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Introduction

The Sunset Ridge fluorite deposit was discovered by Tenneco in 1980 during mineral reconnaissance of the Fra Cristobal Range, Sierra and Socorro Counties, New Mexico (Fig. 1). The fluorite fissure-vein deposit occurs within the West Vein at the western margin of the Fra Cristobal Range, midway on the boundary between protracted secs. 26 and 35, T. 10 S., R. 3 W., NMPM, in the Pedro Armendaris (Spanish) land grant no. 33, which remains unsurveyed in the U.S. rectangular system. The occurrence is at the southern end of a 1,000-ft- (300-m-) long ridge, here named Sunset Ridge. The prospect was evaluated in 1981 by geologic mapping, geochemical sampling, and drilling of three angle core holes.

The geology of the Fra Cristobal Range has been mapped and described in part by Bushnell (1953), Thompson (1961), Cserna (1956), Jacobs (1956), McCleary (1960), Warren (1978), Lozinsky (1982), and Sarkar (in preparation).

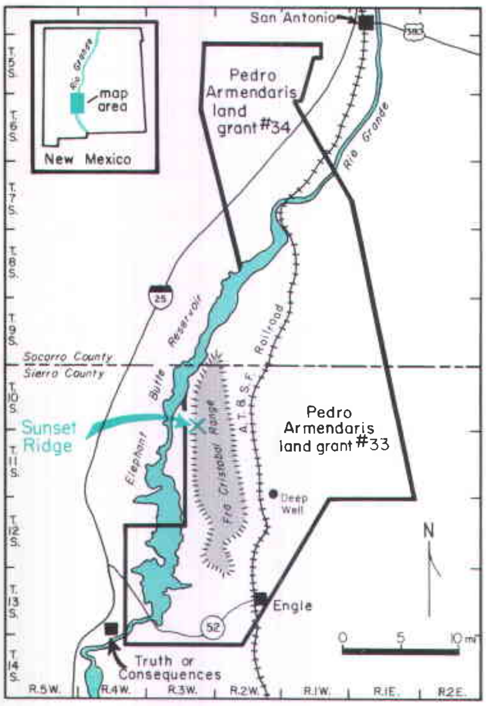

FIGURE 1—Index map of the Sunset Ridge area, Fra Cristobal Range, Sierra County, New Mexico.

The first documentation of fluorite in the Fra Cristobal Range was by Walker (1914). Peale (1949) explored the extensive vein systems in the range and identified many fluorite occurrences.

Sunset Ridge deposit

Sunset Ridge is the topographic expression of the West Vein, a thick, resistant, composite-quartz vein that occupies the north-trending West Vein fault (Figs. 2 and 3). The vein dips steeply westward and is partly exposed along the fault trace for a strike length in excess of 5 mi (8 km). Fissure zones in the West Vein fault have been opened repeatedly, mineralized chiefly with quartz, and brecciated. The planar orientation of minerals and breccia fragments in the fissure and subsequent weathering are responsible for the well-developed exfoliation joints that give the vein outcrop a platy appearance. The local true thickness of the West Vein is uncertain, but it is estimated to be at least 130 ft (40 m) at Sunset Ridge. Hanging-wall rocks remain unknown because they are covered by talus and alluvium and were not intercepted by the drill holes. The footwall is composed of fractured and brecciated Precambrian granitic rocks (Figs. 4 and 5).

Late fissures in the West Vein at Sunset Ridge are filled with tectonically remobilized, coarse-grained, fluorite-breccia fragments with a matrix of fluorite, milky quartz, and sparse hematite. The most prominent fluorite-filled fissure, or "main zone," is exposed along the crest of Sunset Ridge and is associated with abundant milky quartz veinlets. The remainder of the West Vein is mostly quartz with disseminated iron oxides. The main zone is preferentially eroded relative to the enclosing quartz vein. The zone ranges from 5 to 13 ft (1.5 to 4.0 m) in true thickness and is approximately 400 ft (120 m) in exposed strike length (Fig. 6). Rock-chip samples collected from across the main zone range from 37.6% to 62.5% equivalent CaF_2, as calculated from specific ion and distillation analyses for fluorine. Smaller fluorite zones are partly exposed for hundreds of feet along the strike of the main zone.

All three of the core holes intercepted the main zone up to 300 ft (90 m) downdip from the vein outcrop. The deposit remains open

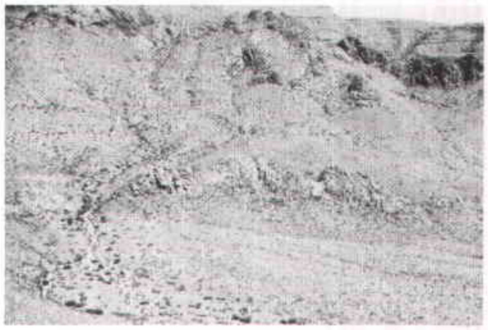

FIGURE 2—View to east of Sunset Ridge, Fra Cristobal Range. The north-trending ridge is the resistant West Vein. Precambrian granitic rocks and the Magdalena Group (Pennsylvanian) are exposed in the background.

