BARIUM MINERALS OF THE
SANBORNITE DEPOSITS

Fresno County, California

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The sanbornite deposits along Big Creek and Rush Creek, eastern Fresno County, California are the type localities for ten rare barium minerals (alforsite, bigcreekite, fresnoite, kampfite, krauskopfite, macdonalditie, muirite, traskite, verplanckite, and walstromite). In addition, seven potentially new barium silicates are currently under study.

INTRODUCTION

Sanbornite, a rare barium silicate, was first discovered and described from a small deposit on Trumbull Peak, Mariposa County, California in 1930. During the barite boom of the late 1950's and early 1960's, the Rush Creek and Big Creek deposits in Fresno County were discovered. These deposits represent a mineralogically significant occurrence and an unusual chemical association. At present, similar but smaller deposits are otherwise known only from Tulare and Mariposa counties, California; the Yukon Territory, Canada; and Baja California, Mexico.

The eastern Fresno County barium silicate localities occur along a narrow 5-km belt on the western slope of the Sierra Nevada Mountains, approximately 90 km by road northeast of Fresno. Within the area are relatively steep slopes covered with pine, oak and chaparral, at elevations from 400 to 855 meters. Summers are dry and hot, and winters are wet and cool. The annual rainfall is 76 cm, occurring primarily from November through May. Normally, both Rush Creek and Big Creek are perennial streams, but during extreme droughts Rush Creek may cease flowing for short periods.

To reach the Big Creek sanbornite deposits, proceed east from Fresno on State Highway 180 to

Centerville; north on Trimmer Road via Piedra, Trimmer, and Pine Flat Reservoir to Big Creek; then north for 5.5 km on the unpaved Big Creek Road. The Rush Creek occurrences are an additional 1.5 km north to the junction of U.S. Forest Service Road 10S04, then 2.5 km northwest along this road to Dean's Flat. Figure 3 shows the general location of areas containing multiple sanbornite outcrops.

