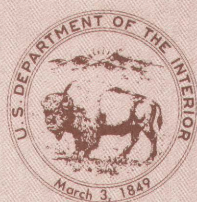


Trace Elements in Magnetic
Concentrates from Stream Sediments
in Southwestern New Mexico—
A Potential Tool for Reconnaissance
Geochemical Exploration in Arid Lands

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By T. G. LOVERING *and* J. A. HEDAL

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TRACE ELEMENTS IN MAGNETIC CONCENTRATES FROM STREAM SEDIMENTS IN SOUTHWESTERN NEW MEXICO— A POTENTIAL TOOL FOR RECONNAISSANCE GEOCHEMICAL EXPLORATION IN ARID LANDS

BY T. G. LOVERING AND J. A. HEDAL

ABSTRACT

Detrital magnetic concentrates were collected from stream sediments at several localities in southwestern New Mexico. The concentrates contain magnetite derived from the gangue of pyrometamorphic 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 the ore metals. Samples were obtained with a hand magnet and were not panned. Analysis of the concentrates reveals geochemical anomalies that are traceable down-drainage for several miles under favorable circumstances. This study shows that detrital magnetic concentrates can be rapidly collected in the field and may provide a useful sample medium for reconnaissance geochemical exploration for certain types of mineral deposits in arid lands.

INTRODUCTION

The use of stream-sediment samples in reconnaissance geochemical exploration for metallic mineral deposits is standard procedure. However, there is less general agreement as to the most useful portion of the sediment sample to analyze. Sediment samples may be separated into various size fractions by sieving, into heavy- and light-mineral fractions by panning, or into magnetic and nonmagnetic mineral fractions with a hand magnet. The magnetic fraction obtained by this last operation normally consists of a nearly monomineralic concentrate of detrital magnetite or "black sand," in contrast to the fine-size fraction obtained by sieving, or the heavy-mineral concentrate obtained by panning, both of which are composed of heterogeneous assemblages of detrital minerals.

Numerous studies of the distribution of ore and indicator elements in various size fractions of stream sediments collected downdrainage from known deposits have shown that the fine fraction (-80 mesh) generally contains a greater concentration of these elements and a longer anomaly train below the deposit than do the coarser fractions, and furthermore, the fine fraction can be analyzed directly without requiring grinding in the laboratory. However, this sample medium may fail to show anomalies related to certain types of deposits such as gold-bearing quartz veins and cassiterite deposits, where the values tend to concentrate in coarser particles. Furthermore, in arid environments characterized by prevalent strong winds, the fine fraction may be so diluted with eolian dust particles as to obscure any locally derived anomalies.

Bulk sediment samples collected at the same localities as the fine fraction samples and subsequently panned to yield a heavy-mineral concentrate will provide a sample medium that largely compensates for deficiencies of the fine-fraction samples, and will generally yield metal anomaly patterns more closely related to updrainage mineral deposits in arid lands than can be derived from the fine-fraction sediment samples. However, collecting and transporting the bulk samples to a water supply, then hand panning each sample to yield an adequate quantity of heavy-mineral concentrate for subsequent analysis requires a considerable amount of time and effort.

Magnetic concentrates share the advantage of fine-fraction sieved sediments in that they can be obtained directly from dry sediment at the sample site, and they share the advantage of panned concentrates in being relatively free from contamination by windblown dust. However, in many areas the abundance of barren detrital magnetite derived from mafic igneous rocks or arenaceous sedimentary rocks can mask anomalies from magnetite that is genetically related to mineral deposits to such an extent that this sample medium is rarely used. Nevertheless, magnetite bodies associated with hydrothermal or contact metasomatic ore deposits commonly contain highly anomalous concentrations of ore metals (Freitsch, 1970, p. 75-89; Kisvarsanyi and Proctor, 1967; Theobald and Thompson, 1959). Anomalous concentrations of zinc and tungsten, reflecting ore deposits of these elements in the upstream drainage basin, have been found in detrital magnetite concentrates from stream sediments more than 32 kilometers (20 mi) downstream from their source (Theobald and Thompson, 1959). Accessory magnetite from quartz monzonite intrusives that are genetically associated with base-metal deposits may also contain anomalous concentrations of these metals (Hamil, 1967).

This pilot study of detrital magnetite in stream sediments, derived from various types of deposits in an arid to semiarid environment, was undertaken to investigate the usefulness of detrital magnetic concentrates as a tool for reconnaissance geochemical exploration in arid lands of the western United States. The study involves three contact metasomatic deposits around felsic intrusives in carbonate rocks (Iron Mountain, Copper Flat, and Hanover), one area of fissure vein deposits in carbonate rocks (Chloride), one quartz monzonite intrusive genetically related to small base-metal deposits (Cuchillo Negro), and one lead-silver-manganese replacement deposit in carbonate rock (Lake Valley) (fig. 1).

We are indebted to our colleagues A. V. Heyl and C. H. Maxwell who suggested the sample localities and provided background information on the geologic setting of the deposits. Sample analyses were performed by D. F. Siems. Map illustrations were prepared by Teresa Feder.

COMPOSITION OF MAGNETIC CONCENTRATES

Although "black sand" concentrates are composed predominantly of the mineral magnetite (Fe_3O_4), they commonly contain many other mineral impurities, which may be present as surface films and fracture coatings, small inclusions, or foreign particles cemented by and adhering to detrital magnetite grains.

Elements, other than iron, which are determined by spectrographic analysis of these concentrates, may be either bound within the mineral lattice of the magnetite, substituting for ferrous or ferric iron or filling holes in the lattice; or else they may be important constituents of foreign minerals associated with the magnetite. These elements may be divided into four groups on the basis of their ability to substitute for iron in the magnetite lattice and their prevalence in associated minerals in magnetic concentrates. Group 1 elements, abundant in magnetite but not in accessory minerals, include V and Zn. Group 2 elements, abundant both in magnetite and accessory minerals, include Co, Cr, Mg, Mn, Sn, and Ti. Group 3 elements with limited substitution in magnetite, but abundant in accessory minerals, include Be, Bi, Cu, Mo, Ni, Sc, and W. Group 4 elements, which are not concentrated in magnetite, but are present in accessory minerals, include Ag, As, Au, B, Ba, Cd, La, Nb, Pb, Sb, Sr, Y, and Zr. Table 1 shows the median concentrations and observed range of concentrations of 25 elements detected in one or more of the 30 samples collected in this study; elements are arranged in order of decreasing median concentration.

SAMPLE LOCALITIES, SAMPLING, AND ANALYTICAL PROCEDURES

All of the deposits that were sampled in this investigation are in Grant and Sierra Counties, N. Mex.; their approximate locations are shown on figure 1. Samples were collected downdrainage at 100-meter

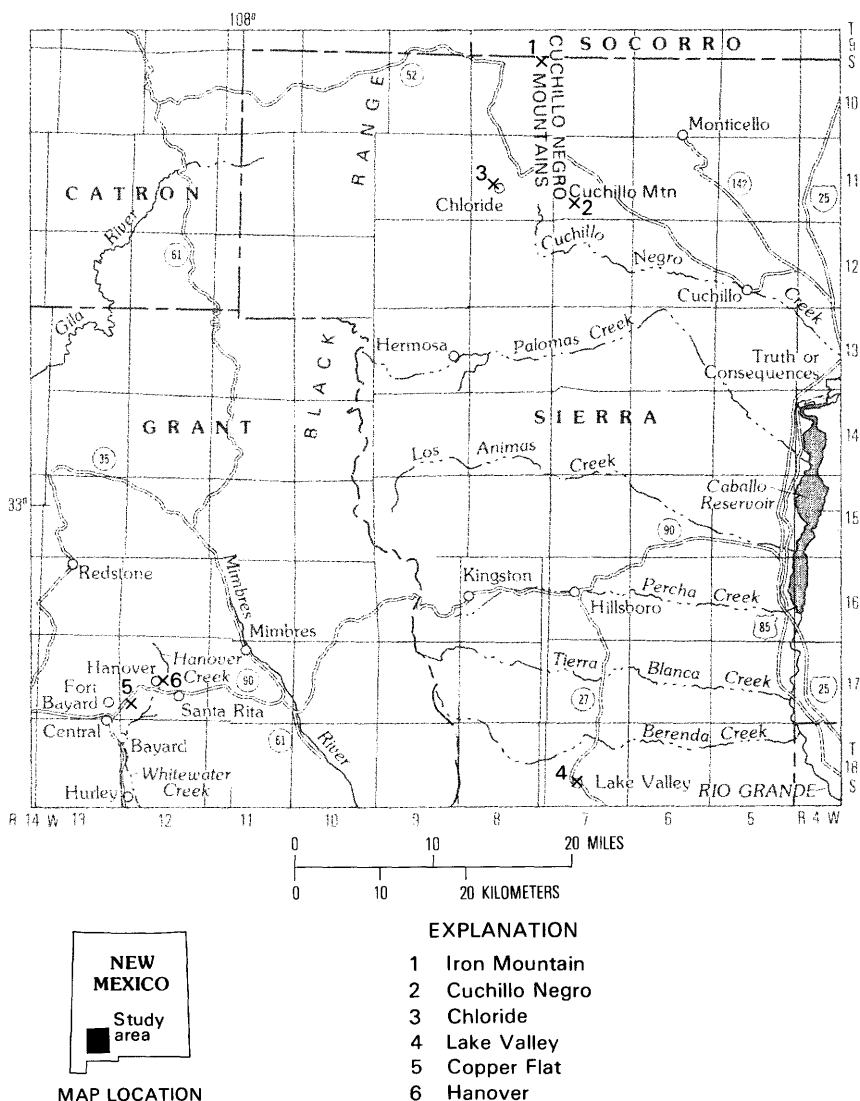


FIGURE 1.—Index map showing location of areas from which magnetic concentrates were collected.

