Circular 121

Geochemical Background Values in Iron-Bearing Rocks of Rio Arriba County, New Mexico

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NEW MEXICO STATE BUREAU OF MINES & MINERAL RESOURCES

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by Donald F. McLeroy

Socorro

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New Mexico State Bureau of Mines and Mineral Resources

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CONTENTS

Page	
iii	PREFACE
1	ABSTRACT
1	LOCATION
1	PREVIOUS INVESTIGATIONS
3	GEOLOGIC SETTING
4	Iron deposits
6	SPECTROCHEMICAL ANALYSES
9	SUMMARY
11	REFERENCES

ILLUSTRATIONS

Figures

2	*1 — Index map of Cleveland Gulch, Iron Mountains, and Canon Plaza area, Rio Arriba County, New Mexico*
5	*2 — Geologic map of Cañon Plaza area, New Mexico*

Tables

7	*1 — Semi-quantitative spectrochemical analyses of whole-rock samples*

PREFACE

The study of the geochemistry of the iron-bearing rocks in Rio Arriba County was undertaken as part of a larger study of the geology of the Precambrian rocks and the genesis of the banded iron-formation within these rocks. During this larger study the potential for additional mineral deposits in Rio Arriba County became apparent. If ore deposits are to be found within the Precambrian of this area, it will be necessary to utilize geochemical and geophysical exploration methods because much of the area has considerable overburden. Geochemical values and the overall geological picture are presented here to assist geochemical or geophysical prospecting for hidden ore deposits in Rio Arriba County. Determining what constitutes a true geochemical anomaly in a given test area is often difficult, expensive, and time consuming. With the geochemical background values presented in this report, any geochemical prospecting data can be better interpreted to locate areas with true geochemical anomalies for more detailed exploration.

This work was greatly assisted by Dr. Charles F. Park of Stanford University, A. J. Thompson, former Director of the New Mexico State Bureau of Mines and Mineral Resources, and Dr. W. E. Bertholf.

ABSTRACT

Precambrian banded iron-formation occurs within the Moppin Formation and the Ortega Quartzite at Cleveland Gulch, Iron Mountain and Cation Plaza in the San Juan Mountains. At Cleveland Gulch and Iron Mountain magnetite selectively replaced bands in a metavolcanic rock. At Canon Plaza the iron formation occupies a shear zone in the Ortega Quartzite, and the banding is a shearing phenomenon causing segregation of specularite and aluminum silicates. Whole rock spectrochemical analyses of the host rocks and of the iron deposits provide information on the addition and subtraction of ions during hydrothermal replacement and excellent geochemical background values. Only 26 elements were detected in one or more of the samples.

Because the potential for hidden mineral deposits in Rio Arriba County is very good, establishing general trace element background values will greatly assist in future geochemical prospecting in this area.

LOCATION

Mineral deposits at Cleveland Gulch, Iron Mountain, and Cañon Plaza are 17 to 30 miles south of the Colorado border within the bounds of the Carson National Forest in Rio Arriba County, north-central New Mexico (fig. 1). Cleveland Gulch is 38 miles northwest of Taos and 70 miles north-northwest of Santa Fe, New Mexico. These deposits are limited to Ts. 27, 28, and 29 N. and Rs. 6, 7, and 8 E.; and situated wholly within the Las Tablas Quadrangle bounded by long 106° and 106°15'W. and lat 36°30' and 36°45'N.

No all-weather roads extend into the area of the deposits. Cleveland Gulch is on unpaved Route 111 ten miles west-southwest of Tres Piedras, a small community on paved Route 285 (fig. 1). Iron Mountain is 12 miles northwest of Cleveland Gulch and 2 miles north of Hopewell Lake over fair weather roads (fig. 1). Cañon Plaza deposit is 8 miles south-southwest of Cleveland Gulch and one mile south of the community of Canon Plaza on unpaved Route 111.

PREVIOUS INVESTIGATIONS

Evan Just (1937) made a reconnaissance map of the Picuris Uplift and the area from Jawbone Mountain to Ojo Caliente in a study of the pegmatites of the area. His separation of the major rock units is still the most workable system in most cases. Butler (1946) studied the Tertiary and Cenozoic geology of part of the subject area. Barker (1958) published on the geology of the Las Tablas Quadrangle.

A generalized geologic map of the Rio Chama country, which included the area under consideration, was published in 1960 by the New Mexico Geological Society (Smith and Muehlberger, 1960). However, it was a compilation from earlier sources and presented no new information. At the same time Muehlberger (1960) wrote a paper on the Tusas Mountains, restating the published work of Just and Barker. In 1968 Bingler did a study of the geology and mineral deposits of Rio Arriba County.

Bromide and Hopewell mining districts are between Cleveland Gulch and Iron Mountain. Bromide mining district was discovered in July, 1881, by D. M. Field and J. M. Bonnett (Jones, 1964). This camp, about *a* mile northwest of Cleveland Gulch, produced mostly silver, copper, and a small amount of gold. Little ore has been produced since the turn of the century. Hopewell district was established a few years before Bromide and had both lode and placer mines (Jones, 1964). The total value of production was around $200,000. Recently an attempt was made at hydraulic gold mining of the gravel in the lower part of Placer Canyon.

Graton *(in* Lindgren, Graton, and Gordon, 1910) studied the Hopewell and Bromide districts and made brief reference to the iron deposits on Iron Mountain. Jahns (1946) in his detailed study of the pegmatites of the Petaca District (fig. 1) presented information on the general geology of the area. Kelley (1949), in a compilation of the iron deposits of New Mexico, mentioned the Iron Mountain deposit. Kyanite deposits in the Petaca District were studied by Corey (1960).