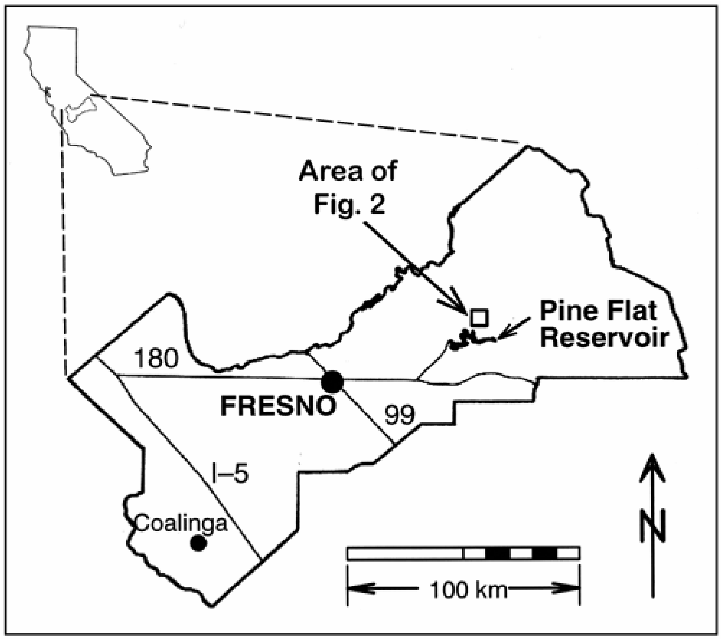


Figure 1. **Location map.**

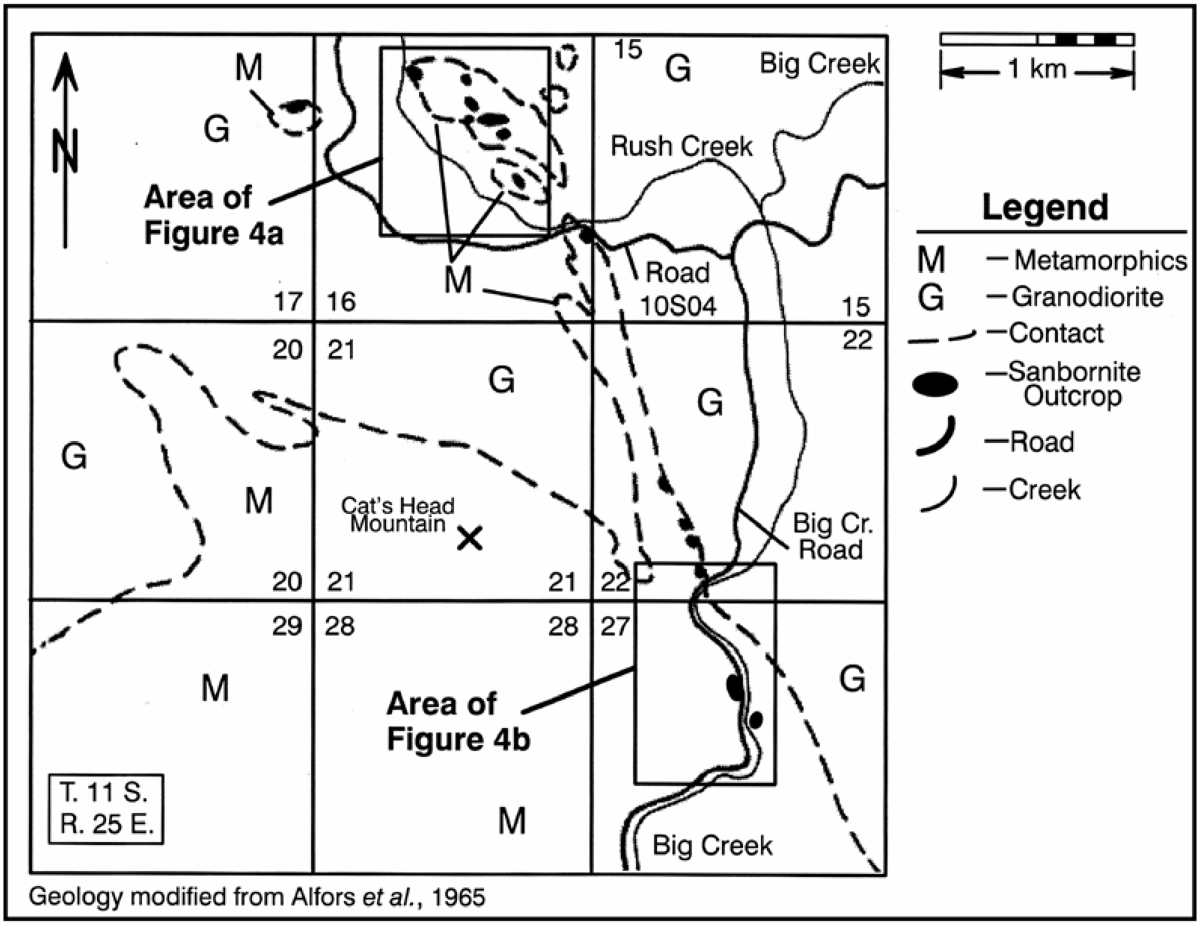
HISTORY

Sanbornite ($BaSi_2O_5$) was first described as a new mineral by Rogers (1932) as a major constituent of three lens at Trumbull Peak, Mariposa County, California. Subsequent research established that G. M. Landers of North Fork, California, had in 1957, submitted a sample to the California Division of Mines from roughly 4 or 5 km southeast of Rush Creek. This sample had been identified as sanbornite and also contained the rare barium-iron silicate gillespite. Mr. Landers could not be located, so a diligent field search was undertaken to determine the source of the sample. Late in 1961, the source was located at a road cut along Big Creek (Fig. 4b, Site 6). Further prospecting revealed eight additional outcroppings of sanbornite-bearing rock in the vicinity. Mining claims were then established at both Rush Creek and Big Creek by one of the authors (REW) and have been retained up to the present.

Field work at Rush Creek, the second California occurrence, has focused primarily on mapping and sampling in conjunction with resource estimation. Samples submitted to the California Division of Mines and Geology for analysis were confirmed to be sanbornite (Matthews and Alfors, 1962). This stimulated a return to the area that revealed numerous additional exposures (Fig. 4a, Sites 1–4).

Soon after the discovery of sanbornite in the area, small quantities of several unidentified minerals were discovered in the deposits (Stinson and Alfors, 1963). Several people collected examples of these for further study, and as a result seven new barium silicate minerals were characterized: *fresnoite, krauskopfite, macdonaldite, muirite, traskite, verplanckite,* and *walstromite* (Alfors *et al*., 1965). *Alforsite*, a barium member of the apatite group, was later described from Big Creek by Newberry *et al.* (1981). An additional seven potentially new silicate species still remain under study.

During the 1960's, the relatively large quantities of sanbornite in the region generated some interest as a possible source of barium for the chemical industry. However, because of processing difficulties there was no commercial production at that time (Weiler *et al*., 1964). Subsequent investigations have included geologic mapping, core drilling (Matthews, 1963), and metallurgical testing. The most recent activity on the mining claims has been directed toward specialized ceramic products and chemicals by one of the authors (REW). During this fieldwork, REW recognized a potentially new mineral based on its unusual cleavage and fluorescence (Stinson and Alfors, 1964). Additional data on the structure of this mineral, later named walstromite, are provided in Glasser *et al*. (1968).



Geology modified from Alfors *et al.*, 1965

Figure 2. **General geology of Rush Creek and Big Creek, with major sanbornite outcrops indicated.**

GEOLOGY

At Big Creek and Rush Creek, sanbornite-quartz rock and spatially associated foliated quartzite, both of which contain barium minerals, occur within metasedimentary blocks in migmatite adjoining a Cretaceous granodiorite pluton (Weiler *et al*., 1964). The quartzite is present within a narrow zone roughly 5 km long that strikes generally northwest-southeast and dips steeply eastward (Fig. 3). Sanbornite-quartz rocks, the result of contact metamorphism, developed sporadically along this zone as foliation-parallel tabular bodies ranging from less than a meter across to lenses as large as 10 by 60 meters. They are weakly to strongly foliated, and are composed of layers containing 90% sanbornite alternating with quartz-rich layers containing 10% sanbornite. The sanbornite-rich layers vary from a few centimeters to meters thick and are discontinuous along strike.

Variable small amounts of calcite and sulfides are present in sanbornite-bearing rock. The principal sulfide is pyrrhotite, with subordinate pyrite, minor galena, sphalerite and chalcopyrite. These generally form anhedral grains up to 1 cm, averaging 1 to 3 mm. Except for quartz, barium-free silicates are only minor constituents of the sanbornite rock. The quantity and species of accessory barium minerals display no apparent correlation with the quartz to sanbornite ratio.

Figure 3. **View of the Rush Creek sanbornite locality, facing east. Sanbornite outcrops adjoin tall trees just right of center and are along both sides of the trail to the left of center. Rush Creek flows from left to right at the bottom of the ridge. California Division of Mines photo.**

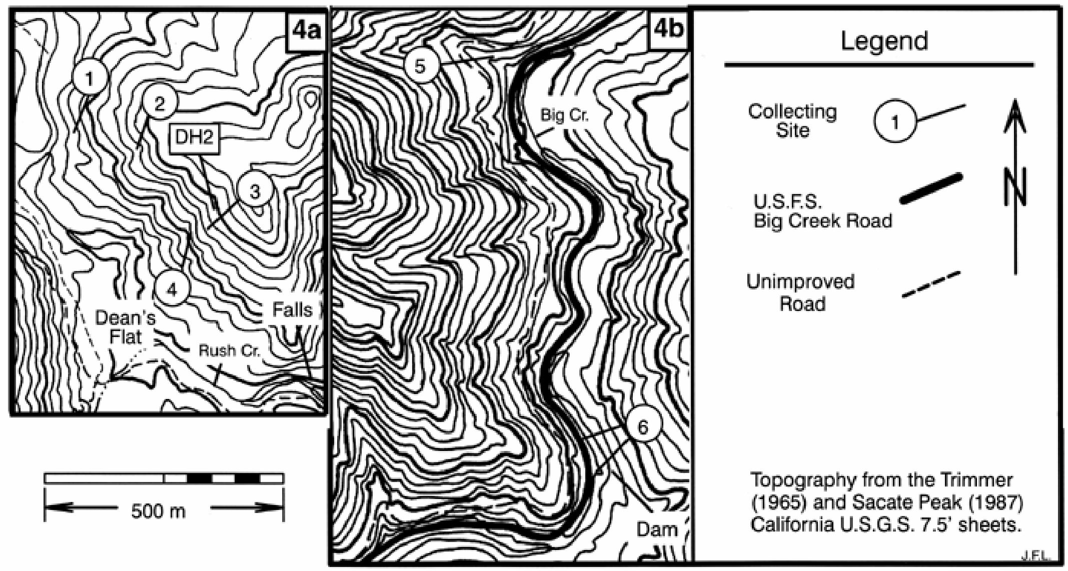


Figure 4. **Barium silicate localities; 4a covers parts of Sections 22 and 27 along Big Creek Road; 4b shows a portion of Section 16 with U.S. Forest Service Road 10S04.**

