U.S. GEOLOGICAL SURVEY CIRCULAR 997

Geochemical Sampling in Arid Environments by the U.S. Geological Survey

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This report discusses geochemical sample media and describes case histories leading to the selection of nonmagnetic heavy-mineral concentrates for mineral resource potential evaluation studies by the U.S. Geological Survey

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By Margaret E. Hinkle

ABSTRACT

The U.S. Geological Survey (USGS) is responsible for the geochemical evaluations used for mineral resource assessments of large tracts of public lands in the Western United States. Many of these lands are administered by the Bureau of Land Management (BLM) and are studied to determine their suitability or non-suitability for wilderness designation.

Much of the Western United States is arid or semiarid. This report discusses various geochemical sample media that have been used for evaluating areas in arid environments and describes case histories in BLM wilderness study areas in which stream-sediment and heavy-mineral-concentrate sample media were compared. As a result of these case history studies, the nonmagnetic fraction of panned heavy-mineral concentrates was selected as the most effective medium for reconnaissance geochemical sampling for resources other than gold, in arid areas. Nonmagnetic heavy-mineral-concentrate samples provide the primary analytical information currently used in geochemical interpretations of mineral resource potential assessment of BLM lands.

INTRODUCTION

The arid region of the United States includes most parts of the states of Arizona and Nevada, as well as parts of Oregon, Idaho, Utah, Colorado, New Mexico, and California. This area is characterized by receiving less than 10 inches of annual rainfall (fig. 1). It encompasses 700,000 square miles, much of which lies within the Basin and Range physiographic province. The adjacent semiarid lands receive 10–20 inches of annual rainfall. Most of this arid and semiarid land is managed by the Bureau of Land Management (BLM), and is being evaluated for mineral resource potential under the Federal Land Policy and Management Act of 1976 (Public Law 94–579). Under this law, the BLM must review all public lands under its jurisdiction and determine their suitability or nonsuitability for wilderness designation. Areas recommended as suitable for wilderness designation by the BLM are also required to have mineral surveys conducted by the U.S. Geological Survey (USGS) and the Bureau of Mines (Beikman and others, 1983).

Most exposed mineral deposits in this vast region were discovered long ago by prospectors. Additional exposed and near-surface deposits have been discovered more recently by geologists using geologic mapping techniques, geophysical techniques, and drilling. Consequently, exploration emphasis has shifted from the search for more easily discovered deposits to the search for environments that might be favorable for concealed mineral deposits. A variety of techniques are used in the search for concealed mineral deposits, and for evidence of environments favorable for mineral deposits, with increasing importance placed on the role of geochemical prospecting methods.

Geochemical exploration for mineral deposits includes any method of mineral exploration based on the systematic measurement of one or more chemical properties of a naturally occurring material, such as the trace-element analysis of samples of rocks, soils, and stream sediments (Rose and others, 1979). In arid environments, the sample media selected, in addition to rocks, have generally been stream sediments and heavy-mineral concentrates. The same geochemical techniques and sample media that are used in exploration for favorable mineral environments are used in the mineral resource assessment of public lands carried out by the U.S. Geological Survey.

This report discusses sample media that have been selected by geochemists for exploration in arid environments, and the reasoning behind those selections. Sample media used, and the preparation and analysis of these media, are also described. The
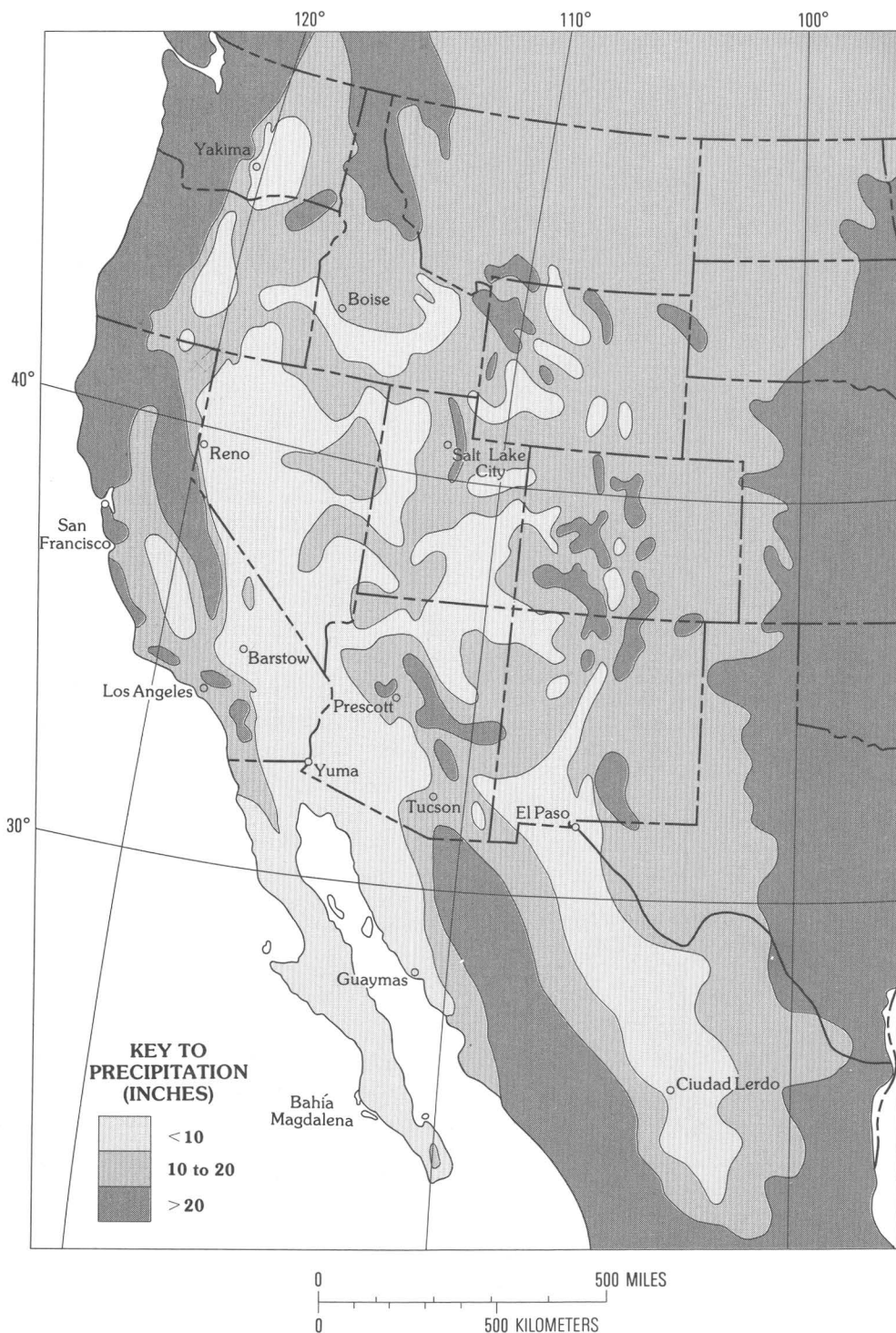
FIGURE 1.—Average yearly precipitation in western North America. (Modified from E. C. Jaeger, 1957, p. 14.)

effectiveness of stream-sediment and heavy-mineral concentrate sample media are compared in case histories that resulted from studies in BLM wilderness study areas in the Western United States. The report discusses the rationale behind the selection of sample media for BLM mineral resource assessments.

PREVIOUS INVESTIGATIONS

STREAM SEDIMENTS

Stream sediments generally represent the rock material eroded from within a drainage basin. Trace

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elements contained within the lattice of rock-forming minerals and within minerals formed during weathering probably make up the greatest proportion of the element variation in most stream sediments (Meyer and others, 1979). Material that is transported by moving water has been the most common geochemical sampling medium used in arid regions, despite the fact that most stream channels are dry most of the time. Chemical weathering of rocks is generally not significant in arid areas because of the lack of rainfall. Therefore, transport of weathered material away from bedrock sources is largely mechanical, and only occurs during infrequent rainfalls.

The sediment material most often chosen for geochemical exploration is the minus-80-mesh fraction (material smaller than 0.18 mm), although the minus-60-mesh fraction (less than 0.25 mm) and even the very fine minus-200-mesh fraction (less than 0.075 mm) have been used.

Stream sediments can be transported for long distances by flash floods and therefore can indicate the presence of mineralized rocks far from the source. However, elements of geochemical interest in the finer fractions described above may be so diluted by quartz, feldspar, and other components of unmineralized rock also present in these fine sediments, that the upstream source of mineralization may not be detected by chemical analysis of the sediment.

Wind-blown dust can also dilute fine sediments. Griffitts and Cooley (1978) noted that analyses of the minus-200-mesh fractions of stream-sediment samples from the Sheeprock Mountains in Utah did not yield as much evidence for the presence of nearby beryllium as did analyses of the plus-200-mesh fractions. They attributed the lower beryllium concentrations in the minus-200-mesh material to dilution of the samples by wind-blown dust.

Coarser sediment fractions have been used successfully in geochemical exploration programs in desert areas. In the southeastern desert of Egypt, Soliman (1981, 1982) successfully used the minus-1-mm fraction of sediments collected from dry arroyos in surveys for copper alone, and for copper, gold, tin, and niobium mineralization. The 18- to 35-mesh (0.5- to 1.0-mm) size fraction was also selected for stream-sediment reconnaissance for uranium in the seven western states under the National Uranium Resource Evaluation Program (Leach, 1977). Both the minus-30 to plus-80-mesh (0.18- to 0.60-mm) and minus-10- to plus-30-mesh (0.60- to 2.0-mm) fractions of stream sediments have been successfully used in geochemical reconnaissance studies in Saudi Arabia (Overstreet, 1978; Cheeseman and Thekair, 1979).

Bugrov (1974) found that different kinds of geochemical sampling techniques could be successfully applied to prospecting for ore deposits in the eastern desert of Egypt. He found that by removing the minus-0.25-mm fraction of stream sediments, which is mostly eolian material, the elemental concentrations of tin, molybdenum, and copper in the minus-1.0 to plus-0.25-mm fraction of stream sediments were enriched. Panning to produce heavy-mineral concentrates also removed eolian material and concentrated minerals that contained tin, tungsten, tantalum, niobium, and zirconium.

Coarse alluvium collected from dry washes and sieved to minus-2-mm was used by El Shazly and others (1977) to delineate beryl and tourmaline occurrences in the southeastern desert of Egypt. The elements beryllium, lithium, and boron were detected in the minus-2-mm sediment and correlated well with the chemistry of the underlying bedrock. However, the elements copper, nickel, lead, zinc, and cobalt were either not detected or were only detected in very low concentrations in alluvium, even though these elements were present in higher concentrations in the underlying bedrock; the loss of these elements was attributed to leaching by waters containing chloride and sulfate ions.

HEAVY-MINERAL CONCENTRATES

Panned heavy-mineral-concentrate samples derived from stream sediments have been used for many years in geochemical reconnaissance for ore deposits. The panned concentrates may be chemically analyzed "as is" after panning, or they may be further separated by density (using heavy liquids such as bromoform) and (or) separated on the basis of magnetic susceptibility into different magnetic and nonmagnetic fractions.

Heavy-mineral concentrates have two advantages over stream sediments in arid environments: (1) Diluting minerals such as quartz and feldspar have been removed in the panning process, and (2) The concentrate sample can be separated into different fractions, each of which may be studied under the microscope to confirm the presence of ore-related minerals determined by chemical analysis.

Examination of the sample under a binocular microscope is useful to confirm the presence of minerals that are indicated by the chemical composition of the sample. Microscopic examination is also necessary to determine the presence of contaminants, such as lead shot, scrap metal, and other metallic artifacts, that will cause false metal anomalies in samples.

Analyses of panned heavy-mineral concentrates "as is" and after removal of magnetite have been successfully used for geochemical reconnaissance in Saudi Arabia (duBray and Doebrich, 1981; Woolf, 1983). Ayalon and others (1981) separated heavy-mineral concentrates from stream-sediment samples collected near the Gulf of Aqaba into seven magnetic fractions. The element content of each magnetic fraction correlated with the mineralogical content of the fraction, which, in turn, could be related to bedrock type.