The only recent study involving the deposits was published by Bertholf in 1960. He studied part of the North Cleveland Gulch deposit (fig. 1), conducted a magnetometer survey of parts of the deposit, and had beneficiation tests run on a few samples of the iron ore.

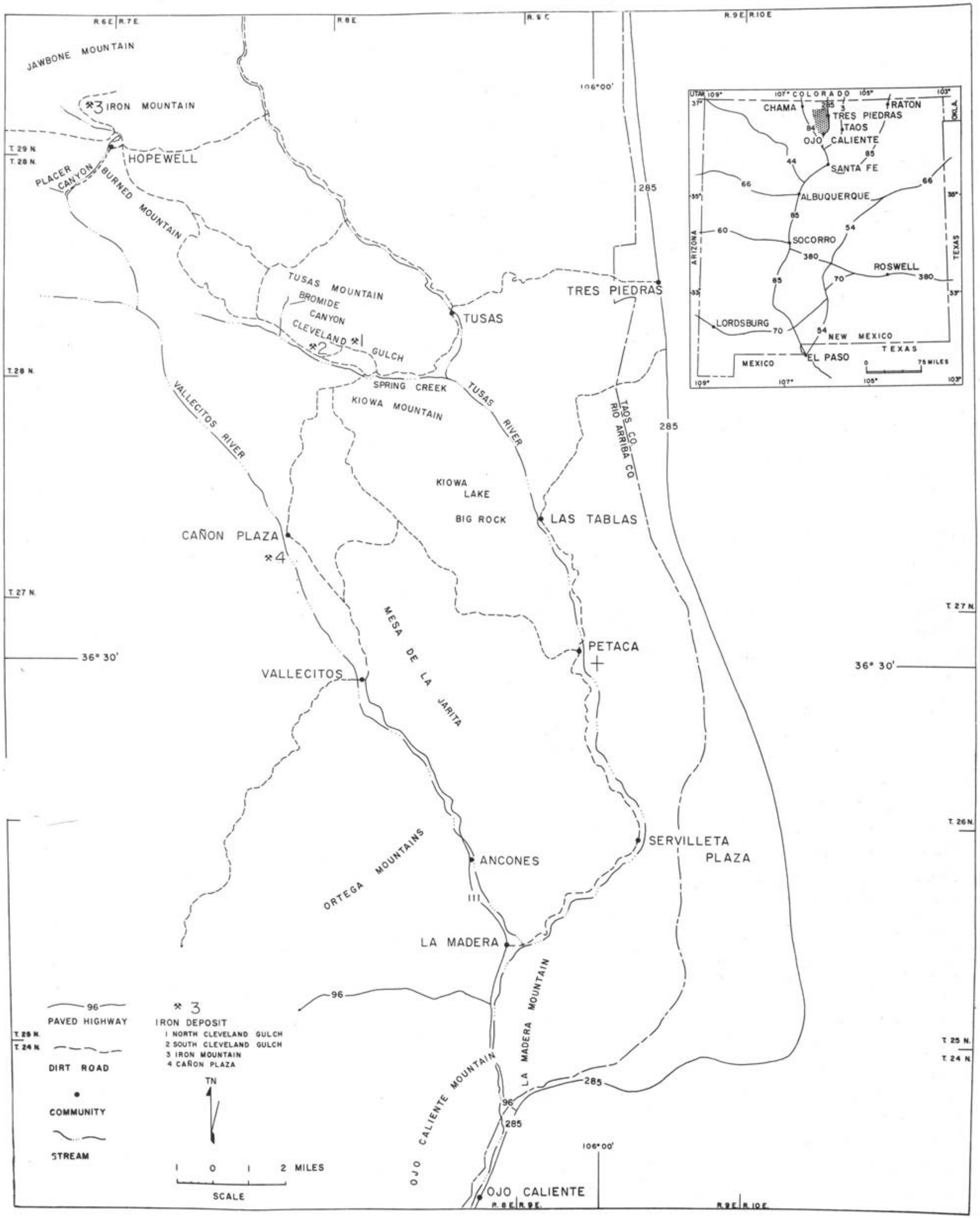

Figure 1— Index map of Cleveland Gulch, Iron Mountain, and Canon Plaza area,
Rio Arriba County, New Mexico.

GEOLOGIC SETTING

Cleveland Gulch, Iron Mountain, and Canon Plaza are in the Precambrian rocks of the New Mexico San Juan uplift. The uplift is flanked on the east by the San Luis Basin, butts into the Sangre de Cristo uplift on the southeast, plunges into the Rio Grande trough to the south, and merges into the Chama basin on the west.

The San Juan Mountains in this part of New Mexico consist of a sequence of late Precambrian metamorphic and intrusive rocks surrounded by Cenozoic sedimentary and volcanic rocks. In the area under consideration, the oldest unit, the Moppin Formation, is composed of schist, amphibolite, phyllite, and quartzite. Lying conformably, or nearly so, above the Moppin is the Ortega Quartzite, a thick formation of quartzite with minor schist and amphibolite. Iron mineralization is present in both the Moppin and the Ortega. These formations have been intruded and metamorphosed by the Tusas intrusives, which have batholithic dimensions. Greisen occurs along the contact of the Tusas intrusion on the southwest flank of Tusas Mountain. The banded iron deposits, base and precious metal vein deposits, greisen and pegmatites apparently formed during the intrusion.

The rocks have been deformed into large nearly isoclinal folds plunging steeply toward the west-northwest. The two major folds are the Hopewell anticline and Kiowa syncline, adjoining on the southwest. This structural pattern is modified in some places by smaller folds. Only a few faults occur in the Precambrian, many trending northeast. Schistosity parallels bedding planes in most outcrops.

