND TRIASSIC BASINS

Reconnaissance sampling of Atlantic Coastal Plain sedimentary rocks has been done along the inner edge of the Coastal Plain from Alabama north to New Jersey, and the Triassic basins have been very sparsely sampled from South Carolina to Massachusetts. Detailed sampling has been done in the inner Coastal Plain of northern South Carolina and southern North Carolina. The Triassic has been sampled in detail in the Farmington basin of northern North Carolina, in parts of southern North Carolina near Mt. Gilead, and in northern Virginia.

An upland area of 15 square miles on the inner Coastal Plain near Jefferson, S. C., has been in-

vestigated and sampled in detail. Several streams draining this small area yield appreciable gold in panned samples; several to as many as 50 particles of gold, ranging from silt to very coarse sand size, have been obtained in concentrate from a single pan. Samples obtained from sand and gravel layers in the Coastal Plain sediments, both in outcrop and from auger holes, also have yielded gold.

Triassic sandstone and conglomerate in the Mt. Gilead area, North Carolina, contain from 0.10 to more than 2.0 ppm Au. Streams in the area yield particles of gold in panned concentrates, although they are not as abundant as in concentrates from the Jefferson, S. C., area. Coastal Plain sediments have gold values as high as 2.0 ppm. Traces of gold have been found in conglomerate in a small Triassic basin at Farmington, N. C., but higher values come from samples of quartz and schist exposed in a small area in the center of the basin; these rocks have from 1.0 to 12 ppm Au.

The Triassic rocks of southern Pennsylvania have not been examined in any detail, but three of four samples of siltstone, sandstone, and diabase had gold contents of as much as 4.5 ppm. These rocks are to be further investigated.

Five of seven samples of Triassic diabase near Leesburg, Va., showed detectable amounts of platinum minerals, and several more samples are being analyzed. Several zinc anomalies, containing as much as 7,000 ppm (0.7 percent), have been found along the border fault zone of the Triassic basin north of Leesburg.

As much as 4,000 ppm Cu, 2,000 ppm Ni, 5,000 ppm Cr, and 1,500 ppm Co have been found in samples of weathered diabase and schist beneath the Coastal Plain sediments in South Carolina. (J. P. Minard, Washington, D. C.)

TRACE ELEMENTS IN GRAPHITIC SCHIST, ALABAMA AND GEORGIA

From northeastern Alabama and northern Georgia, 24 out of 100 samples of graphitic schist of Precambrian and Paleozoic age contain detectable amounts of gold ranging from 0.02 to 3.8 ppm. The gold-bearing samples came from the Wedowee, Ashland, Canton, and Brevard Formations of Crickmay (1936, 1952), mostly from the Blue Hill-Gregory Hill mine in Tallapoosa County, Ala. Gold-bearing samples from eastern outcrop belt of the Wedowee Formation seem to contain a little less boron, barium, cobalt, chromium, copper,

iron, manganese, magnesium, nickel, lead, scandium, titanium, vanadium, and yttrium than barren samples from the same unit, and about the same amount of beryllium, lanthanum, molybdenum, niobium, strontium, zinc, and zirconium. The trace element content of graphitic schists is similar to the trace element content of eugeo-synclinal black shales and about the same as an average shale. (F. G. Lesure, Washington, D. C.)

GOLD IN SEDIMENTARY ROCKS, GREAT LAKES REGION

Sedimentary rocks of the Great Lakes region have been studied to determine whether they contain fossil placers derived from the Canadian Shield gold province to the north. The rocks sampled range in age from Precambrian to Cretaceous. Analytical results ranged from 20 ppb Au, the lower limit of detection, to 300 ppb. Of the 618 samples analyzed, 25 or 4 percent had detectable gold. The mean gold content of these 25 samples was 58.5 ppb. The mode was 20 ppb.

Sandstones and conglomerates of late Precambrian, Cambrian, Ordovician, Mississippian, Pennsylvanian, and Cretaceous age were sampled. None had more than trace amounts of gold. The highest value was 300 ppb from a Precambrian conglomerate near Brokaw, Wis. Glauconitic Franconia Sandstone (Upper Cambrian) and the Fond du Lac Sandstone of Winchell (1899) (Upper Precambrian) each had one sample in seven that contained more than 20 ppb Au. Only one of 37 samples of the Olean Conglomerate Member of the Pottsville Formation had more than 20 ppb Au.

Gold has been reported in the phosphatic, pyritic, and carbonaceous basal Maquoketa Shale (Upper Ordovician) in northwestern Illinois, and 45 samples of this unit were collected in Iowa, Illinois, and Missouri. One sample contained 20 ppb Au, the rest less than 20 ppb.

A kame terrace near Marquette, Mich., reported to contain appreciable gold, was sampled. The panned heavy-mineral concentrates from 32 samples of sand all contained less than 20 ppb Au.

Several samples of carbonate, a sample of halite, and a sample of gypsum from the sedimentary rocks of the Great Lakes region have from 20 to 60 ppb Au, which suggests that syngenetic chemical processes may have resulted in the removal and concentration of the gold contained in sea water.

Paleocurrent studies were made of basal Cambrian sandstones and some Precambrian

sandstones to determine source directions in order to relate anomalous gold values in the sandstones to known or unknown source gold deposits in the Precambrian rocks of the Canadian Shield. A Cambrian divide between two marine current systems was found in northern New York. This divide was infrequently covered by the sea, and dunes are preserved which indicate a prevailing wind from the east. Parts of the Chapel Rock Member of Munising Formation of Hamblin (1958) (Upper Cambrian), heretofore called marine, were found to be of eolian origin. The large-scale crossbedding of this unit records winds from the southeast. (D. A. Seeland, Denver, Colo.)

CRETACEOUS BLACK SANDS, ROCKY MOUNTAIN REGION

Deposits of fossil black sandstone of Late Cretaceous age have been reported at 105 localities in the Rocky Mountain region of the conterminous United States. Minerals of possible economic interest include ilmenite, altered ilmenite, titaniferous magnetite, a variety of intergrown iron-titanium oxides such as ulvospinel-magnetite, chromite, zircon, rutile, monazite, niobium-bearing opaque minerals, and gold. Gold is not abundant, but deposits of Wyoming and Colorado contain as much as 1.3 ppm. In Wyoming, the younger deposits contain the higher gold contents.