In a study of mineralization in northern Sonora, Mexico, both a minus-80-mesh stream sediment and material for a heavy-mineral-concentrate sample were collected at more than 1,200 sites. Heavy minerals were separated from the panned concentrate using bromoform and were then further separated into several magnetic and nonmagnetic fractions using an isodynamic separator. The fraction that was non-magnetic at 0.6 amperes was analyzed and used for geochemical interpretation because this fraction contained most of the primary and secondary ore minerals and was found to be geochemically independent of rock type (Turner and others, 1982).

The USGS began extensive use of heavy-mineral-concentrate samples following the geochemical study of the Hillsboro and San Lorenzo quadrangles in southwestern New Mexico (Alminas and others, 1975a, b, c; Alminas and Watts, 1978; Hedlund, 1979; Watts and others, 1979). In this study, the concentrate samples were separated into fractions that were non-magnetic and magnetic at 1.0 ampere. The nonmagnetic fraction contained light-colored, high-density accessory minerals, such as zircon, sphene, clinozoisite, and apatite, and, in mineralized areas, primary and secondary ore minerals, such as fluorite, galena, barite, scheelite, cassiterite, pyrite, chalcopyrite, molybdenite, and wulfenite. High metal concentrations in the nonmagnetic fraction occurred where primary and secondary ore minerals were exposed and were being mechanically transported to the stream bed.

The magnetic fraction from this area contained secondary hydrous iron and manganese oxides derived from fracture fillings and joint coatings. This material was mechanically transported to the stream bed. In mineralized areas, the magnetic fraction contained metal-rich oxides that were believed to result from processes associated with mineralization and later weathering.

Under certain geologic conditions, the most magnetic fraction of stream sediments (detrital magnetite) can be useful as a supplemental sample medium. Lovering and Hedal (1987) collected detrital magnetite with a hand magnet from dry sediment at several localities in southwestern New Mexico. The samples contained magnetite derived from the gangue of pyrometasomatic or hydrothermal base metal, tungsten, and tin deposits in carbonate host rock, and accessory magnetite derived from felsic plutonic rocks that are genetically associated with these deposits. Magnetite from these environments commonly contains abnormally high concentrations of ore metals. Analysis of the samples revealed geochemical anomalies that could be traced downdrainage for several miles.

Overstreet and Day (1985) surveyed the literature on the use of magnetic concentrates in geochemical exploration. In their review, the term "magnetic concentrates" referred to those minerals in panned concentrates that have a magnetic permeability considerably greater than one, a positive magnetic susceptibility, and that are attracted to a permanent magnet. These characteristics permit the magnetic fraction to be separated simply from the less magnetic components of concentrates. Magnetic concentrates are recovered readily by hand magnet from alluvial sediments or panned concentrates. They have been used successfully in exploration as a geochemical sample medium for copper, zinc, cobalt, chromium, molybdenum, niobium, vanadium, tin, and beryllium, particularly in arid environments where alluvial sediments may be contaminated by eolian debris.

However, according to Overstreet and Day, the ferromagnetic fraction of raw concentrates has been found to be less effective in general regional applications than either of the fractions of the raw concentrates magnetic at 0.6 ampere or nonmagnetic at 0.6 ampere. The ferromagnetic concentrate is a special-purpose medium. It may be the most suitable geochemical sample medium for the platinum-group metals where native alloys of these elements are in micron-size particles that defy gravity concentration. In the search for titanium and vanadium in deposits of titaniferous magnetite, the ferromagnetic concentrate appears to be the best geochemical sample medium.

SOILS

Desert soils tend to be very thin, with poorly developed profiles. The trace element composition corresponds generally to the underlying parent material (Lovering and McCarthy, 1978). Because soils are derived from a more restricted source area than are alluvial samples, desert soils are more suitable for studies of selected deposits than for reconnaissance geochemical sampling (fig. 2). In addition, the usefulness of soil samples is limited to
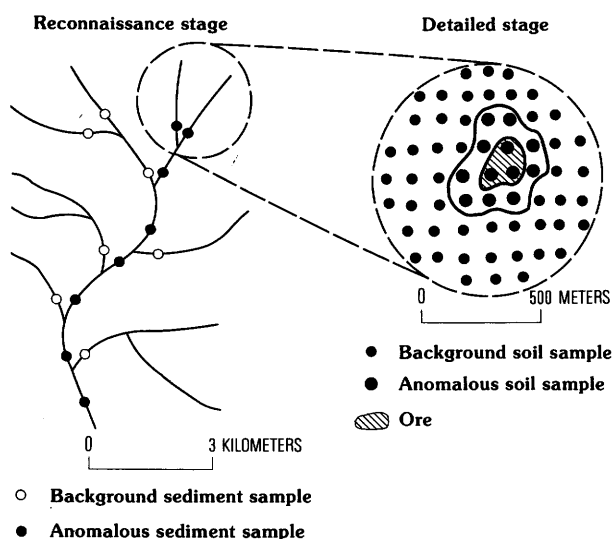
FIGURE 2.—Model of reconnaissance exploration using stream-sediment samples as contrasted to detailed exploration using soil samples. (Figure modified from Rose and others, 1979, p. 3.)

areas of low to moderate topographic relief because of problems in interpreting analyses of transported material. Another potential problem arises in sampling strongly wind-winnowed soils; high-density minerals, such as zircon and magnetite, may become enriched in these soils due to the removal of lower density minerals (Petrov, 1976, p. 271).

In spite of the potential problems described above, Snoep and Zeegers (1979) successfully used soil samples for a detailed study of the Socos deposit in Peru. Analyses of the soil samples showed that molybdenum was the most reliable element to indicate the location of primary mineralization in this area of 10–25 mm annual rainfall. In addition, multielement analyses of the samples enabled these researchers to forecast the size of the deposit.

WATERS

The use of surface water for geochemical sampling is rarely possible in desert areas. However, wherever springs, seeps, or wells are prevalent, water may prove to be a good sample medium to use to complement other geochemical sampling media. Analyses of waters collected from springs were useful for geochemical assessment of mineral resource potential in the Riordan's Well and South Egan Range Bureau of Land Management Wilderness Study Areas in Nevada (Hofstra and others, 1984; Rowan and others, 1984), because anomalous element concentrations in the water samples correlated well with anomalies in stream sediments and panned heavy-mineral concentrates.

Because interpretation of data resulting from multicomponent water analyses may not be straightforward due to various hydrologic and lithologic effects on the groundwater, factor analysis is often used to relate data from the water analyses to the geologic setting. Factor analysis is a statistical technique for resolving a large number of elements into a smaller number of components. These components can be examined for significance in terms of geological processes, types of samples, or other geological and geochemical information (Rose and others, 1979). For example, factor analysis was used successfully to show that element concentrations in water samples from deep irrigation wells are spatially related to a deeply buried porphyry copper deposit near Casa Grande, Arizona (Nowlan and others, 1981).

VEGETATION

Deep-rooted trees and plants can be useful sample media in desert environments because they can assimilate elements dissolved in groundwater flowing through concealed ore deposits, as long as the water comes into contact with the ore minerals and then the roots.

El Shazly and others (1971) made use of twigs, stems, and roots of two species of acacia trees to locate sulfide mineralization in the eastern desert of Egypt. In this area, analyses of copper, nickel, zinc, lead, and cobalt in acacia twigs yielded better geochemical anomalies than did analyses of corresponding alluvium samples. No differences in element concentrations were seen for the two species of acacia.

Although no elemental differences were seen for the two species of tree in the Egyptian example, different plant species, as well as different parts of a plant (for example, leaves, twigs, or roots) may accumulate different concentrations of elements. Therefore, the same plant species and the same part of the plant should be used for biogeochemical sampling in a given area. Selection of a single plant species that is uniformly present throughout a reconnaissance area may be difficult, and pilot studies will be required to select the best two or three species for the area. Plants should be sampled within a relatively short period of time, because of seasonal variations in the plants.

Chaffee and Hessin (1971) used soils and the leaves and stems of creosote, ironwood, and foothill paloverde to locate the concealed Vekol porphyry copper deposit southwest of Casa Grande, Arizona. Although anomalous concentrations of copper and molybdenum in soils located the buried deposit, the concentrations of these elements were much higher in the ash of plant

parts, and, in addition, the plant anomalies covered a larger area because the roots of the plants passed through barren alluvium and reached the buried deposit.

Chaffee (1976) conducted a biogeochemical survey over the Mineral Butte copper deposit, Pinal County, Arizona. Species collected were mesquite, catclaw acacia, blue paloverde, and ironwood. The first three of these species are phreatophytes that have deep and extensive root systems that may reach the permanent water table. Ironwood is not a true phreatophyte but grows larger in this area near stream channels where water is commonly available throughout the growing season. Results of analyses of ash from the vegetation were compared to results of analyses of soil and rock samples collected in the same area. Some conclusions from this study were as follows:

1. The relative abundances of copper, zinc, and molybdenum in the rocks and soils of the study area were not directly reflected by plants growing in the same materials.
2. The concentration of a given element varied with the plant species and plant part sampled.
3. All elements were not necessarily enriched in the same part of a given plant species.
4. Samples that contained anomalous concentrations of an element in the ash of both leaves and stems of a plant species were generally more reliable indicators of significant anomalies than were samples containing anomalous concentrations in only one part of the plant.
5. The Mineral Butte copper deposit was best located in this biogeochemical survey using the distribution of copper anomalies in plant ash.
6. The copper deposit was best located using analyses from mesquite samples. Catclaw acacia analyses were almost as effective; blue paloverde analyses may also be useful. Analyses from ironwood were much less effective in locating the deposit.

OTHER SAMPLE MEDIA

The sample media discussed previously are the most commonly used for geochemical exploration and mineral resource evaluation. However, other media are used on an experimental basis and should be mentioned. Data from these unconventional media are generally used to supplement more conventional data.

Soil gases are the most commonly used nonroutine medium. The samples are analyzed for carbon dioxide, oxygen, helium, sulfur compounds, and hydrocarbons. Anomalous concentrations of these
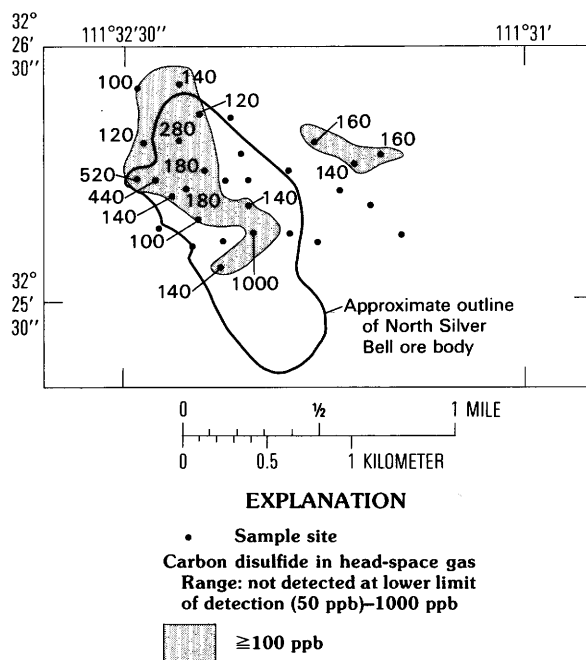

FIGURE 3.—Carbon disulfide in soil gases at the North Silver Bell deposit, near Tucson, Arizona (from Hinkle and Dilbert, 1984, p. 331).

volatiles rising from oxidizing minerals may help to detect concealed deposits (Hinkle, 1986; Hinkle and Dilbert, 1984; Lovell and others, 1980, 1983).

Interstitial gases between soil grains are collected by pounding a hollow probe about 0.5-meter into the ground, inserting a hypodermic needle through the septum of an air-tight fitting attached to the probe, and withdrawing the gas with a hypodermic syringe. Soil-gas samples are generally analyzed by gas chromatography or mass spectrometry.