FIGURE 3—View to north of the West Vein at Sunset Ridge, Fra Cristobal Range. ☞

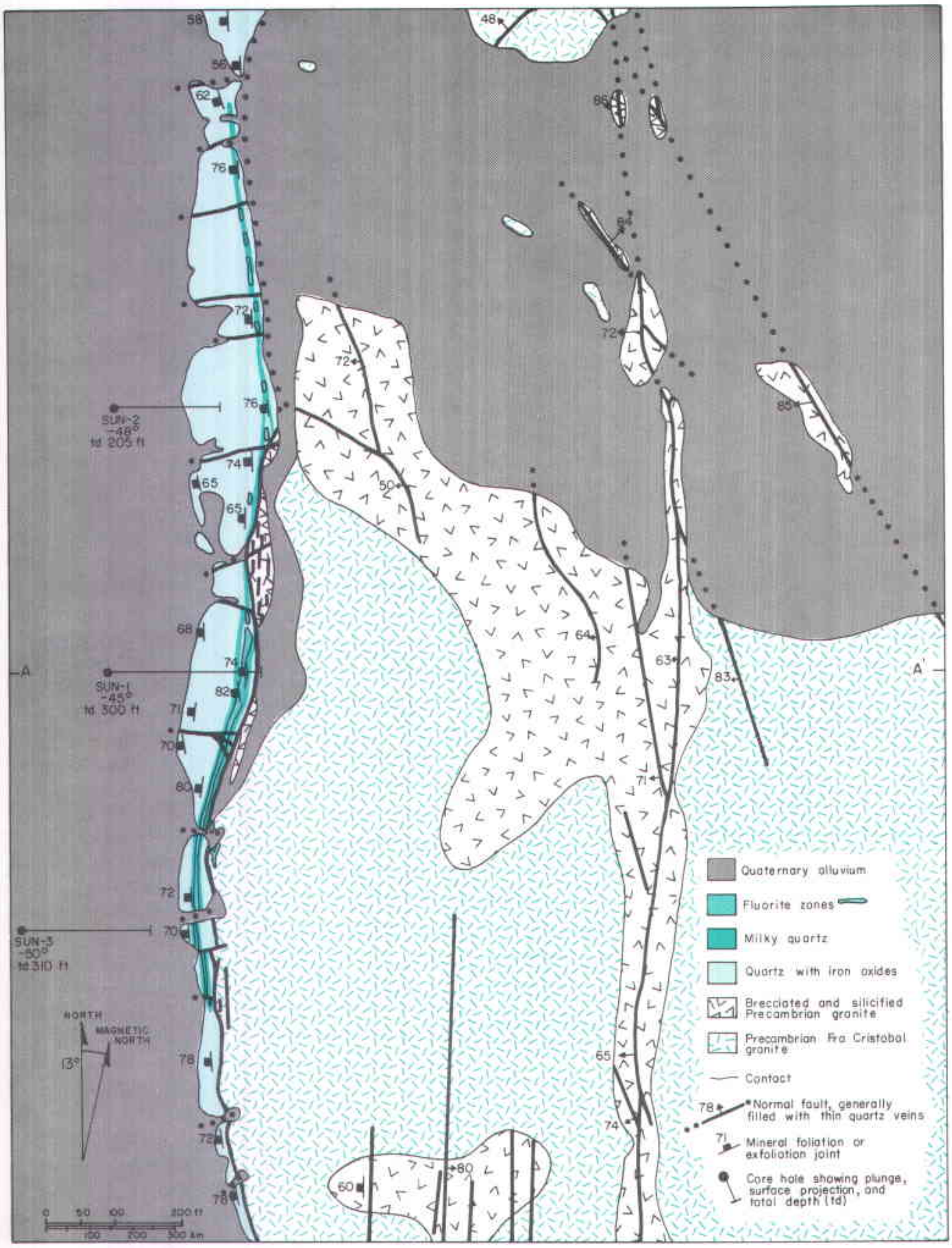

FIGURE 4—Simplified geologic map, Sunset Ridge area, Fra Cristobal Range, Sierra County, New Mexico.

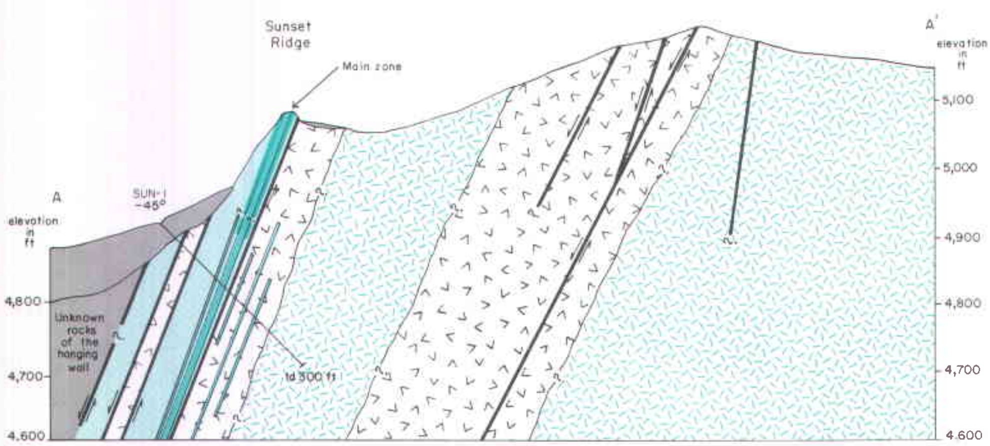

FIGURE 5—Geologic cross section, Sunset Ridge fluorite deposit, Fra Cristobal Range, Sierra County, New Mexico. See map legend in Fig. 4 above.