Iron-titanium oxides show regional variations, with titaniferous magnetite most abundant in Montana, and ilmenite most abundant in New Mexico, Arizona, and Utah. Wyoming deposits are composed of a variety of complexly intergrown iron-titanium oxides along with ilmenite, titaniferous magnetite, and chromite. Most of the deposits in the south (southern Colorado, Utah, Arizona, and New Mexico) show extreme alteration of iron-titanium oxides with formation of anatase, rutile, brookite, goethite, and hematite from original detrital iron-titanium oxides. Three samples from a sandstone near Escalante, Garfield County, Utah, contain an average of 2.1 percent rutile, and one sample has 3.9 percent rutile. Black sandstones in this area contain more rutile than do those elsewhere in the Rocky Mountains, suggesting the existence of a rutile province that warrants further study.

In general, older deposits, probably derived largely from sedimentary rocks, are richer in ilmenite, zircon, monazite, and rutile, although there are some exceptions. Younger deposits, especially those of Montana and northern and

eastern Wyoming, are dominated by volcanic mineral suites; titaniferous magnetite, intergrown iron-titanium oxides, oxyhornblende, pyroxene, sphene, apatite, euhedral biotite, and euhedral zircon are common. Rock fragments of volcanic origin are also abundant in many of these deposits. Trace elements in the heavy minerals include cerium, niobium, tin, vanadium, hafnium, cobalt, lanthanum, nickel, ytterbium, neodymium, and yttrium. Most of these elements are in monazite and zircon, but very rich samples of black sandstone from Montana contain over 0.10 percent V, suggesting that a significant amount of vanadium could be recovered from a magnetite concentrate. Niobium is probably present in niobium-bearing opaque minerals and in ilmenite.

These black sandstone deposits vary greatly in size and grade, but the aggregate content of heavy minerals is large, probably well in excess of 50 million tons. Certain deposits contain substantial heavy-mineral reserves. For example, the Dugout Creek deposit in Wyoming is over 2.7 miles long with a maximum exposed width of 1,500 feet; the Sanostee deposit in New Mexico is over 8,000 feet long with a maximum width of 1,000 feet and contains in excess of 2,000,000 tons of heavy-mineral-rich sandstone; and a group of overlapping deposits at Choteau in Montana covers an area more than 2 miles long and 1.5 miles wide. Many of the deposits, especially in Montana, Wyoming, and New Mexico, should be readily strippable because they cap buttes as a result of their resistance to erosion. They are, however, well indurated and could not be processed as easily as recent beach placers. (R. S. Houston, Laramie, Wyo.)

GOLD IN EOCENE AND YOUNGER ROCKS, NORTHWESTERN COLORADO

The shaly unit correlative with the Tipton Tongue of the Green River Formation has been mapped through most of the north and northwest part of the Craig 30-minute quadrangle as part of a study of gold-bearing Cenozoic rocks in northwestern Colorado. The distribution of gold in modern sediments derived from the Tertiary rocks appears to reflect two principal controls. Most of the richest samples are near the outcrop of the Tipton, apparently reflecting deposition of gold near the arm of the Green River lake in which the Tipton was deposited.

The most likely explanation at present is deposition in the deltaic fans bordering the lake. The richest samples also have a fairly linear trend suggestive of a principal gold-bearing stream system on a particular fan. Within that system the optimum site for gold accumulation appears to be near the apparent pinchout of the Tipton along the east limit of its outcrop.

South of the Little Snake River, a series of cobble-gravel terraces of Quaternary and perhaps late Tertiary age are clearly derived from the Sierra Madre Range in Wyoming. The presence of basaltic cobbles shows these terraces to be younger than the Browns Park Formation (Miocene?). The terraces appear to have only traces of gold. (P. K. Theobald, Jr., Denver, Colo.)

SILVER CONTENT OF PHOSPHORIA FORMATION, JACKSON HOLE, WYO.

The silver content of phosphatic black shale and mudstone near the base of the Phosphoria Formation (Permian) has been determined on samples from four localities near Jackson, Wyo. The sampled zone lies 7 to 14 feet above the base of the Phosphoria, is 1 to 7 feet thick, and contains 40 to 70 ppm Ag. (J. D. Love, Laramie, Wyo.)

HEAVY METALS IN ROCKS OF THE COLORADO PLATEAU

In a systematic study of the heavy-metal content of Mesozoic rocks of the Colorado Plateau, 6,028 samples have been prepared to date and submitted for quantitative analyses of gold, silver, copper, and mercury. Semiquantitative spectrographic analyses for 30 elements are also being made. Analytical data are complete for about 60 percent of the samples. Some results of the study are the following:

1. The Moenkopi Formation (Triassic) (323 samples) is significantly low in iron, magnesium, copper, lead, mercury, yttrium, beryllium, and nickel and high in chromium, cobalt, silver (0.26 ppm), and gold (0.016 ppm), as compared with a standard recently published by Turekian and Wedepohl (1961). This finding supports the interpretation that sediments which make up the Moenkopi were eroded from weathered terranes and deposited in an arid oxidizing environment.
2. Among the rocks of different textures in the Moenkopi, claystones contain significantly

more trace metals than the sandstones and siltstones. Iron, copper, and nickel are more than four times as high; gold (0.04 ppm) is twice as high. Siltstones show significant differences from the formation average; they are low in silver and high in manganese and chromium. Relative to the average for the formation, the medium- and fine-grained and very fine grained sandstones are significantly higher in copper and the very coarse and coarse sandstones are significantly higher in barium and lower in mercury.