Rocks of the Moppin Formation can be classified into seven broad types: muscovite schist, phyllite, amphibolite, biotite-quartz schist, chlorite-feldspar-calcite schist, chlorite-quartz-feldspar schist, and quartzite. Amphibolites and chlorite-feldspar-calcite schist are metamorphosed tuffs and flows of andesitic to basaltic composition. This origin is supported by the presence of relict ophitic textures, amygdules, and relict porphyritic textures, and by the overall composition. Fine-grained rocks interspersed with coarse-grained rocks of similar composition were probably tuffaceous, and the coarse-grained rocks may have been flows. Absence of much quartz indicates these rocks were relatively mafic. Muscovite schist and phyllites are metamorphosed rhyolitic tuffs and flows except for one unit at Cleveland Gulch which is a metamorphosed arkose.

The hypothesis of an igneous origin for these units is based on relict porphyritic textures, flow banding, and relict tuffaceous textures. High silica and potassium content indicates that these units were silicic in original composition. Their extrusive nature is evidenced by concordant relations, flow banding, and very fine-grained matrix. Biotite-quartz schists and chlorite-quartz-feldspar schists were probably intermediate flows and tuffs; however, one biotite-quartz schist at Cleveland Gulch may have been a sedimentary rock because it is spacially related to a quartzite. An igneous origin for most of these rocks is based on their relict porphyritic textures, amygdules, and close relationship to other metamorphosed igneous rocks.

Many of the coarser grained rocks may have been hypabyssal intrusions. Metamorphosed, crosscutting, porphyritic granodiorite intrusives are common on Iron Mountain. The presence of extensive thin beds of metamorphosed rhyolite, some of which display flow banding, interspersed throughout the Moppin Formation and the presence of silicic tuffs indicate that deposition of the Moppin rocks was continental. One distinctive metarhyolite can be traced for 12 to 14 miles along strike -- a lateral extent not likely if deposition were subaqueous. Other thin rhyolite flows can be traced for several miles. Local small basins and stream beds were the sites of deposition of sandstone bodies. These deposits are preserved today as quartzite and quartz-muscovite schists which are very limited in areal extent. Intrusive rocks are present and some may have been emplaced contemporaneously with the extrusives. Other plutons, including porphyry dikes, came after the initial folding and some metamorphism. These plutons do not include those emplaced much later with the Tusas igneous complex.

The Ortega Quartzite is characterized by basal feldspathic or conglomeratic quartzite deposited on continental volcanic deposits of the Moppin Formation, conglomeratic lenses throughout the quartzite, detrital iron oxide, considerable amounts of aluminum silicate, and interspersed volcanic deposits. Direct evidence for continental origin of the sand is lacking, although at least some of it was probably beach sand. The basal conglomeratic and feldspathic beds represent initial deposition as the sea encroached on the continent. As the sea transgressed, finer, more rounded quartz sand was deposited. The strand line showed much fluctuation during Ortega deposition.

Tusas intrusive rocks are fine to coarse grained and foliated to non-foliated, ranging in composition from dominantly granite to granodiorite. These different lithologies of the intrusive complex may represent several different times of emplacement, although in places they represent zoning of the intrusion. The iron mineralization, the greisen, the copper mineralization in Bromide Canyon, and possibly the gold-quartz veins are related to the granitic phase of the intrusion.

Several mafic dikes trend almost north-south in the Tusas rocks north of Hopewell Lake. The rocks in this area have been metamorphosed to chlorite-plagioclase schist, with the foliation parallel to the sides of the dikes.

Massive milky quartz veins are the only other igneous-related rock found in the area studied in the present report. These veins are numerous on Iron Mountain and at Cañon Plaza, and are found in most of the Precambrian outcrops.

In most places faults trend in the same direction as fractures. Where faults could be mapped in the field or on aerial photographs, they roughly paralleled the bedding planes in the Moppin and Ortega rocks, or trended northeast approximately perpendicular to the beds on the southwestern flank of the Hopewell anticline.

Cation Plaza deposit is in a northwest-trending shear zone. A few hundred feet southwest of the mineralized shear zone is another shear zone containing less iron, but iron content is higher than in the country rock (fig. 2).

Many of the mineral deposits in the Las Tablas Quadrangle are along prominent northeast or northwest fault-fracture zones. Most of these zones can be spotted on aerial photographs. The iron deposit at Cañon Plaza is along a northwesterly-trending fault zone, but iron deposits at Cleveland Gulch and Iron Mountain more or less parallel the strike of the Moppin rocks and no faulting is in evidence.

Iron Deposits

Precambrian iron deposits at Cleveland Gulch and Iron Mountain (fig. 1) usually have good continuous banding. The dark bands are composed of mostly magnetite with usually a small percentage of quartz and varying percentages of the following (in decreasing order of abundance): chlorite, muscovite, calcite, biotite, epidote, feldspar, tourmaline, rutile, and garnet. The light-colored bands are composed almost entirely of quartz with a small amount of magnetite and a very small amount of any other minerals present in the whole rock analysis. Apatite is almost completely restricted to the quartz-rich bands. These deposits are hydrothermal replacement deposits of pre-existing banded Precambrian metamorphic rocks (McLeroy, 1970).

Plaza deposit is limited in extent; it is also strikingly different in character from the three previously described deposits. Outcrops are scarce, and throughout most of its length the deposit is only about 1 to 2 feet wide. At only one locality was it up to 10 feet wide. The deposit is in a shear zone which in some places is nearly parallel to the strike of the enclosing Ortega Quartzite. At other localities the shear zone cuts across the strike of the Ortega beds.

Banding is poor to fair with component layers usually pinching and swelling over short distances. Banding is formed by alternation of specularite-rich layers and quartz-aluminum silicate-rich layers. In many places the banding is highly contorted indicating post-band deformation. Also, the specularite causes pronounced schistosity in the deposit.