Gases adsorbed on soils are another type of sample. This sample utilizes the soil as a natural trap to adsorb gases rising from below. Adsorbed gases are removed from soil by heating samples in closed containers. The gas over the soil in the container (the headspace gas) is removed by inserting a hypodermic needle through a septum in the cap of the container and withdrawing the gas with a hypodermic syringe. These gas samples are also analyzed by gas chromatography or mass spectrometry.

Soil samples were collected over the North Silver Bell copper deposit near Tucson, Arizona (Hinkle and Dilbert, 1984). Analyses of the volatile constituents derived from the soils showed that anomalous concentrations of helium, carbon disulfide, and sulfur dioxide occurred over the ore body; whereas, anomalous concentrations of carbon dioxide and carbonyl sulfide occurred over the alteration zones around the ore body. Figure 3 shows the carbon disulfide content of gases derived from soils.

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Both soils and soil-gas samples were collected along three traverses across the copper-zinc deposit at Johnson Camp in southeastern Arizona. The ore occurs as isolated sulfide and oxidized sulfide replacement bodies in limestone host rock and is covered by 10 to 225 meters of alluvium. Samples were analyzed for helium by mass spectrometry and for carbon dioxide and sulfur compounds by gas chromatography. Anomalous concentrations of carbon dioxide and helium in soil gases and anomalous concentrations of carbon dioxide degassed from soils were found over and adjacent to the ore bodies. Carbonyl sulfide and carbon disulfide degassed from soils were found in the vicinity of ore bodies occurring to within 150-meters depth, but not to 225-meters depth (Hinkle, 1986).

Results of several soil surveys in the vicinity of concealed gold deposits show that an aerobic spore-forming soil bacterium, *Bacillus cereus*, often occurs in greater numbers or as a greater percentage of the *Bacillus* population in soils overlying mineralized bedrock than in adjacent, unmineralized terrain. These differences may be of use in locating concealed mineral deposits. Other studies of penicillin resistance in soil bacteria over two copper deposits indicate that *B. cereus* might thrive over many mineral deposits. The ability of *B. cereus* to resist antibodies produced by metal-tolerant fungi in the soil gives *B. cereus* an advantage over other bacterial species in metalliferous soils, and appears to be a general phenomenon that may have broad applicability in geochemical exploration (Parduhn and others, 1985).

A procedure has been developed (Watterson, 1985) to estimate the numbers of *B. cereus* spores in soils and stream-sediment samples. The test is currently under investigation for its potential in mineral exploration, especially for buried deposits.

COMPARISON OF MEDIA

Many reconnaissance geochemical sampling programs involve the collection of two or more sample media and the preparation of subsamples from some of the media. More than one kind of sample is commonly collected in a pilot program to determine the best sample type for the area, while at other times whole regions are sampled using different media in order to compare the geochemistry of the different media to different rock units, or to different types of mineral deposits.

The two most common media collected for comparison are stream sediments and panned heavy-mineral concentrates. Theobald and Allcott (1973) compared five size fractions of stream sediments (plus-10, minus-10 to plus-30, minus-30 to plus-80, minus-80 to plus-200, and minus-200 mesh) in a pilot study in Saudi Arabia. Concentrations of boron, barium, and nickel in sediments finer than minus-80-mesh showed no variation, probably because of dilution by eolian sands. Analyses of the minus-10 to plus-30 size fraction distinguished rock types best. This sediment fraction and the nonmagnetic fraction of panned concentrates were selected as the two media for the study. The nonmagnetic fraction of panned concentrates was needed to detect molybdenum and tungsten anomalies in this environment.

DuBray (1981) compared five media in a granitoid terrane in Saudi Arabia. The minus-10 to plus-30 and minus-30 to plus-80 fractions of stream sediments, the minus-10 to plus-30 and minus-30 to plus-80 fractions of the nonmagnetic portions of panned heavy-mineral concentrates, and the ferromagnetic portion of the panned heavy-mineral concentrates were compared in this study. The greatest element enhancements were in the minus-30 to plus-80 and minus-10 to plus-30 fractions of the nonmagnetic portion of heavy-mineral concentrates. DuBray concluded that there was no need to sieve the nonmagnetic fraction and that the unsieved nonmagnetic fraction of stream sediments as well as rocks were the best sample media in this terrane.

The minus-0.5-mm (minus-35-mesh) fraction of stream sediment and a heavy-mineral concentrate were selected by the Bureau of Land Management (BLM) for 1,250 sample sites in portions of the California Desert Conservation Area. Results of semi-quantitative spectrographic analyses of these samples by the U.S. Geological Survey were used by the BLM to classify these areas for geology, energy, and mineral (GEM) resources (Lambie and others, 1983).

Bugrov and Shalaby (1975) compared several sample media in a geochemical survey in the eastern desert of Egypt. They determined that either cold-extraction analyses of the minus-0.075-mm fraction or spectrographic analyses of the minus-1.0-mm fraction of stream sediments was superior to panned heavy-mineral concentrates or bedrock samples for reconnaissance surveys in this area.

Huff (1970) sampled vegetation, soil, and well water around alluvium-covered copper deposits in Pima County, Arizona. The objective of the work was to find sample media that could "see" through about 50 meters of alluvium to the deposits below. The vegetation sampled consisted of shallow-rooted xerophytes, such as cacti and grass, and the deep-rooted phreatophytes, such as mesquite and palo-verde. The roots of mesquite and paloverde may reach

TABLE 1.—Copper and molybdenum content of soils and plants collected on or near Prospect hill Pima County, Arizona

[Table from Huff, 1970, table 2. All values are in parts per million]

Sample description	Samples collected on hill		Samples collected on alluvium 20–200 feet from foot of hill	
	Copper	Molybdenum	Copper	Molybdenum
Soil	40, 40, 40, 40, 60, 60, 60, 80, 100, 120, 120, 100, 300, 400.	1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 2, 2, 2, 5. .	10, 10, 10, 10, 15, 15, 15, 15, 15, 15, 15, 15, 15, 15, 20, 20.	1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 2, 2, 2, 2, 5.
Plants (after ashing):				
Mesquite, leaves	300, 450, 600.	30, 30, 45.	60, 80, 120, 120.	14, 15, 20, 30.
Mesquite, twigs	120, 120, 150.	8, 10, 15.	80, 80, 120, 120.	6, 6, 10, 14.
Palo verde	50, 70, 100.	2, 3, 6.	20, 30, 50.	2, 2, 6.
Grass	50, 100.	5, 6.	30, 50.	5, 8.
Jumping cholla	30, 70.	2, 2.	30, 30.	1, 3.
Prickly pear	15, 30.	1, 1.	10, 15.	1, 2.
White thorn	20, 70.	3, 4.	20, 30.	3, 8.
Ocotillo	300.	8.	--------	--------

the permanent ground-water table approximately 80 meters below the ground surface in this area. Samples were collected on and around a small mineralized hill, referred to as "Prospect hill" in table 1, to compare results from analyses of the various sample media. Except when collected directly over mineralized bedrock, soil samples did not contain significant quantities of copper, or of molybdenum, which is derived from molybdenite associated with primary copper ore. The ash of mesquite leaves and twigs contained higher concentrations of copper and molybdenum than did the ash of other vegetation collected in the same area.

Mesquite samples collected up to 12 kilometers away from the copper deposits showed the greatest molybdenum concentrations in the same areas where ground water had high molybdenum concentrations, which suggested that most of the molybdenum in mesquite was derived from the ground water rather than from the alluvium. Huff concluded that phreatophytes, such as mesquite, and ground waters were the best sample media for copper exploration in the Sonoran Desert environment of southern Arizona.

Chaffee and others (1976) compared untreated panned concentrate samples with minus-60-mesh (minus-0.25-mm) stream sediments and with the leaves and stems of mesquite and oak trees found in arroyos near and downstream from La Caridad porphyry copper deposit in Sonora, Mexico. These samples were analyzed by various techniques for as many as 37 elements. Although the minus-60-mesh stream sediment was considered to be the best

medium, any of the three media (stream sediments, panned concentrates, vegetation) were found to be adequate for locating this deposit (figs. 4–6).

SAMPLE PREPARATION AND ANALYSIS

PREPARATION

The two sample media most commonly used for mineral resource assessment by the USGS are stream sediments and panned heavy-mineral concentrates. By convention, the stream sediments are usually sieved to minus-80-mesh.

The panned heavy-mineral samples are first dried, then subjected to separation by bromoform (see fig. 7 for method of separation). Bromoform (specific gravity 2.80–2.89) separates the remaining quartz, feldspar, micas, and other low-density accessory minerals as well as clays and organics from the high-density heavy minerals which may contain ore minerals. The resulting heavy-mineral sample is separated into three fractions using a large electromagnet (in this case, a modified Frantz Isodynamic Separator[1]). The most magnetic material, primarily magnetite, is not analyzed. The second fraction, largely ferromagnesian silicates and iron oxides, is saved for analysis and archival storage. The third fraction (the least magnetic material contains zircon, sphene, and nonmagnetic ore minerals such as

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[1]Use of trade names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.
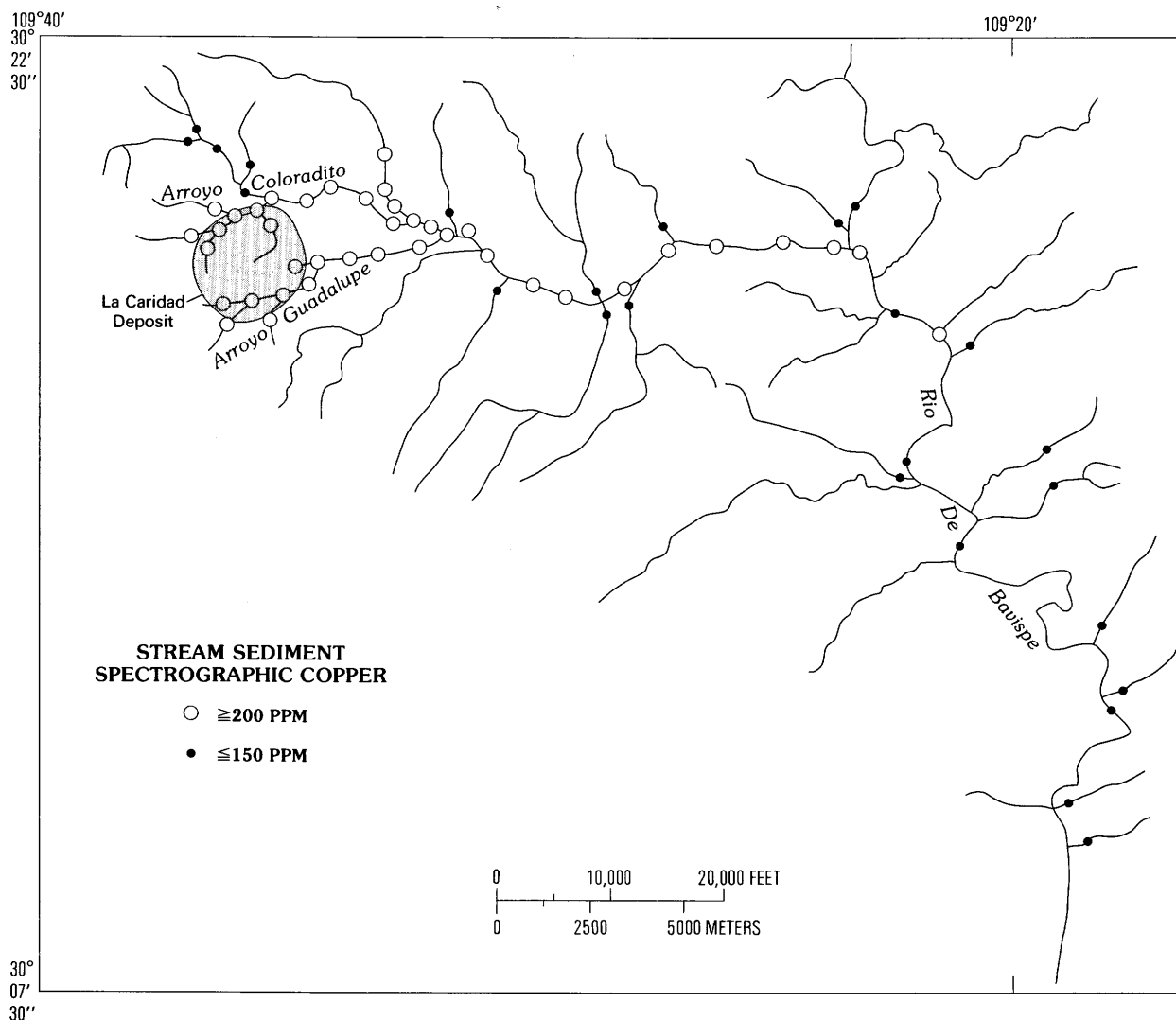
FIGURE 4.—Distribution of total copper in stream sediment, La Caridad porphyry copper deposit, Sonora, Mexico (from Chaffee and others, 1976, fig. 6).

metallic sulfides and their oxidation products) is split into two fractions. One half is hand ground for spectrographic analysis; the other half is saved for mineralogical analysis. The magnetic separates prepared by this procedure are the same separates that would be produced by using a Frantz Isodynamic Separator set at a slope of 15° and a tilt of 10° with a current of 0.1 ampere to remove the magnetite and ilmenite, and a current of 1.0 ampere to split the remainder of the sample into paramagnetic and non-magnetic fractions (fig. 7).