at depth and laterally. The known portion of the main zone averages 9 ft (2.7 m) in thickness and contains approximately 34% equivalent CaF_2. Additional fluorite zones were identified in all core holes. These minor zones range from 1 to 13 ft (0.3 to 4.0 m) in estimated true thickness and occur within both the West Vein and brecciated granitic footwall rocks.

Structural setting

Many major fluorite districts of the world are located along or near continental rift zones and lineaments (Van Alstine, 1976). The Rio Grande rift is one such zone. Many of the fluorite mines and prospects of New Mexico, Colorado, and, possibly, Mexico are distributed along this major north-trending system of Miocene to Recent grabens. These structural basins formed during regional extension and are bounded by faults that have normal displacements up to or exceeding 10,000 ft (3,000 m). The grabens are filled with thick, semi-consolidated, detrital material and exhibit high heat flow (Reiter and others, 1975). These conditions promote the convective circulation of geothermal solutions that may be favorable for epithermal mineralization. As a result, quartz, fluorite, barite, and base-metal sulfides have been deposited into open spaces and have replaced favorable host rocks along major boundary faults of the rift.

The north-trending West Vein fault is the most prominent of many subparallel faults that form the boundary between the Fra Cristobal uplift to the east and a graben in

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the Rio Grande rift to the west. This fault strikes N. 15° W.–N. 15° E., dips 53°–84° W., and may have more than 5,000 ft (1,500 m) of normal separation at Sunset Ridge. Lee (1907) and Bryan (1938) were first to map the fault, but they did not name it. The name "West Vein fault" is adopted here after an unpublished minerals-reconnaissance report on the Fra Cristobal Range (Peale, 1949). Later researchers have called it Hot Springs fault (Bushnell, 1953; Jacobs, 1956; McCleary, 1960; and Thompson, 1961), Rio Grande fault (Cserna, 1956), and Walnut Wells fault (Warren, 1978).

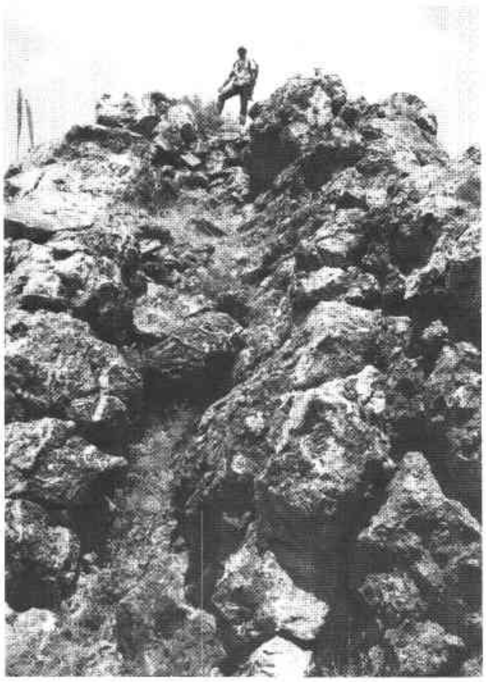

FIGURE 6—View to north of main fluorite zone at Sunset Ridge, Fra Cristobal Range. The fluorite zone is preferentially eroded.

Fissures in the West Vein fault served as the most significant structural control on fluorite mineralization. Major fluorite fillings have been brecciated and tectonically remobilized by repeated fault motion. The main fluorite zone may be controlled by a strike flexure along the West Vein or, as suggested by aerial photographs, by the low-angle intersection of two normal faults. At Sunset Ridge, the alignments of joints and foliations in the main fluorite zone fall into two distinct populations that vary in strike. The northern population of attitudes has an average strike of N. 11° W. and a dip of 74° W., and the southern population has an average strike of N. 10° E. and a dip of 74° W. A difference of 21° in strike supports either of the two possible structural–genetic models. The enclosing composite-quartz vein contains scattered foliations that average due N. in strike and dip 74° W. Another structural consideration, based on drill holes, is that the main fluorite zone may dip more steeply than the enclosing quartz vein. Fissures commonly occur along steeper segments of normal faults where extension is more nearly perpendicular to the fault plane.

Granitic rock fragments are locally abundant in the West Vein, and drill holes intercepted one major horse of silicified granite breccia. Numerous lesser-normal faults that are subparallel to the master fault occur in the granitic footwall rocks. These faults are filled locally with thin quartz veins that may contain minor fluorite or base-metal minerals. The faults are associated spatially with wide zones of variably silicified tectonic breccia. Major west-dipping, northwest- and northeast-trending normal faults also are common in the footwall rocks. Fluorite, barite, and manganese-oxide deposits are localized along faults of similar strike elsewhere in the Fra Cristobal Range. These structures are cut by the system of north-trending faults at Sunset Ridge. Minor east-trending Quaternary(?) normal faults displace the West Vein, granitic rocks, and perhaps some older alluvium. These small-displacement, steeply-dipping faults are subparallel to one set of joints in the vein.