3. Among stratigraphic subdivisions of the Moenkopi, the Tenderfoot Member contains generally more of all the trace metals than the entire formation. The Shnabkaib Member, a gypsum-limestone evaporite facies, is low in most trace metals, but significantly high in magnesium, strontium, lead, and silver. The Holbrook and Wupatki Members are generally low in trace metals, particularly magnesium which is present in only one-fourth the average formation concentration. The Hoskinnini Member is generally slightly low in most of the trace metals, but individual metals show no significant differences. Limestones and dolomites (containing more than 74 percent carbonates) and certain calcareous siltstones (50 to 74 percent carbonates) show a low content of nearly all trace metals, including titanium, barium, zirconium, iron, and mercury.
4. Mudstones from the top of the Moenkopi in areas in which uranium has been mined show large variations in metal content. Strontium, copper, yttrium, nickel, cobalt, beryllium, and gold (0.09 ppm) are four times as abundant as in the whole formation, whereas calcium, manganese, and silver are only one-fourth as abundant as in the entire formation. It seems likely that the metal content of these mudstones has been affected by metal-rich solutions related to the uranium deposits in the basal strata of the overlying Chinle Formation. It is probable that systematic sampling of these mudstones in the Colorado Plateau region would yield both large- and small-scale geochemical anomalies of value to a program of exploration for uranium deposits. (R. A. Cadigan, Denver, Colo.)

GOLD CONTENT OF APPALACHIAN AND MIDWESTERN COALS

Analyses of 100 samples of ash from coal from Appalachian and interior coal fields all showed less than 0.05 ppm Au. These samples were selected from about 1,000 samples previously collected by Taisia Stadnichenko and Peter Zubovic and are believed to be representative of their respective coal provinces. (J. D. Vine, Denver, Colo.)

GOLD CONTENT OF WASTE PRODUCTS FROM COAL

Traces of gold were found in several samples among about 75 samples of materials such as coal ash and coal-washing waste products received from various industrial plants. These samples have been separated into light and heavy components and will be reanalyzed to check the presence and mode of gold occurrence. (J. D. Vine, Denver, Colo.)

COVARIATION AMONG ELEMENTS IN BLACK SHALE

Analyses of covariation among element concentrations have been made for 17 suites of samples of black shale accumulated in many types of geologic environments. Results indicate considerable diversity among the geochemical associations. Minor elements most commonly enriched in association with organic material are vanadium, molybdenum, zinc, lead, chromium, and silver, whereas nickel, copper, cobalt, lanthanum, selenium, uranium, and titanium are only occasionally enriched in the same association. (J. D. Vine, Denver, Colo.)

GOLD CONTENT OF PYRITE FROM CARLILE SHALE

Pyrite from 30 feet of beds in the upper part of the Carlile Shale (Upper Cretaceous) was reported 12 years ago to contain 100 to 500 ppm Au. The shale contains about 2 percent pyrite, and therefore might have contained 2 to 10 ppm Au. The rock was resampled and analyzed to check this long-overlooked information, but all samples contained <0.02 ppm. (D. R. Shawe, Denver, Colo.)

CRETACEOUS AND TERTIARY CONGLOMERATES, UTAH AND IDAHO

A regional study of Upper Cretaceous and lower Tertiary orogenic conglomerates in northern Utah and southern Idaho has shown that the gold content of the rocks sampled is negligible and that the heavy-mineral suites are not useful

for stratigraphic correlations. The Evanston Formation (Upper Cretaceous and Paleocene) of southwestern Wyoming is now known to extend into northeastern Utah. (T. E. Mullens, Denver, Colo.)

GOLD CONTENT OF MARINE PHOSPHORITES

The gold content of a composite sample of phosphate nodules from Blake Plateau has been reported as 7 ppb, suggesting that other phosphorites should be checked as possible sources of byproduct gold. Therefore, the gold content of seven concentrates of marine apatite from four regions (Florida, Montana, North Carolina, and Morocco) was determined by a combined neutron activation-fire assay method. Eleven determinations were made. The highest gold content was 3 ppb, indicating that phosphorite probably cannot be considered as a potential source of gold with present technology. (Z. S. Altschuler, Washington, D. C.)

GOLD CONTENT OF MANGANESE NODULE, BLAKE PLATEAU

The gold content of a manganese nodule from Blake Plateau off northern Florida is a few tenths of a part per billion.

HEAVY MINERALS IN VAN HORN SANDSTONE, TEXAS

A detailed study of heavy minerals and possible fossil placer deposits in the Van Horn Sandstone of western Texas was begun in 1968 under a research grant to the University of Texas. The Van Horn is a Precambrian fluvial arkosic sandstone and conglomerate exposed over an area of about 100 sq mi in Culberson and Hudspeth Counties, westernmost Texas. The formation has a thickness of 800 feet or less, is unmetamorphosed and structurally simple, and was derived from an igneous source to the north. Some gold has been reported in placer deposits derived from the Van Horn. The project will include mapping of primary sedimentary structures, grain-size analyses, and petrographic studies, the aim being to reconstruct the paleoenvironments in which the formation was deposited. (A. J. Scott, Austin, Tex.)

RESEARCH IN GEOCHEMISTRY MERCURY CONTENT OF THE ATMOSPHERE

The use of mercury in the atmosphere as a potential exploration tool was discussed in Geological

Survey Circular 609, published in 1969. Tests carried out in several mining districts (Cortez and Ivanhoe, Nev.; Coeur d'Alene, Idaho) have shown that the mercury content of gas contained in soil overlying mineralized ground is higher—in some places more than an order of magnitude higher—than in soil on barren ground. Analyses of the soils indicate that the mercury is not in the soils themselves and therefore probably was derived from bedrock sources. Variable thicknesses of soil did not adversely affect usefulness of the method in outlining the gold deposit at Cortez, where maximum cover was 100 feet; furthermore, high concentrations of mercury were found atop the Sheep Creek Range north of Battle Mountain, Nev., where the mercury source may be covered by as much as 1,000 feet of basalt.

The presence of mercury vapor over some ore deposits at ground level suggested that some might also be present in the air at considerably higher altitude, and therefore the mercury content in air at 100 to 1,000 feet altitude was measured from a light aircraft in Arizona. Air over two mercury deposits contained 10 to 20 times background amounts of mercury, and air over two porphyry copper deposits, 5 to 10 times background. The 200-foot altitude was found to be the highest at which appreciable amounts of mercury were found, but some was detected at as much as 1,000 feet above terrain.