STANDARD ANALYTICAL TECHNIQUES

Optical emission spectrography is the most common method of analysis of geochemical samples by the USGS. In the spectrographic method used, a 10-mg or smaller sample is vaporized in a direct-current electric arc (Grimes and Marranzino, 1968). Spectrographic results are obtained by visual comparison of spectra derived from the sample against spectra obtained from standards made from pure oxides and carbonates. Standard concentrations are geometrically spaced over a given order of magnitude of concentration as follows: 100, 50, 20, 10, and so forth. Samples whose concentrations are estimated to fall between those values are assigned values of 70, 30, 15, and so forth. The precision of the analytical method is approximately plus or minus one reporting interval at the 83-percent confidence level and plus or minus two reporting intervals at the 96-percent confidence level (Motooka and Grimes,
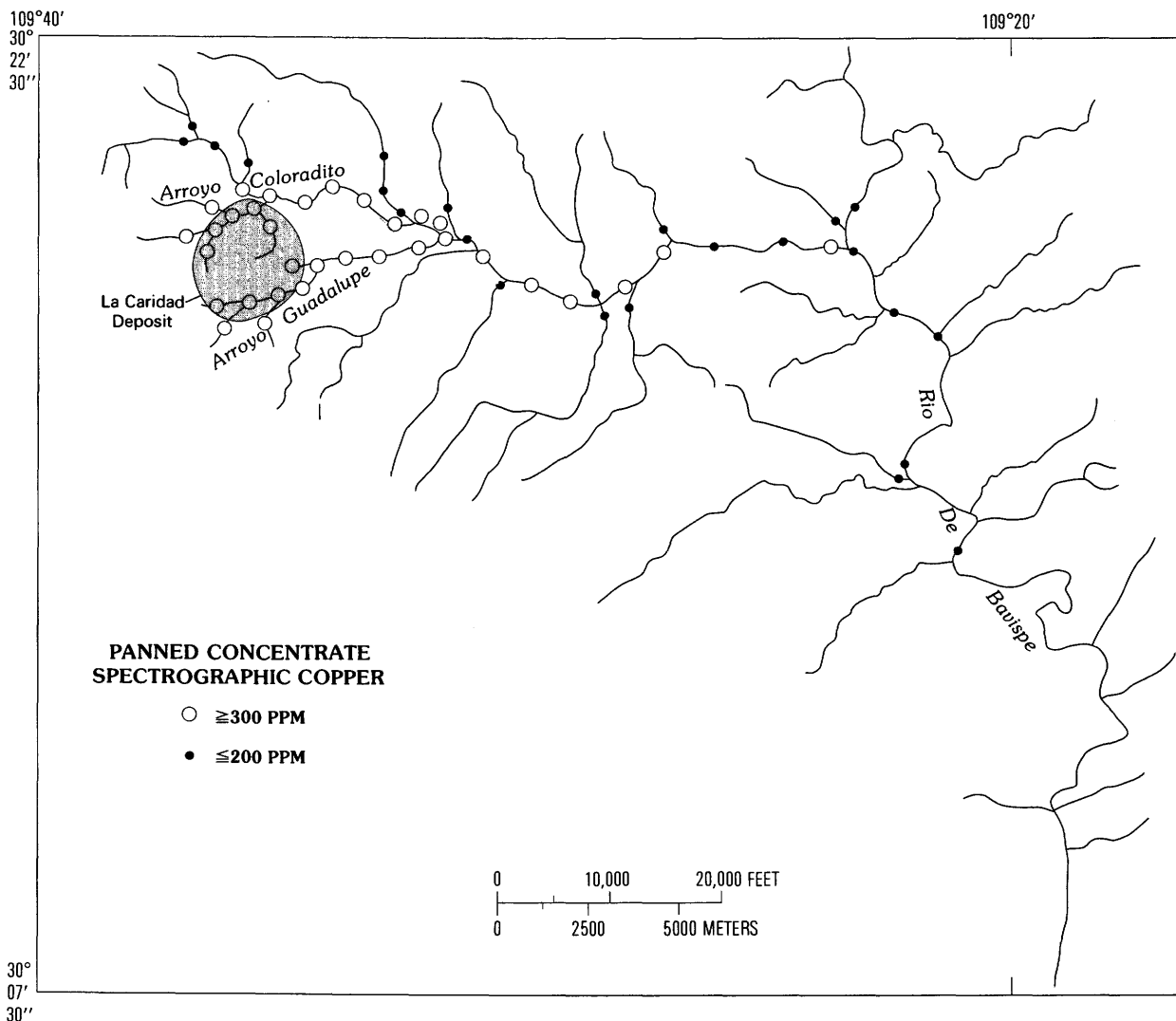
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FIGURE 5.—Distribution of total copper in panned concentrates, La Caridad porphyry copper deposit, Sonora, Mexico (from Chaffee and others, 1976, fig. 12).

1976). Table 2 shows the elements analyzed and their lower and upper limits of determination.

Wet chemical analytical methods, especially those for atomic absorption analysis, are also frequently used to supplement the emission spectrographic analyses. Table 3 lists the elements analyzed and chemical methods commonly used. Inductively Coupled Plasma (ICP) analytical methods are also used.

PARTIAL-EXTRACTION TECHNIQUES

In many instances, the lower limits of analytical determination for elements in rock and stream-sediment samples are too high for reconnaissance exploration and for exploration for blind ore deposits (Alminas and Mosier, 1975). The contrast between anomalous and background concentrations of metals can often be improved by comparing concentrations of metals that can be chemically leached from the surface of the sample, rather than by using an analysis of the total sample.

Higher concentrations of surficially bound elements occur more frequently in humid environments, where chemical leaching is more prevalent, than in arid environments. However, partial-extraction analysis can be used to determine the concentration of elements adsorbed or loosely bound on the surface of sediments, soils, and rocks collected in arid environments.

Copper in stream sediments and panned concentrates, collected near La Caridad porphyry copper deposit in Sonora, Mexico, was determined by
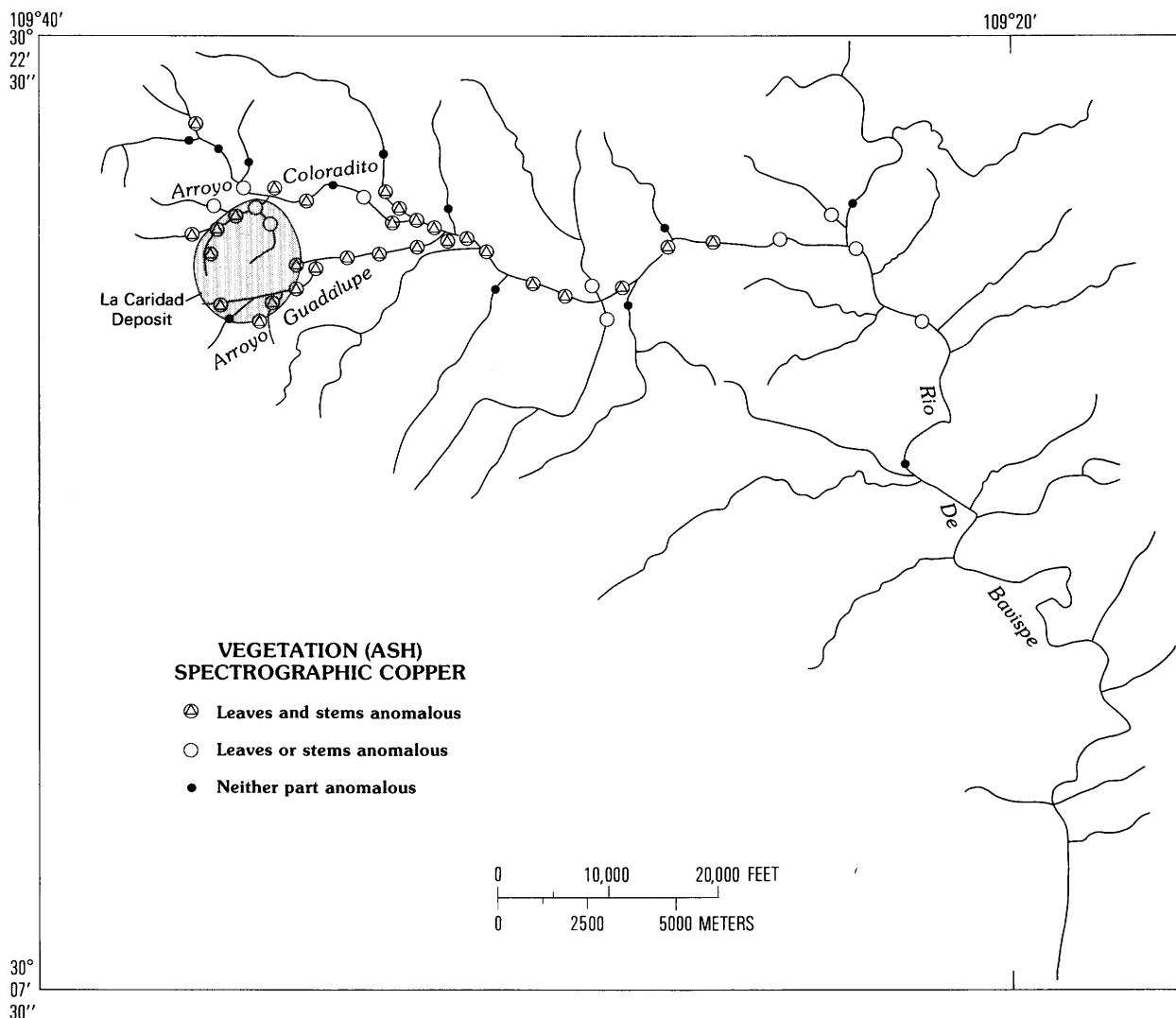
FIGURE 6.—Distribution of total copper in vegetation ash, La Caridad porphyry copper deposit, Sonora, Mexico (from Chaffee and others, 1976, fig. 16).

a cold-extractable method using a biquinoline extraction of copper leached from the sample with 6N hydrochloric acid (Ward and others, 1963). Results of these partial-extraction analyses gave anomaly patterns identical to the patterns for total copper analyses of these same media, although the magnitudes of the partially extracted copper concentrations were lower (Chaffee and others, 1976).

One of the most popular partial-extraction techniques used by the USGS is the oxalic-acid leach of Alminas and Mosier (1975). They determined that the dried residues remaining after boiling the stream-sediment samples with 1.5 N oxalic acid yielded analytical data equal in sensitivity and contrast to data obtained from heavy-mineral concentrate samples. The trace metals are derived from leached iron and manganese oxides in the dried residue sample.

Increasing clay content progressively dilutes the quantity of metals leached from a sample; therefore, the method may not produce useful data from clay-rich samples. Calcium-rich samples are not usable because ore-related metals may co-precipitate with calcium oxalate and thus be removed from the leachate (Alminas and Mosier, 1975).