Footwall rocks

The footwall of the West Vein fault at Sunset Ridge is composed of the Fra Cristobal pluton, a Precambrian, composite, granitic stock or batholith with inclusions of metasedimentary rocks. The dominant intrusive rock, here informally named the Fra Cristobal granite, is of somewhat uncertain age. In 1982, a K–Ar age of the granite was determined to be 850 ± 29 m.y. by Geochron Laboratories, Cambridge, Massachusetts. The age date was obtained from a concentrate of partly chloritized biotite in granite core from a drill hole in protracted sec. 11, T. 11 S., R. 3 W. Similar rocks in south-central New Mexico have Rb–Sr whole-rock isochron and U–Pb zircon age dates that range from 1.2 to 1.65 b.y. (Condie and Budding, 1979). A chemical analysis of granite from the same core hole is provided in Table 1. The composition falls within the group of high-potassium Precambrian granitic rocks in south-central New Mexico (Condie and Budding, 1979).

TABLE 1—WHOLE-ROCK ANALYSES (from Skyline Labs, Inc., Wheat Ridge, CO).

Composition	Fra Cristobal granite core Sec. 11, T. 11 S., R. 3 W. (in percent)	Main fluorite zone Sunset Ridge surface (in percent)
SiO_2	69.0	36.6
Al_2O_3	14.30	0.77
Fe_2O_3	2.60	0.73
TiO_2	0.33	0.08
MnO	0.061	0.010
MgO	0.74	0.051
Na_2O	3.30	0.06
K_2O	4.60	0.35
CaO	1.4	—
Ca	—	31.88
F	0.11	30.00
Ba	0.066	0.310
SO_4	<0.10	0.15
SrO	0.015	0.012
Rb_2O	0.036	0.007
Li_2O	0.003	0.007
P_2O_5	0.05	<0.02
CO_2	0.4	<0.1
Moisture	0.2	0.1
L.O.I. (750°C)	1.6	0.3
Total	98.8	101.4

Frank E. Kottlowski provided a petrographic description of a sample of Fra Cristobal granite (Cserna, 1956):

> The granite is lightly gneissic with a tendency for alignment of mica plates and elongated quartz crystals. The rock is medium- to coarse-grained, hypidiomorphic-granular. Minerals are quartz 22%, orthoclase 41%, microcline 26%, albite 9%, muscovite 2%, minor biotite, hornblende and magnetite. The quartz is anhedral, 1–4 mm in diameter, strained and in part clouded with inclusions. Feldspars are subhedral laths, 3–8 mm long, altered to sericite and kaolinite. Micas are in scattered flakes, less than 1 mm long; near hornblende crystals, they are concentrated in lenses. Hornblende is pleochroic from aqua to greenish yellow-brown, euhedral to subhedral, less than 1 mm long, altered in part to chlorite, iron oxide, and chalcedony.

The Fra Cristobal granite is typically altered. Mafic minerals are converted mostly to chlorite or hematite. If magnetite originally existed at Sunset Ridge, it is now oxidized to hematite. A portable magnetometer failed to reveal significant differences in magnetic susceptibility among the Fra Cristobal granite, the West Vein, and alluvial cover. The granite is also variably altered by potassium metasomatism, but the Sunset Ridge area is not particularly affected. Elsewhere in the Fra Cristobal Range, small altered zones with brick-red microcline and minor muscovite occur within the granite. These metasomites are similar to larger bodies in the Precambrian intrusive rocks of the Caballo Range (Staatz and others, 1965).

The Fra Cristobal pluton contains large inclusions of partly assimilated chlorite schist, chlorite-feldspar gneiss, and amphibolite. These deformed inclusions were not observed at Sunset Ridge, but they are particularly abundant in the northern Fra Cristobal Range. Abundant, small, Precambrian(?) dikes and irregular granitic intrusives that are composed of simple granite pegmatite, monzonite, quartz monzonite, and alaskite cut the Fra Cristobal granite. The degree of gneissic banding in the late intrusives is the same as, or less than, that found in the older granite. The late dikes are devoid of mafic silicate minerals and have traces of specular hematite or limonite pseudomorphs after pyrite.

