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GEOLOGY OF MINERALIZATION AND ASSOCIATED ALTERATION IN THE CAPITAN MOUNTAINS, LINCOLN COUNTY, NEW MEXICO

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Abstract—The Capitan pluton is one of the largest Tertiary intrusives in New Mexico. It is a single-phase but texturally and compositionally zoned pluton that ranges from a roof zone of graphic granite to an intermediate zone of aplite to a core of porphyritic granite. Four types of mineral deposits occur in the Capitan Mountains: (1) iron skarn and vein deposits, (2) manganese veins, (3) vein and breccia deposits of quartz and fluorite, locally with anomalously high concentrations of thorium, uranium, rare-earth elements, gold and silver, and (4) feldspar. Minor alteration is associated with most iron deposits; however, extensive zoned calcsilicate alteration occurs at the Capitan iron deposit. Clay and sericitic alteration is locally associated with the manganese veins and vein and breccia deposits of quartz and fluorite. Field relationships, as well as petrologic, fluid inclusion microthermometry and chemistry, and isotopic data support a magmatic-hydrothermal source for the vein and breccia deposits and the iron skarn deposits. The most important resource in the area is the Capitan iron deposit (Smokey mine). The resource potential for thorium, uranium, rare-earth elements, and locally gold and silver in the vein and breccia deposits of quartz and fluorite veins is uncertain due to lack of subsurface data.

INTRODUCTION

The Capitan Mountains form an east-west-trending mountain range, about 35 km long and 5–8 km wide, in central Lincoln County, south-central New Mexico (Fig. 1). The range consists of a single-phase, but texturally and compositionally zoned, Tertiary granitic pluton (Allen, 1988; Allen and McLemore, 1991) associated with iron skarn and vein deposits, manganese veins, and vein and breccia deposits of quartz and fluorite with anomalously high concentrations of thorium, uranium, rare-earth elements (REE), gold and silver. Feldspar, which is used in manufacturing glass, may also have potential in the Capitan Mountains. Although minor manganese and uranium have been produced from the Capitan Mountains in the past, the only current production is from an iron skarn deposit, the Smokey mine, which is used as aggregate by the Tijeras cement plant near Albuquerque, New Mexico. In addition, the Mina Tiro Estrella claim is yielding mineral specimens, some of museum quality.

The area has received little detailed study until recently. Earlier investigations of the Capitan Mountains were reconnaissance petrologic studies and regional geologic mapping (Knopp, 1933; Sidwell, 1946; Patton, 1951; Kelley and Thompson, 1964; Kelley, 1971) or examinations of the mineral deposits (Sheridan, 1947; Soulé, 1947, 1949; Kelley, 1949, 1952; Collins, 1956; Griswold, 1959; Butler, 1964; Harrer and Kelly, 1963; McLemore, 1983; Tuftin, 1984; McLemore et al., 1988a, b; Ellinger, 1988). Recent studies have focused on the petrology and geochemistry of the Capitan pluton (Allen, 1988; Allen and McLemore, 1991) and on the geochemistry and origin of the quartz vein and breccia deposits (Willis et al., 1989; Phillips et al., 1990a, b, 1991; Phillips, 1990).

The purpose of this paper is to describe the diverse types of mineral occurrences and associated alteration in the Capitan Mountains and assess the mineral resource potential. This study also provides insights into understanding the relationship of the petrogenesis and the mineralization of the Capitan pluton. This work is based upon synthesis of published and unpublished reports, field investigations, and petrographic, mineralogic and geochemical studies.

GENERAL GEOLOGIC SETTING

The Capitan pluton is one of the largest Tertiary intrusives in New Mexico and has been dated at 26.2 ± 1.2 Ma (K/Ar on biotite, Allen, 1988). The granitic pluton is one of several Tertiary intrusives in south-central New Mexico that form the Lincoln County porphyry belt (Kelley and Thompson, 1964; Allen and Kottlowski, 1981, p. 28). The pluton is also a prominent feature of the Capitan lineament (Fig. 1; Chapin et al., 1978). The Capitan lineament is a major west-northwest-trending zone that transverses central New Mexico (Fig. 1) and is characterized by the alignment of various igneous and structural features (Allen and McLemore, 1991). It includes such features as the Matador arch of west Texas, the 27.9 ± 1.4-Ma-old diabase dikes near Roswell (Aldrich et al., 1986), the Capitan pluton, vents of the Recent Carrizozo basalt flows, and the 27.9 ± 1.1 Ma Jones Camp dike in eastern Socorro County (Aldrich et al., 1986). Near Socorro, the Capitan lineament becomes truncated by the Socorro Accommodation Zone (SAZ), previously known as the Socorro transverse shear zone (Chapin, 1989).