(330-ft) intervals in close proximity to the deposits and at intervals of about 2 kilometers (1.6 mi) farthest from the deposits.

The sampling procedure consists of attaching one end of the keeper bar on a horseshoe magnet to one pole of the magnet and inserting the other end into a concentration of "black sand" (detrital magnetite) in dry stream sediment. The bar with magnetic particles clinging to it is then transferred to a sample container and the upper end of the bar is detached from the magnet, allowing the adhering particles to drop into the sample container. This process is repeated until an adequate sample (about 10 g) is obtained. The keeper bar is then wiped

TABLE 1.—*Median concentrations, anomaly thresholds, and concentration ranges of elements in magnetic concentrate samples from New Mexico*

[N = detection limit]

Element	Median	Anomaly Threshold	Range
Percent			
Fe	30.	---	20-50
Ca	1.	2.	2-3
Ti	1.	2.	.2->2
Mg	.5	1.5	.2-2
Mn	.3	.7	.1->1
Zn	.1	.2	.05-1
Parts per million			
V	700	2,000	100-3,000
Cr	200	1,000	100-3,000
Zr	200	700	70-1,000
Ba	200	500	<50-500
Cu	150	500	15-2,000
Sr	<200	300	N-700
Ni	100	200	30-500
Pb	50	200	20-700
La	50	100	N-100
Co	50	100	30-100
W	N(<70)	70	N-1,000
Y	30	70	<20-100
Sn	N(<15)	30	N-700
Sc	12	15	N-20
Nb	N(<30)	50	N-70
B	<20	20	<20-100
Mo	N(<7)	10	N-700
Bi	N(<15)	15	N-50
Be	5	7	2-30

clean and reattached across the poles of the horseshoe magnet. Sample containers are then sealed, appropriately labeled, and stored for transportation to the analytical laboratory, where they are ground to a fine powder with ceramic plates and analyzed semiquantitatively for 31 elements with a D.C. arc spectrograph.

RESULTS OF INVESTIGATION

Detrital magnetite samples, derived from each of the deposits investigated, show characteristic compositional features which differ from any of the other sample suites. Median concentrations and ranges for each element in the samples from each area are shown in table 2.

CONTACT METASOMATIC DEPOSITS

The three contact metasomatic deposits sampled differ from each other in their geologic setting and in the types of mineral deposits with which they are associated. The Iron Mountain deposit in Sierra County consists of contact metasomatic iron ore in Paleozoic sedimentary rocks that have been intruded by Tertiary granite, aplite, and porphyritic rhyolite. Contact metasomatic skarn zones consist dominantly of garnet, magnetite, and hematite as well as a large variety of accessory minerals. Minor Cu, Be, Mo, Sn, and W mineralization is associated with the iron.

The Copper Flat deposit in the Central mining district, Grant County, consists of an unexposed granodiorite porphyry lacolith cut by a slightly younger quartz latite porphyry stock or plug intruded into Lower Mississippian Lake Valley Limestone and the overlying Middle and Upper Pennsylvanian Oswaldo Formation, a calcareous unit with a basal 9-meter (30-ft) thick shale unit. The stock or plug is surrounded by an irregular belt of alteration and replacement in the limestone and shale. The shale unit is altered to hornfels and the Oswaldo Formation to magnetite, sphalerite, and garnet with minor chalcopyrite adjacent to the stock. This deposit was first prospected for copper about 1900 and has since produced some iron ore and a considerable quantity of zinc.

The Hanover area, also in Grant County, is characterized by a large northerly trending stock of granodiorite porphyry, intruded into the Oswaldo Formation at the southern end. The stock is cut by a complex network of granodiorite porphyry and quartz monzonite porphyry dikes. The Oswaldo Formation limestone, at the contact with the granodiorite stock, has been metasomatized to a calc-silicate skarn

TABLE 2.—*Distribution of elements in magnetic concentrates from six areas in New Mexico*

[n = number of samples, M = median concentration, R = concentration range, N = not detected]

Element	Iron Mountain (n = 5)		Copper Flat (n = 9)		Hanover (n = 2)	Cuchillo Negro (n = 2)	Chloride (n = 8)		Lake Valley (n = 4)	
	M	R	M	R	R	R	M	R	M	R
Percent										
Fe	50	30-50	30	20-50	50	30	20	20-30	40	30-50
Mg	1.5	.7-2	.3	.2-.5	.2-1	.3-.7	.7	.5-1	.7	.5-1
Ca	.5	.3-3	1	.7-1.5	.3-.5	1-2	1.5	1.5-2	.5	.2-1
Ti	.3	.2-1.5	.5	.2-1.5	.5-.7	1.5-2	2	1.5-2	>2	>2
Mn	>1	.7->1	.3	.2-.5	.3-.7	.1-.15	.3	.2-.5	.7	.7-1
Parts per million										
B	20	<20-20	20	<20-20	<20-20	N	<20	<20-20	<20	<20
Ba	150	<50-200	200	150-500	200-300	150-500	200	200-500	200	200-500
Be	20	7-30	10	7-15	3-5	5-7	5	3-7	2	2-3
Bi	<20	N-50	N	N-20	N	N	N	N	N	N
Co	70	30-70	70	30-100	50	70	50	50-70	100	100
Cr	100	100-200	200	150-700	150-300	3,000	1,500	700-2,000	1,000	700-1,000
Cu	20	15-30	700	300-2,000	150-1,000	150	150	100-150	200	100-200
La	50	N-100	70	50-100	<50	N	50	<50-100	50	N-100
Mo	20	20-700	20	<10-70	N-10	N	N	N	N	N-10
Ni	50	30-70	200	100-500	50-100	500	150	100-150	200	200
Pb	30	20-50	500	200-700	30	150	70	50-100	200	100-700
Sn	500	150-700	N	N-300	N	N	N	N-50	20	N-50
Sr	N	N	<200	<200-200	<200-200	200-500	300	200-700	<200	<200-200
V	150	100-500	300	200-700	700-3,000	1,500	1,000	500-1,500	1,500	1,500
W	N	N-1,000	N	N	N	N	N	N	N	N
Y	30	<20-100	50	50-70	20	<20-20	30	30-50	30	30-50
Zn	10,000	700-10,000	3,000	2,000-5,000	500-700	1,500-2,000	1,000	1,000-1,500	1,000	1,000
Zr	100	70-150	150	100-200	500-1,000	300	500	200-700	700	700-1,000

containing masses of magnetite garnet rock from which a considerable quantity of iron ore has been produced. Beyond the borders of this contact zone there are several large zinc-lead vein and replacement ore bodies in the Oswaldo Formation.

IRON MOUNTAIN

The Iron Mountain deposit is on the western flank of the north end of the range locally known as the Cuchillo Negro Mountains in northern Sierra County in secs. 35, 2, 3, 10, and 11, T. 9-10 S., R. 8 W. (fig. 2). It extends about 5.6 kilometers ($3\frac{1}{2}$ mi) north-south, and ranges in width from 0.4 to 0.8 kilometer ($\frac{1}{4}$ to $\frac{1}{2}$ mi). An iron-rich skarn zone has developed at the upper contact of a Tertiary granitic intrusive and the overlying Paleozoic sedimentary rocks. Limestone beds near the contact have been converted to a massive tactite composed dominantly of coarsely crystalline magnetite, garnet, and hematite, cut by small fractures containing deuteric or hydrothermal fluorite, apatite, diopside, hornblende, quartz, feldspar, idocrase, spinel, biotite, chlorite, scheelite, powellite, willemite, helvite, bertrandite, pyrite, pyrrhotite, sphalerite, and galena. Massive tactite grades outward through a zone of "ribbon rock" consisting of alternating crenulated layers of magnetite and of fluorite mixed with a variety of silicate minerals, into an outer zone of coarsely recrystallized limestone with scattered inclusions of epidote and tremolite (Jahns, 1944).