Hanging-wall rocks

The hanging wall of the West Vein at Sunset Ridge is concealed by at least 125 ft (38 m) of Quaternary talus and alluvium, and it was not intersected by exploration drill holes. The hanging wall may contain the Fra Cristobal pluton and portions of the approximately 5,000 ft (1,500 m) of overlying Paleozoic, Mesozoic, and Cenozoic sedimentary rocks. In probable order of abundance, these strata include carbonate rocks, shales, sandstones, evaporites, and conglomerates. Possible Paleozoic units are the Bliss Sand- ☞

stone (Cambrian–Ordovician), El Paso Group (Ordovician), Magdalena Group (Pennsylvanian), Abo Formation (Permian), Yeso Formation (Permian), Glorieta Sandstone (Permian), and San Andres Limestone (Permian). Possible Mesozoic and Cenozoic rocks in the hanging wall may include clastic sedimentary units of the Mesaverde Formation (Cretaceous), McRae Formation (Cretaceous–Paleocene), and Santa Fe Group (Miocene–Pleistocene). Interpretations of ground and airborne magnetic data indicate that local Cenozoic basaltic rocks are not present. Excellent descriptions and measured sections of formations in the Fra Cristobal Range are provided by Bushnell (1953), Cserna (1956), Jacobs (1956), McCleary (1960), Thompson (1961), and Warren (1978).

A considerable volume of quartz-vein breccia is present in the West Vein and could represent fragmented jasperoid that replaced Paleozoic limestone. No unreplaced limestone fragments were seen at Sunset Ridge, but Paleozoic carbonate rocks are known to exist in the hanging wall of the West Vein fault along the strike from Sunset Ridge. The nearest hanging-wall exposures are of San Andres Limestone, 1.5 mi (2.4 km) to the south, and Bar–B Formation limestone of the Magdalena Group, 2.5 mi (4.0 km) to the north–northeast. The San Andres Limestone is host for brecciated barite–galena mineralization near Hackberry Canyon, 4.4 mi (7.1 km) south of Sunset Ridge, and also hosts minor replacement fluorite mineralization in the hanging wall of the West Vein fault, 1.5 mi (2.4 km) south of Sunset Ridge. Barite–fluorite replacement mineralization occurs at various locations adjacent to major normal faults in the Magdalena Group within the Fra Cristobal Range. In the concealed hanging wall at Sunset Ridge, possible Paleozoic limestone may host major replacement-type fluorite deposits.

West Vein mineralization

The West Vein at Sunset Ridge is composed of fine-grained quartz, coarse-grained fluorite, and granitic rock fragments. Iron oxides, barite, and clays occur in minor amounts; traces of pyrite, "psilomelane," calcite, gypsum, galena, and copper minerals also have been identified. The weathered and partly covered surface of the West Vein is mostly quartz with disseminated iron oxides. The known minerals are listed in Table 2 according to their relative abundances. Vein-mineral paragenesis (Fig. 7) is complex, and our knowledge of it is likely to be modified with additional study. More than 95% of the volume of West Vein mineralization may be hypogene. Epithermal solutions deposited minerals into open spaces between breccia fragments and in fissures that formed during episodic extensional faulting. Minor, late-stage minerals were introduced into existing open spaces during a period of relative tectonic quiescence. This late mineralization may have originated from mixed hypogene and supergene (mesogene) solutions. Some of the earlier mineralization was altered by oxidation and dissolution, and was locally redistributed in the mesogene environment.

Quartz is the most abundant mineral in the West Vein. It was deposited in 12 or more distinct episodes of cross-cutting vein mineralization. Most quartz was deposited prior to the first fluorite mineralization. The earliest quartz deposit is barren and milky. Subsequent quartz deposits contain disseminated pyrite, commonly oxidized to limonite. The last quartz veinlets emplaced prior to the first fluorite mineralization contain disseminated red hematite. Continued faulting along the West Vein opened narrow fissures that were filled with barren, milky-quartz veinlets. Subsequently, wider fissures were filled with coarse-grained fluorite. Later faulting brecciated and mechanically remobilized the fluorite. Milky quartz and reddish hematite were deposited interstitially between fluorite fragments. The resulting fluorite breccia contains single-crystal fragments up to 1.5 inches (3.8 cm) across (Fig. 8). These fluorite fragments exhibit well-developed internal (111) cleavage and are generally transparent

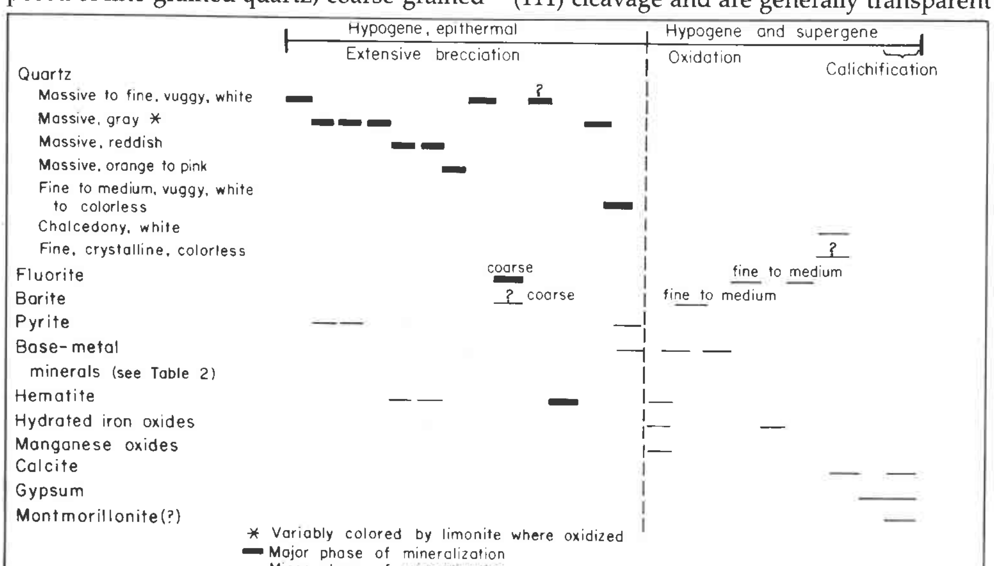

FIGURE 7—Paragenesis of the West Vein at Sunset Ridge, Fra Cristobal Range, Sierra County, New Mexico.