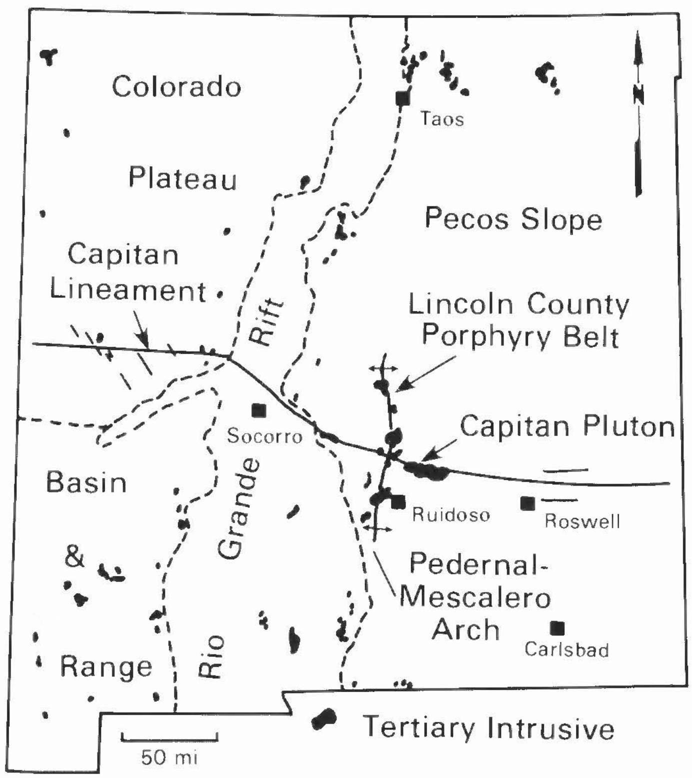

FIGURE 1. General location and tectonic features surrounding the Capitan pluton.

The Capitan lineament is a major tectonic feature that is roughly perpendicular to the Rio Grande rift and periodically has leaked magma since about 33 Ma.

The Capitan pluton is a single-phase, but texturally and compositionally zoned pluton that ranges from a roof zone (west end) of a high-silica (77.2% SiO_2) micromiarolitic graphic aplite to a transition zone of equigranular aplite (73.0% SiO_2), to a core of fine-grained, amphibole-biotite, porphyritic granite (east end). Chemically, the Capitan pluton is an alkali feldspar granite, with some samples of the porphyritic granite approaching a more typical granite (according to the classification of De la Roche et al., 1980). The petrology and geochemistry of the Capitan pluton is further described by Allen and McLemore (1991).

MINING HISTORY AND PRODUCTION

Unlike many areas of New Mexico, mineral exploration activity in the Capitan Mountains is relatively recent. The mineral deposits (Fig. 2) have received minor exploration and development activity, although some production has occurred.

The most economically important mineral deposits in the Capitan Mountains have been the iron skarn deposits. Extensive study of the largest of the iron skarn deposits, now known as Smokey iron mine (Fig. 3), occurred in the 1940s as part of a national program designed to assess the nation's iron resources (Soulé, 1947, 1949; Kelley, 1949, 1952; Sheridan, 1947). Reserves at that time were estimated to be about 1 to 3 million tons of ore averaging 45–48% Fe (Kelley, 1949, 1952). The deposit has been in production sporadically since the 1950s, and for the past ten years or so iron ore has been produced sporadically from the Smokey mine for aggregate for the Tijeras cement plant. Total production is unknown, but much of the deposit remains undeveloped. Other smaller iron skarn and vein deposits occur in the Capitan Mountains (Table 1; Fig. 2; Harrer and Kelly, 1964).

In the 1940s and 1950s, manganese veins were discovered in the Capitan Mountains. Total production is unknown but probably small based on the limited extent of the workings. Approximately one ton of ore averaging 54% Mn was mined from the Arabella pit at the eastern end of the Capitan Mountains (Fig. 2) and shipped to Socorro (Griswold, 1959).

During the major uranium boom in the 1950s, radioactive anomalies were discovered in the Capitan Mountains (Collins, 1956; McLemore, 1983). Thorium and some uranium were found in vein and breccia zones of quartz and fluorite near Capitan Gap (Fig. 2). A thorium mill was built by the New Mexico Thorium Company on the south side of the mountains near Thorium Canyon, but never went into production. Approximately 3 tons of uranium-bearing iron ore from Bear Canyon (Fig. 2) was shipped to Grants, New Mexico in 1954, but it only contained an average grade of 0.02% U_3O_8 (McLemore, 1983).

More recently, the area has been examined for REE and feldspar. However, no serious exploration has occurred. The Mina Tiro Estrella claim is currently being mined for high quality quartz crystals sold as mineral specimens (Hanson, 1989).

MINERAL DEPOSITS

Iron skarn and vein deposits

Numerous iron skarn and vein deposits occur throughout Lincoln County and are spatially associated with Tertiary igneous intrusives (Harrer and Kelly, 1963; Griswold, 1959; McLemore, 1991, fig. 1). The largest of these deposits is the Capitan iron deposit, now the site of the Smokey iron mine. The Capitan iron deposit is estimated to contain 1 to 3 million tons of ore averaging 45–48% Fe (Kelley, 1949, 1952).

The Capitan iron deposit is a skarn deposit; calcsilicate minerals are associated with the iron deposit. The deposit consists of a series of