Iron ore was mined here in the early 1900's, and during the 1940's small deposits of beryllium and tungsten were mined and stockpiled. A dump sample of siliceous iron ore from a mine near the summit of the Iron Mountain ridge contains anomalously high concentrations of Be, Bi, Cd, Co, Cu, F, In, Mo, Pb, Sn, Te, V, W, and Zn. Nonmagnetic heavy-mineral concentrates from streams draining the Iron Mountain district give strong anomalies for tin and tungsten.

Five magnetic concentrate samples were collected from a stream draining westward from the southern end of the Iron Mountain ridge (fig. 2). The results of spectrographic analyses of these five samples are shown in table 3.

Sample 1, from the area of tactite just below a prospect pit, contains highly anomalous concentrations of Mn, Bi, Mo, Sn, W, and Zn. Concentrations of these elements in the samples collected farther downstream show an irregular fluctuation that cannot be readily explained, but the farthest downstream sample (5), taken nearly 3 kilometers (2 mi) below the deposit, is still highly anomalous in Mn, Be, Sn, and Zn.

COPPER FLAT

The Copper Flat deposit is in the Central mining district, Grant County, about 5 kilometers (3 mi) west of the old townsite of Santa Rita in secs. 19 and 30, T. 17 S., R. 12 W. (fig. 3). At Copper Flat a small irregular stock of quartz latite porphyry of probable Late Cretaceous age has intruded the basal shale unit and overlying impure limestones of the Middle and Upper Pennsylvanian Oswaldo

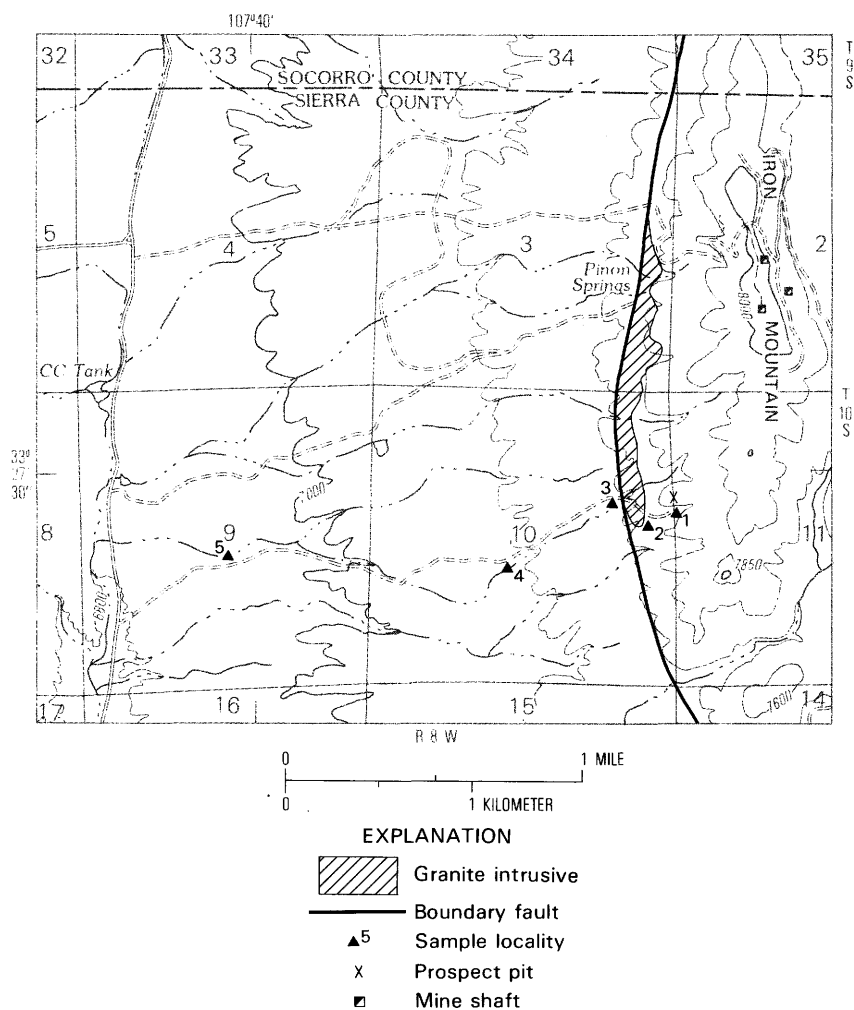


FIGURE 2.—Location of magnetic concentrate samples from Iron Mountain district.

TABLE 3.—*Analyses of magnetic concentrates from stream sediments in the Iron Mountain district*

[Ag, As, Sb, and Sr not detected. N, not detected. D. F. Siems, analyst, USGS]

Element	Sample Nos.				
	1	2	3	4	5
Percent					
Fe	50	30	30	50	50
Mg	1.5	.7	2	1.5	1.5
Ca	3	1.5	.3	.3	.5
Ti	.2	1.5	.3	.3	.5
Mn	>1	.7	>1	>1	>1
Parts per million					
B	<20	20	20	<20	20
Ba	<50	70	200	150	150
Be	7	7	30	20	30
Bi	20	N	N	50	<20
Co	70	70	30	50	70
Cr	100	150	700	100	200
Cu	20	30	15	15	30
La	N	50	100	N	100
Mo	700	20	30	20	20
Ni	50	70	30	50	50
Pb	50	20	30	30	50
Sc	N	20	<10	<10	<10
Sn	700	150	500	500	700
V	100	500	100	150	150
W	1,000	N	N	100	N
Y	<20	100	30	20	50
Zn	10,000	2,000	10,000	700	10,000
Zr	150	150	70	100	70

Formation. This stock is approximately 0.6 kilometer (1,800 ft) long east-west by 0.3 kilometer (900 ft) wide at the surface, and is surrounded by a belt of metasomatically altered rock consisting of a silicate hornfels containing garnet, epidote, chlorite, actinolite, tremolite, quartz, and chlorite. Within this hornfels are tabular and lenticular bodies of magnetite and hematite, locally containing abundant marmatitic sphalerite with subordinate chalcopryrite and supergene chalcocite (Hernon and others, 1964; Hernon and Jones, 1968).