Secondary iron and manganese oxides are significant in geochemical exploration. These oxides commonly occur as coatings on rocks, as concretions, and as colloidal-sized particles in stream sediments and soils, and the oxides strongly scavenge many ore-related metals in the weathering zone. These secondary oxides and their associated metals can be partitioned into different mineral phases and chemical forms by selective extraction techniques. Knowledge of the distribution of metals in various weathering

products is valuable for selecting sample media and extraction procedures, and in helping evaluate the significance of analytical data (Chao and Theobald, 1976).

Filipek and Theobald (1981) subjected samples of minus-80-mesh stream sediments from the North Silver Bell copper deposit near Tucson, Arizona, to a series of chemical extractions originally designed to separate different weathering fractions of samples from humid environments. The following fractions are effectively separated by this extraction scheme: (1) carbonates and exchangeable metals, (2) manganese oxides, (3) organic compounds and sulfides, (4) hydrous iron oxides, and (5) residual crystalline minerals (fig. 8). Jarosite and chrysocolla, two major minerals found in the North Silver Bell area, were found to dissolve over two or more steps of the extraction scheme. Results of these extractions showed that caution must be used when applying partial solution techniques to investigate geochemical partitioning in an arid (or semiarid) environment. The attribution of unique phases, such as manganese oxides or organic compounds, to a given extraction can lead to incorrect interpretations of weathering processes. Copper, lead, and zinc were extracted by acetic acid from samples near the mineralized zone, suggesting the occurrence of hydromorphic processes within the stream sediments in this area. In contrast, the residual fractions of the sediment samples gave the longest dispersion trains away from the deposit, suggesting that mapping total metal concentrations is most effective for reconnaissance surveys in arid environments for locating metal deposits.

The use of partial dissolution techniques in geochemical exploration is expanding in the USGS. Through understanding and application of appropriate selective and specific extractions, the effects on metal distribution caused by mineralization and those resulting from lithological and environmental factors can be differentiated. Knowledge gained from the use of partial dissolution techniques aids in the interpretation of chemical analytical data in relation to the geochemistry of the area sampled. Further development of these techniques and demonstration
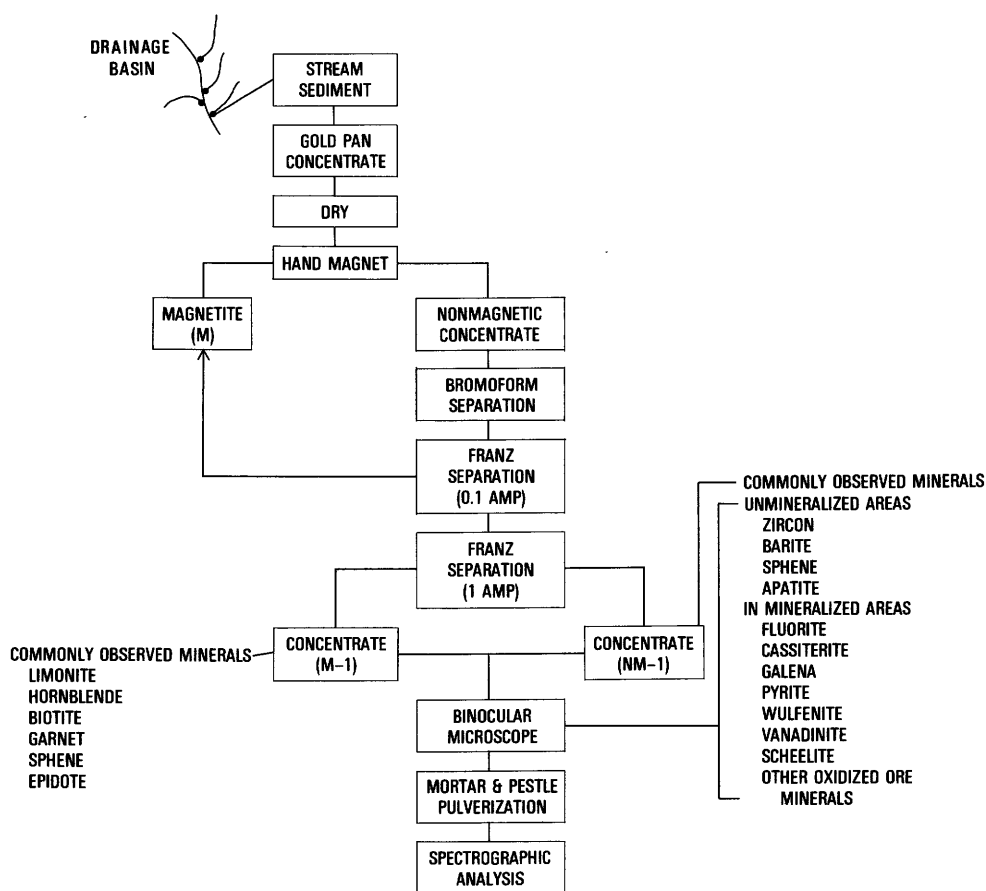

FIGURE 7.—Flow sheet for separation of sediment samples into magnetic (M) and nonmagnetic (NM) fractions (from Meyer and others, 1979, p. 427).

TABLE 2.—Limits of determination for the spectrographic analysis of rocks and stream sediments, based on a 10-mg sample

[The spectrographic limits of determination for heavy-mineral-concentrate samples are two reporting units higher than the limits given for rocks and stream sediments]

Elements	Lower determination limit	Upper determination limit
	Percent	
Iron (Fe)	0.05	20
Magnesium (Mg)	.02	10
Calcium (Ca)	.05	20
Titanium (Ti)	.002	1
	Parts per million	
Manganese (Mn)	10	5,000
Silver (Ag)	0.5	5,000
Arsenic (As)	200	10,000
Gold (Au)	10	500
Boron (B)	10	2,000
Barium (Ba)	20	5,000
Beryllium (Be)	1	1,000
Bismuth (Bi)	10	1,000
Cadmium (Cd)	20	500
Cobalt (Co)	5	2,000
Chromium (Cr)	10.	5,000
Copper (Cu)	5	20,000
Lanthanum (La)	20	1,000
Molybdenum (Mo)	5	2,000
Niobium (Nb)	20	2,000
Nickel (Ni)	5	5,000
Lead (Pb)	10	20,000
Antimony (Sb)	100	10,000
Scandium (Sc)	5	100
Tin (Sn)	10	1,000
Strontium (Sr)	100	5,000
Vanadium (V)	10	10,000
Tungsten (W)	50	10,000
Yttrium (Y)	10	2,000
Zinc (Zn)	200	10,000
Zirconium (Zr)	10	1,000
Thorium (Th)	100	2,000

of their ability to identify mineral deposits will lead to fuller utilization of partial dissolution techniques in geochemical exploration (Chao, 1984).

ROCK ANALYSIS STORAGE SYSTEM

Upon completion of all analytical work, the analytical results are entered into a computer-based file called Rock Analysis Storage System (RASS). This data base contains both descriptive geological information and analytical data. Any or all of this information may be retrieved and converted to a binary form for computerized statistical analysis or publication (VanTrump and Miesch, 1977).

CASE HISTORIES FROM THE U.S. GEOLOGICAL SURVEY

Results of sample media studies in arid environments by the USGS confirm the results described under "Previous Investigations." The case histories described here are results of mineral resource potential assessment studies of public lands proposed for wilderness designation by the Bureau of Land Management (BLM), especially in the California Desert Conservation Area (CDCA).

INYO MOUNTAINS WILDERNESS STUDY AREA

The Inyo Mountains Wilderness Study Area (CDCA–122, fig. 9) is located in the BLM California

TABLE 3.—Chemical methods commonly used by the U.S. Geological Survey Branch of Geochemistry

[AA = atomic absorption; I = instrumental; SI = specific ion; S = spectrophotometry; and F = fluorometry]

Element or constituent determined	Sample Type	Method	Determination limit (micrograms/ gram or ppm)	Analyst	Reference
Gold (Au)		AA	0.05		Thompson and others, 1968
Mercury (Hg)		I	0.02		Modification of McNerney and others, 1972, and Vaughn, and McCarthy, 1964.
Arsenic (As)		AA	5 or 10		Modification of Viets, 1978
Antimony (Sb)		AA	2		
Zinc (Zn)		AA	5		
Bismuth (Bi)		AA	1		
Cadmium (Cd)		AA	0.1		
Cobalt (Co)		AA	5		Ward, and others, 1969.
Copper (Cu)		AA	5		
Lead (Pb)		AA	5		
Nickel (Ni)		AA	5		
Zinc (Zn)		AA	5		
Fluorine (F)		SI	100		Hopkins, 1977.
Indium (In)		AA	0.2		Hubert and Lakin, 1973.
Thallium (Tl)					
Molybdenum (Mo)		AA	1		Modification of Rao, 1971.
Tellurium (Te)		AA	0.1		Chao and others, 1978
Tin (Sn)		AA	1		Welsch and Chao, 1976.
Tungsten (W)		S	0.5 or 1		Welsch, 1983.
Uranium (U)		F	0.05 or 1		Modification of Centanni and others, 1956.

Desert Conservation Area, on the eastern flank of the Inyo Mountains between Owens and Saline Valleys, west of Death Valley National Park in Inyo County, California. Stream sediments, sieved to minus-80-mesh, and the nonmagnetic (at 1.0 ampere) fraction of the panned heavy-mineral concentrate were used as sample media. These samples were analyzed by emission spectrography.

For the most part, stream sediments collected in the Inyo Mountains Wilderness Study Area (WSA) and contiguous areas did not contain trace elements known to be associated with mineralized rocks, in high enough concentrations to be detected by the analytical methods used, even when the samples were collected below mines and in known mineralized areas. These disappointing results probably occurred for several
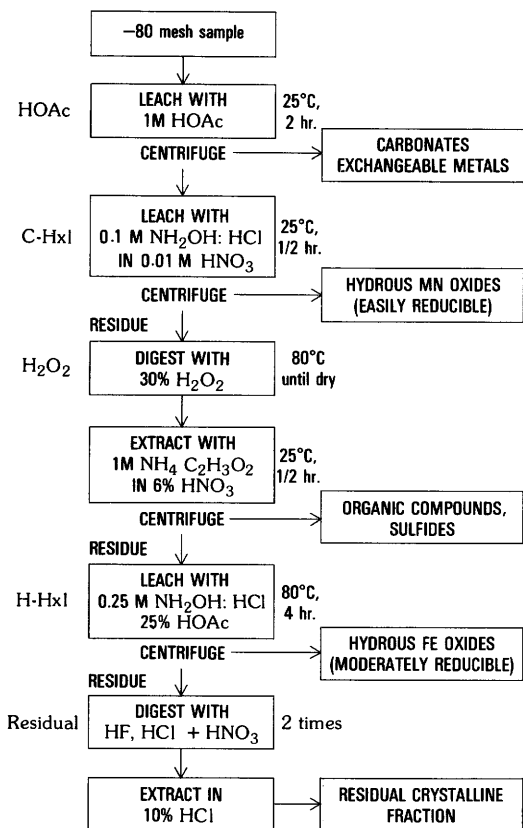
FIGURE 8.—Flow chart for the chemical fractionation of sediments and outcrop samples (from Filipek and Theobald, 1981, p. 160).

FIGURE 9.—Location of the Inyo Mountains Wilderness Study Area, Inyo County, California.

reasons, among them the loss of some resistant refractory ore minerals that might have been retained in the discarded plus-80-mesh stream sediments, and excessive dilution of the stream sediments by wind-blown sediment to the point where chemical detection of ore and ore-related elements was virtually impossible. The nonmagnetic fraction of the panned heavy-mineral concentrates, however, was very effective for detecting trace elements and thus delineating mineralized areas. Figures 10 and 11 compare analytical results for the two sample media (from J. E. Kilburn and D. E. Detra, written commun., 1985). After removal of the rock-forming silicates, clay minerals, and organic material, the content of ore and ore-related elements was enhanced to the point where it could be measured by the spectrographic method used. Furthermore, the variation in dilution by sedimentary processes was lessened.