Cañon Plaza has a unique assemblage of minerals. Instead of magnetite, specularite is the iron oxide. In addition to quartz, the rock contains andalusite, kyanite, sillimanite, vesuvianite, gahnite, tourmaline, rutile, garnet, muscovite, and apatite. One of the most interesting features is the presence of the polymorphs andalusite, kyanite, and sillimanite in a single specimen. In some hand specimens, andalusite up to 7 millimeters and kyanite up to 5 centimeters long are present. Kyanite may change color from blue to pink along a single grain. Sillimanite forms feathery masses in quartz grains and was observed only in thin section. Presence of the three polymorphs of aluminum silicate in a single specimen is rare. Hietanen (1956) made a complete study of an assemblage of the three aluminum silicates in the Belt Series of Idaho. He attributed their presence to fluctuation of temperature and pressure around a field where all modifications may exist in equilibrium during complex regional and thermal metamorphism. Probably disequilibrium could also account for their presence. At Canon Plaza, no intergranular sillimanite was found, suggesting equilibrium may not have been attained. If this assemblage does represent an equilibrium assemblage, it would have formed near the triple point for the three poly morphs on a pressure-temperature diagram, and would indicate a temperature of about 300°C at a pressure of about 8 kilobars (Morey, 1964). However, these phase boundaries have not been established experimentally and should not be accepted as definite until additional laboratory work has been completed. It is highly improbable that the assemblage at Cation Plaza was in equilibrium, and as a consequence, phase boundaries would be meaningless for this area.

Samples of Ortega Quartzite in the vicinity of the Canon Plaza deposit contain grains of kyanite and sillimanite. Possibly much of the kyanite and sillimanite in the shear zone was inherited from the quartzite. However, apparently more kyanite is present than in the quartzite. This excess kyanite probably was introduced by aluminous-rich mineralizing fluids that invaded the shear zone. Even though high pressure during metamorphism favors the formation of kyanite over the other polymorphs -- thus suggesting that kyanite is formed only under this condition -- kyanite is found in pegmatites where no stress seems to have been present (Barth, 1952). Corey (1960) believed that kyanite deposits on La Jarita Mesa were formed in part by "injection of siliceous hydrothermal solutions containing assimilated aluminous material." Consequently, the andalusite and at least part of the kyanite are believed to have been emplaced by the mineralizing fluids which entered the shear zone.

Metasomatism is supported by the presence of gahnite. Deer, Howie, and Zussman (1962) stated "The zinc spinel, gahnite, occurs chiefly in granitic pegmatites... but is also found in contact altered limestones and in metasomatic replacement veins and ore bodies." Presence of gahnite and a shear zone, irregular pinching and swelling of the deposit, the crosscutting nature of the zone, and the apparent absence in the unaffected Ortega rocks of the elements necessary to make up the unique mineral assemblage, indicate that the shear zone has received epigenetic mineralization.

The aluminum silicates, in general, have their long axes aligned parallel to the schistosity of the specularite. Near the

