

BARIUM SILICATE MINERALOGY OF THE WESTERN MARGIN, NORTH AMERICAN CONTINENT, PART 1: GEOLOGY, ORIGIN, PARAGENESIS AND MINERAL DISTRIBUTION FROM BAJA CALIFORNIA NORTE, MEXICO, WESTERN CANADA AND ALASKA, USA

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INTRODUCTION:

The presently known extent of Ba-silicate occurrences along the western margin of the North American continent ranges from Baja California Norte, Mexico in the south to the Brooks Range, Alaska in the north, is about 5700 km. These localities include (1) Greens Creek, Dry Delta, Ruby Creek, O'Brien Creek, Galena Prospect and the Bonanza Creek deposits, Alaska; (2) the Gun claim, Birr claim, and Tom deposit, Yukon Territory, and the Wigwam deposit and Ice River Complex, British Columbia, Canada; (3) Coyote Peak diatreme, Kalkar Quarry, and Ash Creek, California. (4) Pacheco Pass road cut, Dallas Gem mine, Victor claim, Mina Numero Uno, Junnila mine, and the Lost Hills drill hole, California. (5) The Esquire claims, the Baumann prospect, and Trumbull Peak, California; and the El Rosario and Madrelena mines, Baja California Norte, Mexico.

The purpose of this study is to examine the individual site mineralogy and geology and determine if there is a consistent or common thread between them. Published works exist for the southernmost sites that include the eastern Fresno, Mariposa, San Benito, Santa Cruz, Humboldt and Tulare counties in California and the two sites in Baja California Norte. Grouping of individual sites based on mineralogy and geology may provide clues to the origin of the barium and other elements. Some sites, in fact, may be termed as isolated occurrences based on local chemical sources and fluid conditions. Also, from the common minerals present along this study trend, some clues may be gained concerning the conditions of formation such as pH, Eh, temperature, concentration of elements, and pressure.

Some of these sites contain only one or two Ba-silicates while others contain at least twenty five out of a total of 44 for the entire study region. This range may suggest the volume and extent of the initial chemistry and the geochemical processes during mineral formation. Although the first of these Ba-silicates was formally described in the 1920's, there are still

additional minerals being discovered and described. Correlation between the individual site mineralogy, including accessory minerals not containing barium, may give clues to the paragenesis of this group of interesting minerals.

Lastly, mineral synthesis of some major barium silicates will enhance our understanding of the conditions of formation and relationships between site mineralogy and laboratory synthesis results.

STUDY METHODOLOGY:

The initial part of this study is to compare each locality with respect to its geological setting with a listing of rock types, geological period and type of event that resulted in the formation of the barium silicate minerals. This first comparison is shown in Table 1.

Following this comparison, the total barium silicate occurrences will be divided into seven distinct groups (or single sites) based on their locality and regional grouping. Each locality will be discussed based on available literature and specific mineral samples with respect to general geological features. Where available, site photos will be shown. Individual mineral photos will be presented in Part 2 of this study.

Based on the above locality information, the next part of this study is to compare the abundance of each mineral with respect to the individual mineral sites and their percentages within that group. This will give data with respect to the range of each mineral from Baja California in the south to Alaska in the north. Within this comparison will be the various elements contained in each specific barium silicate mineral with respect to the geological features associated with the minerals. Specific minerals associated with the barium silicates will be discussed. This data will be presented in a series of charts.

The last part of this study will be to compare the origin and geology of each major group to see if there are specific trends in the barium silicate formation over the entire south to north trend.

GEOLOGICAL SETTINGS:

Table 1. This table compares the known individual Ba-silicate localities with their geological age, rock types and formations.