BARIUM MINERALS

Twenty three barium species have been identified from the sanbornite deposits at Big Creek and Rush Creek. Ten are type-locality minerals; the others occur elsewhere and are common to extremely rare. In addition, seven potentially new species are currently known and several are under study. In the following descriptions of the barium minerals, emphasis is placed on the diagnostic features that are most useful in the identification of hand-specimens by the collector. Table 1 summarizes six sites at Big Creek and Rush Creek where barium silicates and other minerals may be found. Specific localities are shown in Figures 4a and 4b. Chemical formulas, except as noted, are from *Fleischer's Glossary of Mineral Species 2004* (Mandarino and Back, 2004).

Alforsite $Ba_5(PO_4)_3Cl$

Alforsite, which was formally described as a new mineral from the Big Creek locality by Newberry *et al*. (1981), honors geologist John T. Alfors of the California Division of Mines and Geology. John was one of the initial investigators of the sanbornite deposits. The mineral is colorless and difficult to distinguish from other barium silicates without microchemical analysis such as EDS associated with an SEM. It is widely disseminated in banded, gneissic portions of the sanbornite-quartz rock, associated with locally abundant celsian, fluorapatite and witherite, and lesser amounts of fresnoite, walstromite and pyrite (Site 6).

Alforsite, a member of the apatite group, occurs as isolated subhedral grains and minute hexagonal plates less than 0.05 mm across. It is colorless and difficult to distinguish from other barium silicates without microchemical analysis such as EDS associated with an SEM. It is widely disseminated in banded, gneissic portions of the sanbornite-quartz rock, associated with locally abundant celsian, fluorapatite and witherite, and lesser amounts of fresnoite, walstromite and pyrite (Site 6). Alforsite, for which the Fresno County sanbornite deposits are the type locality, was named for geologist John T. Alfors of the California Division of Mines and Geology, who was one of the initial investigators of the sanbornite deposits (Newberry *et al*., 1981).

Anandite $(Ba,K)(Fe^{2+},Mg)_3(Si,Al,Fe)_4O_{10}(S,Cl)(O,OH)_2$

Anandite, a brittle mica, was first identified from samples collected by one of the authors (REW) at a Big Creek road cut in 1982 (Site 6). It is extremely uncommon, and is always associated with gillespite in quartz-rich layers of that single outcrop. Anandite also has been identified from Site 5 closely associated with three unidentified barium silicates, mineral 27 and minerals 39a and 39b. The Big Creek area represents the second world occurrence for this unusual mineral. Anandite is silvery black, foliated to blocky, with a silky, undulatory sheen, but otherwise appears similar to biotite, a mineral not present at the site.

The type locality for anandite is Wilagedera, North Western Province, Ceylon (now Sri Lanka) (Pattiaratchi, 1967). Investigations reported by Lovering and Widdowson (1968) indicate the formula for anandite from that locality to be $Ba(Fe^{2+}, Mg)_3[(Si_2(Fe^{3+},Fe^{2+},Si)_2O_{10-x}](S,Cl)(OH)$. Analyses by D. E. Appleman of the Smithsonian Institution (personal communication, 1985), and recent analyses by one of the authors (J.F.L.), confirm the presence of S and Cl in the Big Creek anandite.

Barite $BaSO_4$

Barite is quite rare at the Big Creek-Rush Creek sanbornite outcrops. Notably it has been identified at Sites 2 and 5 and from the drill core hole. Grains and masses are creamy white to light yellow.

Bazirite $Ba(Zr,Sn,Ti)Si_3O_9$

Bazirite was first identified at these deposits from specimens collected by one of the authors (REW) in 1982 at Big Creek. The mineral generally forms colorless anhedral grains typically less than 1 mm across, and is widely but sparingly present in the quartz-rich portions of virtually all of the sanbornite outcrops. However, at one locality (Site 5), bazirite locally abounds as subhedral grains, aggregates and hexagonal plates to 1.5 mm disseminated in white granular celsian. It is readily identified by its bright blue-white fluorescence under shortwave ultraviolet light. Bazirite is isostructural with benitoite and pabstite, both uncommon barium minerals. Analysis of Big Creek bazirite specimens by D. E. Appleman of the Smithsonian Institution (personal communication, 1983a), yielded the formula $Ba(Zr,Sn,Ti)Si_3O_9$, with 85% of the tetravalent sites occupied by Zr and the remainder equally divided between Sn and Ti.

Microchemical tests are usually required to distinguish bazirite from similar fluorescent minerals such as benitoite and scheelite, which also occur in the sanbornite-quartz host rock.

Benitoite $BaTiSi_3O_9$

Benitoite was identified by X-ray powder diffraction and electron microprobe analyses as a minor constituent from a section of drill core taken at Rush Creek in 1962 (Stinson and Alfors, 1964) (Fig. 4a, DH-2). The mineral was described as small (<1 mm), colorless anhedra associated with sanbornite, celsian, witherite, pyrrhotite and quartz. Benitoite is similar to bazirite in fluorescence, radiating an intense blue-white color under shortwave ultraviolet light. Benitoite has also been identified in the sanbornite-quartz rocks at Site 6 by EDS.

Bigcreekite $BaSi_2O_5 \cdot 4H_2O$

Bigcreekite, formally described by Basciano *et al.* (2001), has been recognized sparingly from only one of the gillespite-sanbornite localities in rock blasted from a road cut (Site 6). The blasted rock has been extensively scrutinized, and the vast majority of available material has probably been collected during years past. Bigcreekite exhibits opaque, white cleavage surfaces, and fills secondary fractures 1 mm thick that transect foliation in the quartz-rich sanbornite rock, accompanied by muirite, verplanckite, and mineral 10. Bigcreekite has also been identified in quartz-sanbornite rock exposed at Trumbull Peak (Dunning and Cooper, 1999).