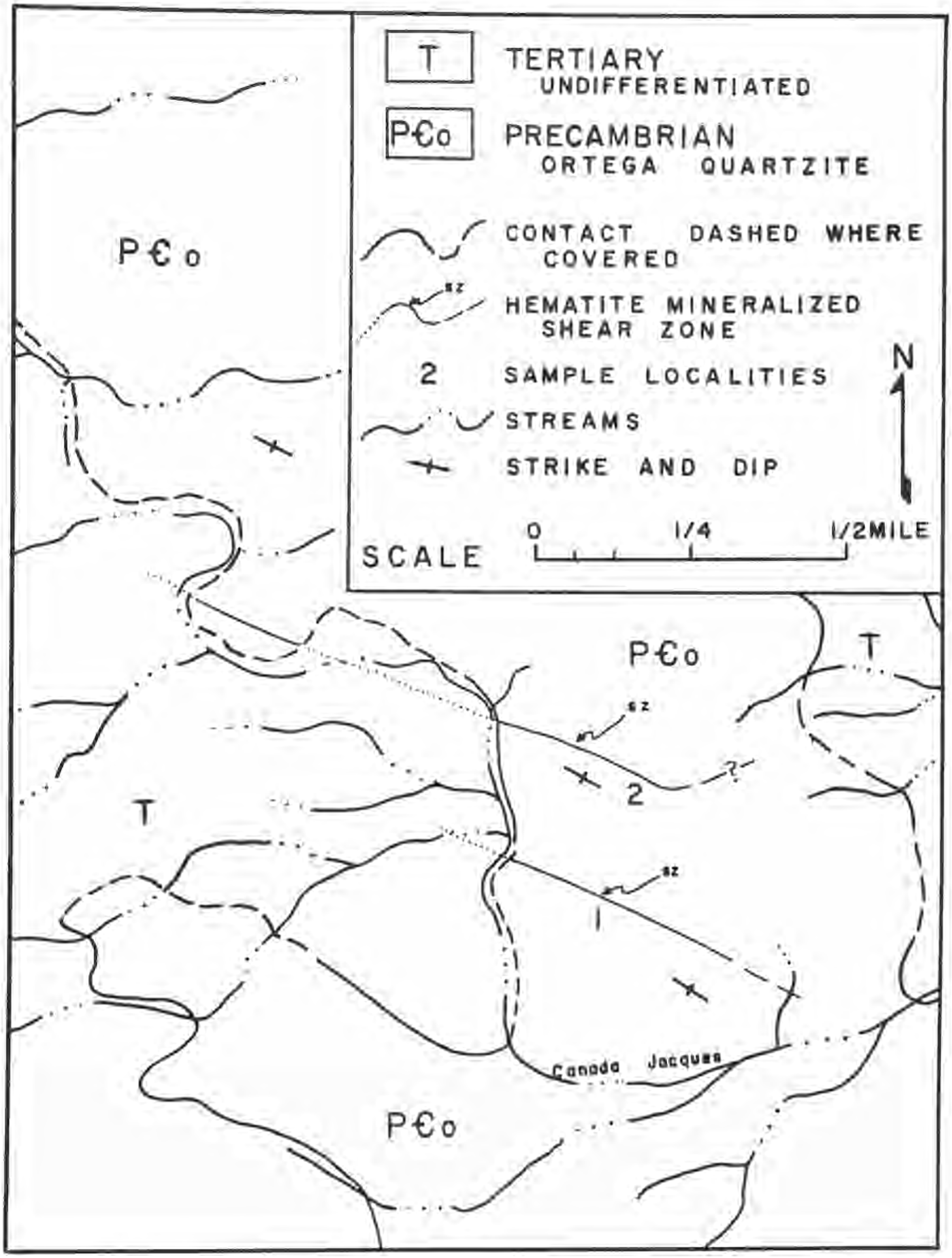

Figure 2— Geologic map of Canon Plaza area, New Mexico.

contact of the deposit, the layers are highly contorted indicating deformation during the late stage of band formation, or after the formation of the mineral suite. Near the center of the deposit, however, the layers show very little effect of late deformation. Quartz recrystallized to large optically continuous grains with muscovite or sillimanite grains usually within the quartz. Near the contact, but away from the highly contorted part, the specularite bands pass through some of the large quartz grains and other minerals without apparent deflection or other effect. Nearer the middle of the deposit the components of the bands become more segregated, and the large optically continuous quartz grains appear to be partly changed to a fine-grained equidimensional mosaic resembling the quartz mosaics of the Cleveland Gulch-Iron Mountain iron-formation.

SPECTROCHEMICAL ANALYSES

Table 1 is a compilation of semi-quantitative spectrochemical analyses of 62 whole-rock samples from the iron deposits and enclosing rocks at Cleveland Gulch, Iron Mountain, and Canon Plaza. The general analytical procedure outlined by Myers and others (1961) was used in analyzing these rock samples. Each rock sample was first pulverized and passed through a 200-mesh sieve. The sample was then split and placed in the carbon electrode cavity and burned 30 seconds in a Bausch and Lomb Littrow spectrograph. Each of the plates was checked for 50 elements, but only 26 of the elements are present in one or more of the samples. Amounts of the elements were determined in the following ranges:

Symbols	Percent
5	1 or more (large amount)
4	0.1-1.0 (moderate amount)
3	0.01-0.1 (small amount)
2	0.001-0.01 (trace)
1	Less than 0.001 (faint trace)
D	Detected

Percentage ranges such as these have the intrinsic disadvantage of being difficult to represent in tables and on graphs. However, values of 0 - 5 percent have been arbitrarily assigned to the percentage ranges on table 1. A concomitant difficulty in this arrangement is the inherent ambiguity of meaning of the assigned value. For example, if a value of 2 is given to two elements, one element might actually be present in the amount of 0.01 percent and the other in the amount of 0.001 percent. In using the assigned values in the comparison of elements, a somewhat distorted picture would emerge. In the present study, however, emphasis is placed on the elements in each sample and their relative amounts rather than actual amounts of each element.

The following descriptive material points out the element variations in individual iron deposits, suggests the minerals which might contain the elements in their structure, compares the content of the various iron deposits, and indicates differences between the iron deposits and surrounding rocks. A brief comparison of molybdenum, silver, lead, gallium, copper and ferride content (titanium + vanadium + manganese + cobalt + nickel) of the deposits to their content in country rocks is included because these elements are present in most analyses and do not form major components in the minerals present.

North of Cleveland Gulch, boron is found in only two samples. Less than 0.001 percent was detected; it probably is from tourmaline. Sodium, aluminum, potassium, and calcium are possibly concentrated in feldspar grains, although calcite, muscovite, and biotite are also present and may account for most of these elements. Magnesium is present in some samples in moderate amounts, probably in chlorite and biotite. Phosphorus is noted in only one sample and is from apatite. Titanium is present in small amounts in 15 of the 28 samples. It may have replaced ferric iron in magnetite, but is probably, for the most part, in the form of rutile. Vanadium, present in 21 of the 28 samples, averages 0.001 percent - 0.01 percent. This element may be substituting for ferric iron in magnetite or possibly for aluminum. Chromium was not detected in the 28 samples. Manganese is found in small to moderate amounts in all 28 samples and probably substitutes for ferric iron in magnetite. Cobalt is found in only one sample and probably substitutes for iron in magnetite. Nickel is common and is found in 20 of the 28 samples, mostly in small amounts. The nickel could substitute for ferrous iron in magnetite, but may be in another mineral structure. Copper is common in moderate to large amounts and is found in 25 of the 28 analyses. Although not observed in either thin or polished sections, copper is believed to be in the form of native copper or cuprite. Zinc was detected in very faint traces in 8 samples and possibly substitutes for ferrous iron. Gallium is present in 15 samples, mostly in trace amounts, and probably substitutes for aluminum.

Very small amounts of germanium were detected in 4 samples and these may have been in the rutile. Molybdenum is found in 13 samples, mostly in trace amounts. Where the molybdenum is located in the mineral suite is uncertain; it may form its own mineral but none was noted in thin or polished sections. Silver is present in 18 samples, mostly in trace amounts, and apparently is associated with molybdenum or with the copper. A trace amount of tin occurs in 2 samples, and may be in chlorite or biotite. Lead is in 18 of the samples, and possibly substitutes for sodium or calcium.