LOCALITY	GEOLOGICAL AGE
WESTERN METAMORPHIC BELT GROUP	
El Rosario mine, Mun. de Ensenada, Baja California Norte, Mexico	Metasedimentary roof pendant bounded by granitic rocks consisting of granodiorite and quartz monzonite. Late Cretaceous (Mesozoic) (66-101 Ma) sedimentary rocks
La Madrelena mine, Tres Pozos, Baja California Norte, Mexico	Metasedimentary roof pendant bounded by granitic rocks consisting of granodiorite and quartz monzonite. Late Cretaceous (Mesozoic) (66-145 Ma)
Baumann Prospect, Chickencoop Canyon, Tulare County, California	Paleozoic metasedimentary roof pendant bounded by granitic rocks of granodiorite and quartz monzonite. Western Metamorphic Belt of the Sierra Nevada Cretaceous (Mesozoic)
Esquire claims, Big Creek/Rush Creek area, eastern Fresno County, California	Contact metamorphism of sedimentary rocks by Late Cretaceous (Mesozoic) granodiorite pluton. Western Metamorphic Belt of the Sierra Nevada Cretaceous (Mesozoic)
Trumbull Peak, west face, above Incline, Mariposa County, California	Isolated lenses in quartzite; low-grade dynamic metamorphism in Paleozoic metasedimentary rocks. Western Metamorphic Belt of the Sierra Nevada Cretaceous (Mesozoic).
SOUTHERN DIABLO RANGE GROUP	
Drill hole in Lazard area, Lost Hills oil fields, Kern County, California	Al-rich regionally metamorphosed rock of greenschist to amphibolite facies (Franciscan, Jurassic). Found with piemontite, dumortierite in heavy mineral fractions.

Dallas Gem mine, Victor claim, Junnila mine, Mina Numero Uno, San Benito County, California	Fracture filling brecciated zone of metamorphosed greywacke and basalt yielding greenstone and blue-schist of the Franciscan Formation, Jurassic.
Pacheco Pass road cut, Santa Clara County, California	Jadeite metagraywacke rock contact with ultramafic rock of the Franciscan Formation, Jurassic. High P – Low T
COAST RANGE GROUP-SOUTH SITE	
Pacific Coast Limestone Products Quarry (Kalkar), Santa Cruz, Santa Cruz County, California	Fault-induced contact metamorphism of limestone (Sur Series) pre-Cretaceous, forming calc-silicate rocks.
COAST RANGE GROUP-NORTH SITE	
Coyote Peak diatreme, Bald Hills, Orick, Humboldt County, California	Mafic alkalic diatreme (igneous plug) intruding Franciscan Formation (Jurassic).
Ash Creek, tributary of Russian River, Mendocino County, California	Rocks of the Franciscan Formation (Jurassic).
NORTHERN GROUP-SOUTH SITES	
Wigwam deposit, Akolkolex River area, British Columbia, Canada	Metamorphosed Mississippi-Valley base-metal deposit in a silicified zone of the Cambrian-age Badshot Formation (Paleozoic). Mineralization is part of a prograde metamorphic assemblage whose P-T conditions are (2-5 kbars/ 300-425°C).
Greens Creek mine, Admiralty Island, Skagway-Yakutat-Angoon Borough, Alaska	Contact metamorphism of sedimentary-exhalative massive sulfide deposit. Mesozoic-late Triassic.
Glacial moraine at Dry Delta, Yukon-Koyukuk Borough, Alaska Range, Alaska	Metamorphosed ferruginous siliceous sediments or contact metamorphic rocks. Paleozoic-Silurian age.
Unnamed Cu deposits along Taylor Highway and O'Brien Creek, Fortymile District, Southeast Fairbanks Borough, Alaska	Paleozoic greenschist-facies black carbonaceous quartzite. Sedimentary-exhalative massive sulfides occur within buff-colored celsian-bearing quartzite.
Galena prospects, Nome District, Nome Borough, Alaska	Paleozoic sediments/metasediments. Marble, graphitic rocks, schists. Dolomitization, silicification and oxidation. Late Devonian-Mississippian (Paleozoic) base metal + Ag-Au-Ba-F
Zinc Mountain ridge, Ice River Valley, Field, Kootenay District, British Columbia, Canada	Cambrian and lower Ordovician age (Paleozoic) sedimentary rocks that were folded and faulted during the mid-Mesozoic.
NORTHERN GROUP- NORTH SITES	
Tom deposit, Macmillian Pass, Watson Lake Mining District, Itsi Mountains, Yukon Territory, Canada	Contact metasomatic deposit developed in Ordovician-Devonian (Paleozoic) sedimentary rocks at the margin of the quartz monzonite stock.
Gun claim, Macmillian Pass, Watson Lake Mining District, Itsi Mountains, Yukon Territory, Canada	Contact metasomatic deposit developed in Ordovician-Devonian (Paleozoic) sedimentary rocks at the margin of the quartz monzonite stock.
Birr claim, Macmillian Pass, Watson Lake Mining District, Itsi Mountains, Yukon Territory, Canada	Contact metasomatic deposit developed in Ordovician-Devonian (Paleozoic) sedimentary rocks at the margin of the quartz monzonite stock.
THE ARCTIC (BROOKS RANGE) GROUP	
Ruby Creek Prospects, Cosmos Hills, Ambler District, Northwest Arctic Borough, Brooks Range, Alaska	Mineralized metasedimentary rocks of Paleozoic-Devonian or Mississippian age.
BTcc Prospects, Shungnak District, Northwest Arctic Borough, Brooks Range Alaska	Syngenetic deposit in Paleozoic-Devonian or Mississippian age metasedimentary rocks.
Bonanza Creek, Wiseman Quadrangle, North Slope Borough, Brooks Range, Alaska	Pyritized zone in metasedimentary rocks of Paleozoic-Devonian or Mississippian age.
Sun group of prospects, Shungnak District, Northwest Arctic Borough, Brooks Range, Alaska	Paleozoic-Devonian felsic to andesitic volcanic, volcanislastic and intercalated pelitic sedimentary rocks. High P-low T.