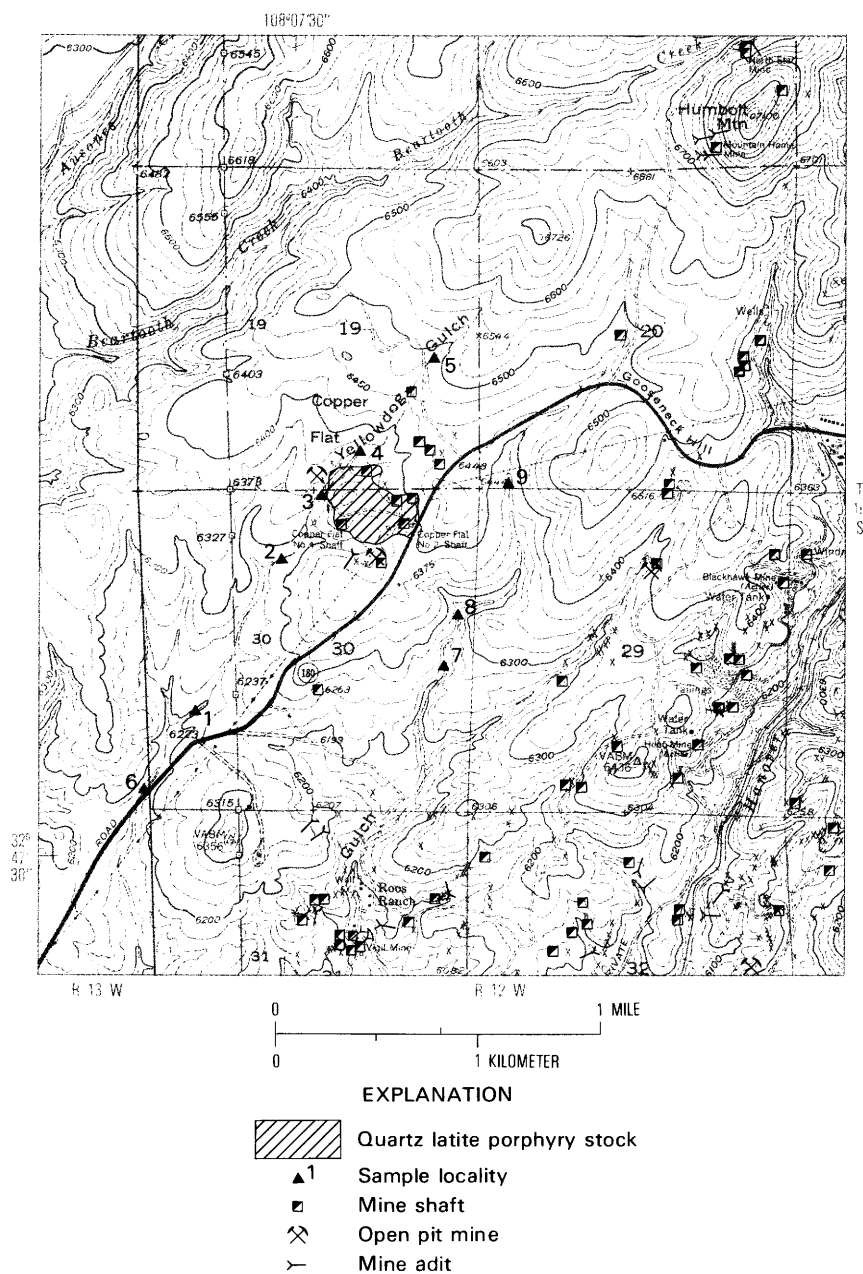


FIGURE 3.—Magnetic concentrate sample localities in the Copper Flat area. Base from U.S. Geological Survey 1:24,000, Fort Bayaud, 1947, and Santa Rita, 1951.

The area was first prospected for copper about 1900, and later, iron ore was mined from surface deposits. Mining of zinc ore began about 1942, and continued until the mines were closed in 1947. During this period, approximately 170,000 tons of zinc ore were produced from the deposits at Copper Flat (Muller and Storms, 1948).

Samples of silicified rock (jasperoid) from the dump of one of the old mines contain small amounts of pyrite, sphalerite and galena, cuprite, smithsonite, and cerrusite in a gangue of quartz, hematite, garnet, tremolite, and actinolite. Analyses of these samples showed anomalously high concentrations of V and Mn plus slightly anomalous Cr, Cu, Pb, and Zn.

Six magnetic concentrate samples were collected from Yellowdog Gulch, which drains the western part of the Copper Flat mineralized area; and three additional samples were taken from Gold Gulch, which drains the eastern part of the area (fig. 3). Spectrographic analyses of these nine samples are shown in table 4.

All of the samples from this area show anomalously high concentrations of Mn, Be, Cu, Pb, and Zn; and all, except sample 5 from Yellowdog Gulch upstream from the mine area, are high in Mo. The three samples from Gold Gulch, east of Copper Flat, also show anomalously high concentrations of Ba, Ni, and Sn; this may reflect contributions from a different source, such as the Mountain Home Mine group on Humboldt Mountain at the head of the gulch. Sample 6, farthest downstream on Yellowdog Gulch, contains considerably more copper and molybdenum and somewhat more zinc than the next upstream sample. Sample 6 was taken just below the junction of a small tributary gulch on the north, which drains the unprospected western part of Copper Flat, and may indicate the presence of an undeveloped ore deposit in this area.

HANOVER AREA

The Hanover mining area is in secs. 21, 22, T. 17 S., R. 12 W. in the Central mining district, Grant County, about 2 to 5 kilometers (1½–3 mi) east of Copper Flat. Here a large northerly trending pluton of Tertiary granodiorite porphyry was intruded into the Middle and Upper Pennsylvanian Oswaldo Formation at the southern end of the pluton and into older Paleozoic sedimentary rocks farther north. The stock is cut by numerous northerly trending dikes of quartz monzonite porphyry and granodiorite porphyry; and the sedimentary rocks, which the pluton intrudes, contain large sills of hornblende quartz diorite of probable Cretaceous age. A belt of contact metasomatic alteration, as much as 240 meters (800 ft) wide, is irregularly developed

TABLE 4.—*Analyses of magnetic concentrates from stream sediments in the Copper Flat area*

[N = not detected; D. F. Siems, analyst]

	SW.		Yellowdog Gulch				NE.	S. Gold Gulch		N.
Element	Sample Nos.									
	6	1	2	3	4	5	7	8	9	
Percent										
Fe	50	30	20	30	30	30	30	30	30	
Mg	.3	.2	.2	.3	.3	.2	.5	.5	.3	
Ca	1	.7	.7	1	.7	.7	1.5	1.5	1.5	
Ti	.5	.3	.3	.7	.3	.7	1.5	.7	.2	
Mn	.3	.5	.3	.3	.3	.5	.5	.3	.2	
Parts per million										
B	<20	20	20	20	20	<20	20	20	20	
Ba	150	200	200	200	200	200	200	500	300	
Be	7	10	7	10	15	10	10	10	10	
Bi	N	20	N	20	N	N	N	N	N	
Co	100	50	30	70	70	70	70	70	70	
Cr	150	150	150	300	200	200	700	300	150	
Cu	2,000	300	300	1,000	500	500	2,000	1,000	700	
La	50	70	70	70	100	70	50	70	100	
Mo	70	15	10	20	10	<10	50	70	70	
Ni	150	150	100	200	200	200	300	500	500	
Pb	200	500	500	500	700	500	700	500	700	
Sc	10	15	15	20	15	15	10	10	10	
Sn	30	N	N	N	N	N	300	20	30	
Sr	<200	<200	<200	200	200	<200	200	<200	<200	
V	500	300	200	300	300	300	700	500	300	
Y	50	50	50	70	70	50	50	70	70	
Zn	5,000	3,000	3,000	3,000	2,000	3,000	2,000	2,000	3,000	
Zr	150	150	150	200	200	100	200	200	150	

in the Oswaldo Formation adjacent to the contact with the pluton. This belt of skarn consists of magnetite nearest the contact grading outward into garnet and epidote, and into pyroxene at the outer edge. Accessory minerals include quartz, calcite, pyrite, chlorite, actinolite, and tremolite. The porphyry adjacent to the contact has locally been converted into an aggregate of scapolite, zoisite, epidote, and garnet. Within the contact zone chalcopyrite, cubanite, pyrrhotite, and sphalerite locally form small ore bodies; larger replacement ore bodies of sphalerite and galena are present in the limestone beyond the contact metasomatic zone (Knopf, 1933; Hernon and Jones, 1968).

Magnetic concentrate samples were collected at two localities in the Hanover area. Sample 1 comes from the mouth of a small gulch draining easterly into Hanover Creek about 800 meters ($\frac{1}{2}$ mi) north of Hanover. Sample 2 comes from the mouth of a small gulch that drains

TABLE 5.—*Analyses of magnetic concentrates from stream sediments in the Hanover area*

[N = not detected; D. F. Siems, analyst]

Element	Sample 1	Sample 2
Percent		
Fe	50	50
Mg	.2	1
Ca	.3	.5
Ti	.7	.5
Mn	.3	.7
Parts per million		
B	<20	20
Ba	300	200
Be	5	3
Co	50	50
Cr	300	150
Cu	150	1,000
La	<50	<50
Mo	N	10
Ni	100	50
Pb	30	30
Sc	<10	N
Sr	<200	200
V	3,000	700
Y	20	20
Zn	500	700
Zr	1,000	500

westerly into Hanover Creek about 1,400 meters (4,000 ft) north of Hanover. Spectrographic analyses of these samples are shown in table 5.

The high iron content of both samples indicates that they are relatively pure magnetite concentrates. The Mn, Ba, Cu, V, and Zr contents of sample 1 are somewhat higher than normal. Sample 2 is anomalously rich in manganese and copper, and slightly high in molybdenum. The absence of anomalous concentrations of zinc and lead in these samples is surprising in view of the abundance of zinc in the peripheral pyroxene-rich zone of contact metasomatic alteration, and of both zinc and lead replacement deposits in the unaltered limestone beyond the zone. Evidently, in this area, these elements either were not abundant when the magnetite formed, or were expelled from the early high-temperature magnetite zone at the contact, whereas copper was retained.

FISSURE VEIN DEPOSITS

Although the main purpose of this study was to investigate the composition of detrital magnetite concentrates derived from contact metasomatic ore deposits, for purposes of comparison, some samples were also collected from an area where most of the ore has been derived from fissure veins.