At Iron Mountain and South Cleveland Gulch the elements and minerals are similar to those north of Cleveland Gulch. At Canon Plaza a few additional elements are present; quantities are much greater than at the other deposits; and the

TABLE I - SEMI-QUANTITATIVE SPECTROCHEMICAL ANALYSES OF WHOLE-ROCK SAMPLES

Symbols for percentage ranges: 5 = 1% or more; 4 = 0.1% to 1%; 3 = 0.01% to 0.1%; 2 = 0.001% to 0.01%; 1 = less than 0.001%; D = Detected

	Be	B	Na	Mg	Al	Si	P	K	Ca	Ti	V	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	Mo	Ag	Sn	Sb	Pb
Banded iron formation, North Cleveland Gulch																								
2019327	-	-	3	4	5	5	-	3	D	-	3	2	5	-	1	4	-	-	-	1	D	-	-	D
2019359	-	-	5	4	5	5	-	2	-	1	3	1	5	-	2	4	D	1	-	3	2	-	-	D
2019366	-	-	5	4	5	5	-	1	-	1	3	2	5	2	2	4	D	1	-	2	1	-	-	D
2019377	-	-	5	5	5	5	-	D	D	1	2	1	5	-	D	4	D	1	-	-	D	2	-	2
2019380	-	-	5	5	5	5	-	D	D	1	2	1	5	-	D	4	D	1	-	1	1	-	-	2
2019388	-	-	4	3	4	5	-	2	-	2	D	2	5	-	3	5	-	-	-	3	2	-	-	D
2019397	-	-	4	4	4	5	-	2	-	2	D	3	5	-	3	5	D	-	-	3	3	2	-	3
20193103	-	-	5	3	4	5	-	-	-	-	-	1	5	-	-	4	-	-	-	-	D	-	-	-
20193107	-	-	3	3	4	5	-	-	-	-	-	2	5	-	3	5	-	-	-	D	1	-	-	-
20193116	-	-	3	3	3	5	-	-	-	-	-	2	5	-	2	4	-	-	-	1	D	-	-	-
20193133	-	-	4	3	5	5	-	-	-	1	3	2	5	-	3	4	-	D	-	2	D	-	-	D
20193142	-	-	4	3	5	5	-	-	-	D	2	2	5	-	1	4	-	D	-	D	D	-	-	D
20193164	-	-	3	4	4	5	-	-	-	D	2	4	5	-	3	4	D	3	-	-	2	-	-	3
20193167	-	-	3	3	4	5	-	-	-	-	2	4	5	-	3	4	-	2	-	-	2	-	-	2
20193185	-	-	4	3	4	5	-	2	-	-	-	2	5	-	D	4	-	-	-	-	1	-	-	1
20193195	-	-	-	3	4	5	-	2	-	D	2	4	5	-	3	5	-	-	-	D	-	-	-	-
S2019320	-	-	2	3	4	5	-	-	-	1	1	3	5	-	-	-	-	-	-	-	-	-	-	-
S2019337A	-	-	-	3	3	5	-	-	-	-	-	3	5	-	-	4	-	-	D	-	-	-	-	-
S2019337B	-	-	-	4	4	5	-	-	-	-	1	3	5	-	2	4	-	-	-	-	2	-	-	-
S2019344A	-	-	5	3	4	5	-	-	-	1	4	2	5	-	-	4	-	D	D	-	-	-	-	2
S2019344B	-	-	-	4	3	5	-	-	-	-	-	D	5	-	-	3	-	-	-	-	-	-	-	-
S2019347	-	-	5	3	4	5	-	-	-	1	4	2	5	-	-	4	-	D	D	-	-	-	-	2
S2019348	-	-	5	3	4	5	-	-	-	-	-	3	5	-	-	4	-	D	D	-	-	-	-	-
S2019349	-	-	2	3	3	5	-	-	-	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-
21185	-	D	4	5	4	5	-	-	-	1	3	3	5	-	1	-	-	1	-	-	-	-	-	-
21186	-	D	4	5	4	5	1	-	-	1	3	3	5	-	1	4	-	1	-	-	-	-	-	1
21189	-	-	3	4	5	5	-	3	-	-	1	2	5	-	3	4	D	1	-	1	3	-	-	D
211810	-	-	3	4	5	5	-	3	-	-	2	3	5	-	4	5	D	2	-	3	3	-	-	1
Banded iron formation, South Cleveland Gulch																								
S2019350	-	-	-	3	3	5	-	-	-	-	-	2	5	-	-	5	-	2	-	-	-	-	-	-
S2019351	-	-	3	4	4	5	-	-	1	1	1	3	5	-	-	-	-	-	-	-	-	-	-	-
S2019352	-	D	-	4	3	5	-	-	-	-	1	3	5	-	1	-	-	-	-	-	-	-	-	-
S2019353	-	-	-	4	5	5	-	-	-	-	-	3	5	-	-	4	-	-	D	-	-	-	-	-
S2019361	-	-	3	4	4	5	-	2	-	-	1	3	5	-	3	4	-	2	-	2	3	-	-	-
Banded iron formation, Iron Mountain																								
22203C87	-	-	5	4	5	5	-	-	-	3	5	2	5	2	1	5	-	3	-	-	3	-	-	D
22203I18	-	-	-	4	5	5	1	-	-	-	-	2	5	-	-	5	-	D	D	-	-	-	-	2
22203I19	-	-	5	5	4	5	-	-	1	-	1	1	5	-	-	-	-	1	-	-	-	-	-	-
22203L86	-	1	3	4	3	5	-	-	-	-	3	3	5	-	1	-	-	1	-	-	-	-	-	-
222030177	-	-	-	3	3	5	-	-	-	-	-	2	5	-	-	4	-	D	-	-	-	-	-	-
Banded iron formation, Cañon Plaza																								
2110M	3	-	4	3	3	5	3	3	1	4	2	2	5	-	3	4	3	3	-	3	4	D	1	3
2110M1	-	D	4	5	5	5	3	4	3	5	3	4	5	3	5	4	4	3	-	-	-	-	1	2
2110M2	-	5	3	4	5	5	2	3	-	4	4	-	5	2	4	4	4	1	-	-	-	-	D	-
2110C3	-	5	4	3	5	5	3	2	2	5	3	2	5	-	3	4	2	3	-	-	-	1	1	3
2110C6	4	5	5	3	4	5	3	4	2	4	4	4	5	-	4	4	3	4	-	4	4	D	1	4
2110C7	-	-	-	3	4	5	-	4	-	5	1	-	5	-	4	4	2	1	-	2	1	-	-	-
Metamorphic rocks, North Cleveland Gulch (A = Amphibolite; CS = Chlorite schist; BS = Biotite schist; Q = Quartzite; MS = Muscovite schist; P = Phyllite; BQS = Banded quartz-muscovite schist)																								
2019330 (A)	-	-	5	4	5	5	-	2	D	4	5	3	5	2	3	4	D	2	-	2	2	-	-	D
2019351 (CS)	-	-	-	5	5	5	-	4	3	-	3	4	5	3	5	5	2	1	-	1	D	-	-	D
2019366A (BS)	-	-	5	4	5	5	-	3	4	1	3	2	5	2	2	4	D	2	-	2	1	-	-	D
2019373 (Q)	-	-	-	4	4	5	-	D	-	-	-	3	5	-	1	4	-	-	-	D	D	-	-	-
2019382 (BS)	-	-	5	5	5	5	-	D	-	1	2	2	5	1	2	4	D	1	-	D	D	1	-	2
2019385 (BS)	-	-	5	4	5	5	-	3	-	3	3	-	5	-	2	4	-	-	-	-	2	-	-	D
20193113 (Q)	-	-	-	3	3	5	-	-	-	-	-	3	5	-	1	4	-	-	-	-	D	-	-	-
20193188 (MS)	-	-	4	3	3	5	-	1	-	-	-	2	5	-	3	4	-	-	-	2	3	-	-	1
20193198 (P)	-	-	4	4	5	5	-	4	-	3	5	2	5	1	3	4	-	2	-	-	2	-	-	-
S2019344C (BQS)	-	-	5	2	4	5	-	2	-	3	2	3	5	-	3	4	-	1	-	1	2	-	-	-
Metamorphic rocks, South Cleveland Gulch (M = meta-arkose; A = Amphibolite)																								
S2019341 (M)	-	-	5	2	5	5	-	3	-	5	4	3	5	-	3	4	-	1	-	1	-	-	-	-
S2019342 (M)	-	-	4	4	4	5	-	2	-	4	5	3	5	-	3	4	-	-	-	-	-	-	-	-
S2019345 (A)	-	-	5	2	5	5	-	2	-	4	5	4	5	D	4	5	-	4	-	2	-	-	-	-
S2019346 (M)	-	-	3	2	3	5	-	2	-	4	4	4	5	-	4	4	-	D	-	1	1	-	-	D
S2019354 (A)	-	-	5	5	4	5	-	4	1	4	5	4	5	3	5	4	-	3	-	-	-	-	-	-
Metamorphic rocks, Cañon Plaza (SQ = Sheared quartzite; Q = Quartzite)																								
2110SZ (SQ)	-	2	-	3	3	5	-	3	-	4	3	-	5	-	3	4	-	1	-	-	3	-	-	D
2110CYR (Q)	-	-	-	3	4	5	-	1	-	3	-	-	5	-	3	4	-	-	-	-	2	-	-	-
Granitic intrusive near Cleveland Gulch																								
21184	-	-	5	3	5	5	-	D	-	1	-	3	4	-	1	3	-	1	-	-	1	-	-	D