REGIONAL GROUPING OF LOCALITIES:

The Ba-silicate localities compared in this study can be arranged into seven general regional groups based on common geographical location, mineralogy and geological criteria. Individual minerals common to the majority of the sites can be helpful in constructing similar geological settings and fluid conditions.

These groups include (1) The Western Metamorphic Belt Group, (2) The Southern Diablo Range Group, (3) The Coast Range Group-South Site, (4) The Coast Range Group-North Site, (5) The Northern Group-North Sites, (6) The Northern Group-South Sites, and (7) The Arctic (Brooks Range) Group.

The Western Metamorphic Belt Group:

The Ba-silicate localities within this group consist of the El Rosario and La Madrelena claims, Baja California Norte, Mexico; and in California, the Baumann Prospect, Tulare County; Trumbull Peak, Incline, Mariposa County; and four claims in eastern Fresno County (Esquire #1, #7, #8, and Snow Cap claims). All of these mineral localities are associated with plutonic intrusive events that metamorphosed pre-existing sedimentary deposits into metasediments containing a series of rare barium silicates and associated minerals.

El Rosario mine, El Alamo, Mun. de Ensenada, Baja California Norte, Mexico (31° 34' N, 116° 02' W).

The El Rosario mine is located near the small town of El Alamo along the western hills of the Sierra Juarez range, about 62 km SE of Ensenada. Both gillespite and sanbornite occur in a vein of metasediments. Associated minerals identified in the mine include ilmenite, magnetite, turquoise, wavellite, massicot, litharge, gold, galena and epidote. It is inferred that the original barium that formed the two Ba-silicates identified in the metasedimentary rocks had its original source in sub oceanic sediments that were uplifted and then metamorphosed as a roof pendant bounded by granitic rocks consisting of granodiorite and quartz monzonite (Mesozoic). Gillespite and sanbornite are the only barium silicate minerals reported from this locality. No locality photos were available for this mine. Hinthorne (1974) and Werner (1980) give an account of the regional and local geological features of this mine.



Figure 1. Locality Map for the El Roserio mine, Baja California Norte, Mexico.