Celsian $BaAl_2Si_2O_8$

The rare barium feldspar, celsian, was confirmed by M. C. Stinson of the California Division of Mines and Geology (personal communication, 1982a). It is distributed sparingly throughout the deposits, but is abundant in several areas where it forms seams up to 6 cm thick (Site 5). Celsian occurs as fine-grained, white to gray masses in quartz-rich portions of the deposits, and at the boundary between sanbornite-bearing rock and the surrounding metamorphic rocks. Where bazirite, traskite or alforsite are present, celsian is more abundant than elsewhere. It is rather nondescript, similar to quartz in appearance but grayish with a hint of yellow. Unlike quartz, it generally occurs in clumps and forms more or less equant, blocky grains that display crystal faces and cleavages.

Edingtonite $Ba[Al_2Si_3O_{10}] \cdot 4H_2O$

Edingtonite has been identified from one small (20-cm) outcrop where it has developed in masses and white veinlets to 1 cm thick (Site 5) (D. E. Appleman, personal communication, 1982a). Only a very modest amount has been found, associated with sanbornite, pyrrhotite, and good-quality fresnoite. Edingtonite may be confused with opal or clay in hand specimen, as it is dull, white, chalky and massive. It is probably a weathering product of sanbornite.

Fencooperite $Ba_6Fe_3Si_8O_{21}(CO_3)_2Cl_3 \cdot H_2O$

Fencooperite is a newly recognized mineral species from Trumbull Peak Mariposa County, California (Roberts *et al.* 2001). During the study of this mineral, material from the Big Creek area was also examined for the possibility of a second occurrence of fencooperite. Several sanbornite-quartz samples from the Esquire #7 claim (Site 6) were found to contain thin veins of very rare black fencooperite. Individual grains are less than 1 mm and anhedral with an uneven to subconchoidal fracture. Chemically, it is the second silicate-carbonate of barium discovered in nature after kampfite.

Fresnoite $Ba_2TiOSi_2O_7$

Fresnoite is plentiful in many sanbornite outcrops as tiny, bright yellow, anhedral grains (<1 mm) widely disseminated throughout the sanbornite-bearing rocks. Its color is most intense in sunlight, appearing a pale cream under artificial illumination, and it fluoresces pale yellow to green under shortwave ultraviolet light. At several Rush Creek localities between Sites 3 and 4, examples showing good crystal face development can be found. The mineral is generally concentrated in thin bands within quartz-rich layers, along with celsian, titantaramellite, and pyrrhotite at Site 6. Fresnoite, for which the Fresno County sanbornite deposits are the type locality, was named after the county by Alfors and Stinson (1965).

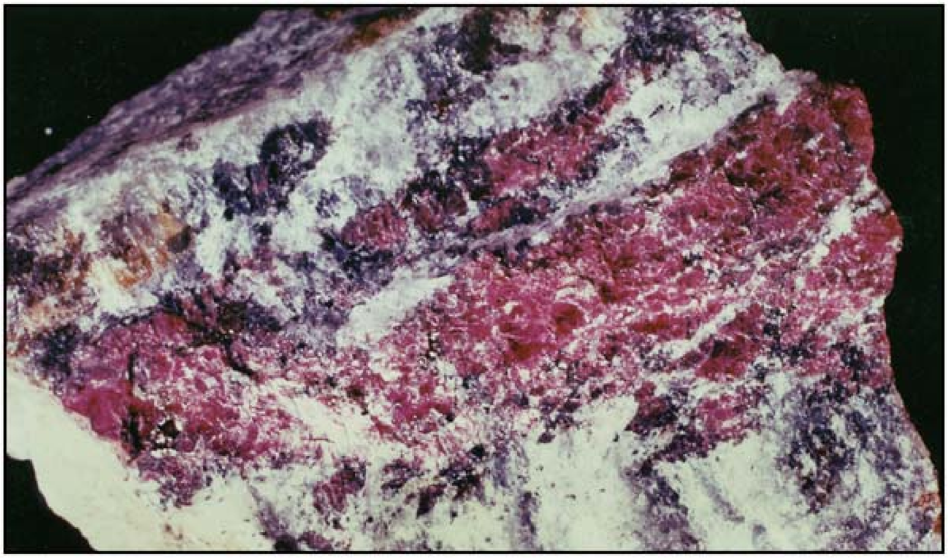


Figure 5. **Hand specimen, 9 cm, showing red gillespite, from Site 6. John Alfors photo.**

Gillespite $BaFe^{2+}Si_4O_{10}$

Whereas gillespite is common at sanbornite localities elsewhere in the world, at the Fresno County deposits it is relatively rare. Its bright rose-red to blood-red color and platy habit, however, are conspicuous (Fig. 5). At Rush Creek, the mineral is present only sparingly as cleavages to 1 cm associated with sanbornite and quartz, frequently along fractures (Site 1). Cleavage plates up to 5 cm across have been taken from a vertically dipping sanbornite body about 2 meters long at a road cut next to Big Creek (Site 6). These plates are associated with anandite, titantaramellite, muirite, and mineral 10. In 1961, some of the best gillespite, muirite and verplanckite specimens to date were collected along the watercourse in blasted rock from that cut. Over the ensuing years, however, most if not all of that material has been removed.

Recently, gillespite was discovered in the footwall of a near-vertical, foliated, vein-like sanbornite body about 1 meter thick (Site 5). The majority of this material is strongly to weakly weathered, but occasionally, fresh plates have been found.

Kampfite $Ba_6[(Si,Al)O_2]_8(CO_3)_2Cl_2(Cl,H_2O)_2$

Kampfite was first discovered within large cleavages of sanbornite from Rush Creek at Site 4 and formally described by Basciano, *et al*. (2001). Here it forms gray to pale blue, rounded grains to 2 mm. It is typically entirely enclosed in quartz, associated with traskite, titantaramellite, fresnoite, celsian, witherite, pyrrhotite and mineral 10. Kampfite subsequently has been found rarely along Big Creek at several additional outcrops (Sites 5 and 6).