mineralogy is different. The chief difference in the mineralogy is the presence of aluminum silicates and of specularite instead of magnetite. In 3 of 7 samples analyzed from Cañon Plaza, beryllium is present. Beryl may have been present, but was not noted in the thin sections from this deposit; vesuvianite was present and the beryllium could be in this mineral. The high percentage of boron in most specimens from Cañon Plaza is from tourmaline. The mineral distribution of the other elements is probably similar to that at Cleveland Gulch and Iron Mountain.

In thin section the iron formation at Cañon Plaza changes somewhat from the edge of the deposit to the center, but the trace element content at the contact and in the middle is similar. The middle part of the deposit has, in general, slightly more sodium, magnesium, phosphorus, vanadium, nickel, zinc, and lead. It also has some cobalt which is lacking in the contact part. The middle section has less beryllium, boron, titanium, gallium, molybdenum and silver. Tin, not detected in the middle, is present at the contact. In general these differences are minute and probably result from the change in the relative amounts and kinds of minerals.

Trace element contents of North and South Cleveland Gulch deposits are important in establishing the relationship of these two deposits. South Cleveland Gulch has much less sodium and vanadium; less potassium, nickel, copper, molybdenum, silver; more manganese; and no lead. The most significant differences are the low vanadium and absence of lead south of Cleveland Gulch. These differences possibly reflect different environments of emplacement of the iron. Iron Mountain deposit differs from North Cleveland Gulch deposit in that it has no potassium and molybdenum, less nickel and copper, more gallium; and cobalt is present.

Mason (1958) listed average amounts of elements in crustal rocks. A comparison of the 26 elements present in the iron deposits with his list shows that all the iron deposits are low in sodium, calcium, magnesium, potassium and aluminum; this condition is expectable considering the mineralogy of the deposits. Of more interest are the ferrides. The amounts of vanadium and manganese in the iron deposits are of the same order of magnitude as the average for the crust; titanium, chromium, cobalt, and nickel tend to be lower than the average for the lithosphere. Gallium and lead are around the average for the lithosphere, but molybdenum and silver show enrichment in most samples. Copper is highly enriched averaging over 0.1 percent. Turekian and Wedepohl (1961) listed the distribution of the elements in the crust by rock types. The highest copper content they list for the crustal rocks is 250 ppm in deep-sea clays, much below the amount of copper in these samples.