In addition to the above studies, a set of samples from 40 sites in the Inyo Mountains WSA and nearby areas was selected for further analyses. The samples consisted of 40 minus-80-mesh stream sediments and 40 samples each of three fractions of heavy-mineral concentrates: (1) 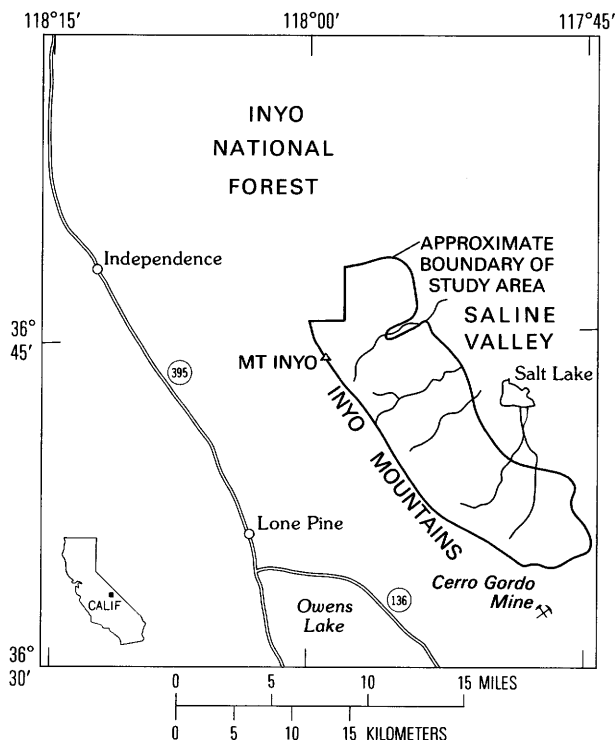the most magnetic fraction (largely magnetite), (2) the fraction containing mostly ferro-magnesian minerals and iron oxides, and (3) the fraction nonmagnetic at 1.0 ampere. Emission spectrographic analyses were performed on all the samples. In addition, ICP analyses were performed on the stream sediments, the magnetic fraction, and the ferromagnesian mineral fraction of the concentrates. Atomic absorption analyses were also performed on the stream sediments.

Results of the analyses showed that the emission spectrographic, atomic absorption, and ICP analyses of the stream sediments yielded data that were essentially equivalent for the purpose of geochemical interpretations. However, neither the stream sediments nor the ferromagnesian minerals, regardless of analytical treatment, indicated the presence of elemental dispersion trains away from a metallic source.

The most useful data for geochemical interpretation came from the spectrographic analyses of the nonmagnetic material. These data indicated elemental dispersion trains away from metallic sources.

The most magnetic, or the magnetite fraction, of the concentrate samples did not yield data useful for geochemical interpretations in this area. Gold was not detected by any analytical procedure in any of the sample media, although some of the sample sites were
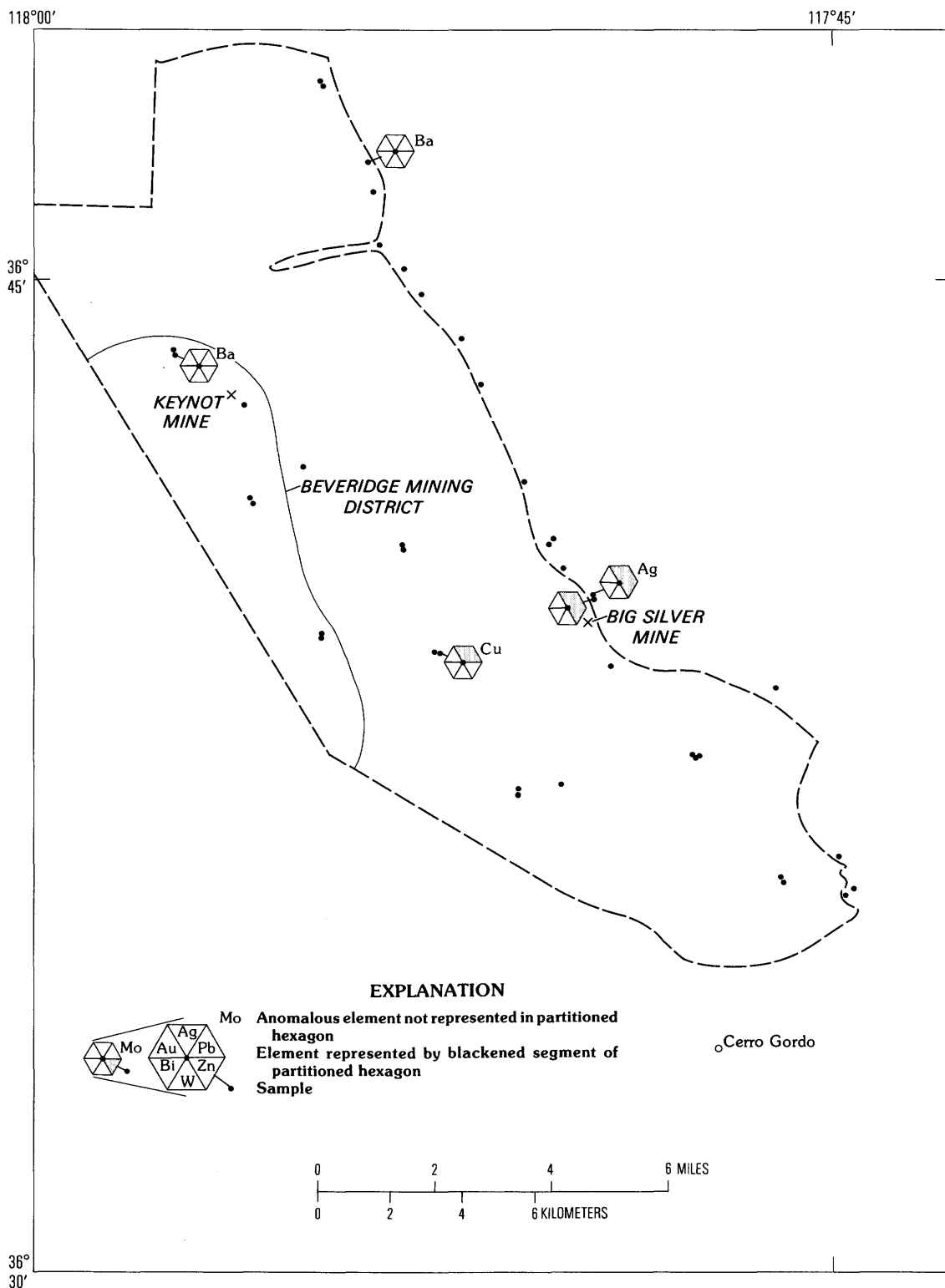
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FIGURE 10.—Anomalous elements in stream-sediment samples, Inyo Mountains Wilderness Study Area, California (from J. E.Kilburn and D. E. Detra, written commun., 1986).

located in areas where a possibility existed that gold might be detected in the samples (J. E. Kilburn and D. E. Detra, written commun., 1985).

A portion of the nonmagnetic fraction of the panned heavy-mineral concentrate samples was retained for mineralogical identification under the

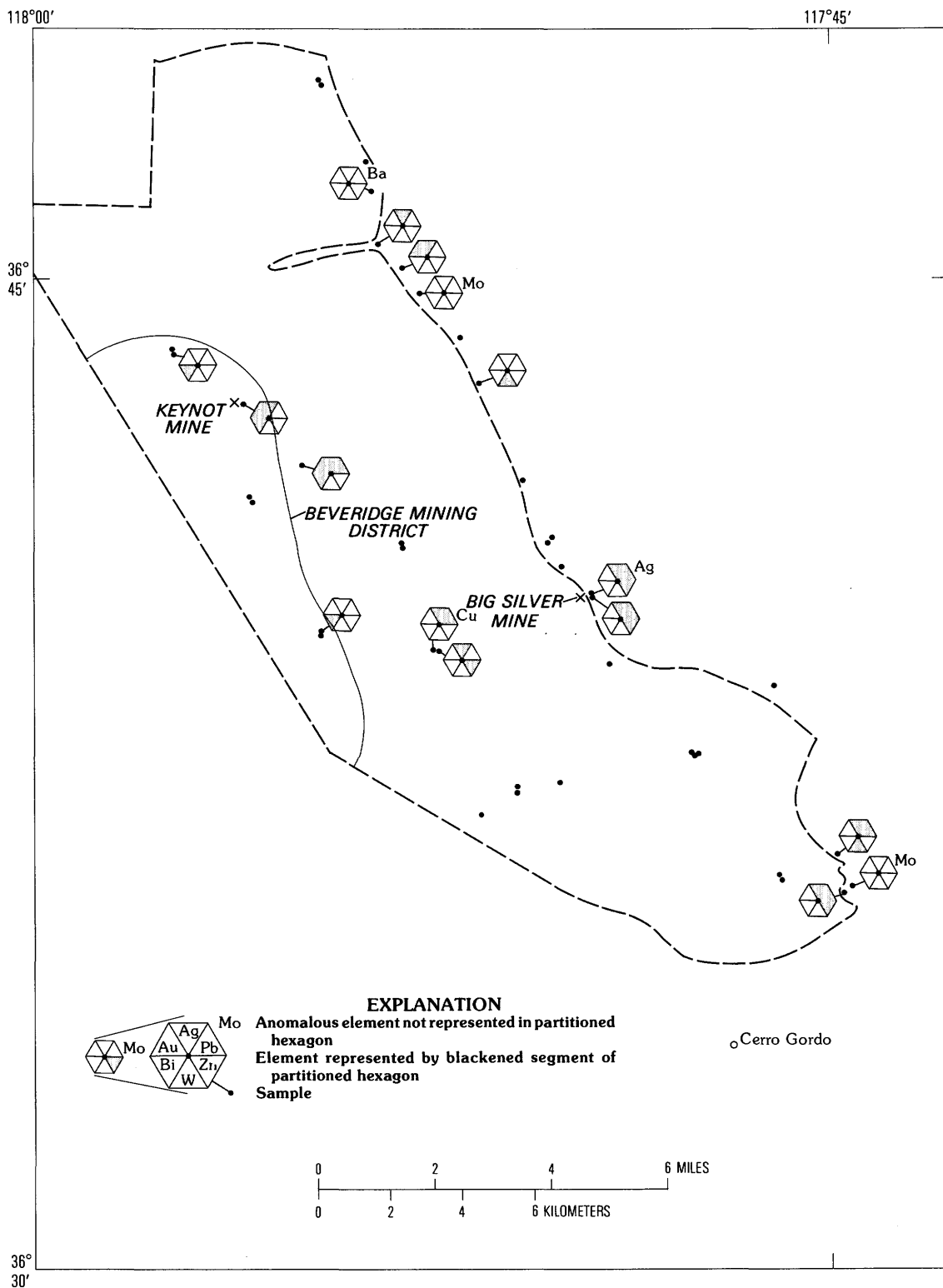FIGURE 11.—Anomalous elements in the nonmagnetic fraction of panned heavy-mineral concentrates, Inyo Mountains Wilderness Study Area, California (from J. E. Kilburn and D.E. Detra, written commun., 1986).