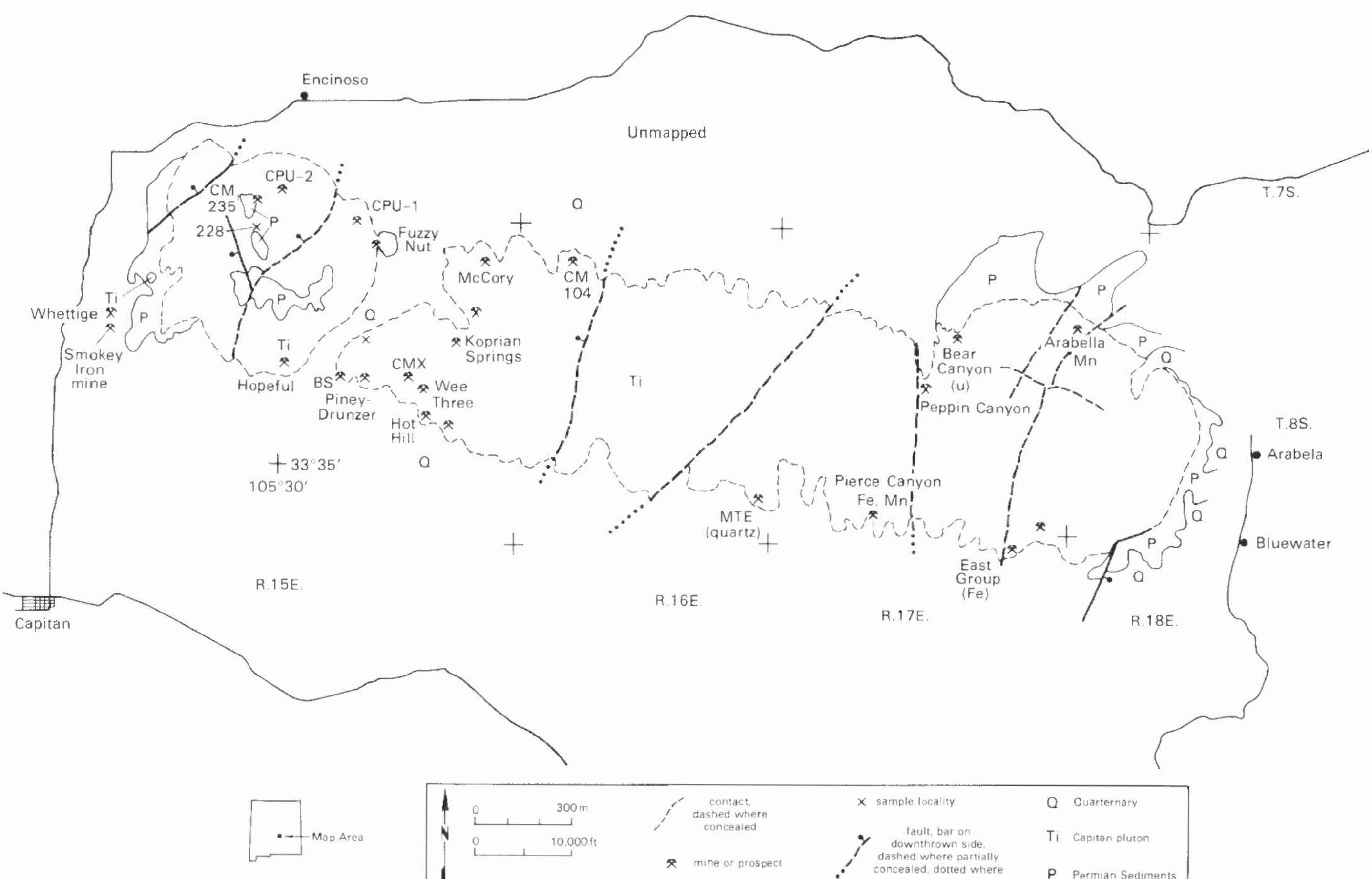

FIGURE 2. Mineral deposits in the Capitan Mountains.

FIGURE 3. View of Smokey iron mine.

FIGURE 4. View of replacement lens of magnetite-hematite in the Smokey pit.

iron-replacement bodies in the Permian San Andres Limestone (Fig. 4) Drilling has confirmed the presence of the Capitan pluton at a depth of 25–50 m (Kelley, 1952). Ore minerals consist of magnetite, hematite and martite in a gangue of calcite, quartz, fluorite, pyroxene, tremolite, actinolite, epidote, phlogopite and trace garnet (X-ray diffraction studies). The deposit is zoned (Kelley, 1952). The inner core zone consists of barren, unaltered limestone and sandstone and is partially surrounded by a semicircular zone of epidote with little phlogopite, pyroxene, tremolite and iron oxides. The next zone consists of phlogopite and iron oxides with lesser tremolite but little or no epidote. An irregular zone of tremolite and iron oxides with little or no phlogopite or epidote partially surrounds the phlogopite zone. The outer zone consists of iron oxides replacing the limestone. Kelley (1952) suggested that the iron ore body occurs in a collapse structure formed by partial dissolution of limestone during Triassic or pre-Triassic time.

Several smaller iron skarn and vein deposits occur throughout the Capitan Mountains (Table 1, Fig. 2). The CM 235 prospect occurs in the limestone roof pendent of the western Capitan Mountains (Fig. 2). Small iron skarn and replacement bodies occur in the thin limestone overlying the Capitan pluton and are similar to the Capitan iron deposits. Magnetite and hematite occur with actinolite, tremolite and garnet. Fluid inclusions in some garnet crystals contain several daughter minerals similar to fluid inclusions found in the vein and breccia deposits of quartz and fluorite.

Elsewhere in the Capitan Mountains, the iron replacement and vein deposits are small and contain only iron oxides without any calcsilicate minerals (i.e. Pierce Canyon, Peppin Canyon, Bear Canyon). These deposits are typically low grade (less than 40% Fe), but selected samples may contain anomalously high amounts of gold and/or silver and sometimes uranium (Tables 1, 2; Tuftin, 1984). Other iron deposits in Lincoln County also contain sporadic values of these elements. However, these iron deposits *do not* contain gold, silver or uranium in significant concentrations to be recovered economically. These deposits are not a potential iron resource because of small size and low grade. However, the potential is excellent for use as an aggregate.

Manganese

Manganese oxides fill fractures and form small veins less than a meter wide at the Arabella mine in the porphyritic granite (Table 1, Fig. 2). Total strike length is less than 40 m. Total manganese content is relatively low, less than 30% (Tuftin, 1984), although hand-sorted material averaging 54% was shipped in the 1950s (Griswold, 1959). Feldspars in the porphyritic granite have been altered to clay minerals and sericite and partially replaced by manganese oxides. Mafic minerals

TABLE 1. Brief descriptions of mineral occurrences and deposits in the Capitan Mountains. *Chemical assays reported in Table 2.