TABLE 2—West Vein mineralogy at Sunset Ridge in order of apparent abundance. Elements listed with an asterisk (*) are present as constituents of granitic-rock fragments.

Major elements	Minor elements	Trace elements
Quartz Fluorite	Microcline* Hematite Goethite Barite Plagioclase* Chlorite* Muscovite* Clays*	Pyrite Psilomelane(?) Calcite Gypsum Malachite Chrysocolla(?) Chalcopyrite Galena Chalcocite Cuprite(?) Covellite(?) Azurite(?)

and colorless, purple, or green, if fresh. Weathered fluorite is commonly whitish and opaque. Traces of coarsely crystalline, beige to white barite in small breccia fragments are associated with fluorite and also occur elsewhere in the vein without associated fluorite.

The major period of fluorite mineralization was followed by two late periods of quartz mineralization. Primary base-metal sulfides were deposited in openings within the younger of these two quartz phases. Chalcopyrite, pyrite, and arsenopyrite(?) crystallized first. Galena commonly was deposited as overgrowths on chalcopyrite crystals. Quartz veins with base-metal sulfides generally occur in the fractured granitic footwall rocks without attending fluorite.

Minor late-stage minerals filled local voids in breccias, fractures, joints, and solution cavities. The late-stage minerals are not fractured and therefore appear to have formed after the cessation of major displacement along the West Vein fault. Some fluorite breccia contains solution vugs that are partly filled with later fluorite and associated minerals. Minor iron and manganese oxides occur as colloform coatings on fractures and around breccia fragments in the granite and vein quartz. Weathering has altered some pyrite to limonite, and chalcopyrite is partly converted to chalcocite and subsequently to malachite and chrysocolla(?). Trace cuprite(?) also

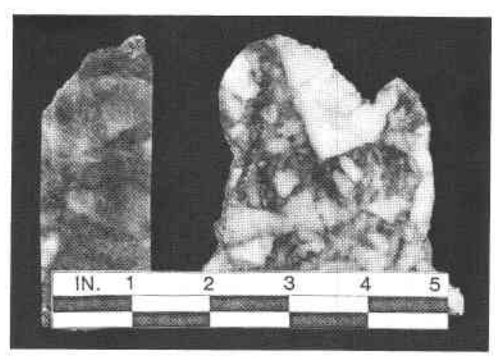

FIGURE 8—Core and surface samples of fluorite breccia with fluorite, milky quartz, and hematite matrix from Sunset Ridge, Fra Cristobal Range.

may have formed from chalcopyrite. Late-stage barite crystallized as tiny laths in open spaces prior to malachite crystallization, whereas small, modified cubes of purple fluorite crystallized on the malachite coatings and in other voids. These unbrecciated fluorite crystals commonly have internal ghosts of limonite and may have formed by dissolution and redeposition of the earlier brecciated fluorite. Traces of chalcedony, finely crystalline quartz, white poker-chip calcite crystals, gypsum, and caliche were deposited sequentially after the last fluorite crystals.

West Vein geochemistry

Core and surface-rock samples from Sunset Ridge were submitted to commercial laboratories and assayed for fluorine by quantitative techniques, and 55 elements above atomic number 21 were analyzed by semi-quantitative x-ray fluorescence. Concentrations of up to 30.4% F, 7.8% Fe, 6.0% Ba, and 0.45% Mn were encountered. All other detected elements showed concentrations of less than 0.2%. A quantitative whole-rock analysis for the main fluorite zone is provided in Table 1. Forty-four stream-sediment samples from the prospect area were sieved to −80 mesh and assayed quantitatively by commercial laboratories for fluorine, barium, and metals.

Geochemical data indicate that fluorite is negatively correlated with base-metal minerals, barite, and hematite. The greatest stream-sediment fluorite value, 4,000 ppm F, was determined in a sample collected about 640 ft (195 m) downstream from the main fluorite zone. Stream sediments derived chiefly from silicified footwall rocks contain the largest base-metal values: up to 72 ppm Cu, 111 ppm Pb, 226 ppm Zn, and 3 ppm Mo. All sediment samples from stream channels on footwall rocks contain 2,000–15,800 ppm Ba. Similar barium values occur downstream from known barite occurrences in the West Vein, but they do not correspond directly with the main fluorite zone. Hematitic quartz is spatially associated with major fluorite concentrations; however, the greatest iron, manganese, and titanium values occur in core samples of fractured footwall rocks.