microscope. Trace-element concentrations in the analyzed portions of the nonmagnetic samples corresponded well with the mineralogical composition that was identified in the samples. Therefore, the
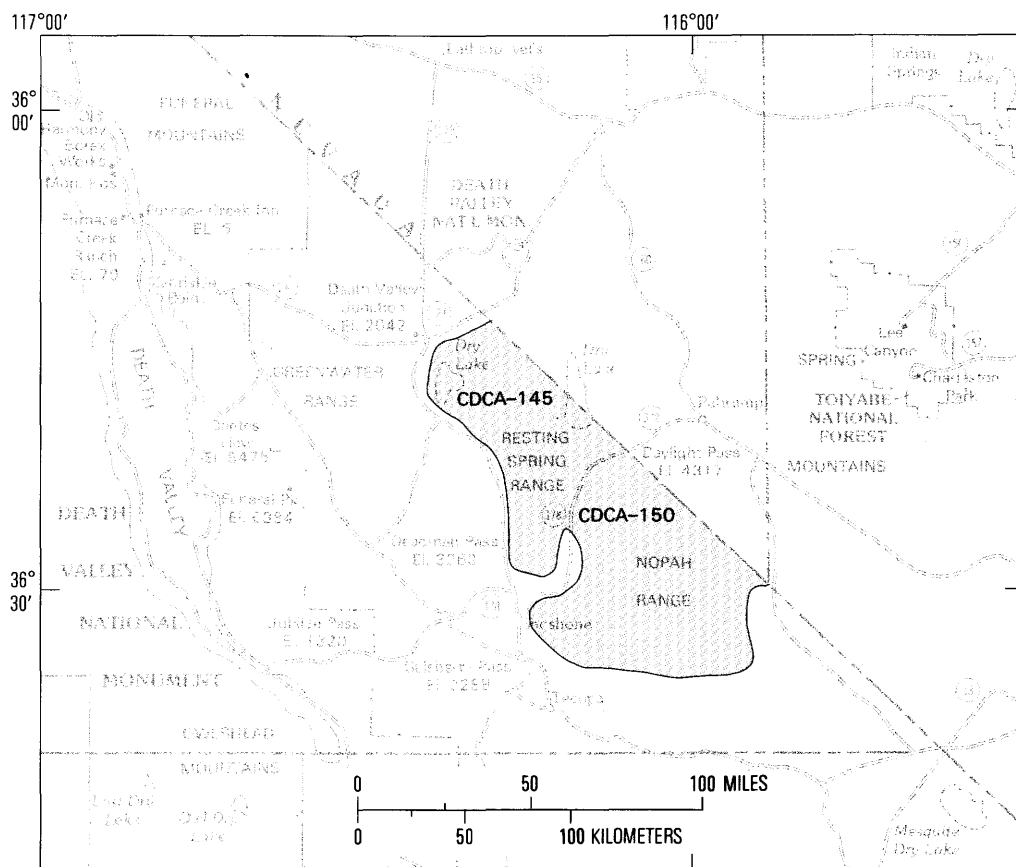
nonmagnetic heavy-mineral concentrates were used as the sample medium for the geochemical appraisal.

NOPAH AND RESTING SPRING WILDERNESS STUDY AREAS

The Nopah and Resting Spring Wilderness Study Areas (CDCA–145, CDCA–150) consist of the central part of the Nopah Range, which is located east of Death Valley National Park, California, between California State Highway 127 and the California-Nevada boundary (fig. 12). Minus-80-mesh stream sediments and the nonmagnetic (at 1.0 ampere) fraction of panned heavy-mineral concentrates were collected for the geochemical reconnaissance of the area. In this study, the minus-80-mesh sediments were resampled later in the same year. All samples were analyzed by emission spectrography. Strong element anomalies in the nonmagnetic heavy-mineral concentrate samples delineated an area of mineralized rocks near the site of an old mine. Element anomalies in the minus-80-mesh stream sediments collected in the spring of the year were weak, but they also

delineated the same area of mineralized rocks. However, the minus-80-mesh stream sediments collected in the fall of the same year did not delineate the area of mineralized rocks. Replicate analyses of selected samples from both sets of sediments confirmed previous results. The discrepancy in analytical results between minus-80-mesh stream-sediment samples collected in spring and fall of the same year may be due to differences in composition of the sediments between spring and fall field seasons; hydromorphic enhancement of the metal content during winter runoff could have increased metal contents of the spring samples; however, wind-blown dust could have diluted the fall samples (C. L. Smith, written commun., 1983).

INDIAN PASS AND PICACHO PEAK WILDERNESS STUDY AREAS

The Indian Pass (CDCA–355) and the adjacent Picacho Peak (CDCA–355A) Wilderness Study Areas are located in easternmost Imperial County, California, about 25 miles (40 km) north-northwest of Yuma, Arizona (fig. 13).
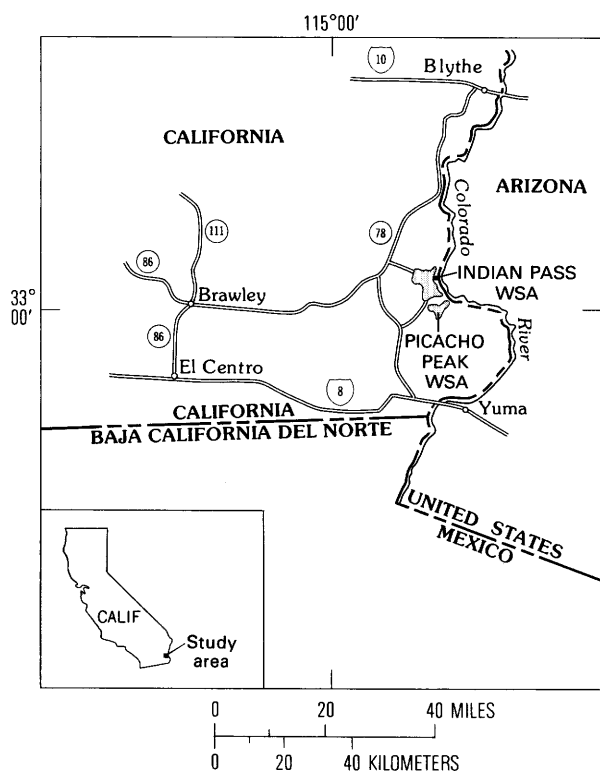
FIGURE 13.—Location of the Indian Pass and Picacho Peak Wilderness Study Areas, Imperial County, California.

Sample media used in these two areas were the minus-80-mesh stream sediments, the nonmagnetic (at 1.0 ampere) fraction of heavy-mineral concentrates, and rocks. All the sample media were analyzed by emission spectrography. In addition, the stream sediments and the rocks were analyzed by wet chemical procedures.

Analysis of the nonmagnetic fraction of heavy-mineral concentrates derived from stream sediments proved to be the most useful in delineating areas of possible mineralization within the WSA's. A plot of anomalies for barium, strontium, tungsten, bismuth, gold, silver, and arsenic in heavy-mineral concentrates showed two areas within the Indian Pass WSA with distinctive multielement geochemical signatures. High concentrations of tungsten and bismuth occur in the northwestern quadrant of the WSA, where alteration and mineralization seem to be localized near the contact of the Orocopia Schist and an intruding granite. The northeastern quadrant of the WSA was characterized by high concentrations of arsenic, barium, antimony, strontium, and boron in non-magnetic heavy-mineral concentrates; mineralization here is thought to be related to hot-spring activity localized near faults.

Analysis of minus-80-mesh stream sediments proved to be of minimal value for this study. Stream sediments in the northeastern quadrant of the Indian Pass WSA showed anomalous arsenic. Gold was not detected in the sediment samples. Apparently, dilution by quartz, feldspar, and other common rock-forming minerals was so great that elements related to mineralization were not anomalous in this sample medium (Smith and others, 1987).

Many rock samples contained anomalous elements. Spectrographic analyses showed high concentrations of arsenic, copper, and zinc; however, atomic absorption analyses indicated high concentrations of arsenic, gold, silver, antimony, zinc, and tungsten in rocks.

KELSO DUNES WILDERNESS STUDY AREA

The Kelso Dunes Wilderness Study Area (CDCA–250, fig. 14) lies in central San Bernardino County, California, about 60 miles west of the Colorado River.

Yeend and others (1984) collected samples from sites on the dunes and from sites in dry washes around the dunes. A raw sand sample and a sand sample for heavy-mineral concentration were collected at each site. Four sites were sampled at each dune: the windward face, dune crest, slip face on the leeward side, and trough between dunes. All samples were analyzed by emission spectrography. In addition, selected samples were analyzed for gold by atomic absorption procedures.

The geochemical populations for all elements within the concentrate samples showed little variability. Analyses of the raw sands showed somewhat greater variability than the concentrate analyses; however, statistical analyses of these data did not identify any geochemical associations characteristic of economic mineralization.

Sand samples from dune crests generally contained higher concentrations of iron, titanium, manganese, cobalt, chromium, niobium, vanadium, yttrium, and zinc than did samples collected on other parts of the dunes. These elements were determined to be associated with magnetite, which was observed to be enriched on many dune crests, and to be unrelated to any mineral resource (Yeend and others, 1984).

SOUTH PROVIDENCE MOUNTAINS WILDERNESS STUDY AREA

The South Providence Mountains Wilderness Study Area (CDCA–262, fig. 15) is located in San Bernardino County, southeastern California, in the southern part of the Providence Mountains. The area
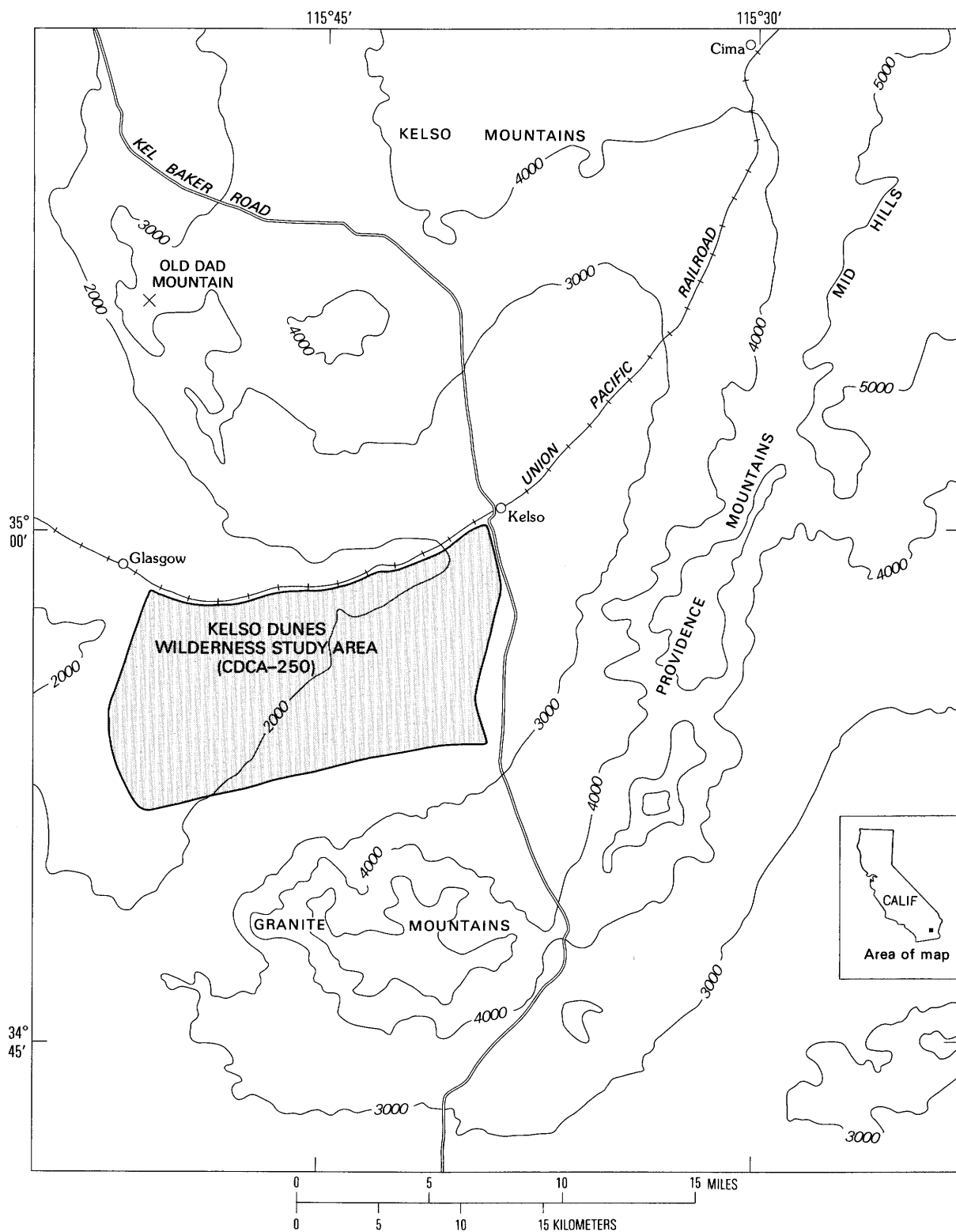
FIGURE 14.—Location of the Kelso Dunes Wilderness Study Area, San Bernardino County, California.

generally encompasses terrain lying south of Foshay Pass and north of Interstate Highway 40.