Krauskopfite $BaSi_2O_4(OH)_2 \cdot 2H_2O$

Krauskopfite, one of the rarer species at the deposits, is restricted to a single site above Rush Creek, where it occurs with macdonaldite in white veinlets up to 5 mm thick (Site 3). The veinlets are found in brecciated, weathered, surficial rinds on quartz-rich sanbornite rock. Stinson and Alfors (1964) concluded that both species are products of sanbornite weathering. Krauskopfite is opaque to translucent white, and occurs as cleavage masses and occasional elongated tabular cleavages on fracture surfaces. Individual cleavages are less than 3 mm across (Fig. 6). As yet, no terminated crystals have been found. Krauskopfite can be distinguished from macdonaldite by its two perfect cleavages and non-radiating habit. The mineral, for which the Fresno County sanbornite deposits are the type locality, was named for professor Konrad B. Krauskopf of Stanford University in recognition of his contributions to the economic geology of eastern Fresno County (Stinson and Alfors, 1964).

***Figure 6.* Krauskopfite veinlet 2 mm thick surrounded by limonite-stained quartz, from Site 4. John Alfors photo.**

***Figure 7.* Macdonaldite rosettes on a 10-cm hand specimen, from Site 4. John Alfors photo.**

Macdonaldite $BaCa_4Si_{16}O_{36}(OH)_2 \cdot 10H_2O$

Macdonaldite is widespread in the sanbornite deposits but is found as well-developed crystals at only a few places, notably Sites 3 and 6. A product of sanbornite weathering, it precipitated in narrow fracture fillings near outcrop surfaces, forming radiating crystal rosettes up to 1 cm across (Fig. 7). Macdonaldite is translucent to transparent, white to colorless, and superficially similar to aragonite. In cavities, free-standing, terminated, colorless orthorhombic crystals have been collected, accompanied by krauskopfite and walstromite. The mineral, for which the Fresno County sanbornite deposits are the type locality, was named for Professor Gordon A. Macdonald of the University of Hawaii in recognition of his contributions to the economic geology of eastern Fresno County (Stinson and Alfors, 1964).

Muirite $Ba_{10}Ca_2Mn^{2+}TiSi_{10}O_{30}(OH,Cl,F)_{10}$

Muirite is most abundant along Big Creek (Site 6), though it can be found elsewhere. It occurs as tiny (<1 mm), isolated, equant grains concentrated along narrow bands in both sanbornite-rich and quartz-rich rock. Its principal diagnostic feature is a bright orange color (Fig. 8). Most grains are anhedral, but with a little effort euhedral tetragonal crystals can be obtained. Attendant phases include gillespite, fresnoite, titantaramellite and walstromite. Muirite, for which the Fresno County sanbornite deposits are the type locality, was named by Alfors and Stinson (1965) after John Muir, a mountaineer, conservationist and naturalist who made important early observations concerning the geology and glaciology of the Sierra Nevada Mountains.

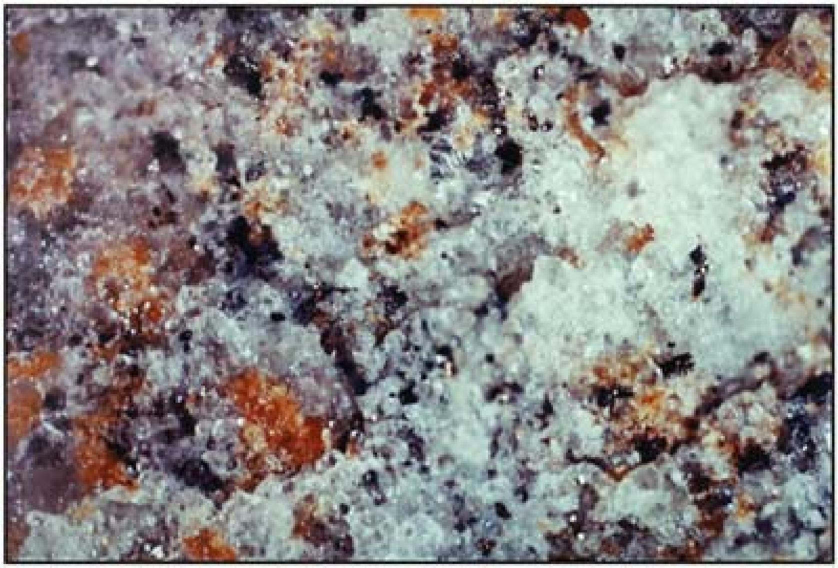


Figure 8. **Muirite grains with sanbornite and quartz (field of view is 4 x 7 mm). John Alfors photo.**

Pellyite $Ba_2CaFe_2^{2+}Si_6O_{17}$

Pellyite has been recognized in several areas at both Big Creek and Rush Creek (Sites 2 and 5). The best specimens have been produced from Site 5, where the mineral forms veinlets to 1 cm thick in sanbornite-rich rock. The veinlets transect foliation, suggesting late-stage deposition. The mineral resembles pale to dark brown quartz; it is massive, exhibits conchoidal fracture, and is spatially associated with gillespite and titantaramellite. Pabst and Harris (1984) provide an update on pellyite mineralogy and on other localities.

Figure 9. **Sanbornite cleavage, 13 cm, from Site 4. John Alfors photo.**

Sanbornite $BaSi_2O_5$

Sanbornite is the most abundant of the barium silicates at Big Creek and Rush Creek. Bodies of this mineral host many of the other species and are readily accessible to collectors. Sanbornite most commonly is white to colorless, but where exceptionally pure and translucent it is pale green. Its high specific gravity (>3.7), one perfect micaceous cleavage, and pearly luster are diagnostic features (Fig. 9). The mineral typically developed as bodies of tightly packed cleavage plates less than 1 cm in diameter within massive quartz bands that generally parallel foliation. However, at several outcrops above Rush Creek, significantly larger plates have been found (Site 2). The largest of these cleavages, collected in the early 1960’s, measures 20 cm long and 8 cm thick; it is preserved in the Harvard Mineralogical Museum.

Figure 10. **Titantaramellite crystal, about 2 mm across, with quartz etched from calcite and witherite matrix. SEM photo by Gail Dunning.**

Titantaramellite $Ba_4(Ti,Fe^{3+},Fe^{2+},Mg)_4(B_2Si_8O_{27})O_2Cl_{0-1}$

Titantaramellite occurs to some extent in almost all of the sanbornite rock as opaque, dark brown to greenish brown, flattened crystals 1 mm to 5 mm long (Fig. 10). Rare, sizable titantaramellite crystals to 2 cm have been found associated with bazirite, gillespite, anandite and tremolite (Site 6). The largest titantaramellites, collected by one of the authors (REW) in 1982, are totally enclosed in white granular celsian (Site 5). Though equant, these crystals are brittle, and thus extremely difficult to extract individually. About 35 years ago, excellent, lustrous, dark brown euhedra to 1.5 cm in a sanbornite-quartz-calcite matrix were found at Site 4. Extraction of these thin, tabular crystals proved difficult, but with a good deal of care and a great deal of luck a few smaller individuals, some doubly terminated, were removed. The extraction technique involves application of dilute HCl where sanbornite and calcite predominate within a specimen, and recovery of the insoluble titantaramellite. No other technique has worked well. Unfortunately, localities where etching is possible are the exception rather than the rule.

