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BERYLLIUM-FLUORINE MINERALIZATION AT AGUACHILE MOUNTAIN, COAHUILA, MEXICO

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ABSTRACT

Bertrandite is found at the Aguachile Mountain fluorite deposit as the only beryllium mineral in a low temperature, low pressure hydrothermal environment. This type of occurrence plus a radial aggregate habit of slender crystals have not been previously reported for bertrandite. From a study of the mineralogy, paragenesis, petrology and geology of the deposit, it is believed that the beryllium is closely related to an alkali quartz microsyenite located in the center of Aguachile Mountain. This occurrence is another example of the association of beryllium minerals with fluorite and offers additional evidence for the importance of the beryllium-fluorine complex in nature.

INTRODUCTION

This paper deals with the hydrothermal beryllium-fluorine mineralization occurring on the north rim of Aguachile Mountain in northern Coahuila, Mexico, approximately 80 miles south southeast of Marathon, Texas. The fluorite deposit was discovered in 1955. Beryllium mineralization in the form of bertrandite was recognized in late 1956. This deposit is economically significant and is believed to represent a new type of beryllium occurrence. The presence of bertrandite as a primary mineral was unique at the time of discovery. It is the only beryllium mineral so far identified in the deposit and accounts for all known beryllium values. The ore body averages approximately 0.3 per cent BeO.

GEOLOGY

Aguachile Mountain is essentially a dome of sedimentary rocks intruded by high-silica igneous rocks and is a classic example of cauldron subsidence, ring dike development, and subsequent mineralization. A brief résumé of the geological history of Aguachile Mountain is as follows:

1. Doming of Cretaceous sedimentary rocks by igneous activity.
2. Collapse of the apical part of the dome through cauldron subsidence, with formation of a central basin.
3. Emplacement of a ring dike of rhyolite porphyry, about one mile in diameter, in a circular fault zone along which the cauldron-producing displacement occurred. The principal fluorite-bertrandite deposits occur along the inner margin of this ring dike as replacements and void fillings in brecciated limestone.
4. Intrusion of a body of alkali quartz microsyenite porphyry (referred to in this report as the central plug) through the collapsed segment near the center of the basin.

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The outside diameter of the mountain at its base is about three miles; the inside diameter of the basin, measured from the rim, is 1–1.5 miles. The distance from the center of the alkali quartz microsyenite porphyry (plug) to the principal fluorite-bertrandite zone is about one-half mile.

For the detailed geology of the Aguachile area see McAnulty *et al.* (1962).

Igneous Petrology

There are two types of igneous rocks related to the beryllium-fluorine mineralization at Aguachile Mountain.

1. Rhyolite. The Aguachile ring dike is a rhyolite porphyry which is reddish-gray and has an aphanitic matrix (95%) with a few small, white feldspar phenocrysts. It consists of quartz (20%), altered potash feldspar (75%), and magnetite, hematite and minor accessories (5%). Sodic plagioclase is present only in trace amounts; no mafic minerals are present.

   A rhyolite sample from the Aguachile ring dike contains 9.6 ppm beryllium. Three samples of rhyolite collected three to five miles from Aguachile contain 2.6 ppm to 5.4 ppm beryllium.
2. Alkali quartz microsyenite. The Aguachile central plug is an alkali quartz microsyenite which is porphyritic, with an aphanitic matrix tan to gray, and speckled brown and black; it contains ten per cent sanidine phenocrysts. Modal analysis yields: potash feldspar (76%), quartz (7%), riebeckite (7%), high-iron chlorite derived from riebeckite (8%), magnetite and accessories (2%). In some samples studied all of the riebeckite is altered to the high-iron chlorite. Riebeckite and its alteration product occur as anhedral crystals interstitial to the potash feldspar (agpaitic texture). Three specimens of the alkali quartz microsyenite have from 9.9 ppm to 10.6 ppm, beryllium.

Petrographically, the Aguachile area is related to the alkalic igneous rocks of the Big Bend area, Texas (Lonsdale, 1940, and Goldich and Elms, 1949).