CHLORIDE DISTRICT

The Chloride mining district lies largely in secs. 18, 19, 20, and 30, T. 11 S., R. 8 W., on the eastern flank of the Black Range in Sierra County, about 15 kilometers (10 mi) southwest of the Iron Mountain deposit (fig. 4). The rocks exposed in this district consist of isolated fault blocks of Pennsylvanian Magdalena Limestone and overlying Permian Abo Formation, capped by and locally overlying a thick pile of Tertiary andesite flows and tuffs in large gravity slide blocks. The andesite is also locally covered by erosion remnants of younger Tertiary rhyolite flows and tuffs. Ore deposits consist of Cu, Pb, Zn, Au, and Ag ore bodies in large westerly and northwesterly trending veins. Where these veins cut andesitic host rock, the ore is largely gold and silver with some copper in a quartz gangue, whereas those in limestone yield Pb, Zn, Cu, and Ag ore with little gold in a gangue of quartz and calcite. Primary ore mineral assemblages vary in different parts of the district. The most common are: free gold, auriferous pyrite, argentite, chalcopyrite, bornite, covellite, tetrahedrite, galena and sphalerite, that have accessory pyrite, chlorite, barite, and talc (Harley, 1934, p. 82-84).

This district produced about \$200,000 worth of mixed base- and precious-metal ore prior to 1930, after which it was largely dormant until the 1981 increase in the price of precious metals stimulated renewed exploration and development of some of the old mines in the area.

A panned concentrate of nonmagnetic heavy minerals collected about 500 meters (1,500 ft) down Chloride Creek below the old Nana Mine contained anomalously high concentrations of lead and copper. Another sample from about 300 meters (900 ft) farther downstream was anomalously high in lead.

Four magnetic concentrate samples were collected from stream sediments along lower Mineral Creek in the northern part of the district, and another four along lower Chloride Creek, in and just east of the central part of the district (fig. 4). Spectrographic analyses of the eight samples collected in this area are given in table 6.

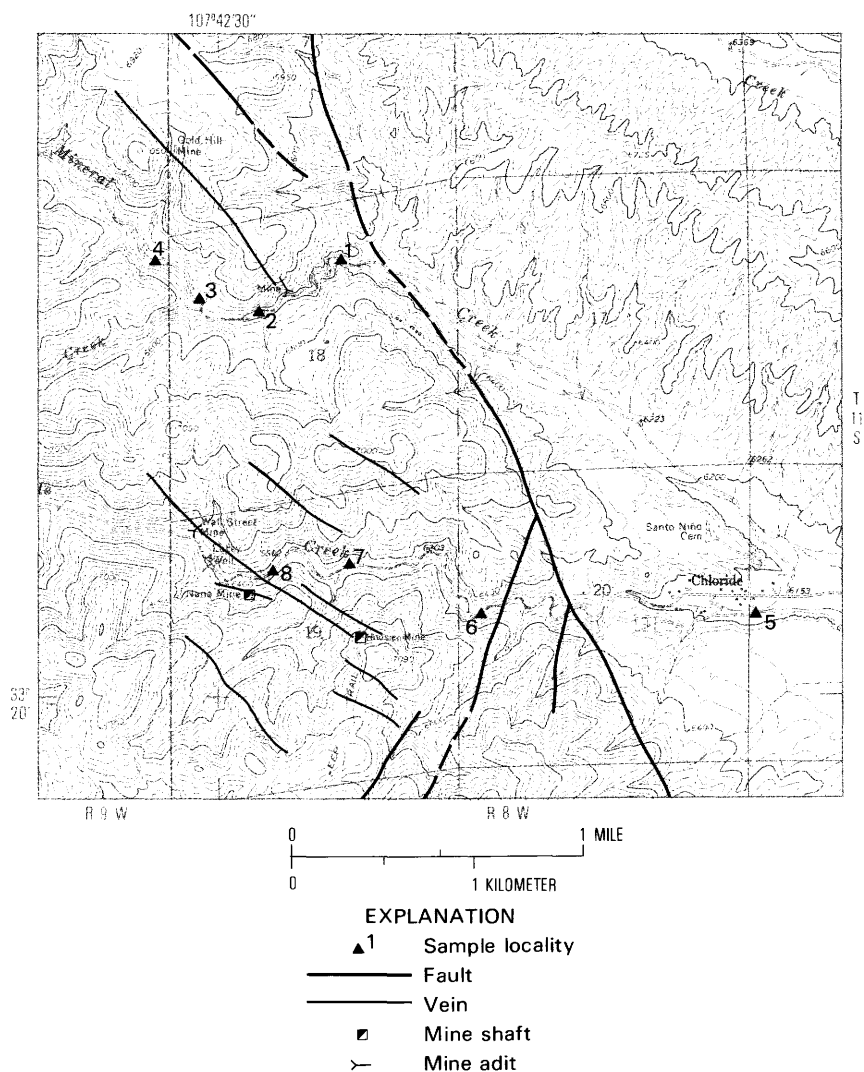


FIGURE 4.—Magnetic concentrate sample localities in the Chloride district. Base from U.S. Geological Survey Winston, 1:24,000, 1965.

These samples are remarkably uniform in composition, the variation in concentration of both major and minor elements among the four samples from each of the two creeks is no more than could reasonably be expected from four replicate analyses of the same sample, with the exception of tin. The samples from Chloride Creek appear

TABLE 6.—*Analyses of magnetic concentrates from stream sediments in the Chloride district*

[N = not detected; D. F. Siems, analyst]

	E.	Mineral Creek			W.	E.	Chloride Creek		W.
Element	Sample Nos.								
	1	2	3	4	5	6	7	8	
Percent									
Fe	20	20	20	30	20	30	20	20	
Mg	.5	.5	.5	.5	1	.7	.7	1	
Ca	1.5	1.5	1.5	1.5	2	1.5	1.5	1.5	
Ti	2	1.5	1.5	2	1.5	2	2	2	
Mn	.3	.2	.3	.3	.3	.5	.3	.3	
Parts per million									
B	<20	20	<20	<20	<20	<20	20	20	
Ba	200	200	200	200	500	200	300	300	
Be	7	5	5	7	3	5	5	5	
Co	70	50	50	70	50	70	50	50	
Cr	1,000	1,000	700	1,500	1,500	2,000	1,500	1,500	
Cu	150	150	100	100	150	150	150	150	
La	50	100	70	70	<50	50	50	50	
Ni	150	150	100	150	100	150	100	150	
Pb	100	100	70	100	50	50	50	50	
Sc	20	20	15	20	20	20	20	20	
Sn	N	30	N	N	20	N	N	50	
Sr	200	300	300	300	700	300	500	500	
V	1,000	1,500	1,000	1,000	500	1,000	1,000	700	
Y	30	50	30	50	30	30	30	30	
Zn	1,000	1,000	1,000	1,000	1,000	1,500	1,000	1,000	
Zr	500	500	700	700	200	300	300	300	

to contain slightly more Mg, Ba, Cr, and Sr, whereas those from Mineral Creek are slightly richer in La, Pb, V, and Zr. Tin-bearing hydrothermal veins are present in the upper drainage basins of both streams about 10 kilometers (6 mi) to the west, and may account for the sporadic occurrence of tin in these magnetic concentrates. The uniformity in composition of these samples is all the more remarkable in view of the fact that they consist of very impure magnetic concentrates, as shown by their low iron content.

Although these samples contain slightly higher than normal amounts of copper and zinc, the uniformity in their composition suggests that they consist of detrital accessory magnetite derived from the volcanic rocks, rather than hydrothermal magnetite associated with the vein deposits. This conclusion is further supported by the observation that magnetite is not a common gangue mineral in the veins.

QUARTZ MONZONITE INTRUSIVE

CUCHILLO NEGRO AREA

A large quartz monzonite stock on Cuchillo Mountain intrudes Pennsylvanian Magdalena Limestone. Several small contact metasomatic, vein and replacement deposits of Cu, Pb, and Zn with a little Ag, have been developed in the limestone close to its contact with this intrusive. These deposits appear to be genetically related to the quartz monzonite stock. Two magnetic concentrate samples were collected from the upper basin of Cottonwood Creek in the SE $\frac{1}{4}$, sec. 29, T. 11 S., R. 7 W. from the southern and northern forks of this creek, close to their confluence. The drainage basins of both tributaries are entirely within the stock, so the magnetic concentrates should represent detrital accessory magnetite derived from the stock. Nonmagnetic heavy-mineral concentrates were also collected at the same localities for comparison. Spectrographic analyses of these samples are shown in table 7.

Both of the magnetic concentrate samples consist of rather impure magnetite as shown by their relatively low iron content. They have very similar compositions, suggesting that the magnetite in both samples is probably derived from accessory magnetite in the stock. The Zn, Pb, and Ni content of these samples is anomalously high, and the Cu content slightly high. The corresponding nonmagnetic heavy-mineral concentrates are much higher in copper and lead than the magnetic concentrates, and contain comparable amounts of zinc. These metals probably have been derived from small base-metal sulfide-bearing veins cutting the stock in the upstream drainage basins of the streams. There is considerably more variation in composition between the two nonmagnetic heavy-mineral concentrates than between the corresponding magnetic concentrates, probably reflecting the more heterogeneous mineralogical composition of the former.