Name	Location	Type of Deposit	Description
Smokey Iron mine	10,11,13,14,15, T8S R14E	Iron skarn/replacement	Large open-pit exposing lenses of magnetite-hematite replacing limestone of the San Andres Formation. Skarn minerals include magnetite, epidote, phlogopite, and tremolite. Estimated size 1-3 mill tons of Fe ore (Kelley, 1949). Total production unknown.
Whettige	26,35 T7S, R14E	Iron skarn/replacement	Iron replacement deposits in Permian limestone.
Unnamed	SE1/4 NE1/4 sec. 30 T7S R15E	Iron skarn/replacement or vein	Magnetite nodules in cleared area in alluvial material.
CM 235 prospect	NW1/4 SE1/4, SE1/4 NE1/4 sec. 31 T7S R15E	quartz/fluorite vein, iron skarn/replacement	*Small pits (5 x 5 x 1 m) in fractured and brecciated granophyre granite containing small cubes of fluorite quartz, and hematite. Sample assayed 2.0 ppm Ag (Table 3). Some pits are in iron skarn/replacement deposits in limestones of the San Andres Formation with garnet, magnetite, hematite, and actinolite/tremolite.
CPU-1	SE1/4 SE1/4 sec. 33 T7S, R15E	quartz/fluorite vein	Open cut in brecciated granophyre granite containing veins of quartz, fluorite, feldspar, and Mn-Fe oxides.
CPU-2	E1/2 SW1/4 sec. 33 T7S, R15E	quartz/fluorite vein	*Two brecciated veins exposed by shallow trenches in granophyre granite. Veins strike north-northeast with a vertical dip and are 0.5 m wide. Veins consist of quartz, adularia, Fe-Mn oxides, fluorite, and clay minerals.

Table 1 (cont'd)

Name	Location	Type of Deposit	Description
Fuzzy Nut prospect	SW1/4 NW1/4 sec. 3 T8S, R15E	quartz/fluorite vein	*A shallow pit (15 x 5 m) in granophyre granite consisting of quartz, fluorite, goethite, maghemite/hematite, calcite , pyrolusite, garnet, apatite, and clay minerals. Calcite occurs as white coatings and as brown hematite-calcite nodules.
Hopeful prospect	SE1/4 SW1/4 sec. 17 T8S, R15E	quartz/fluorite vein	Shallow pit (5 x 2 x 1 m) in fractured and brecciated granophyre or aplite granite. Veins of hematite, Mn oxides, fluorite, calcite, and clay minerals are cut by a northwest-trending clay-filled fracture.
BS prospect	NE1/4 SE1/4 sec. 21 T8S, R15E	quartz/fluorite vein	Shallow pit (15 x 5 m) in aplite granite.
Piney-Druzer prospects	SE1/4 SE1/4 sec. 16, SW1/4 SW1/4 sec. 15, NE1/4 NE1/4 sec. 21, NW1/4 NW1/4 sec. 22 T8S, R15E	quartz/fluorite vein	*Series of pits, trenches, and bulldozer cuts along radioactive fractures and faults in aplite granite. Veins consist of quartz, fluorite, hematite, and Mn oxides. Radioactivity up to 2000 times background. Sample assayed 8.9 ppm Ag (Table 3).
CMX	SW1/4 SE1/4 sec. 15, T8S R15E	quartz/fluorite vein	No workings. Thin quartz and feldspar veins, up to 50 m long, trending east-west in fractured granophyre granite.
Wee Three	SE1/4 SE1/4 sec. 15, NE1/4 NE1/4 sec. 22 T8S, R15E	quartz/fluorite vein	*Series of small pits and cuts in fractured and brecciated aplite granite with veins of quartz, feldspar, calcite, hematite, Mn oxides, and minor fluorite.
Hot Hill prospect	SW1/4 SW1/4 sec. 23, T8S, R15E	quartz/fluorite vein	*Trench cut into fractured and brecciated granophyre granite exposing N60°E trending vertically-dipping veins of quartz, fluorite, calcite, feldspar, Fe oxides, and clay minerals. Radioactivity up to 200 times background. Some selected samples assayed up to 49 ppm Au and 7.9 ppm Ag (Table 3). Tuftin (1984) reports 0.18% Mn.
Koprian Springs prospect veins	NW1/4 SW1/4 sec. 11 T8S, R15E	quartz/fluorite vein	*Small pit in brecciated aplite granite exposing veins of fluorite, quartz, hematite, feldspar and hematite.
Unnamed	NW1/4 sec. 16 T8S, R15E	quartz/fluorite vein	Shallow pits in aplite-granophyre granite with thin quartz veins.
McCory prospects	NW1/4 sec. 1 T8S, R15E	quartz/fluorite vein	*Several veins exposed by pits and trenches in fractured and brecciated aplite granite. Veins consist of quartz, fluorite, hematite, feldspar, and possibly allanite. Up to 200 times background radioactivity. A few samples assayed 10-17 ppm Ag (Tuftin, 1984) and up to 7800 ppm total rare-earth elements (Table 3).
CM 104 prospect	NE1/4 SE1/4 sec. 6 T8S, R16E	quartz/fluorite vein	*Several bulldozer cuts in fractured aplite granite exposing veins of quartz, feldspar and fluorite.
Mina Tiro Estrella (MTE)	NE1/4 sec. 35 T8S, R16E	quartz/fluorite vein	Shallow pit partially exposing brecciated zone in aplite granite containing vein striking N48°E, dipping 52°SW and 275 m long. Vein minerals include quartz, titanite, allanite, feldspar, chlorite/epidote, tourmaline(?), and clay minerals (Hanson, 1989).
Pierce Canyon prospects (Tide prospects, Bear Cat, Bumble Bee)	W1/2 SW1/4 sec. 30 T8S, R17E	iron skarn	Series of pits and cuts exposing magnetite-hematite lenses in porphyritic granite. One lense is 10 m diameter and averages 60% Fe (Tuftin, 1984).
Peppin Canyon prospects	NE1/4 sec. 26 T8S, R15E	iron skarn/replacement	Shallow pit exposing magnetite-calcite lenses near contact of San Andres Limestone with aplite granite.
Bear Canyon uranium prospect, Copeland Canyon, Pine Lodge	Sec. 3 T8S, R16E; Sec. 33, T7S, R17E	iron skarn/replacement and iron veins	*Several shallow pits and short adits exposing magnetite-hematite zones in porphyritic granite near the contact between the San Andres Limestone and granite. The zones appear to be small (several tens of meters in diameter) and low grade (45% Fe; Tuftin, 1984). A small shipment of ore for uranium was sent in 1956 (Bear Canyon; McLemore, 1983). Iron ore up to 59% Fe and up to 24 ppm Ag (Tuftin, 1984).
Arabella manganese mine	N1/2 sec. 12 T8S, R17E	manganese vein	Open pit exposing 2 ft wide manganese vein (strike N60°W, 30°NE dip) averaging 41% Mn (Griswold, 1959; Tuftin, 1984). Selected samples assayed 0.7 ppm Au, 45% Mn and 24 ppm Ag, 25% Mn (Tuftin, 1984).
Big Ben	NW1/4 sec. 31, T7S, R15E	iron skarn/replacement	Two shafts exposing magnetite-hematite lenses in granite (Harrer and Kelly, 1963).