When titantaramellite was first discovered at Rush Creek, it was identified as taramellite by Alfors and Stinson (1965). Alfors and Pabst (1984) subsequently reported the differences between iron-rich taramellite from the type locality at Candoglia, Piemonte, Italy, and the titanian analog found at Big Creek–Rush Creek and elsewhere in North America. As a result, titantaramellite is now considered a separate species.

Barian Tobermorite $(Ca,Ba)_5Si_6O_{15}(OH)_2 \cdot 5H_2O$

Tobermorite is a relatively rare calcium silicate, a notable occurrence being the Crestmore quarry, Riverside County, California (Murdock and Webb, 1969). At Big Creek, the mineral contains Ca:Ba ratio of 5:1 (Appleman, personal communication, 1982b). Tobermorite forms white, somewhat pearly, compact, short fibers to 3 mm associated with muirite, fresnoite and mineral 10. Barium-rich tobermorite so far has been found only along Big Creek (Sites 5 and 6).

Traskite $Ba_9Fe_2^{2+}Ti_2(SiO_3)_{12}(OH,Cl,F)_6 \cdot 6H_2O$

Traskite, first discovered at Rush Creek, occurs as tiny (<1 mm), isolated, reddish brown, translucent anhedra widely distributed in certain sanbornite-quartz exposures. The best specimens are enclosed within the quartz-celsian matrix of larger, coarser-grained sanbornite cleavages from Rush Creek (Site 2). Associated species include fresnoite, titantaramellite, kampfite and two as yet undescribed minerals (minerals 10 and 21). Traskite can be distinguished from titantaramellite, with which it is often confused, by its red color and equant habit. Alfors and Stinson (1965) named the species, for which the Fresno County sanbornite deposits are the type locality, after John B. Trask, first State Geologist for California. Revisions to the chemistry were later published by Alfors and Putman (1965).

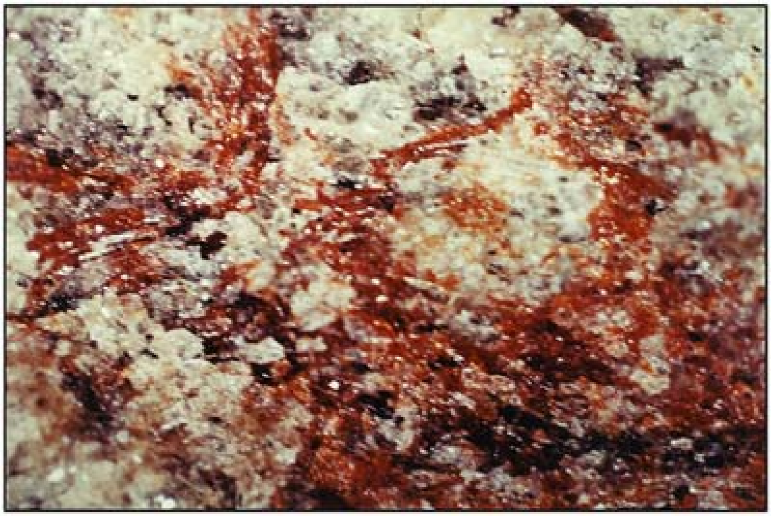


Figure 11. **Verplanckite crystal (note elongation) (field of view 7 mm), from Site 6. John Alfors photo.**

Verplanckite $Ba_{12}(Mn,Fe,Ti)_6(Si_4O_{12})_3(OH,O)_2Cl_9(OH,H_2O)_7$

Verplanckite is found at several localities in the Rush Creek area but it is most easily recognized and collected at Big Creek (Site 6). There, it occurs as radial clots and translucent, pale to dark brownish orange, prismatic single crystals to 3 mm, embedded in quartz-sanbornite rock (Fig. 11). Its elongated hexagonal habit and brown color distinguish verplanckite from muirite, which is bright orange, and from traskite, which is red. Associated species include fresnoite and pyrrhotite. The mineral, for which the Fresno County sanbornite deposits are the type locality, was named for William E. Ver Planck, formerly a geologist with the California Division of Mines and Geology (Alfors and Stinson, 1965).

Figure 12. **Reflection from walstromite cleavage about 2 cm long. Gail Dunning photo.**

Walstromite $BaCa_2Si_3O_9$

Following sanbornite and gillespite, walstromite is the coarsest-grained mineral in the deposits, and is second only to sanbornite in abundance. It occurs widely as clots and layers of interlocking masses and also as isolated anhedral crystals in sanbornite-quartz rock, more frequently within the quartz-rich zones. Individual crystals range in size from 2 mm to 2.5 cm. Walstromite is white to gray with three perfect cleavages, but otherwise is similar in appearance to sanbornite (Fig. 12). Unlike sanbornite, however, walstromite fluoresces reddish pink to orange under both longwave and shortwave ultraviolet light. The best specimens have been collected along Big Creek at Site 5 and from the road cut and from road fill at Site 6. Walstromite, for which the Fresno County sanbornite deposits are the type locality, is named after one of the authors (REW), who discovered it in 1960 while prospecting for barite. Rare samples of walstromite also have been identified from Trumbull Peak (Dunning and Cooper, 1999) and the Baumann prospect (Walstrom and Dunning, 2003).

Witherite $BaCO_3$

Witherite is fairly common in small amounts throughout the deposits, principally as opaque, white to gray, earthy masses closely associated with sanbornite, calcite, barite, kampfite and of the undescribed species (mineral 10) at Sites 2 and 4. Witherite was first identified in the diamond drill holes completed at Rush Creek (Weiler *et al*., 1964).