Minus-80-mesh stream sediments, the nonmagnetic (at 1.0 ampere) fraction of heavy-mineral concentrates, and rocks were used in the study area. All samples were analyzed by emission spectrography.
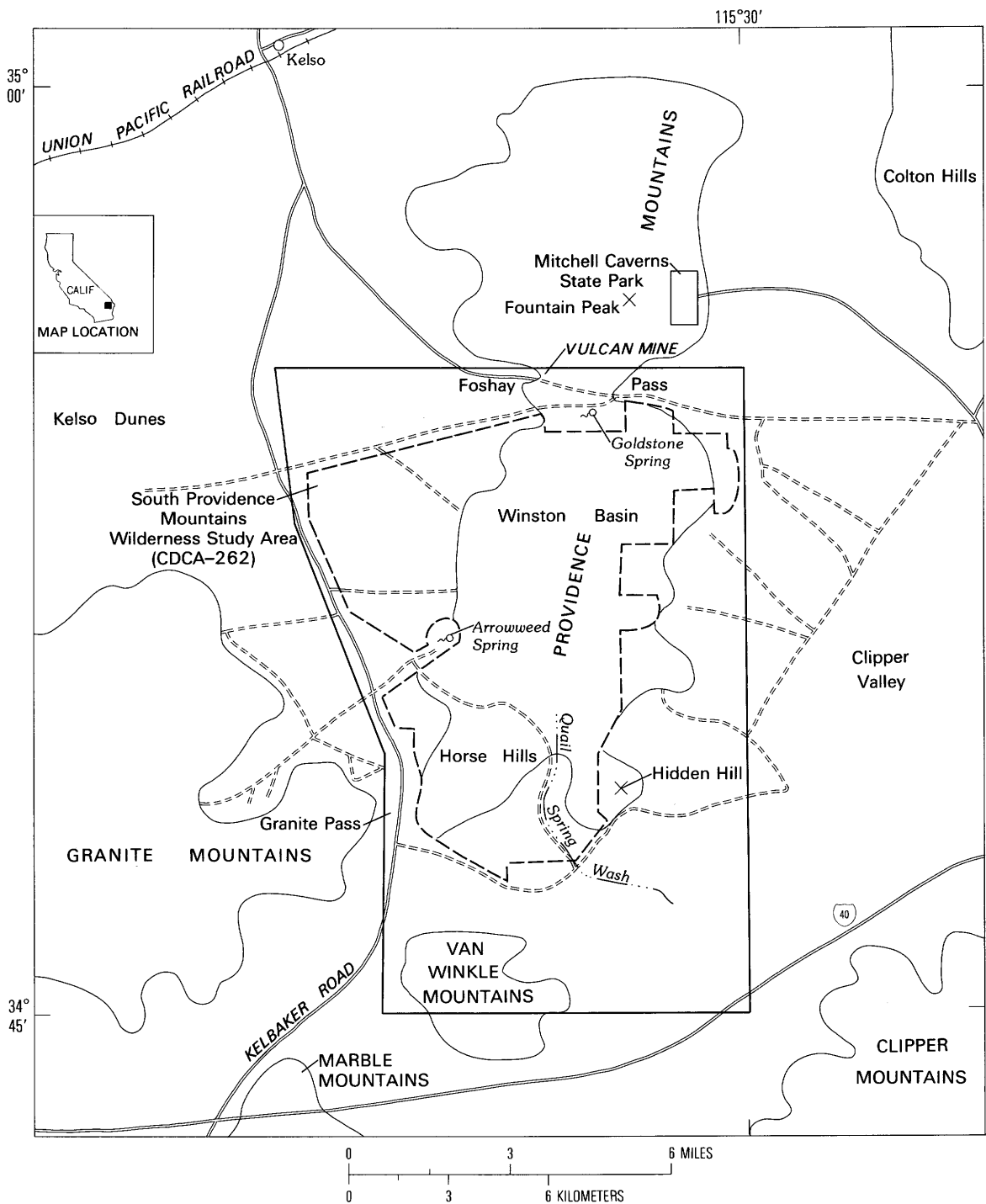
FIGURE 15.—Location of South Providence Mountains Wilderness Study Area, San Bernardino County, California.

In addition, the stream sediment and rock samples were analyzed by atomic absorption procedures for gold, arsenic, bismuth, cadmium, antimony, zinc, and mercury.

In some parts of the area, both stream sediments and concentrates contained anomalous concentrations of ore-related elements. For the stream sediments, areas interpreted as having highest resource potential were defined by a silver-arsenic-gold-bismuth-copper-mercury suite of elements. Anomalous concentrate samples had a distinctive element suite of silver-gold-copper-lead-strontium (with or without barium, bismuth, and molybdenum). Some of these anomalies could be traced to old mines in the area. Other anomalies indicated potential for undiscovered mineral resources (Miller and others, 1984).

RIORDAN'S WELL WILDERNESS STUDY AREA

The Riordan's Well Wilderness Study Area (NV–040–166) is located in east-central Nevada approximately 12 miles southeast of the town of Currant, east of U.S. Highway 6 and west of Nevada Highway 318 (fig. 16).

Geochemical assessment of the metallic mineral resource potential in this area was based on samples of minus-80-mesh stream sediment, the nonmagnetic (at 1.0 ampere) fraction of the heavy-mineral concentrates, and spring and well waters. All the analytical data from these media were subjected to factor analysis. Samples of rock that showed evidence of mineralization were also collected and analyzed but were not subjected to factor analysis.

All the sample media contained anomalous concentrations of metallic elements. Two areas in the wilderness study area were determined to have moderate potential for gold-tungsten mineralization such as occurs in the nearby Troy mining district. These areas are located along the southwestern margin and at the northwest boundary of the study area. The areas were outlined by anomalous concentrations of one or more of the elements—tungsten, tin, molybdenum, bismuth, lead, and zinc—in the nonmagnetic heavy-mineral concentrates; gold and lead in rocks; and arsenic in stream sediments.

Two other areas, located in the south-central and north-central parts of the WSA, were determined to have moderate potential for epithermal precious-metal mineralization. These areas were outlined by anomalous concentrations of one or more of the following elements or constituents: zinc in heavy-mineral concentrates; gold, silver, arsenic, antimony, boron, zinc, copper, and molybdenum in rocks; arsenic, zinc, boron, and silver in stream sediments; and arsenic and sulfate ion in spring waters (Hofstra and others, 1984).
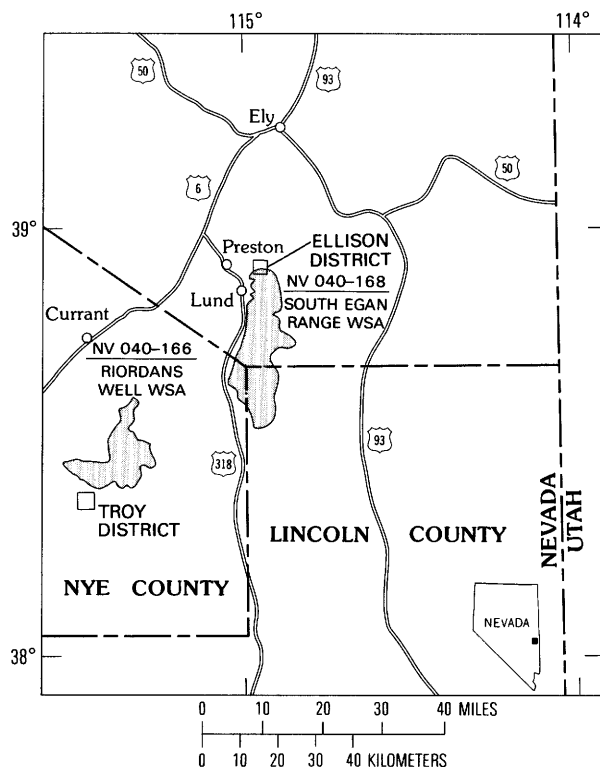

FIGURE 16.—Location map of Riordan's Well and South Egan-Range Wilderness Study Areas, Lincoln, Nye, and White Pine-Counties, Nevada.

SOUTH EGAN RANGE WILDERNESS STUDY AREA

The South Egan Range Wilderness Study Area (NV–040–168) is located in east-central Nevada at the junction of White Pine, Lincoln, and Nye Counties, about 25 miles south of the town of Ely, and lying between Nevada Highway 318 on the west and U.S. Highway 93 on the east (fig. 16).

Geochemical assessment of the metallic mineral resource potential in this area was based primarily on samples of minus-80-mesh stream sediment and the nonmagnetic (at 1.0 ampere) fraction of heavy-mineral concentrates. Supplemental information was obtained from analyses of spring and well waters. All data resulting from analyses of these media were subjected to factor analysis. Rock samples were also collected, mainly from outcrops showing evidence of mineralization; rocks were analyzed but not subjected to factor analysis. Geochemical anomalies in the South Egan Range WSA tended to be broadly distributed throughout the area, rather than clustered as in the nearby Riordan's Well WSA.

One region of previously identified mineralization is located at the northern end of the WSA and includes the southern portion of the Ellison mining district where veins were mined for precious and base metals.

A porphyritic intrusion with potential for molybdenum mineralization lies below the near-surface vein system. This region was defined by anomalous concentrations of one or more of the elements lead, copper, zinc, tin, molybdenum, and bismuth in concentrates. Only a few stream-sediment samples contained anomalous concentrations of elements in this region; these elements were silver and arsenic. Rock samples generally had anomalous concentrations of a large number of metallic elements, including silver, bismuth, cadmium, copper, molybdenum, tin, tungsten, lead, zinc, arsenic, and antimony. Spring water samples collected east of the study area contained anomalous lead and copper concentrations.

A second area of known mineralization also occurs in the northern part of the WSA. This area has subeconomic disseminated gold and silver mineralization and was delineated by anomalous concentrations of copper, lead, zinc, and cobalt in concentrates and copper, arsenic, and nickel in the stream sediments (Rowan and others, 1984).

CONCLUSIONS

From this review of previous investigations it can be seen that the study of a nonmagnetic fraction of heavy-mineral-concentrate sample medium is the most effective method for locating metals, such as copper, lead, zinc, tin, and tungsten, in arid environments. The use of this medium has consistently enabled researchers to delineate areas of known and potentially mineralized rocks. Such identification of mineralized areas can be expected, provided that the mineralized rocks are exposed to erosion. Concentration of the heavy minerals by panning and then separation of the minerals by the use of bromoform and magnetic susceptibility isolates those minerals, such as metallic sulfides and their oxidation products, which can be related to mineralization.

Stream sediments, in comparison, may or may not delineate even known and exposed mineralized areas. The dilution of sediment by other rock-forming minerals, such as quartz and feldspar, or by eolian dust makes stream sediments less effective than the nonmagnetic fraction of panned heavy-mineral concentrates for locating mineralization in arid environments.

However, the relative success in locating base-metal mineralization with nonmagnetic concentrates does not imply that this is the only sample medium that should be used for exploration or mineral resource assessment. For example, gold may not be detected in concentrate samples because the distribution of gold in nature is often heterogeneous. Therefore, in the search for gold deposits, all sample media collected should be analyzed for elements, such as arsenic, antimony, or mercury, which may be associated with gold.

Partial-solution chemical techniques have been successfully used in various studies to extract ore-related metallic elements from stream sediments collected in arid areas, and to obtain data that are comparable to data obtained from nonmagnetic heavy-mineral concentrates. In some situations, partial-solution techniques might replace nonmagnetic heavy-mineral concentrates as a preferred sample medium for geochemical exploration in arid environments.

For current BLM mineral resource assessment work, the U.S. Geological Survey relies heavily on data that are obtained from analyses of the nonmagnetic fraction of panned heavy-mineral concentrates. Supplemental information may also be obtained from analyses of other sample media, such as stream sediments, rocks, waters, plants, soils, soil gases, or from bacteria surveys. Use of the most effective sample media for the environment enhances the value of the mineral resource assessment.

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