Although the contact metasomatic magnetite around the Iron Mountain stock, a few miles to the northwest, is rich in Mo, Sn, W, and Be, the accessory igneous magnetite in these samples shows no detectable Mo, Sn, or W, and only small amounts of Be, despite the fact that the igneous intrusives in both places are similar.

REPLACEMENT DEPOSIT IN LIMESTONE

LAKE VALLEY DISTRICT

The old Lake Valley mining district is in sec. 21 and the NW $\frac{1}{4}$ sec. 28, T. 18 S., R. 7 W. on Apache Hill, approximately 24 kilometers (15 mi) south of Hillsboro in southern Sierra County (fig. 5). It was

TABLE 7.—*Analyses of magnetic and nonmagnetic heavy-mineral concentrates from Cottonwood Creek, Cuchillo Negro area*

[N = not detected; D. F. Siems, analyst]

Element	S. Fork Cottonwood Creek		N. Fork Cottonwood Creek	
	Magnetic concentrates	Nonmagnetic concentrates	Magnetic concentrates	Nonmagnetic concentrates
Percent				
Fe	30	0.5	30	2
Mg	.3	.15	.7	.2
Ca	1	20	2	20
Ti	1.5	1.5	2	2
Mn	.1	.05	.15	.07
Parts per million				
Ag	N	N	N	3
Ba	150	500	500	50
Be	5	<1	7	<1
Co	70	<5	70	10
Cr	3,000	70	3,000	200
Cu	150	1,000	150	700
La	N	1,000	N	1,000
Ni	500	10	500	10
Pb	150	2,000	150	20,000
Sc	10	10	15	10
Sr	200	500	500	700
V	1,500	500	1,500	2,000
Y	<20	700	20	700
Zn	2,000	2,000	1,500	700
Zr	300	>2,000	300	>2,000

discovered in 1878 and produced about 5.8 million ounces of silver and some lead prior to 1893. The district was then largely dormant until the second World War, when about 50,000 tons of siliceous manganese ore was mined.

The rich silver ore came from irregular replacement mantos in Lower Mississippian Lake Valley Limestone on the north side of the southeasterly trending Lake Valley fault. This limestone forms the low northerly trending ridge of Apache Hill, and dips easterly. To the west, a valley is cut into the underlying Upper Devonian Percha Shale, and is flanked by a higher ridge (Quartzite Ridge) on the west side that is composed of the Ordovician El Paso Limestone and Lower and Middle Silurian Fusselman Dolomite, which are on the hanging wall side of the large northeasterly trending Berenda fault. To the east of the mining district, the Lake Valley Limestone is unconformably overlain

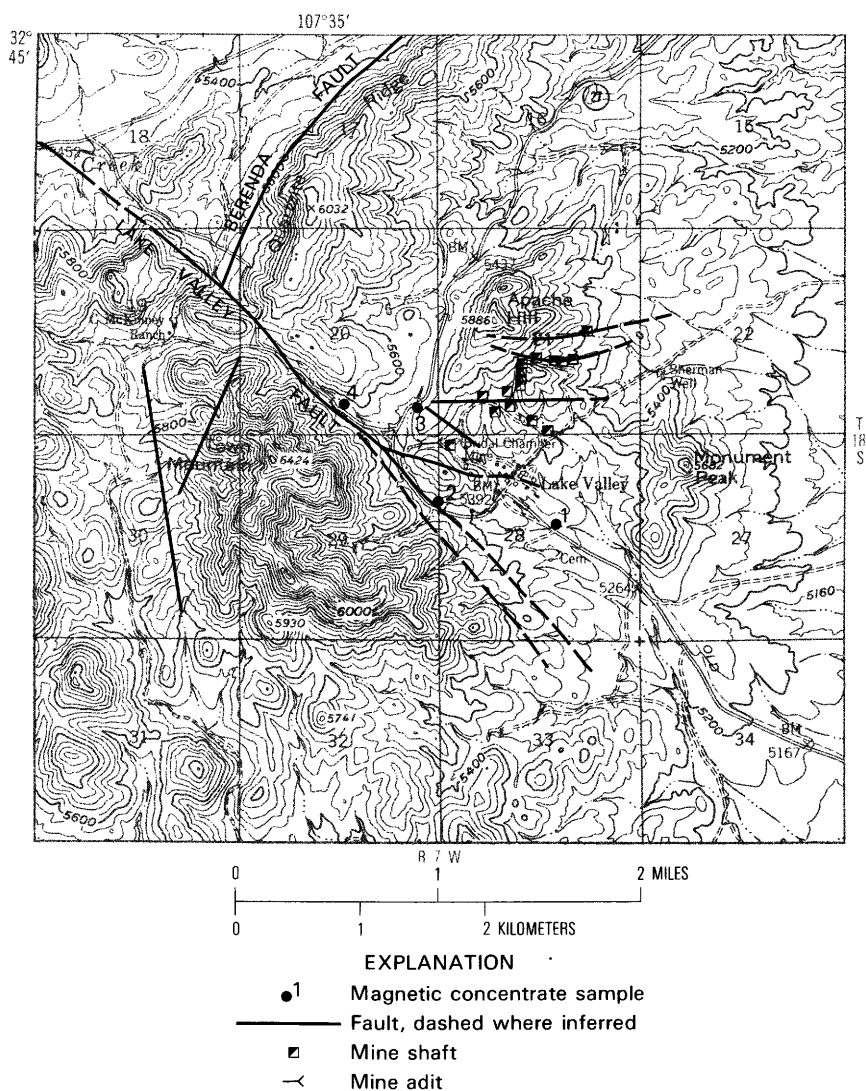


FIGURE 5.—Location of magnetic concentrate samples in the Lake Valley area. Base from U.S. Geological Survey Lake Valley, 1:62,500, 1962.

by Tertiary andesite. South of the Lake Valley fault, the Tertiary andesite, on the foot wall side of the fault, is overlain by a large mass of upper Tertiary rhyolite, which forms Town Mountain.

The Lake Valley Limestone has been subdivided into three members, the basal Andrecito Limestone Member overlying the Percha Shale is barren. The ore bodies are localized at the contact of the middle (Alamogordo) member with the upper (Nunn) member, and are largely

in the basal part of the upper member. The contact between the middle and upper members has been extensively silicified. In the southern part of the district, close to the Lake Valley fault, this siliceous floor has been fractured, brecciated, and recemented by ore, which penetrates downward about 1 meter (3.3 ft) into the underlying Alamogordo. Farther north, the silicified contact zone marks the base of the ore. Large barren siliceous replacement bodies (jasperoid) are also extensively exposed in the lower Paleozoic carbonate rocks on Quartzite Ridge to the west of the district.

The main ore minerals were cerrusite and cerargyrite with minor embolite, native silver, vanadinite and wulfenite and very sparse hypogene galena, pyrite, and ankerite, in a gangue of manganiferous calcite, limonite, and manganese oxides. There are some small hot spring deposits of travertine in the southern part of the district, close to the Lake Valley fault.

The ore deposits are unique in this region, and their origin is still controversial. They were long regarded as supergene deposits derived from primary sulfide deposits in the Lake Valley Limestone to the west, before it was removed by erosion, and that the ore metals were transported by ground water to the present site; or possibly, primary lead-silver sulfide ore bodies formed at the present site and subsequently oxidized and slightly redistributed by supergene solutions. An alternative explanation is that they are of primary hydrothermal origin, formed near the surface by solutions related to those which formed the hot spring travertine deposits in Quaternary time (C. H. Maxwell, U.S. Geological Survey, oral commun., 1982).

Samples of red and grayish-green jasperoid from the top of the Alamogordo Member in the main district are enriched in silver and lead, and some jasperoid bodies in the Fusselman Dolomite close to the Lake Valley fault west of the main district also contain anomalously high concentrations of silver, molybdenum, lead, and zinc (Young and Lovering, 1966, p. D15-D16). A sample of hydrothermal calcite from the dump of a small prospect on the southwest side of the boundary fault, about 150 meters (450 ft) west of the road junction and about 400 meters ($\frac{1}{4}$ mi) west of the Lake Valley district, contains anomalously high concentrations of lead and zinc. Non-magnetic heavy-mineral concentrates from the stream valley followed by N. Mex. Highway 27, west of Apache Hill, contain anomalously high concentrations of lead. Similar samples from the wash followed by the Lake Valley fault show sporadic zinc anomalies upstream from the district and strong lead and silver anomalies adjacent to the district and downstream for at least $1\frac{1}{2}$ kilometers (1 mi) beyond it. Four magnetic concentrate samples were collected from stream sediments in the vicinity of the Lake Valley district (fig. 5). Spectrographic analyses of these samples are given in table 8.