INCOMPLETELY CHARACTERIZED MINERALS

Several minerals from the sanbornite deposits have yet to be characterized and are potentially new species. Preliminary investigation of specimens collected by one of the authors (REW) has been conducted by D. E. Appleman of the Smithsonian Institution beginning in 1981. Additional study was then undertaken by Dr. E. E. Foord (now deceased). Dr. Anthony Kampf (Los Angeles County Museum) is currently studying one of these potentially new phases. Their numerical designation reflects their position in a series of samples taken by one of the authors (REW) beginning in 1981.

Mineral 10 $Ba_4(Fe^{2+},Mg)(Al,Fe^{3+},Ti)_3Si_6(O,Cl)_{25}$

Mineral 10 was collected during the mid-1960's by one of the authors (REW) and is more common than the other incompletely characterized species. It is scattered sparingly throughout most of the sanbornite rock outcrops as irregular, medium to dark blue grains generally less than 1 mm in diameter. Along with kampfite, it is locally abundant fringing large sanbornite cleavages at Site 4. In one outcrop at Site 5, it forms bright green grains surrounding small white cleavages of barian tobermorite, and also as black veins with a dark blue streak up to 5 mm thick along the border of a 10-cm walstromite lens. Mineral 10 is commonly found with gillespite, muirite, anandite and pyrrhotite at Site 6.

Microprobe analysis of several blue grains extracted from the host rock gives the formula $Ba_{4.01}(Fe^{2+}_{0.96}Mg_{0.04})_{1.00}(Al_{2.82}Fe^{3+}_{0.14}Ti_{0.03})_{2.99}Si_{5.96}(O_{17.7}Cl_{7.3})_{25}$ (E. Foord, personal communication, 1991). X-ray powder diffraction patterns of this mineral from two sites along Big Creek and above Rush Creek match similar material from Trumbull Peak (Dunning and Cooper, 1999), Chickencoop Canyon (Walstrom and Dunning, 2003) and from the Gun claims, in the Yukon. These patterns are consistent with the mineral cerchiaraite (Basso *et al*. 2000), the Mn^{3+} analogue of the series consisting of the Fe^{2+} and Mn^{2+} members. To date no individual crystals have been isolated to perform a structure evaluation.

Mineral 21 $SiO_2 \cdot nH_2O$ (?)

Mineral 21 has to date been found only at Site 2 above Rush Creek, where it occurs sparingly along transverse fractures that have occasionally developed between large sanbornite cleavages. It forms white, radiating, somewhat flattened crystals to 5 mm across (Fig. 13). As shown by electron microprobe analyses, it is a hydrous secondary phase containing primarily SiO_2 (between 91% and 94%), and has not yet been identified with any known mineral (D. E. Appleman, personal communication, 1983b; E. E. Foord, personal communication, 1991).

***Figure 13.* Mineral 21 with rosette of acicular macdonaldite crystals (field of view 2 mm). SEM photo by Gail Dunning.**

Mineral 27 Ba-(Fe,Al) Silicate-Phosphate

Mineral 27 has been identified at two separate localities along Big Creek. At Site 5 it occurs as individual and groups of clove brown acicular crystals to 5 mm partially embedded in white, granular celsian along with large, tabular titantaramellite, bazirite, green ferroan diopside, tremolite and actinolite (Fig. 14) and closely associated with jet black platy anandite and minerals 39a & b. At Site 6 it occurs along cleavage planes of altered gillespite also closely associated with both anandite and minerals 39a & b. Microprobe analysis (University of Chicago) shows that the mineral is a Ba-(Fe,Al)-silicate-phosphate. It is monoclinic with large cell dimensions and a specific gravity of 3.75. A preliminary structure motif consists of edge-sharing Fe octahedral sheets to which silicate tetrahedra are bonded on either side, with the barium atoms and phosphate groups in the region between these slabs. The unit cell data suggests similarities to the mineral yoshimuraite. The individual thin crystals are twinned and strongly distorted, resulting in poor diffraction data.

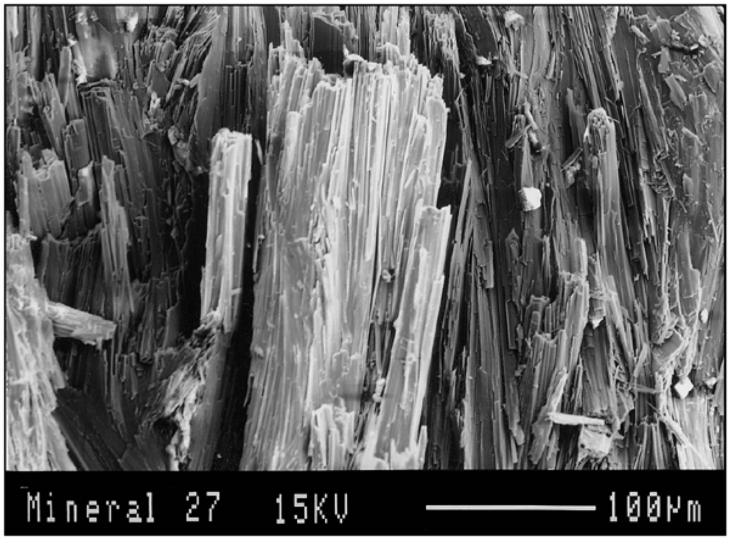


***Figure 14.* Mineral 27, a large crystal about 200 µm long. Greg Ferdock photo.**

Mineral 39a, 39b $Ba(Fe,Mn)_2(FeO)Si_2O_7(Cl,OH)$?

This mineral was discovered by G. Dunning in 1998 while examining the alteration products of gillespite at Sites 5 and 6. It occurs as foliated layers along cleavages of gillespite and is closely associated with anandite and mineral 27. It is dark brown with red internal reflections. Individual crystals have been noted at site 5. X-ray powder diffraction and EDS tests show that this mineral shows a close similarity to the intergrown minerals ericssonite and orthoericssonite. The one exception is that the manganese and hydroxyl have been replaced by ferric and chloride ions, characteristic of the vein chemistry at these two sites. During the mineralogical work at Trumbull Peak, this same pair of minerals was discovered on a single sample of quartz-sanbornite rock (Dunning and Cooper, 1999). To date no detailed work has begun on these potentially new analogues of ericssonite and orthoericssonite.