have been altered to chlorite and replaced by manganese oxides. Thin veinlets of manganese oxides less than 1 mm wide also cut the porphyritic granite. Anomalously high gold (0.79 ppm Au) and silver (24 ppm Ag) have been reported from samples taken from the Arabella mine (Tuftin, 1984).

The Arabella deposit is small, low grade and does not consitute a potential resource of manganese. The gold and silver resource potential is uncertain; more sampling is required to determine if there is a potential resource. Furthermore, if a gold-silver resource is present, detailed metallurgical testing is required because gold and silver recovery from manganese ore is difficult.

Elsewhere in the Capitan Mountains, manganese oxides are associated with some iron skarn and vein deposits, and with vein and breccia deposits of quartz and fluorite (Table 1). However, manganese concentrations are typically low, with a few local exceptions (Tuftin, 1984), and these occurrences do not constitute a potential resource.

Vein and breccia deposits of quartz and fluorite

Numerous vein and breccia deposits of quartz and fluorite, some with anomalously high concentrations of thorium, uranium, rare-earth elements, gold and silver cut the Capitan pluton along its flanks and western end. These deposits occur in the granophyric aplite and aplite portions of the Capitan pluton but not in the porphyritic granite. The veins occur as open-space fillings in breccia and shear zones and along fractures and faults (Fig. 5). The breccia deposits consist of silicified fragments of the aplite up to a meter in diameter (Fig. 6). They vary in size from a few centimeters to over a meter wide and up to 300 m long.

The veins have a diverse mineralogy. The Mina Tiro Estrella veins consist of quartz, feldspar, allanite, titanite, chlorite, epidote, clay minerals, hematite and magnetite. In addition, Hanson (1989) reported the occurrence of actinolite and microlite. Clear to smoky quartz, some forming Japanese-law twins up to several centimeters long, are currently found at the prospect. Titanite and allanite are enriched in rare-earth elements (Table 3).

Elsewhere, the vein and breccia deposits consist of quartz, feldspar, hematite, thorite and allanite (identified in X-ray diffraction and petrographic studies). Fluorite occurs in many but not all deposits. Calcite occurs as a late-stage vug-filling at some veins. Apatite and garnet occur at the Fuzzy Nut prospects.

Alteration of the Capitan pluton in the vicinity of these veins is minor. Silicification, chloritization, hematization, sericitization and clay alteration occurs in the brecciated zones and within a few meters of some veins. Other veins exhibit only minor alteration. More detailed studies of the alteration are under way in order to further understand the mineralization.

Many veins contain anomalously high concentrations of rare-earth elements, uranium and thorium (Table 2), but these concentrations are discontinuous and sporadically distributed with the veins. Some veins

FIGURE 5. Prospect at Hot Hill of quartz veins with rare-earth elements along fractures.

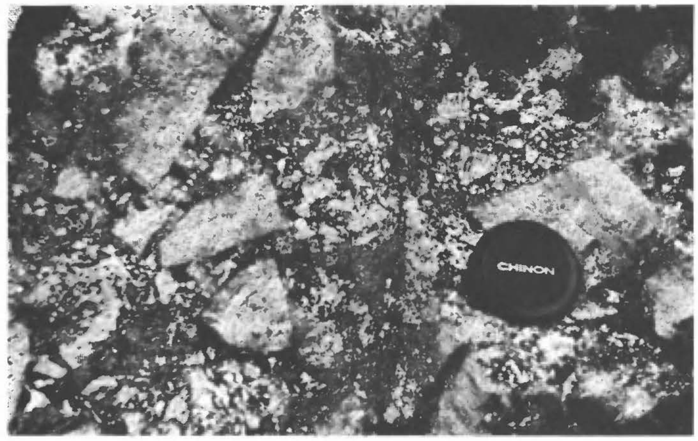

FIGURE 6. Breccia deposits cemented by quartz and iron oxides.

also contain some silver and rarely gold values (Table 2; Tuftin, 1984), but this mineralization is also discontinuous and sporadically distributed. Gold and silver potential should not be overlooked because the Capitan Mountains occur within a belt of gold-silver deposits known as the Great Plains margin (GPM) deposits (North and McLemore, 1986, 1988). GPM deposits are associated with igneous intrusives and spatially associated with iron skarns. Some of the largest gold-producing districts in New Mexico, such as Elizabethtown-Baldy and Ortiz are GPM deposits (McLemore, 1991).