TABLE 8.—*Analyses of magnetic concentrates from the Lake Valley area*
 [N = not detected; D. F. Siems, analyst]

Element	Sample Nos.			
	1	2	3	4
Percent				
Fe	50	50	30	30
Mg	.7	.5	1	.7
Ca	.3	.2	1	.7
Ti	>2	>2	>2	>2
Mn	.7	1	.7	.7
Parts per million				
B	<20	<20	<20	<20
Ba	200	200	500	200
Be	2	2	3	2
Co	100	100	100	100
Cr	1,000	700	1,000	1,000
Cu	200	100	200	200
La	70	100	<50	N
Mo	N	N	10	N
Nb	50	50	50	70
Ni	200	200	200	200
Pb	150	700	200	100
Sc	20	15	15	10
Sn	30	50	N	N
Sr	<200	<200	200	<200
V	1,500	1,500	1,500	1,500
Y	30	50	30	30
Zn	1,000	1,000	1,000	1,000
Zr	700	700	700	1,000

All of the samples from this area contain unusually high concentrations of titanium and manganese. Samples 1 and 2 both appear to consist of relatively pure magnetite, as shown by their high iron content.

The detrital magnetite collected from the stream south of the Lake Valley district is probably derived from the Tertiary volcanic rocks on the south side of the fault that bounds the district, and the anomalously high concentrations of some elements in these samples may represent leakage from buried mineralization along the strong northwest-trending fault zone, which is locally followed by this stream (fig. 5). Magnetite is not present in the gangue of the ore deposits nor is it an accessory mineral in the host rock. These samples are high in lead, particularly sample 2, which was collected just south of the

mining district. A nonmagnetic heavy-mineral concentrate from the same locality contained 10,000 ppm (1 percent) lead, and also 3,000 ppm silver, although silver was below the limit of detection in the corresponding magnetic concentrate. This sample was collected from the main drainage on the south side of the andesite-covered hill south of the Lake Valley fault, so the high lead and silver values could hardly have been derived from the mineralized area of the mines in the Lake Valley district on the north side of the main Lake Valley fault. It must represent leakage of concealed mineralization along the southern split of this fault in the highly altered andesitic volcanic rocks, probably from concealed ore bodies in carbonate rocks below these volcanic rocks. All of the samples, except this one, also run high in copper, and samples 1 and 2 show measurable amounts of tin, although samples 3 and 4, upstream from the district, do not.

DISCUSSION

The suites of elements that are enriched in the majority of magnetic concentrate samples are different for each of the areas sampled. The two contact metasomatic iron deposits in which magnetite forms the gangue of the base-metal mineralization (Iron Mountain and Copper Flat) both showed extensive suites of anomalous minor elements including those of associated ore. The third, Hanover, showed anomalous copper but lacked anomalous zinc, despite large zinc deposits in the outer zone of the contact metasomatic belt, but outside the magnetite zone. Concentrates of detrital primary magnetite derived from the quartz monzonite stock in the Cuchillo Negro area, which is related to contact metasomatic deposits of copper, lead, and zinc showed anomalously high concentrations of lead, but not copper although copper is the predominant base metal in the associated contact metamorphic deposits. Magnetic concentrates from streams draining the area of base-metal vein deposits in the Chloride district did not reflect this mineralization, as anticipated because magnetite is not a gangue mineral of the ore in this district. However, magnetic concentrates from the stream that follows the main fault south of the Lake Valley district does show a variety of anomalous ore elements including lead and manganese, although there is no magnetite associated with the replacement ore deposits of manganese and lead in limestone in this district. However, this stream follows a fault zone with Tertiary andesite on both walls, and is separated from the carbonate rocks containing these deposits by a low andesite-capped hill south of the district. Thus, the metal suite in these magnetic concentrates probably is derived in part from accessory rock magnetite in the andesite, and in part from magnetite related to concealed mineralization at depth along the Lake Valley fault.

The suites of minor elements that are present in higher-than-normal amounts in the majority of magnetic concentrate samples from each of the areas sampled, are shown below.

CONTACT METAMORPHIC IRON DEPOSITS

1. Iron Mountain (5 samples) - Mn, Be, Bi, Mo, Sn, (W?), Zn
2. Copper Flat (9 samples) - Cu, Mo, Ni, Pb, Sn, Y, Zn
3. Hanover (2 samples) - Cu, V, Zr

PRIMARY MAGNETITE DERIVED FROM QUARTZ MONZONITE ASSOCIATED WITH CONTACT DEPOSITS

4. Cuchillo Negro (2 samples) - Ti, Cr, Ni, Pb, Sr, V

BASE-METAL FISSURE VEINS LACKING ACCESSORY MAGNETITE

5. Chloride district (8 samples) - Ti, Cr, Sc, (Sn?), Sr

SILVER-LEAD-MANGANESE REPLACEMENTS IN CARBONATE ROCKS, LACKING ACCESSORY MAGNETITE

6. Lake Valley district (4 samples) - Ti, Mn, Co, Cr, Nb, Ni, Pb, Sn, V, Zr

DISTRIBUTION OF INDIVIDUAL ELEMENTS

BARIUM

This element has too large an ionic radius to substitute for either ferrous or ferric iron, so that in magnetic concentrates it reflects the presence of detrital mineral impurities, generally grains of barite, mechanically trapped with the magnetite. In none of the sample suites did a majority of the samples contain anomalously high barium concentrations, and the samples that were high in barium all show less than 50 percent iron indicating that the sample contained a high proportion of foreign mineral particles.

BERYLLIUM

Beryllium can substitute to a limited extent for iron in magnetite. The only area in which the majority of magnetic concentrates show unusually high amounts of beryllium is Iron Mountain, where the mineral helvite, an iron-manganese-beryllium silicate, occurs in a magnetite gangue in the mineral deposit. Many samples from the Copper Flat area also appear to be slightly enriched in beryllium, although no known beryllium minerals are associated with this deposit.

BISMUTH

Bismuth is not commonly detected in detrital sediment samples of any kind. Its ability to enter the mineral lattice of magnetite is extremely limited, and it most commonly occurs as a minor constituent of complex silver and base-metal sulfide minerals. Yet bismuth is reported in three of the five magnetic concentrates from the Iron Mountain area in concentrations as high as 50 ppm; and it also occurs in detectable amounts in two of the nine samples from the Copper Flat area. Our limited sample information suggests that detectable bismuth in magnetic concentrates is indicative of magnetite closely associated with base-metal mineralization, exposed in the upstream drainage basin.

CHROMIUM

Chromium Cr^{+3} can readily substitute for ferric iron in magnetite; and magnetic concentrates commonly contain as much as 1,000 ppm of Cr. One would normally expect that high chromium content would be indicative of magnetite derived from mafic or ultramafic igneous intrusives, such as those with which chromite deposits are associated. It is, therefore, quite startling that the two magnetic concentrates with the highest chromium content are those composed of accessory magnetite which was derived from the quartz monzonite stock in the Cuchillo Negro area, both samples from this locality contained 3,000 ppm Cr. On the other hand, none of the samples consisting of magnetite derived from contact metasomatic iron deposits contained as much as 1,000 ppm Cr. Thus, the only conclusion justified by the data is that magnetic concentrates with high chromium are unlikely to reflect magnetite associated with contact metasomatic deposits around felsic intrusive bodies.

COBALT

Cobalt is capable of substituting to a limited extent, for ferrous iron in magnetite, and is commonly present in magnetic concentrates in amounts of several tens of parts per million; however, concentrations of 100 ppm or more are unusual. The only area in which the majority of samples showed this much cobalt is the Lake Valley district. The source of this magnetite is not definitely known, so the significance of the high cobalt concentration here is also open to speculation.

COPPER

The Cu^{+2} ion is comparable in size to the Fe^{+2} ion, and the copper content of magnetite increases during the late stage of magmatic differentiation as much as 150 ppm in hydrothermal and contact metasomatic deposits (Freitsch, 1970, p. 77). Higher concentrations are apt to reflect the presence of primary copper minerals in the magnetic concentrates. Magnetic concentrates from the Copper Flat area are consistently high in copper, as is one of the two samples from Hanover. Copper concentrations of 500 ppm or more appear to reflect copper mineralization associated with a contact metasomatic magnetite gangue in the upstream drainage basin, and may also indicate detrital cubanite mixed with the magnetite.