Age and origin of fluorite mineralization

Fluorite deposits in the western United States are considered to be middle to late Tertiary in age (Lamarre and Hodder, 1978). The Sunset Ridge fluorite fills the West Vein fault, one of the major, graben-bounding faults along the Rio Grande rift. Significant regional, intraplate block faulting occurred between 21 m.y. ago and the present (Elston and Bornhorst, 1979). Therefore, fluorite in the West Vein is believed to be Miocene or Pliocene in age.

Lamarre and Hodder (1978) proposed that fluorite deposits in the western United States are related to Tertiary alkalic-igneous rocks. Hypothetically, fluorine was concentrated in alkalic magmas that were generated along subduction zones. They postulated that the fluorine was carried through the crust as SiF_4. However, Tertiary alkalic-igneous rocks are conspicuously absent in the Fra Cristobal Range, and there is no evident relation between the Sunset Ridge deposit and Tertiary volcanic rocks. The nearest Tertiary felsic volcanic center known is the Nogal Canyon cauldron (Deal and Rhodes, 1976), which is 9 mi (15 km) to the northwest.

We propose that the Fra Cristobal pluton may have been the fluorine source for the Sunset Ridge deposit. Fluorine content of the main zone at Sunset Ridge is less than 300 times greater than the concentration of fluorine in partly altered granite (Table 1). Original, unaltered granite probably had accessory fluorite or fluorine-bearing biotite. The extensive alteration of biotite to chlorite and hematite by hydrothermal solutions associated with the Rio Grande rift would have liberated both fluorine and silicon, two major elements in the West Vein. Thermal, meteoric waters may have leached silicon, fluorine, iron, and other elements from the Fra Cristobal pluton with the aid of chemical complexes. SiF_6^{2-} is the prevalent silicon-fluorine complex in natural waters at standard temperature and pressure, but it is unstable if the solution is alkaline or if it has even a low concentration of competitive cations such as iron, aluminum, and calcium (Roberson and Barnes, 1978).

The West Vein fault served as a major conduit for the circulation and possible mixing of meteoric waters. As indicated by multiple episodes of brecciation and complex mineral paragenesis, the fault was repeatedly reactivated and sealed with vein minerals. Fluorite and all other West Vein minerals probably were deposited under epithermal conditions (50–200°C). No high-temperature minerals or associated alterations are evident. Pervasive, periodic, brittle deformation (brecciation and fissuring) indicates that mineralization occurred at relatively shallow depths. The paragenetic association of the main-zone fluorite with hematitic quartz suggests that these minerals were deposited in a near-surface, oxidizing environment.

The most likely mechanisms for fluorite deposition are: increasing the pH, cooling, dilution, or mixing of hydrothermal solutions (Richardson and Holland, 1979). All of these factors contribute to the instability of the SiF_6^{2-} complex. Acidic epithermal solutions may have mixed with cool, near-surface ground waters. Each successive motion of the West Vein fault would have down-dropped the possible limestone in the hanging wall. This would raise the activity coefficient of the calcium cation and increase the pH of the local ground waters. Quartz and, subsequently, fluorite then would be deposited from probable acidic epithermal solutions that circulated or stagnated along the West Vein fault and mixed with ground water or simply cooled. Minor, later fluorite may have been derived from earlier fluorite by local solution and redistribution.

Summary

The Sunset Ridge fluorite deposit (Miocene or younger), at the eastern margin of the Rio Grande rift in south-central New Mexico, is a classic fissure vein. Mineralization is controlled by open spaces within the north-trending, steeply dipping, West Vein fault. The greater part of the West Vein is composed of a quartz envelope around a main fluorite zone that averages almost 10 ft (3 m) in true thickness and ranges from 30% to more than 60% fluorite. Core drilling intersected the main zone and other fluorite zones at depths up to 300 ft (90 m) below the surface. Footwall rocks are composed mostly of fractured Precambrian Fra Cristobal granite. Hanging-wall rocks are concealed by surficial debris, but they may contain granitic or sedimentary rocks. Paleozoic carbonate rocks may occur in the hanging wall and are potential hosts for significant replacement-type fluorite deposits. Fluorite may have been deposited from fluorine-rich epithermal solutions that resulted from alteration and leaching of the Fra Cristobal pluton by hydrothermal fluids that were generated and circulated during the development of the Rio Grande rift. Quartz and fluorite were deposited into open fissures as the epithermal solutions cooled or mixed with alkaline ground waters that contained calcium derived from local carbonate rocks.

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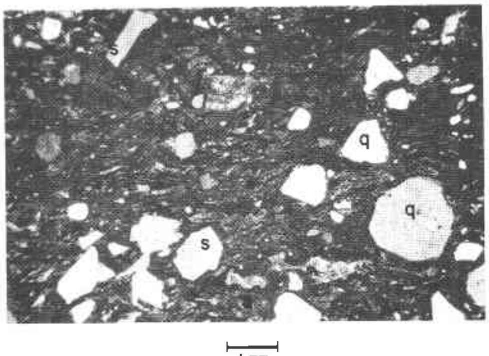


FIGURES 7a, b, c—Lemitar Tuff (samples TS–5, TS–23, DB–10B, all from south and southeast Magdalena Mountains) is a strongly and complexly zoned unit. The Lemitar Tuff is a moderately crystal rich rhyolite at the base (7a) that grades normally upward into a quartz-poor quartz latite (7b), which in turn grades upward into a very phenocryst rich rhyolite (7c).