Although these veins contain sporadic high concentrations of rare-earth elements, thorium, uranium, gold and silver, the resource potential is uncertain. Surface sampling suggests a low resource potential, but there has been no drilling in this area to evaluate the subsurface potential. Mineralized zones at the surface are discontinuous and occur in relatively small zones. However, the extent of these mineralized zones in the subsurface is unknown.

Feldspar

Feldspar, together with nepheline syenite, are important industrial minerals used in manufacturing glass, pottery and ceramics. Alumina is a critical ingredient that improves the workability, retards devitrification, and increases the chemical stability in glass and ceramic products (Leasure, 1973). Soda and potassium act as a flux (Robins, 1986). Most production of feldspar in the United States is from North Carolina, although some production occurs in other states (U.S. Bureau of Mines, 1989). There has not been any recent production of feldspar from New Mexico, although producers are looking for additional resources.

Like most industrial minerals, economic specifications for commercial deposits of feldspar vary according to the manufacturer. These deposits must be low in iron oxide (less than 0.1% for colorless glass and less than 0.5% for green or amber glass) and low in refractory minerals (Leasure, 1973). Beneficiation techniques, such as flotation or magnetic methods, can be used to concentrate feldspar. Additional specifications, such as particle size, may be required and should be obtained from the specific manufacturer or buyer.

The Capitan aplite granite may qualify as a potential feldspar resource. Tuftin (1984) stated that the Capitan pluton is "undesirable as a source of feldspar" on the basis of limited field reconnaissance. Recent, more extensive field and petrographic studies indicate that portions of the Capitan pluton, specifically the aplitic phase, could be suitable for commercial feldspar (Allen and McLemore, 1991). Several samples contain less than 1% total Fe_2O_3 (Allen and McLemore, 1991) and less than a few percent mafic minerals. However, drilling of prospective areas is required to determine the extent of suitable material.

Feldspar deposits in the Capitan Mountains would be economic only if a sufficient tonnage of the material at suitable specifications exists and only if a glass or ceramic factory was developed nearby. The nearest glass factories are in Ciudad Juarez, Mexico, and in Texas and Oklahoma. Shipping costs are prohibitive at present. However, the Capitan aplite granite does provide a potential feldspar resource for the future.

Granitic plutons also may provide suitable material for use as dimension and/or crushed stone. Certainly the Capitan pluton could provide these uses, but distance to prospective markets (Roswell, Albuquerque) is too large to consider such uses at present.

ORIGIN OF THE MINERAL DEPOSITS

It is beyond the scope of this report to discuss in detail the origin of the mineral deposits in the Capitan Mountains, but a few comments are in order. The mineral deposits are most likely derived from the Capitan pluton. Iron skarn deposits are typically attributed to a magmatic source (Einaudi et al., 1981). In the Capitan Mountains, the close proximity of the iron deposits to the Capitan pluton, and the presence of multiple daughter minerals in fluid inclusions in garnet from one of the iron deposits, supports a magmatic origin of the iron skarn and vein deposits. Isotopic and fluid inclusion studies are required to further support this theory.

Field relationships, and petrologic, fluid-inclusion microthermometry

TABLE 2. Chemical analyses from localities in the Capitan Mountains. Au, Ag—fire assay; REE, U, Th—ICP (NMBMMR Chemical Laboratory, Lynn Brandvold and associates). All analyses in parts per million (ppm) except Fe, which is in weight percent.

Name (sample number)	Au	Ag	La	Ce	Nd	Sm	Eu	Gd	Yb	Lu	Y	U	Th	Fe
CM 235 (CM 230)	0.0	0.0	--	--	--	--	--	--	--	--	59	--	8	39.9
CM 235 (CM 235)	0.0	2.0	160	290	59	15	--	16	11	2.4	110	<6	14	--
CPU-2 (7920)	--	--	--	86	59	58	--	7	3.2	--	58	--	--	--
Fuzzy Nut (7922)	--	--	--	89	56	58	--	7	2.7	--	60	--	--	--
Piney (4484)	0.0	5.5	13	91	40	11	--	17	3.7	--	87	--	2460	--
Piney (4485)	0.0	1.4	8	56	21	4	--	7	--	--	10	--	5	--
Piney (4496)	0.0	1.4	25	59	46	11	--	16	3.5	--	61	6	740	--
Piney (4487)	0.00	8.9	30	74	110	30	--	38	12	--	131	--	245	--
Wee Three (7924)	--	--	--	12	--	0.9	--	0.6	--	--	0.3	--	--	--
Hot Hill (218)	49	0.0	48	120	17	12	--	12	5.9	1.6	--	<6	49	--
Hot Hill (219)	0.0	7.9	41	98	36	12	--	14	4.8	1.6	28	4	28	--
Hot Hill (220)	0.0	4.1	33	41	13	10	--	15	1.7	2.1	87	3	33	--
Koprian Springs (7923)	--	--	--	85	323	316	0.3	48	15	--	344	--	--	--
(7921)	--	--	--	56	12	11	--	3.2	--	--	10	--	--	--
McCory (1784)	--	--	2500	4350	1025	96	--	125	32	5	330	200	217	--
(3162)	--	--	91	139	88	20	--	25	11	1	140	--	--	--
CM 104 (CM 104)	0.0	0.0	30	--	43	11	--	12	5.1	1.8	67	5	16	--
(CM 105)	--	--	--	--	--	--	--	--	--	--	57	4	10	--
Bear Canyon (3143)	0.0	21	--	--	--	--	--	--	--	--	--	110	--	--