Mineral 40 Ba-(Mn,Fe)-Cl Silicate

Mineral 40 was discovered in 1998 by G. Dunning while examining quartz-sanbornite rock at Site 6 along Big Creek. The mineral occurs as clear to very light pink radiating, flat crystals along fracture surfaces of quartz-sanbornite rock. X-ray powder diffraction of selected grains shows no resemblance to any known chemical phase. EDS of the light pink flat crystals give major Ba, Mn, Cl, Si and O with minor Fe. No further work has been done on this phase because of the minute size of the crystals. The host rock contains abundant pyrrhotite and layers of fresnoite grains and isolated green uvarovite grains. Only five samples are known.

Mineral 41 Ba-(Mn,Fe) Silicate

This mineral was discovered by G. Dunning in 1998 while examining sanbornite rock from Site 5 along Big Creek. The discovery rock contains a pellyite vein on one end with minor gillespite. On the opposite surface of this sample are several very thin, brownish-yellow flakes. An X-ray powder diffraction of the mineral showed no resemblance to any known chemical phase. The EDS data obtained revealed major Ba, Mn Si and O with minor Fe. Only a single sample is known of this mineral.

PARAGENESIS

An apparent paragenetic timeline was constructed based on the individual mineral relationships observed at each locality. Paragenetic relationships developed from the mineralogy at both the Baumann Prospect, Tulare County and Trumbull Peak, Mariposa County were used to check the observed mineral relationships observed at the Big Creek and Rush Creek deposits. Minerals grouped as individual grains in the primary quartz-sanbornite host rock were placed in the same general time frame. Minerals cutting this host rock were placed later. Minerals that formed along late fractures in the host rock and individual earlier minerals were placed last in the sequence. These observations are relative and open to interpretation based on future data.

Table 2. **Apparent paragenetic timeline for the Big Creek-Rush Creek barium silicate deposits**.

Mineral	Early				Late
Alforsite	———				
Anandite			———?		
Barite	———				
Bazirite	———				
Benitoite	———				
Bigcreekite			———?		
Celsian	———				
Edingtonite				———	
Fencooperite			———?		
Fluorapatite	———				
Fresnoite		———			
Gillespite	———				
Kampfite			———		
Krauskopfite					———
Macdonaldite					———
Mineral 10		———?			
Mineral 21					———
Mineral 27			———?		
Mineral 39a, 39b			———?		
Mineral 40				———?	
Mineral 41				———?	
Murite	———				
Pellyite	———				
Pyrrhotite	———				
Quartz		———			
Sanbornite			———		
Titantaramellite	———				
Tobermorite				———	
Traskite		———			
Verplanckite		———			
Walstromite		———			
Witherite	———				———?

COLLECTING

Collecting can be a real challenge at the Fresno County barium silicate localities. Most exposures are small, widely scattered, and readily overlooked amid the tall grass, thick chaparral and trees. Against that, the site is pleasant for camping, particularly in the spring and fall when neither temperature nor precipitation are incommodious. The best collecting areas are: the W½ of the NE¼ and the NE¼ of the NW¼ of Sec. 16; the S½ of the SW¼ of Sec. 22; and the SE¼ of the NW¼ and SW¼ of the NE¼ of Sec. 27—all in T11S, R25E, M.D.M. One should search for deeply weathered, foliated, gray sanbornite-quartz outcrops. These generally display little relief above ground level. Persistence, along with a good 10-power loupe and a very heavy hammer, will pay dividends in the form of a suite of rare and unusual minerals. Beware of rattlesnakes and poison oak while collecting.

As a final note of encouragement, it is highly likely that at Rush Creek and Big Creek most of the barium silicates are considerably more widespread than is presently known. Each visit by the authors to the property has resulted in the discovery of previously unknown occurrences. For those seeking further information, Murdock and Webb (1969) and Pemberton (1983) provide reference sources with additional data on the minerals at this site, and on other barium localities in California.

While most of the sanbornite outcrops were originally discovered on open public lands, all are now on private property or are under mining claim. Permission to collect must be obtained from the respective owners.

CONCLUSION

To date, the claims at Big Creek and Rush Creek have been explored only on the surface and by two diamond drill holes. As many as 25 barium-containing minerals, ten of which are type species and seven additional ones which may be new, have been found. If these deposits are ever exploited commercially, the chances are good that additional new and/or rare minerals will be discovered. At present, this site affords the species collector and micromounter an excellent opportunity to enhance his inventory in a readily accessible, pleasurable setting.

Exploration-minded collectors might ponder that the five known sanbornite occurrences from the Yukon to Baja California are in roof pendants of metamorphic rocks derived from backarc sedimentary deposits. These regions are on the western margins of granitic plutons and align generally north-south. Similar geologic settings, particularly those exhibiting geochemically anomalous barium, might be prospected for new barium silicate localities.

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***Table 1.* Minerals of the Sanbornite deposits, Rush Creek and Big Creek, Fresno County, California**

Species	Locality						
							Drill
	1	2	3	4	5	6	Hole
Alforsite						X	
Anandite						X	
Aragonite					R		
Barite		X			R		P
Bazirite	C	C	C		C	C	
Benitoite							P
Bigcreekite						X	
Calcite				C	C	R	
Celsian		C			C	C	P
Chalcopyrite							P
Diopside					R		P
Edingtonite					X		
Fencooperite						X	
Fluorapatite						X	
Fresnoite	R	R			C	R	
Galena							P
Gillespite	R				C	C	
Kampfite		X					
Krauskopfite	R		C				

Macdonaldite	R	R	C		R	R	
Mineral 10	R	R			R	R	
Mineral 21		R					
Mineral 27					X		
Mineral 39a & b					X	X	
Mineral 40					X		
Mineral 41					X		
Molybdenite		X					P
Montmorillonite					X		
Muirite						R	
Opal	C	C	C		C	C	
Opal pseud. Krauskopfite	X						
Opal pseud. Macdonaldite		X					
Opal pseud. Sanbornite	C	C	C	C	C	C	
Opal v. Hyalite					R		
Pellyite					R		
Powellite						X	
Pyrite		X			X	X	
Pyrrhotite	C	C	C	C	C	C	P
Quartz	C	C	C	C	C	C	C
Sanbornite	C	C	C	C	C	C	C
Scheelite					X		
Sphalerite							P
Titantaramellite	C	C	R	C	C	C	P
Tobermorite					R	R	
Traskite						X	
Tremolite					C	C	
Uraninite					X		
Verplanckite						X	
Walstromite	R				R	R	
Witherite				X			P
Wollastonite						C	

C = Common; R = Rare; X = Extremely rare; P = Present in unknown proportion

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