Figure 7a, from the lower rhyolite interval, contains approximately 12–15 percent phenocrysts consisting of sanidine (**s**), quartz (**q**), minor plagioclase, biotite and opaques, and traces of zircon and sphene. The groundmass in this sample is partly glassy and contains well-preserved shard structures. This lower interval grades upward over a few ft into a phenocryst-rich quartz latite (Fig. 7b).

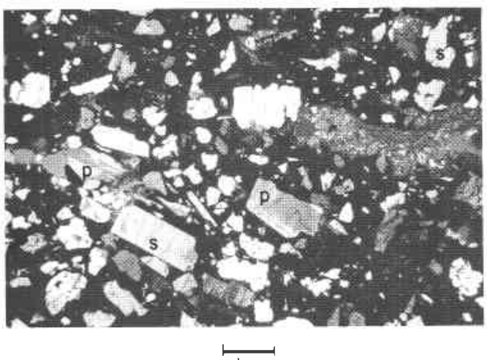


Figure 7b contains abundant sanidine (**s**), plagioclase (**p**), biotite and minor quartz, opaques and pyroxene. This middle zone grades upward over several tens of hundreds of ft into a very phenocryst rich rhyolite (Fig. 7c).

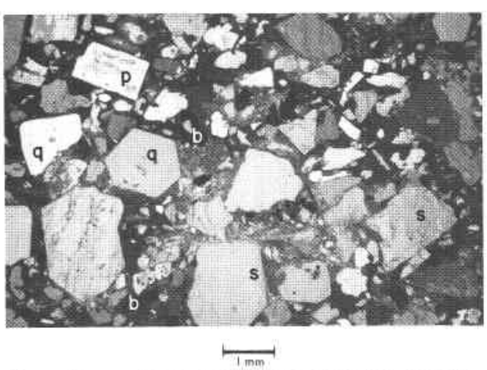
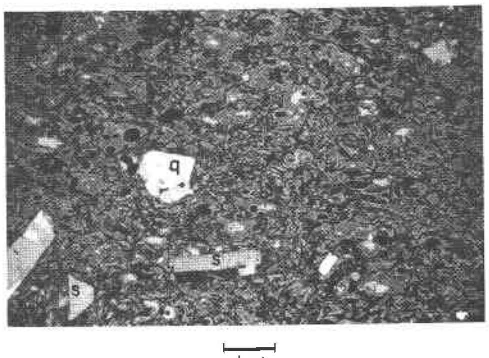


Figure 7c contains abundant quartz (**q**), sanidine (**s**), plagioclase (**p**), and biotite (**b**). Very little groundmass is visible between the phenocrysts in figures 7b and 7c, but large pumice fragments in outcrop attest to the pyroclastic origin.



FIGURES 8a, b—South Canyon Tuff (samples JA–SC–1, Joyita Hills; 8–11–8, southeast Magdalena Mountains) is texturally zoned from phenocryst poor below to moderately phenocryst rich above; mineralogies are similar in both zones.

Figure 8a illustrates a glassy vitrophyre from the base of the lower zone. Small gray, irregularly curved shapes are undeformed glass shards. Note slight compaction around phenocrysts. Subequal amounts of sanidine (**s**) and quartz (**q**) make up the phenocrysts.

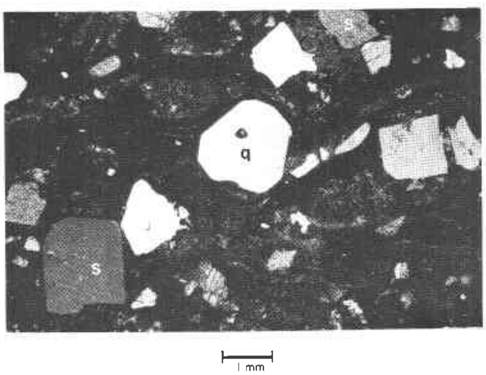


Figure 8b, from the upper interval of this unit, contains more abundant and larger phenocrysts of sanidine (**s**) and quartz (**q**) with minor biotite, but little preserved vitroclastic texture.

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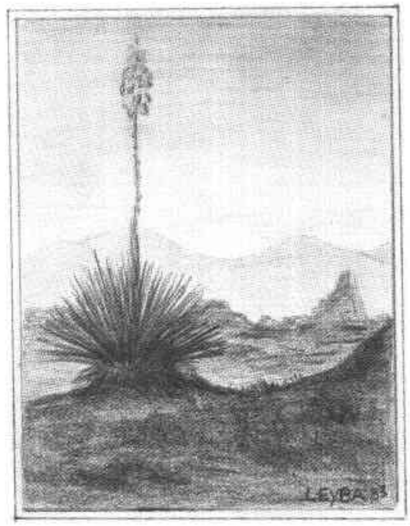

Sunset Ridge fluorite deposit

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