TABLE 3. Electron probe analyses on titanite and allanite from the MTE prospect. Titanite (1), titanite (2), and allanite (1) were analyzed at the Dept. of Earth and Planetary Sciences, Washington University, St. Louis, MO (Willis et al., 1989). Allanite (2) was analyzed at the Dept. of Geological Sciences, University of Michigan, Ann Arbor, MI (E. Essene, personal comm., 1990).

Oxide	Titanite (1) (Wt%)	Titanite (2) (Wt%)	Allanite (1) (Wt%)	Allanite (2) (Wt%)
SiO_2	27.73	28.80	28.35	30.33
TiO_2	29.71	31.03	1.65	0.59
Al_2O_3	1.05	0.91	6.85	10.61
Fe_2O_3	--	--	--	11.71
FeO	4.67	4.29	21.60	7.69
CaO	24.08	24.95	9.23	10.38
MgO	0.24	0.14	1.29	1.16
MnO	0.10	0.12	0.49	--
La_2O_3	0.52	0.50	12.20	9.73
Ce_2O_3	2.08	1.65	11.77	14.89
Pr_2O_3	--	--	--	0.58
Nd_2O_3	1.20	0.93	1.59	1.95
Sm_2O_3	--	--	--	0.24
ThO_2	--	--	--	0.17
P_2O_5	--	--	--	0.01
Nb_2O_5	0.98	0.81	0.01	--
ZrO_2	0.26	0.97	0.03	--
Y_2O_3	0.89	0.79	0.25	--
F_2	1.04	1.17	0.72	0.32
H_2O	--	--	--	1.38
Totals	94.55	96.96	96.03	101.74

and chemistry, and stable isotope data (Phillips, 1990; Phillips et al., 1991) suggest the vein and breccia deposits were derived from hydrothermal fluids from a magmatic source, i.e. the Capitan pluton. These data are further discussed in Phillips et al. (1991) and additional studies are under way. The vein and breccia deposits of quartz and fluorite are associated only with the roof (graphic granite) and intermediate (aplite) zones of the Capitan pluton, suggesting that the mineralization is late-stage, possibly related to cooling and cracking of the pluton.

The origin of the manganese veins, especially the Arabella deposit, is uncertain but most likely related to the Capitan pluton as well. Isotopic and geochemical studies are required to support this theory.

Additional studies are under way to model the petrogenesis of the Capitan pluton (Allen and McLemore, 1991) and the associated mineralization. It is apparent that the mineral deposits in the Capitan Mountains are related to the formation and/or cooling of the Capitan pluton and these additional modeling studies will provide more specific details on this process.

RESOURCE POTENTIAL

Numerous occurrences of iron skarn and vein deposits, manganese veins, vein and breccia deposits of quartz and fluorite, and feldspar are found throughout the Capitan Mountains. The most important resource in the area is the Capitan iron deposit (Smokey iron mine). Currently this deposit is sporadically mined for aggregate. Although several additional iron deposits occur in the area, they are small and low grade and have little or no potential at present. The manganese veins are also low grade and small in size and have little or no potential. Numerous vein and breccia deposits of quartz and fluorite, some with associated thorium, uranium, rare-earth elements, and locally gold and silver occur throughout the western Capitan Mountains. The resource potential is uncertain due to lack of subsurface data. Additional studies are required to determine the resource potential of the quartz-fluorite veins. Portions of the western Capitan pluton are relatively low in mafic minerals and iron and may constitute a feldspar resource.

The resources in the Capitan Mountains are unlikely to be developed in the near future because of rugged terrain, and much of the eastern portion of the range is designated as a wilderness area and withdrawn from mineral entry. Mining of iron ore at the Smokey iron mine continues periodically and production of mineral specimens continues at the Mina Tiro Estrella veins.

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REFERENCES

Aldrich, M. J., Jr., Chapin, C. E. and Laughlin, A. W., 1986, Stress history and tectonic development of the Rio Grande rift, New Mexico: Journal of Geophysical Research, v. 91, no. B6, p. 6199–6211.

Allen, J. E. and Kottlowski, F. E., 1981, Roswell–Ruidoso–Valley of Fires: New Mexico Bureau of Mines and Mineral Resources, Scenic Trips to the Geologic Past, no. 3, 96 p.

Allen, M., 1988, The Capitan pluton, New Mexico: an example of a zoned granite chamber: Geological Society of America, Abstracts with Programs, v. 20, p. A313.

Allen, M. S. and McLemore, V. T., 1991, The geological petrogenesis of the Capitan pluton, New Mexico: New Mexico Geological Society, Guidebook 42.

Butler, P., Jr., 1964, Magnetite from intrusives and associated contact deposits, Lincoln County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 63 p.

Chapin, C. E., 1989, Volcanism along the Socorro accommodation zone, Rio Grande rift, New Mexico; *in* Field excursions to volcanic terranes in the western United States, volume I: southern Rocky Mountain region: New Mexico Bureau of Mines and Mineral Resources, Memoir 46, p. 46–57.

Chapin, C. E., Chamberlin, R. M., Osburn, G. R., White, P. W. and Sanford, A. R., 1978, Exploration framework of the Socorro geothermal area, New Mexico: New Mexico Geological Society, Special Publication No. 7, p. 115–129.