LEAD

The ionic radius of lead is too large for it to substitute for iron in magnetite. Although contact metasomatic magnetite with lead content greater than 100 ppm has been reported (Hegemann and Albrecht, 1954), amounts greater than 100 ppm in magnetic concentrates generally reflect the presence of lead mineral impurities derived from mineralized rocks. High lead values characterize magnetic concentrate samples from Copper Flat, Lake Valley, and Cuchillo Negro. At both Lake Valley and Cuchillo Negro, nonmagnetic concentrates collected at the same localities contain much higher amounts of lead than do the magnetic concentrates.

MANGANESE

The Mn^{+2} ion is similar in size to the Fe^{+2} ion and manganese can substitute to a considerable extent for ferrous iron in magnetite; however, manganese minerals such as siderite and various manganese oxides are also closely associated with magnetite in detrital mineral concentrates. The normal manganese content of our magnetic concentrates ranges from 0.1 to 0.7 percent, manganese values of 1 percent or more are considered anomalous. Samples from Iron Mountain and Lake Valley are rich in manganese, which is abundant in the replacement deposits of the latter area. Although these deposits could not have yielded the magnetite in the magnetic concentrates, their manganese content may reflect an earlier episode of mineralization and primary manganese concentration genetically related to the Lake Valley deposits.

MOLYBDENUM

Molybdenum, as Mo^{+4} , is capable of substituting to a limited extent for ferric iron in magnetite, although its ionic radius is somewhat larger. It is most abundant in accessory magnetite derived from felsic plutonic rocks (Freitsch, 1970, p. 76). Sample suites from the Iron Mountain and Copper Flat areas both contain unusually large amounts of molybdenum. Although no molybdenum deposits have thus far been discovered at either place, its presence in magnetic concentrates may be indicative of base-metal mineralization.

NICKEL

Nickel, like cobalt is capable of limited substitution for ferrous iron in magnetite. It normally ranges from about 50 to 250 ppm, although amounts as high as several percent have been reported from magnetite derived from ultramafic intrusive rocks (Freitsch, 1970, p. 57, 75). Both of the samples of detrital accessory magnetite derived from the Cuchillo Negro quartz monzonite, as well as two samples from Gold Gulch, in the Copper Flat area, contain abundant nickel (500 ppm). The significance of these high values is not known, although Freitsch (1970, p. 13) points out that the presence of sulfides, such as pyrite and pyrrhotite, may produce high nickel values.

STRONTIUM

Like barium and lead, strontium is unable to enter the crystal lattice of magnetite because of its large ionic radius; hence, high strontium values in magnetic concentrates are indicative of contamination by nonmagnetic detrital minerals such as barite and calcite. Only the samples from Chloride Creek show consistently high strontium values, and these do not appear to have any economic significance.

TIN

Tetravalent tin has an ionic radius comparable to that of ferric iron, for which it may substitute in magnetite, and it is reported to be particularly abundant in some contact metasomatic iron deposits (Freitsch, 1970, p. 86). This is well illustrated by the high tin content of the magnetic concentrates from Iron Mountain, and some of those

from Copper Flat. The sporadic occurrence of detectable tin in samples from the Chloride district is probably attributable to a different source, possibly reflecting the presence of cassiterite-bearing veins in the headwater drainage basins, about 10 kilometers (6.2 mi) upstream. Implications of tin in the two downstream samples from the Lake Valley area are unknown, as these magnetic concentrates could not have been derived from the replacement deposits in the mining district. It may indicate leakage from buried deposits along the Lake Valley fault which cuts altered andesite along the stream valley. Tin may also reflect contamination from the leaching of old tin cans.

TUNGSTEN

We were unable to locate any published reports on the tungsten content of magnetite; however the W^{+4} ion has the same radius as Mo^{+4} , which is very close to that of ferric iron, so tungsten should also be capable of substituting to some extent for Fe^{+3} in the crystal lattice of magnetite. According to Rankama and Sahama (1950, p. 629) hydrated tungsten oxide, in the weathering zone of tungsten ore, goes into solution in alkaline waters, and will react with calcium to precipitate secondary scheelite. Tungsten was reported in magnetic concentrates only from the Iron Mountain area, where the upstream sample closest to the ore deposits contains 1,000 ppm tungsten. This suggests contamination of the sample with scheelite, which is an accessory mineral in the magnetite ore. Another sample downstream from this locality has 100 ppm tungsten. The presence of tungsten in magnetic concentrates appears to indicate the existence of tungsten deposits exposed in the upstream drainage basin.

VANADIUM

Trivalent vanadium has an ionic radius similar to that of ferrous iron, for which it substitutes in the magnetite lattice. It is particularly abundant in titaniferous magnetite of mafic and ultramafic rocks, where it may be present in amounts of 1 percent or more. In contact metasomatic iron deposits, it is commonly found in concentrations ranging from a few hundred to about 2,000 ppm (Freitsch, 1970, p. 81). Only a few of the magnetic concentrates obtained in our study contain more than 1,000 ppm V. One of the two samples from the Hanover area has 3,000 ppm V, but the other contains only 700 ppm. All four of the magnetic concentrates from the Lake Valley area exhibit 1,500 ppm V. This consistently high value for all of the samples is unusual, but its significance relative to ore mineralization, if any, is unknown.

ZINC

The Zn^{+2} ion has the same ionic radius as Fe^{+2} for which it can readily substitute in magnetite. It is most abundant in the magnetite of contact metasomatic iron deposits, and in accessory magnetite of certain late-stage mafic intrusive rocks (Freitsch, 1970, p. 79-80). Zinc is commonly present in magnetic concentrates in amounts ranging from several hundred ppm to as much as 10,000 ppm. However, only samples containing 3,000 ppm or more Zn are considered to be anomalously rich in this element. Three of the five samples from the Iron Mountain area contain 10,000 ppm Zn, and six of the nine samples from the Copper Flat area run 3,000 ppm or more in Zn. In both areas, primary zinc minerals are present in a magnetite gangue in the ore deposits. However, the two magnetic concentrates from the Hanover area both contain less than 1,000 ppm Zn, despite the fact that one of these samples was collected from a short tributary of Hanover Creek whose upper drainage basin includes some large zinc deposits. However, these deposits are in or adjacent to an outer zone of contact metasomatic alteration characterized by pyroxene-bearing rock that is separated from the magnetite zone at the intrusive contact by a belt of garnet and epidote-bearing rock. It appears that either most of the zinc in this area was expelled from the magnetite zone during metasomatic alteration or that zinc was not abundant in the early intrusive. Thus, the presence of high zinc values in magnetic concentrates appears to indicate proximity to contact metasomatic iron deposits in which zinc minerals are intimately associated with magnetite.

ZIRCONIUM

Zirconium is a strongly oxyphile element which does not occur in magnetite to any appreciable extent. It is chiefly present in magnetic concentrates in the form of detrital zircon impurities. Although some samples from Lake Valley and one from Hanover contain 700 to 1,000 ppm Zr, this only indicates that zircon is an abundant accessory mineral in the rocks from which the sediments were derived, and has no apparent significance relative to mineral deposits.

SUMMARY AND CONCLUSIONS

Detrital magnetic concentrate samples from stream sediments in southwestern New Mexico show considerable variation in their minor element content. Their composition is a mixture of magnetite and associated nonmagnetic mineral impurities. Detrital magnetite from skarn zones in carbonate rock adjacent to intrusive bodies in which

magnetite is a major gangue mineral for associated mineral deposits exhibits an extensive suite of anomalous minor elements including those of the associated ore deposits (Iron Mountain and Copper Flat). Detrital magnetite derived from skarns in which the magnetite is separated from associated ore deposits because of primary zoning may not reveal anomalous concentrations of the ore metals (Hanover). Detrital magnetite derived from accessory magnetite in an igneous intrusive that is genetically associated with mineral deposits around its margins may contain anomalous concentrations of some of the ore metals (Cuchillo Negro). Detrital magnetite derived from hydrothermal magnetite along fault zones cutting volcanic rocks may also contain an extensive suite of anomalous minor elements that might reflect deep seated mineralization along the fault (Lake Valley). Detrital magnetite from streams draining areas of barren volcanic rocks, even in close proximity to vein deposits that are devoid of accessory magnetite, show no anomalies related to the ore deposits (Chloride district).

Anomalously high concentrations of Zn, Pb, Cu, Mo, and Sn in magnetic concentrates from stream sediments in this region appear to most consistently indicate proximity to mineralized areas. Bismuth and tungsten, if present in detectable amounts, are also good indicators of mineral deposits. Minor element anomalies in detrital magnetic concentrate samples collected during this study suggest the possibility of concealed ore mineralization west of Copper Flat and also along the Lake Valley fault south of the Lake Valley mining district.

Detrital magnetic concentrates can be readily collected from dry stream sediment, and may provide a useful sample medium for reconnaissance geochemical exploration.

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