Resolution of the truckborne and airborne equipment available to date is very poor. However, it is hoped that in 1969 a much more sensitive and convenient instrument will be developed that will provide the resolution needed to determine whether this method does indeed have as much promise as its early tests indicate. (J. H. McCarthy and W. W. Vaughn, Denver, Colo.)

Measurements made of the mercury concentrations in several polymetallic deposits of Tertiary age in east-central and north-central Nevada show that mercury is greatly enriched in the soil gases in the vicinity of these deposits. In contrast, a relatively small concentration of mercury is present in the older (Precambrian) deposits of the Coeur d'Alene district, Idaho. Soil gases in the vicinity of the Nevada deposits contain up to about 200 nanograms Hg per cubic meter,

whereas the soil gases in the Coeur d'Alene district contain only about 10 nanograms Hg per cubic meter. In the Coeur d'Alene district the mine gases below the zone of oxidation contain no mercury, although the sulfide minerals contain up to 65 ppm Hg, thus indicating that little mercury is being released to the atmosphere from the sulfide minerals. The great difference in the amount of mercury vapor emanating from deposits of Tertiary and Precambrian age, respectively, suggests that the readily available mercury has already evaporated from the Precambrian deposits and that mercury vapor is most useful as a prospecting guide in the search for relatively young deposits. (G. B. Gott, Denver, Colo.)

INTERPRETATION OF GEOCHEMICAL ANOMALIES

A detailed soil and vegetation sampling program at Catheart Mountain, Maine, where a recently discovered copper-molybdenum porphyry-type deposit in quartz monzonite occurs beneath a thin blanket of glacial till, showed that strong copper and molybdenum anomalies in both soil and vegetation (red spruce and balsam fir) are genetically related to the deposit and its weakly mineralized alteration halo. However, the high mobility of copper in this acid podzolic environment causes an appreciable migration of copper from the source, so the spatial relationship between the mineralized rock and the copper anomaly is not as strong as for molybdenum. Preliminary analysis of the data suggests, therefore, that the molybdenum content of B-zone soils provides the most useful and direct guide to such deposits in a similar environment. In the alkaline environment of the Basin and Range province, on the other hand, molybdenum is very mobile and copper relatively immobile. At Catheart Mountain, the molybdenum content of twigs and needles of balsam fir trees (and to a lesser degree, red spruce) appears to correlate reasonably well with the molybdenum content of the soils, but the copper content of such trees shows less contrast.

Remote-sensing studies at Catheart Mountain have provided the first concrete evidence that remote sensing of geochemical anomalies in soil and tree-covered areas may be possible. The reflectance of fir and spruce trees growing in metal-rich areas and in areas of only background

metal content has been measured by Prof. Edward Yost of Long Island University. The reflectance curves of specimens rooted in soil anomalously high in copper and molybdenum are significantly different, especially in the near-infrared region, from those of specimens rooted in areas of background metal content. (F. C. Canney, Denver, Colo.)

GOLD IN HUMUS-RICH FOREST SOIL

The utilization of humus-rich forest soil, or mull, in geochemical exploration for gold, with particular emphasis on the Empire district, Clear Creek County, Colo., was discussed in Geological Survey Circular 562.

In the Empire and Breckenridge districts, Colorado, in which the ore minerals are auriferous pyrite with minor lead-zinc sulfides, and in the Cripple Creek and Gold Hills district, Colorado, in which gold tellurides and pyrite are principal ore minerals, the presence of gold in vegetation suggests that gold is mobilized in oxidizing pyritic ore deposits. On the other hand, in some areas of the La Plata and Chicago Creek districts, Colorado, in which gold is associated with lead-zinc sulfides and minor pyrite, the absence of gold in most vegetation samples suggests that gold is only very slightly mobile in oxidizing ore deposits that contain abundant lead-zinc sulfides and minor amounts of pyrite.

In the Mill Canyon area, Eureka County, Nev., gold was found in mull under cedar growing over an auriferous vein of pyrite and sulfosalts in limestone. Distilled wash water used to disperse a sample of this mull contained gold that must have been finely divided or in solution, as no gold was found on the millipore filters (0.45 micron openings) through which the water was filtered.

On the basis of work in Colorado, it had been assumed that acid solutions produced from pyrite were necessary for gold mobilization. It was also assumed that in a limestone host rock no adequate acid solution would be available. The results on samples collected in Mill Canyon cast doubt on the original assumptions and suggest that gold can be mobilized in nature in ways other than the classical MnO_2 plus HCl process.

An area rich in gold, bismuth, and copper and a second area rich in silver, lead, zinc, and molybdenum were revealed in maps of the metal

content of mull ash collected in the Empire district. Statistical analysis of the data showed a high degree of mutual association within these two distinct groups of elements. S. M. Ball, in Geological Survey Professional Paper 63, 1906, suggested long ago that two periods of mineralization may have occurred in this district. (H. W. Lakin, Denver, Colo.)

HEAVY METALS IN ORGANIC ENVIRONMENTS

Research on geochemical processes that may result in the concentration of heavy metals in organic environments is being done at Colorado School of Mines, Golden, Colo., under a research grant. Preliminary results of studies of effects of organic acids—extracted from peat and humate—on the solution and transportation of gold are as follows:

1. The amount of metallic gold dissolved by either organic acid at concentrations of 20 to 80 ppm C was below the limit of detection (<0.020 ppm).
2. Gold colloids are stabilized by organic acids, the stability increasing with concentration of organic acid. Stabilization is effective in the presence of NaCl at concentrations near that of sea water; at sea-water concentration, the gold sol probably would be coagulated.
3. The amount of gold chloride remaining in solution over a period of 2 weeks (initial concentration, 13 ppm) is independent of pH in the range 5 to 9, but gold is reduced by organic acids to metallic colloidal gold.