Collins, G., 1956, Thorium occurrences in the Capitan Mountains area, Lincoln County, New Mexico: U.S. Atomic Energy Commission, Report TM DAO-4-TM-1, 11 p.

De la Roche, H., Leterrier, J., Granclaude, P. and Murchal, M., 1980, A classification of volcanic and plutonic rocks using R_1R_2-diagram and major-element analyses—its relationship with current nomenclature: Chemical Geology, v. 29, p. 183–210.

Einaudi, M. J., Meinert, L. D. and Newberry, R. J., 1981, Skarn deposits; *in* 75th Anniversary Volume: Economic Geology, p. 317–391.

Ellinger, S. T., 1988, A stream sediment geochemical survey of the eastern half of the Capitan Mountains, Lincoln County, New Mexico [M.S. thesis]: Canyon, West Texas State University, 123 p.

Griswold, G., 1959, Mineral deposits of Lincoln County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 67, p. 88–91.

Hanson, T., 1989, Mina Tiro Estrella: Mineralogical Record, v. 20, no. 1, p. 51–53.

Harrer, C. M. and Kelly, F. J., 1963, Reconnaissance of iron resources in New Mexico: U.S. Bureau of Mines, Information Circular 8190, 112 p.

Kelley, V. C., 1949, Geology and economics of New Mexico iron-ore deposits: University of New Mexico, Publications in Geology, no. 2, 246 p.

Kelley, V. C., 1952, Origin and pyrometasomatic zoning of the Capitan iron deposits, Lincoln County, New Mexico: Economic Geology, v. 47, p. 64–83.

Kelley, V. C., 1971, Geology of the Pecos country, southeastern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 24, 75 p.

Kelley, V. C. and Thompson, T. B., 1964, Tectonics and general geology of the Ruidoso-Carrizozo region, central New Mexico: New Mexico Geological Society, Guidebook 15, p. 110–121.

Knopp, V., 1933, The structural relations of the Capitan and eastern border of the Sierra Blanca Mountain groups in Lincoln County, New Mexico [M.S. thesis]: Boulder, University of Colorado, 32 p.

Leasure, F. G., 1973, Feldspar; *in* United States mineral resources: U.S. Geological Survey, Professional Paper 820, p. 217–222.

McLemore, V. T., 1983, Uranium and thorium occurrences in New Mexico: distribution, geology, production, and resources: New Mexico Bureau of Mines and Mineral Resources, Open-file Report 183.

McLemore, V. T., 1991, Base and precious metals deposits in Lincoln and Otero Counties, New Mexico: New Mexico Geological Society, Guidebook 42.

McLemore, V. T., North, R. M. and Leppert, S., 1988a, Rare-earth elements (REE) in New Mexico: New Mexico Geology, v. 10, p. 33–38.

McLemore, V. T., North, R. M. and Leppert, S., 1988b, Rare-earth elements (REE), niobium and thorium districts and occurrences in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Report 324, 28 p.

North, R. M. and McLemore, V. T., 1986, Silver and gold occurrences in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Resource Map 15, 32 p.

North, R. M. and McLemore, V. T., 1988, A classification of the precious metal deposits of New Mexico; *in* Bulk minable precious metal deposits of the western United States: Geological Society of Nevada, Reno, p. 625–660.

Patton, L. T., 1951, Igneous rocks of the Capitan quadrangle, New Mexico: American Mineralogist, v. 36, p. 713–716.

Phillips, R. S., 1990, Geochemistry of hydrothermal Th-U-REE quartz/fluorite veins from the Capitan pluton [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 202 p.

Phillips, R., Campbell, A., McLemore, V. and Willis, M., 1990[a], High temperature, high salinity fluid inclusions in quartz and fluorite from mineralogical veins in the Capitan Mountains, New Mexico: PACROFI III, Program and Abstracts, May 20–22, p. 69.

Phillips, R. S., McLemore, V. T. and Willis, M. A., 1990[b], Mineralogy and geochemistry of veins in the Capitan Mountains, central New Mexico: New Mexico Geology, v. 12, p. 32–33.

Phillips, R. S., Campbell, A. and McLemore, V. T., 1991, New Mexico Geological Society, Guidebook 42.

Robins, J., 1986, Feldspar and nepheline syenite, filling a need?: Industrial Minerals, September, p. 69–101.

Sheridan, M. J., 1947, Lincoln County iron deposits, New Mexico: U.S. Bureau of Mines, Report of Investigations 3988, 19 p.

Sidwell, R., 1946, Sediments from alaskite, Capitan Mountains, New Mexico: Journal of Sedimentary Petrology, v. 16, p. 121–123.

Soulé, J. H., 1947, Capitan iron deposits, Lincoln County, New Mexico: U.S. Bureau of Mines, Report of Investigations RI-4022, 8 p.

Soulé, J. H., 1949, Investigations of Capitan iron deposits, Lincoln County, New Mexico: U.S. Bureau of Mines, Report of Investigations RI-4514, 5 p.

Tuftin, S., 1984, Mineral investigation of the Capitan Mountains wilderness, Lincoln County, New Mexico: U.S. Bureau of Mines, Report MLA 20-84, 20 p.

U.S. Bureau of Mines, 1989, Mineral commodity summaries 1989: U.S. Bureau of Mines, 193 p.

Willis, M. A., Campbell, A. and Phillips, R., 1989, High salinity fluids associated with allanite mineralization, Capitan Mountains, New Mexico: Geological Society of America, Abstracts with Programs, v. 21, p. A287.