North of Cleveland Gulch the iron-formation, in general, has less potassium, calcium, titanium, vanadium, nickel, and gallium than the enclosing amphibolite, biotite and chlorite schists, and phyllite; and somewhat more lead than the three enclosing rock types. These differences are attributed to the difference in mineralogy of the iron-formation and the enclosing rocks, although the manganese and possibly the lead in the iron-formation may have come with the iron. It is interesting that the copper content in the iron-formation is nearly the same as the enclosing metamorphosed volcanic rocks. On the Olympic Peninsula, Washington, and other localities, basalts and tuffs have high native copper contents (C. F. Park, Jr., personal communication). Copper in the samples in the subject area is thought to have been present as native copper in the volcanics before the iron mineralization.

The Canon Plaza iron-formation has beryllium, boron, sodium, phosphorus, calcium, vanadium, manganese, cobalt, zinc, gallium, molybdenum, antimony, and lead, all of which the enclosing Ortega Quartzite lacks. In general, more magnesium, aluminum, potassium, titanium, and nickel are in the iron-formation than in the enclosing rocks. For some reason, in most of the samples studied, silver is slightly more abundant in the quartzite than in the iron-formation.

A comparison of molybdenum, silver, lead, gallium, copper, and ferride content (with the exception of iron) of samples from the four iron localities and country rocks from North Cleveland Gulch, South Cleveland Gulch, and Cañon Plaza is included because these particular elements do not commonly form major structural parts in the minerals present. The iron deposit at North Cleveland Gulch has about the same amount of molybdenum, silver, lead, and gallium as the schists; the schists have more copper and• ferrides. The amphibolite has more molybdenum, silver, gallium, copper, and ferrides, but contains no lead. This trace difference in elements between the iron deposits and the country rocks of North Cleveland Gulch is explained by the fact that more minerals accommodating these elements in their structure are present in the country rocks.

Meta-arkose south of Cleveland Gulch (this meta-arkose encloses most of the iron deposit in Cleveland Gulch) has about the same amount of molybdenum, lead, and silver as the iron-formation, but has higher amounts of gallium, copper, and the ferrides. The amphibolite south of Cleveland Gulch has less silver, more molybdenum, much more gallium, copper, and the ferrides than the iron-formation. The relationship between the iron-formation at Cañon Plaza and the enclosing quartzite was mentioned before. The deposit has more molybdenum, lead, gallium, and the ferrides, and the quartzite has more silver and copper.

SUMMARY

Only 26 elements are recorded in one or more samples of the iron-formation and enclosing rocks at Cleveland Gulch, Iron Mountain, and Cañon Plaza. Of these 26 elements only sodium, magnesium, silver, silicon, potassium, calcium, titanium, vanadium, manganese, iron, nickel, copper, gallium, molybdenum, silver, and lead are present in most of the samples; in addition to the high concentration of iron, copper, molybdenum, silver, and possibly lead are concentrated in the area (i.e., above the average for the crust); five of the other elements are significantly lower than the average for the lithosphere; the most prominent differences at North and South Cleveland Gulch are the low vanadium and absence of lead south of the gulch; elements in the iron-formation from Iron Mountain are similar to those at Cleveland Gulch; a comparison of trace elements from Cleveland Gulch and Iron Mountain with those of Cañon Plaza would not be meaningful because the mineralogy and geologic setting are unique at Canon Plaza; there is little difference in element content and quantity between the iron-formation and enclosing rocks at Cleveland Gulch; the variations present could be due to the quantity and types of minerals in each rock type. Variations in quantity and content of most elements in the analyses are due to mineralogical variations in the rocks analyzed. At Cleveland Gulch and Iron Mountain most of the elements in the iron-formation could have been in the host rock before iron mineralization, but at Canon Plaza many of the elements must have been deposited by the mineralizing fluid.

Except for the conclusions that most of the trace elements at Cleveland Gulch and Iron Mountain were probably present before iron mineralization, and many of those at Cañon Plaza probably were not present before mineralization, no genetic significance is attributed to the trace elements and their distribution. These analyses were completed and are included here (table 1) for the purpose of presenting the kinds and relative amounts of the trace elements in a deposit as a whole, compared with other deposits and country rocks.

One of the least expensive methods of searching for hidden ore bodies is by geochemical prospecting. In many parts of the world where bedrock is covered by a thin to moderate layer of soil, this method of prospecting has been extremely useful in pinpointing ore targets. However, positively establishing a geochemical anomaly is often very difficult without sufficient information about the geology and background geochemical data. Owing to ionic dispersion, ascertaining the exact locality of the mineral or minerals causing a geochemical anomaly is difficult. For instance, a piece of chalcopyrite the size of a basketball covered by 20 or 30 feet of soil on the side of a hill might furnish an anomaly at several hundred square feet downslope from the source. In three dimensions the anomaly would probably look like a tornado with perhaps no part of the surface anomaly over the source.

Even with sufficient evidence concerning soil depth and overall geology, establishing background values is often time-consuming and difficult in the general geochemical exploration program.

The potential for finding hidden mineral deposits in the Precambrian of Rio Arriba County is very good; and establishing general trace element background values should be most helpful in the geochemical prospecting for hidden deposits. For instance, a high and widespread copper content in the soil over greenstones or amphibolites would not be of much significance because these rocks have a high primary copper content (table 1). However, abnormally high abrupt changes in copper or the presence of lead, zinc, silver or other low background elements would indicate additional investigations should be undertaken. Unless an investigator is able to establish good background control, determining geochemical anomalies is extremely difficult. Data provided in table 1 should furnish this background information.

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# # #

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