The solubility of mercury, mercuric sulfide, mercuric oxide, and mercurous chloride in the presence of humic acids also has been investigated. The humic acids were extracted from mountain soil and peat. In the presence of humic acid (carbon concentration 166 ppm), the solubility of mercury and its compounds was three to five times higher than in the absence of humic acid. The association of Hg^{+2} with humic acid was shown by the fact that in the presence of humic acid, Hg^{+2} was retained on Amberlite XAD-1 resin, whereas no Hg^{+2} was retained in the absence of humic acid. This association may be of some consequence in the interpretation of mercury geochemical anomalies. (R. E. Bisque, Golden, Colo.)

ROLE OF SOIL MICROORGANISMS IN SOLUBILIZING MINERALS

The ability of soil microorganisms to solubilize minerals containing various trace elements is

being studied at Colorado State University, Fort Collins, Colo. under a research grant. The first year's work was directed mainly to testing the ability of various soil bacteria and fungi to grow in liquid media containing different concentrations of the metals gold, silver, mercury, copper, lead, manganese, cobalt, chromium, molybdenum, tin, cadmium, uranium, vanadium, tungsten, zinc, and palladium. It was found that one fungus could grow in a concentration of 25 ppm Au, and 12 species of bacteria and fungi could grow in cultures containing 10 ppm Au. On the other hand, cultures containing >5 ppm Ag or Hg were lethal to all organisms tested; some organisms could grow in saturated solutions of copper, manganese, molybdenum, lead, uranium, tungsten, and zinc. Two bacteria species previously reported to be capable of solubilizing native gold (up to 1.5 ppm in solution) were also tested for a period of 3 weeks, with negative results.

Soils and stream sediments from Cripple Creek, Colo., were tested to determine whether specific bacteria or fungi occurred in materials containing gold. No significant differences in numbers or kinds of microorganisms present were found between gold-bearing and barren samples. Work will continue on the solubilization of gold and other minerals by soil microorganisms and on the mechanisms by which gold is released from plant materials known to concentrate gold. (K. G. Doxtader, Fort Collins, Colo.)

SULFUR ISOTOPES, BINGHAM DISTRICT, UTAH

A study of sulfur isotope fractionation in ore deposits of the United States mine area, Bingham district, Utah, is being carried out under a research grant to Oregon State University, Corvallis, Oreg. The aim of the study is to determine the magnitude of sulfur isotope fractionation in mesothermal deposits of base and precious metals peripheral to a major porphyry copper deposit; to identify the possible mechanisms by which fractionation occurred; and to establish the nature and extent of sulfur isotope trends and zonations and their relation to host-rock lithology and structure, ore mineralogy and textures, and depositional processes. Mono-mineralic concentrates of pyrite, galena, sphalerite, chalcopyrite, and tetrahedrite are to be analyzed.

About 90 sulfide samples, including standards, have been prepared, and isotopic analyses made on about one-half of these. Nearly 50 pyrite concentrates representative of the Galena fissure and B-limestone replacement deposits have been submitted for Se:S and Co:Fe determinations. These analyses will be compared with similar analyses made on disseminated pyrite. Preliminary results based on 18 samples indicate that (1) sulfur in massive sulfide deposits is heavier than that from disseminated sulfides, and (2) the depositional sequence of sulfide minerals shows a trend from heavy sulfur to light sulfur. (C. W. Field, Corvallis, Oreg.)

GEOCHEMICAL SAMPLING

Results of stream-sediment sampling studies in three drainage basins of the northwestern San Juan Mountains were published in Geological Survey Circular 592. The areas sampled comprised one in which no gold deposits were known, a second which had a few known veins, prospects, and small mines, and a third containing numerous veins and several productive mines. Gold analyses on a few panned heavy-mineral concentrates from each drainage sufficed to distinguish between barren and mineralized areas and also provided a measure of the relative amounts of gold in mineralized areas. (R. P. Fischer and F. S. Fisher, Denver, Colo.)

SAMPLE PREPARATION

A sample of gold- and silver-bearing quartz-sulfide ore from the dump of the Bartow mine in the San Juan Mountains, southwestern Colorado, was prepared for analysis using two different sequences of crushing, fine grinding, and splitting and two different methods of splitting. Fire assays of eight 15-g portions from each of the four groups of samples showed that for both gold and silver: (1) distinctly better reproducibility is given by samples that are ground to 100 mesh after coarse crushing (one-eighth to one-quarter in.) and prior to splitting (standard deviation for gold 0.36 to 0.57) than by samples that are split before grinding to 100 mesh (standard deviation for gold, 1.08 to 1.17), and (2) splitting of samples using the Jones sample splitter gives almost the same results as splitting by the cone-and-quartering method but is at least twice as fast. The sample contained about 5 ppm Au and 275 ppm Ag. (F. S. Fisher, Denver, Colo.)

The gold content of 205 raw (unconcentrated) samples of Harebell Formation and Pinyon Conglomerate from Jackson Hole, Wyo., has been compared with that of panned concentrates of the same samples. The raw samples weighed 10 to 15 g. Histograms of the distribution of analytical results suggest that the mean gold content of raw samples is 10 to 20 times that of the panned concentrates. Inasmuch as the panned concentrates represent a much larger sample than the raw samples, their analyses should give a more reliable estimate of gold content. Analyses of small unconcentrated samples therefore appear to give spurious results and a probably exaggerated estimate of gold abundance. (J. C. Antweiler and D. A. Lindsey, Denver, Colo.)

STATISTICAL TREATMENT OF GEOCHEMICAL DATA

A STATPAC tape was prepared containing all of the geochemical data collected from the Ely, Nev., district. Preliminary statistical summaries showed that ratios of the metals to silica had a much wider range than the metal analyses alone. The use of these ratios is based on the assumption that the metals traveled in a silica solution and that therefore the metal content of samples should be computed relative to the silica content, not to the weight of the sample.

All geochemical data from the Coeur d'Alene, Idaho, project have been entered into the Rock Analysis Storage System (RASS). Preliminary statistical summaries and tabulations have been obtained, and computer gridding routines for geochemical data and computer plots of geochemical values are being developed.