Mineralogy

Fluorite and calcite constitute about 95 per cent of the deposit. Other minerals include quartz, adularia, bertrandite, kaolinite, iron oxides (hematite, limonite), and trace amounts of a lithium-bearing sericite and aragonite.

Fluorite. Fluorite comprises about 80 per cent of the deposit. Reddish-gray is the dominant color, but other pale hues may be observed. Fine banding is common. Pale bluish-gray euhedral crystals (1 to 5 mm.) are

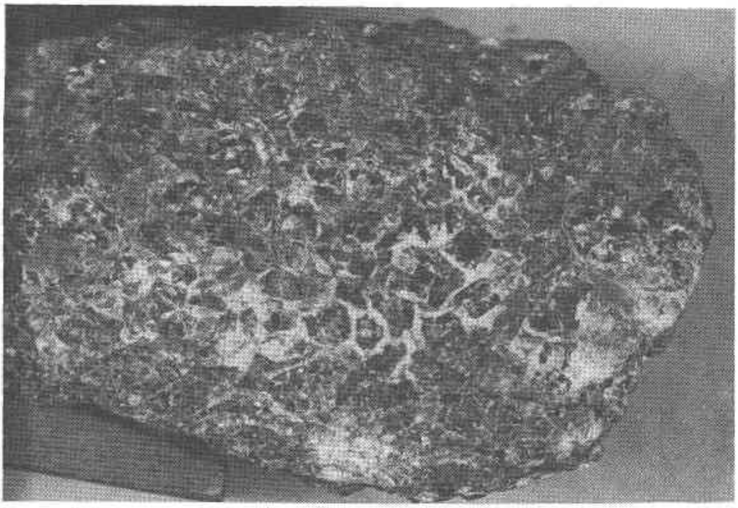

FIG. 1. Hand specimen illustrating coarse euhedral second generation fluorite (dark gray) surrounded by bertrandite (white). In the upper lefthand portion of the specimen the fluorite is surrounded by a brownish calcite. Width of the specimen is about 3 inches. The largest fluorite crystal (right center) is about 5 mm. in diameter.

locally abundant, particularly where richest concentrations of bertrandite occur (Fig. 1). This results in a "porphyritic" texture with euhedral fluorite enclosed in bertrandite, calcite and locally kaolinite.

Three generations of fluorite mineralization are recognizable. The first was the most intense and produced the microcrystalline reddish-gray fluorite. The second, minor in comparison with the first, is represented by the coarse euhedral pale bluish "phenocrysts." The third generation is very minor, paragentically late, and characteristically fills fractures and voids.

Calcite. Calcite comprises about 15 per cent of the ore body. It represents those parts of the brecciated and fractured Cretaceous limestones (chiefly Georgetown formation) in the vicinity of the rhyolite ring dike that were not completely replaced by the fluorine-containing solutions. Small amounts of late calcite also have been recognized.

Bertrandite. Bertrandite, $Be_4(OH)_2Si_2O_7$, is the only beryllium mineral in the deposit as far as the writer has been able to determine. No beryllium has been detected even in trace amounts in adularia, kaolinite, lithium-bearing sericite, etc., but it is likely that traces of beryllium are present in the fluorite. Trace amounts of beryllium are not uncommon in certain vein and hydrothermal fluorites.

Bertrandite occurs in Aguachile fluorite (Figs. 2, 3) as masses of color-

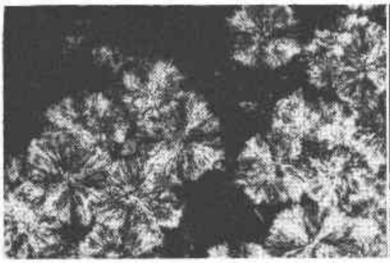

FIG. 2. (Left) Masses of unusually well-developed radiating aggregates of thin bertrandite crystals in fluorite (black) as seen in thin section with crossed polars. Width of photomicrograph is 0.8 mm.