A program designed to convert the now outdated geochemical census punched cards to STATPAC was written, compiled, and executed on stream-sediment geochemical data from central Maine. This program can be used to convert similar data from other projects.

Samples for chemical analysis have been collected in the Midas, Nev., district. Preliminary results indicate that the district does not have disseminated gold deposits of economic value near the surface. However, the presence of a disseminated deposit at depth, or the continuation of near-surface gold-silver veins at depth, are not precluded.

A remote data teleprocessing system is being developed that will provide immediate entry of field geochemical data into RASS, and another

system is being prepared to process data created by the eventual automated mobile and stationary analytical equipment. (R. L. Erickson and J. M. Botbol, Denver, Colo.)

DATA STORAGE AND RETRIEVAL

Computer programs have now been completed for storage of Heavy Metals-Wilderness analytical data on magnetic tape, for correction or replacement of previously stored data, and for search and retrieval of selected data. A special computer program, GEOSUM, has been developed to provide uniform reporting and summaries of geochemical data. The program will produce a readable listing of data, frequency distributions for each element, and estimates of geometric mean and geometric deviation.

Revision of the Request for Analysis form now makes it possible to keypunch descriptive data directly from the form, thus eliminating preliminary transfer of data to a key punch form and facilitating the entering of data into RASS.

Analytical data from the following projects are now or will shortly be routinely entered into RASS:

- Geochemical halos in Utah and Nevada

- Mineral exploration

- Geochemical of mercury

- Aurora and Bodie districts, Nevada and California

- Northwest San Juan Mountains, Colo.

- Southern Appalachians

The data retrieval program was completed in December, and nine data retrievals were made during that month. (R. V. Mendes, Denver, Colo.)

RESEARCH IN GEOPHYSICS

USE OF VERY LOW FREQUENCY WAVES IN GEOPHYSICAL EXPLORATION

An investigation into the use of very low frequency radio waves for geophysical prospecting is being done at the University of Colorado, Boulder, Colo., under a research grant. A number of high-power radio stations transmitting at very low frequencies (3 to 30 kilo-Hertz) have been placed in service during recent years by the U.S. Government. These low-frequency waves are used for time and frequency information, for navigation systems, and for long-distance communication. Inasmuch as these waves propagate in the upper part of the earth, to

depths as great as several hundred feet depending on the earth's conductivity, measurement of local variations in the waves at the surface is a means of detecting conductive ore bodies or other geologic features that might cause variations in electrical conductivity.

A modeling study is being made to develop and improve techniques of interpretation, using a wooden tank $12 \times 12 \times 2$ feet filled with brine to simulate an electrically homogeneous earth and wire grids above and below the tank to produce "pseudo" plane waves. Electrical inhomogeneities are to be placed in the tank and their effects on these "pseudo" plane waves will be measured. (W. L. Flock and F. C. Frischknecht, Boulder, Colo.)

DETECTION OF INDUCED POLARIZATION EFFECT USING NATURAL TELLURIC FIELDS

A feasibility study of the possibility of detecting induced polarization and resistivity effects of frequency-dependent conductors using the earth's natural magnetotelluric fields as primary fields is being carried out at the University of California at Berkeley under a research grant. A modeling study has been done using the Berkeley computer, and measurements of magnetotelluric currents made in the field will be reduced by computer. The study will be completed in 1969. (H. F. Morrison, Berkeley, Calif.)

NEUTRON ACTIVATION AS AN EXPLORATION TOOL

The Geological Survey has for some years been experimenting with neutron activation as an exploration tool—the "silver snooper" of several years ago was a truck-mounted neutron generator used to activate small areas of ground and measure the gamma-ray activity induced in any silver present near the ground surface. Similar equipment is now being tested as a gold detector. In 1968, a 100- μ g californium-252 neutron source was tested at Savannah River, S. C., in collaboration with the U.S. Atomic Energy Commission. Tests were carried out successfully in a water well and also on gold and silver ores buried at shallow depth. The potential importance of californium-252 is due to its small physical size and its spontaneous emission of a large number of neutrons—each gram emits about 2×10^{12} neutrons/second, close to the neutron flux of a power reactor. A borehole 40 feet deep has been drilled in the laboratory floor in Building 104, at

the old Bureau of Standards campus, for testing of borehole techniques for neutron activation of ores using the californium-252 neutron source.

Gold is one of the more difficult elements to work with, primarily because the activation product, gold-198, has a long half-life of 2.6 days. To help solve this particular problem a research grant was awarded to the University of Maryland for a feasibility study on the use of prompt gamma rays for detection of gold. These prompt gamma rays are emitted instantly when a neutron is absorbed in an atomic nucleus. Some work has been done on pure elements, but little is known about possible interferences or other limitations of the method. Certainly, the prompt gamma spectra are known to be complex; but prompt gammas also have higher energies, hence deeper penetration and ability to "see" larger samples. Hopefully, this study will point the way to another possible neutron activation technique. (F. E. Senftle, Washington, D.C.)

DIRECT-READING FIELD DETECTOR FOR SELECTED ELEMENTS

Development of a direct-reading field instrument to convert the multiple energy output of natural radioactivity, neutron activation, or X-ray fluorescence systems to a single output characteristic of various preselected elements is being undertaken under contract by Tracerlab, a Division of Laboratory for Electronics, Waltham, Mass. Such an instrument would make it possible to analyze a spectrum of multiple energies in the field without the need for a costly multichannel analyzer and the difficult interpretation of its complex output.

Research was divided into five phases: (1) mathematical evaluation of applicability of the method, (2) design and construction of a 16-channel breadboard model, (3) construction of a prototype field model, (4) field testing of prototype, and (5) a final report summarizing results of the project. Phases one to three have been completed and phases four and five were in progress at the end of 1968. (F. E. Senftle and A. B. Tanner, Washington, D.C.)

RESEARCH ON ANALYTICAL METHODS DETERMINATION OF THE PLATINUM METALS

A major achievement of analytical research in 1968 was the development of two methods for the rapid accurate measurement of trace amounts of platinum, palladium, and rhodium in rocks;

these methods employ atomic absorption and fire assay-spectrographic techniques, respectively.

DETERMINATION OF PLATINUM AND PALLADIUM BY ATOMIC ABSORPTION

The determination of platinum and palladium by atomic absorption is strongly affected by the depressive effect of other platinum metals, silver, and gold. Studies of this interference have shown that CuSO_4 , LaCl_3 , $\text{La}_2(\text{SO}_4)_3$, ZnSO_4 , $\text{Pb}(\text{NO}_3)_2$, and CdSO_4 in the aspirated solution all overcome the depressive effect to some extent. It has been found that when CuSO_4 alone is used, both copper and sulfate are necessary, as either by itself depresses the absorbance of platinum. This unique action of CuSO_4 is without precedent in atomic absorption spectrophotometry and the mechanism is so far unknown. The best results are obtained using a combination of CuSO_4 and CdSO_4 , each at a concentration of 12,500 ppm, about one-half the concentration needed if CuSO_4 is used alone; as much as 200 ppm each of Rh, Ru, Os, Pd, and Ir, and 20 ppm Au can be tolerated in the determination of platinum, and 200 ppm each of Rh, Ru, Os, Pt, and Ir and at least 500 ppm Au in the determination of palladium.

Development of a rapid and a routine method has been completed. Platinum and palladium are concentrated into a gold bead by fire assay, the bead is dissolved in aqua regia, and a buffer mixture of cadmium and copper sulfates is added, after which the solution is analyzed by atomic absorption. Addition of cadmium and copper sulfates eliminates interelement interference and permits determination of platinum and palladium in the presence of substantial amounts of silver, aluminum, gold, bismuth, cobalt, chromium, iron, mercury, iridium, potassium, lanthanum, magnesium, molybdenum, sodium, nickel, osmium, lead, rhodium, ruthenium, tellurium, titanium, vanadium, yttrium, and zinc. The lower limit of detection is about 0.1 ppm on a 20-g sample. (F. S. Grimaldi and M. M. Schnepfe, Washington, D.C.)

DETERMINATION OF RHODIUM BY ATOMIC ABSORPTION

The determination of rhodium by atomic absorption is made difficult by the positive interference of gold and the negative interference of other noble metals. It has now been discovered that when rhodium is determined in the presence of lanthanum sulfate, not only is interference from other noble metals eliminated but the sensitivity of rhodium measurement is increased. Some 30 other elements in addition to the noble

metals have now been tested and none interferes. It thus appears possible to determine rhodium fairly directly by atomic absorption, and the method is being tested on ores. The limit of detection by this method is 7 ppb, and for an error not greater than ± 15 percent is 10 ppb on a 20-g sample in a final solution volume of 5 ml. (F. S. Grimaldi and M. M. Schnepfe, Washington, D.C.)

CHEMICAL DETERMINATION OF RHODIUM IN ROCKS

A method for determining rhodium in the presence of iridium has been developed for analysis of portions of samples remaining after separation of rock-forming elements and platinum and palladium. Rhodium and iridium are converted to complex chlorides in order to prevent interference by iridium, and rhodium is determined colorimetrically in HClO_4 -HBr medium to which SnBr_2 is added. The sensitivity is about 10 ppb Rh in a 10-g sample. (F. S. Grimaldi and M. M. Schnepfe, Washington, D.C.)

DETERMINATION OF PLATINUM, PALLADIUM, AND RHODIUM BY FIRE ASSAY AND EMISSION SPECTROGRAPHY

A relatively simple, sensitive, and precise method for simultaneous determination of platinum, palladium, and rhodium in rocks has been developed. Samples weighing 15 to 30 g are pre-concentrated into a gold bead by standard fire-assay techniques and the bead is dissolved in aqua regia. After dilution to volume with 1M HCl, 100 microliters of solution is evaporated onto each of two flat-top graphite electrodes and the residue analyzed by emission spectrography. Limits of determination are 10 ppb Pt, 4 ppb Pd, and 5 ppb Rh for a 15-g sample. (Joseph Haffty and L. B. Riley, Denver, Colo.)

DETERMINATION OF OSMIUM AND RUTHENIUM

Research continues on the determination of osmium based on catalysis of the reduction of Ce^{+4} by As^{+3} . Although some problems remain to be solved, it is now possible to determine as little as $0.0003 \mu\text{g}$ Os in 5 ml pure solution (or 0.06 ppb) at the 99.7 confidence level. A plot of reaction rate versus concentration of osmium is straight in the interval 0 to $0.01 \mu\text{g}$ Os in a 5 ml solution (0 to 2 ppb); the determination in the range 0.06 to 2 ppb is more than a magnitude more sensitive than previously reported.

Trace amounts of osmium and ruthenium can now be recovered by extraction of OsO_4 and RuO_4 with CCl_4 following leaching of the sample and oxidation of osmium and ruthenium by silver

peroxide. These elements are stripped into NaOH and osmium is separated from ruthenium by oxidation to OsO_4 using nitric acid (ruthenium is not oxidized to RuO_4 by HNO_3), followed by extracting into CCl_4 . Use of tracers indicates that 80 percent of the ruthenium and 60 percent of the osmium are recovered. Previous low recoveries of both osmium and ruthenium were found to be caused by adsorption on polyethylene and polypropylene containers. The successful isolation of these metals is a major step toward developing a reliable activation method for their analysis. (J. J. Rowe and J. I. Dinnin, Washington, D.C.)

ANALYSIS OF PLATINUM METALS IN CHROMITE

Research continues on the mode of occurrence of the platinum metals in chromite and on the problem of developing a suitable flux for fire-assay determinations of these metals in chromite. None of the common fluxes tested to date effects complete decomposition of chromite.

The following results have been obtained:

1. Rhodium is present in chromite entirely in solid solution. A possible but unlikely alternative explanation of experimental results is that rhodium occurs as uniformly distributed very minute inclusions.
2. Palladium occurs as a separate mineral phase entirely outside the chromite.
3. Platinum is present partly (about 28 percent) as separate phase outside the chromite and partly (about 72 percent) in solid solution or as inclusions in the chromite; further work is planned to more closely determine the mode of occurrence of this metal. (F. S. Grimaldi and M. M. Schnepfe, Washington, D.C.)