FIG. 3. (Right) Radiating aggregate of bertrandite crystals at boundary between fluorite (black) and calcite. Other aggregates may be seen within the fluorite (upper) and calcite (lower right). Thin section photographed with crossed polars. Width of photomicrograph is 0.8 mm.

less to pale yellow, radiating aggregates of thin, locally almost needle-like, length-slow crystals. The radiating aggregates are generally less than 0.15 mm. in diameter. This habit has not been heretofore reported for bertrandite. Some small laths or plates also are observed. No twinning has been recognized. Indices of refraction ($\pm .002$) obtained on small plates in monochromatic sodium light are:

$$\alpha = 1.583, \beta = 1.598, \gamma = 1.608$$

Megascopically, the bertrandite is white and fine-grained. It tends to surround the euhedral second generation fluorite "phenocrysts" and to fill vugs and fractures. It can be differentiated from kaolinite by means of hardness. *X*-ray powder diffraction patterns of Aguachile bertrandite compare almost exactly with the pattern of a bertrandite specimen from Mount Antero, Colorado, obtained from the U. S. National Museum (R 3895). Also, they compare well with *x*-ray powder data reported by Vernon and Williams (1960).

The crystallization of bertrandite in the Aguachile deposit, rather than beryl or some other more common beryllium mineral, may be related at least in part to insufficient aluminum.

An extensive literature search on the occurrence and mineralogy of bertrandite conducted at the time of the discovery in Aguachile (1956) revealed that the mineral had been found previously almost exclusively in pegmatites as an alteration product of beryl or some other beryllium mineral. Only Phemister (1940), Grigoriev and Dolomanova (1955), Novotný (1948), and Parker and Indergand (1957) had described bertrandite from non-pegmatitic environments or as a non-alteration product of other beryllium minerals.

Since the discovery of bertrandite at Aguachile, the mineral has been reported in beryl-bearing quartz veins in the Soviet Union (Chukhov and Smolyaninova, 1956) and in several similar occurrences in the western United States (Norton *et al.*, 1958). More recently, bertrandite has been discovered in three other non-pegmatitic associations:

(1) Mt. Wheeler, Nevada (Stager, 1960); (2) Lake George District, Colorado (Sharp and Hawley, 1960); (3) Spors Mountain, Thomas Range, Utah (Nolan, 1960).

Adularia. Adularia occurs as anhedral to euhedral crystals with rhombic cross-sections, some of which show numerous minute inclusions generally in the central parts of the crystals; clear outer zones are inclusion free. Adularia is not common in the deposit, having been observed only in thin sections, and is usually associated with second-generation fluorite. The presence of adularia is indicative of a low temperature, hydrothermal environment.

Kaolinite. Kaolinite is present in small amounts throughout most of the deposit. It appears to be particularly abundant in bertrandite-rich zones; however, it probably was deposited later than the bertrandite. Kaolinite is also common in vugs and fractures.

Quartz. A small amount of quartz, including chalcedonic varieties syngenetic in the host limestone, is present in the deposit. Paragenetic relationships indicate that the quartz introduced by the mineralizing solutions was deposited later than most of the fluorite.

Lithium-bearing sericite. A soft, white, clay-like mineral was separated from a vug in one sample and identified by *x*-ray diffraction as a mica with the 1M structure (Heinrich and Levinson, 1955). Micas (high-silica sericites) with 1M structures are typical of hydrothermal environments. Lithium was confirmed qualitatively by emission spectrographic analysis (an estimated few tenths of a per cent).

Aragonite. Aragonite occurs sparsely, along with calcite, as a late botryoidal, stalactitic carbonate.

Iron oxides. Late, secondary, soft hematite and limonite occur in small amounts throughout the deposits.