GOLD ANALYSIS

Gold Content of Quartz Standard

Many determinations of gold on the gold quartz standard in the Washington, D.C., laboratories by various methods (neutron activation, isotope dilution, and several chemical procedures followed by atomic absorption) have resulted in a figure of 2.60 ppm, somewhat higher than the figures of 2.0 ppm (fire assay-atomic absorption) and 2.2 ppm (cyanide leach-fluorimetric) previously reported. (H. T. Millard and F. O. Simon)

Gold content of the standard was determined in the Denver, Colo., laboratories by fire assay-atomic absorption as 2.65 ppm, and by cyanide leach-atomic absorption as 2.64 ppm. These results agree closely with the 2.60 ppm deter-

mined in Washington, D.C. (L. B. Riley, Denver, Colo.)

Interlaboratory Comparison of Gold Analyses

Duplicate splits of eight samples of gold ore from Cripple Creek, Colo., have been analyzed by atomic absorption in the Denver, Colo., laboratory of the Geological Survey and by fire assay by the U.S. Bureau of Mines and two reputable commercial laboratories. For ore containing gold in the range of approximately 1 to 5 ppm, the results among the four laboratories are in general closely similar; for ore containing <1 ppm, results varied by factors of as much as eight or more.

NEUTRON ACTIVATION METHODS OF ANALYSIS Activation Analysis for Background Amounts of Gold

A simplified procedure for activation analysis uses a strongly basic anion exchange disk to recover previously irradiated gold from solution. The gold retained on the disk is relatively free from radioactive contaminants, allowing the activity of gold-198 to be determined by gamma-spectrometry. Analyses made by this method on eight Geological Survey standard rocks agree closely with those obtained by more lengthy and complex methods. (H. T. Millard and J. E. McLane, Washington, D.C.)

A simple and practical method for routine determination of background amounts of gold was reported in Geological Survey Circular 599. The method involves irradiation of a 1-g sample in the Naval Research Laboratory reactor for 10 to 16 hours, cooling for 10 days to permit radioactivity to decrease sufficiently for safe handling, fire assay using gold metal as a carrier, and gamma counting of the gold bead. The limit of detection is 0.05 ppb. Although an analysis requires about 3 weeks total elapsed time, less than 8 hours of an analyst's time is needed to process 40 samples. At present, analytical capacity, limited only by availability of reactor time, is 250 samples per month. (J. J. Rowe and F. O. Simon, Washington, D.C.)

Activation Analysis of Uranium

Analysis of uranium by neutron activation using a californium-252 source and both a solid-state detector and a scintillation counter is being studied. Uranium-239, formed when a uranium atom absorbs a neutron, decays by beta emission and an 0.074 MeV gamma. A technique to minimize interference by X-rays from lead and bismuth is being investigated. (F. E. Senftle, Washington, D.C.)

CHEMICAL ANALYSIS WITH LASER-FIRED MICROPROBE

Chemical analysis by the laser-fired microprobe has proved useful for nondestructive in-situ determinations of silver, gold, bismuth, copper, lead, nickel, and vanadium in rocks and minerals as well as organic-rich materials such as vegetation, trees, tar sands, and petroleum. The instrument is especially useful for identifying such things as small inclusions and contaminants in sample storage containers.

The laser microprobe appears to be potentially useful in detecting trace amounts of metals such as copper and silver in vegetation by direct sampling without any preconcentration (such as ashing). Copper has recently been shown to cause the green stain of a tree trunk, and anomalous concentrations of silver have been identified around the new growth of aspen twigs. (F. N. Ward, Denver, Colo.)

ANALYSES OF TELLURIUM IN VEGETATION

An analytical method for determining tellurium in plant samples with a sensitivity of 0.06 ppm in the dry plant or humus has been devised. Using this method, humus samples from the Gold Hill district, Boulder County, Colo., were found to contain from 0.12 to 12.5 ppm Te in mineralized areas. The tellurium-gold ratio in these samples varies from 4 to 24 with a mean of 12.5. Thus tellurium in humus may be useful for delineating gold deposits in telluride districts. (H. W. Lakin, Denver, Colo.)

SENSITIVE METHOD FOR DETECTION OF MERCURY

A new and highly sensitive field test for mercury uses the change in potential of a specific iodide electrode caused by formation of a tightly bound mercury-iodide complex in alkaline solution. Concentrations of mercury as low as 0.1 ppb are easily measured. (F. N. Ward and M. Hinkle, Denver, Colo.)

COUNTER-CURRENT ELUTRIATOR AS GOLD CONCENTRATOR

A counter-current elutriator has been calibrated in terms of total discharge and distribution of velocities within the elutriator as compared to the fall velocities of different sized particles of gold, and the results indicate that the elutriator is probably a highly effective tool for rapid determination of the gold content of unconsolidated sediments or disaggregated sedimentary rocks. Since only water is used, the method is cheaper, faster, and more convenient than other methods of separ-

ation such as heavy liquids. If material coarser than 2 mm is removed from a sample, and the remainder divided into fractions of four sizes, that is, coarser than 0.5 mm, coarser than 0.15 mm, coarser than 0.061 mm, and finer than 0.061 mm, the gold in each fraction can be removed in a matter of minutes; if the elutriator is of an appropriate size for the mass of the fractions, the time depends chiefly on the handling of materials rather than the settling of the gold. Only gold coarser than 0.024 mm will be removed from the finest fractions. These size boundaries are suggested because the fall velocity of gold is about 30 percent higher than quartz in the two coarse fractions and 50 percent higher in the two fine fractions. The greater difference in fall velocity for the fine fractions is desirable because gold in these sizes tends to be flaky. The size of elutriator that would be effective has no evident theoretical limit, and the process might even be adaptable to some commercial operations. Further experimental work is underway to explore

these indications. (H. A. Tourtelot, Denver, Colo.)

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