Paragenesis and Origin

Geologic evidence has established that most of the fluorite was deposited after emplacement of the rhyolite and before intrusion of the alkali quartz microsyenite. Both the rhyolite and the main mass of fluorite (first generation) probably came from the same magma source, but at different stages in the magmatic sequence. The alkali quartz microsyenite appears to be another, still later, differentiate of the same

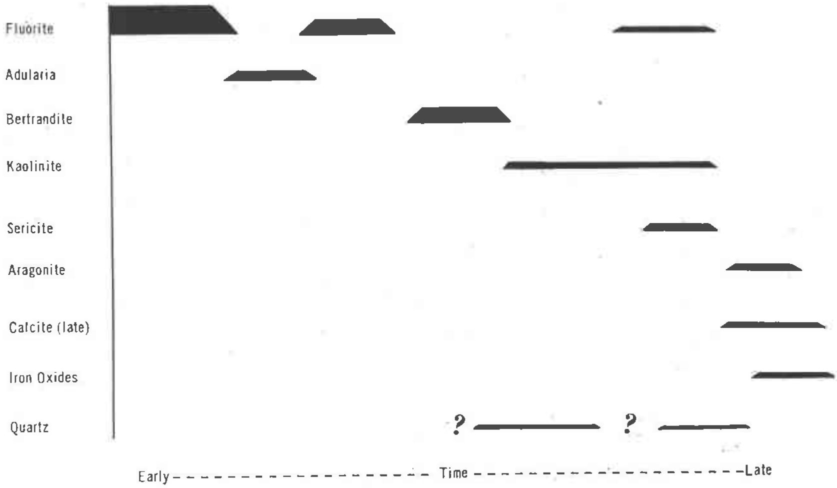

FIG. 4. Paragenetic sequence of minerals at Aguachile.

magma. Geologic studies show that emplacement of the alkali quartz microsyenite and crystallization of the bertrandite were essentially contemporaneous; it is believed, however, that the bertrandite formed before the microsyenite plug was finally emplaced (McAnulty *et al.* 1962).

From geologic and thin section studies the most likely paragenetic sequence appears to be as follows (Fig. 4):

1. Brecciated limestone intruded by rhyolite ring dike after cauldron subsidence.
2. Fluorite—first generation; fine-grained variety; principal part of deposit.
3. Adularia
4. Fluorite—second generation; coarse, euhedral variety
5. Bertrandite
6. Emplacement of alkali quartz microsyenite
7. Kaolinite
8. Fluorite—third generation; minor amount
9. Sericite
10. Aragonite
11. Calcite—late variety
12. Iron oxides—(a) minor opaque hematite
    (b) earthy hematite and limonite

The exact position of quartz in the sequence cannot be accurately determined because of its limited occurrences in the thin sections studied. It may have been formed throughout stages 4 through 8.

McAnulty *et al.* (1962) have observed that several fluorite deposits in the Aguachile area appear to be related to alkalic igneous rocks in the district; however, only the Aguachile deposit contains more than trace amounts of beryllium. The occurrence of relatively high concentrations of fluorine in alkalic rocks is a geochemical fact and thus supports the field observations of McAnulty *et al.* (1962).

Literature studies reveal that alkalic magmas are commonly enriched in beryllium. Borodin (1956) and Warner *et al.* (1959), on the other hand, report that some alkalic rocks show no such enrichment. In the case of the Aguachile deposit, field and laboratory studies strongly suggest that the beryllium came from an alkalic magma and ascended in hydrothermal solutions. The close paragenetic relationship between the alkali quartz microsyenite (containing approximately 10 ppm Be) and the bertrandite particularly favors this suggestion. The formation of a beryllium-fluorine complex (Ringwood, 1955; Beus, 1958) would provide the mechanism for the concentration and transport of the beryllium. It is possible that the second generation euhedral fluorite could represent the crystallization of the fluoride ion of the beryllium-fluorine complex. The close textural relationship of the bertrandite and euhedral fluorite supports this supposition.

Low-temperature, low-pressure hydrothermal conditions prevailed at the time of the formation of the Aguachile fluorite-bertrandite deposit from the following data:

1. No high-temperature or high-pressure minerals are present.
2. Adularia is typically found in low-temperature hydrothermal veins.
3. No evidence of contact metamorphism is found except very minor recrystallization of limestone immediately adjacent to the igneous rocks.
4. The fine-grained texture of the rhyolite and microsyenite suggests a near-surface environment.

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