La Madrelena mine, Tres Pozos, Baja California Norte, Mexico (32° 20' N, 116° 30' W).

The La Madrelena mine is located near the small town of Tres Pozos along the western hills of the Sierra Juarez range, about 23 km south of Tecate. The metasedimentary rocks host alforsite, celsian, cerchiarite-(Fe), gillespite, bazirite, pabstite (?), pellyite, titantaramellite, sanbornite, and witherite. Hinthorne (1974) and Werner (1980) give a brief description of the geology and mineralogy of this deposit. This mine is at the western edge of a large plutonic body mapped as granodiorite which makes up most of the Sierra Juarez range and is part of the Mesozoic batholith of southern California and Baja California (Larsen, 1948).

The deposit is part of a small metasedimentary roof pendant and is about 300 meters long and up to 50 meters wide. It is bounded by granitic rocks of granodiorite and quartz monzonite composition. The sanbornite-quartz rocks occur as a bed in the metasedimentary sequence and in some places are only a few meters from the sharp contact of the metamorphic and plutonic rocks. The pendant rocks immediately adjacent to the sanbornite bed are impure metasedimentary quartzites, schists and minor calc-silicates.

The metasedimentary quartzites are mottled dark gray to black in hand specimen and are extremely tough. The larger quartz grains may be recrystallized chert and the rock is probably a metamorphosed clastic sedimentary rock possibly derived from abyssal marine sediments.

Other pendant rocks adjacent to the sanbornite-quartz beds appear to have been derived from marls or calcareous siltstones. Their mineral assemblage is composed mainly of actinolite, muscovite and quartz.

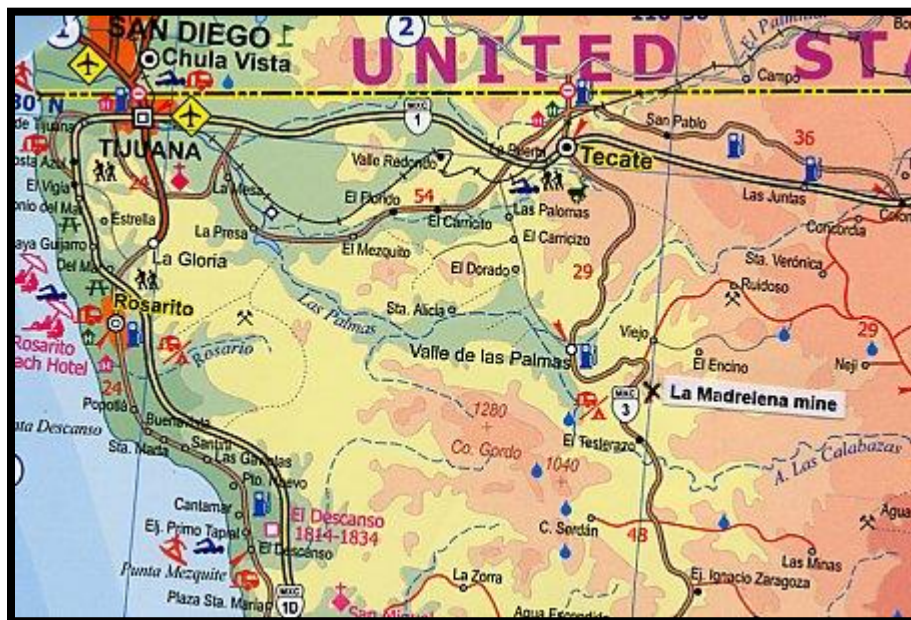


Figure 2. Locality Map for the La Madrelena mine, Baja California Norte, Mexico.

Baumann Prospect, Chickencoop Canyon, Tulare County, California (36° 17' 30" N, 119° 01' W).

Exposed outcrops containing baryte were discovered before 1930 along the metamorphic rock exposure above a small tributary to Chickencoop Canyon. Four small exploratory pits, known as the Baumann Ranch baryte prospect, were dug before 1930 as a possible commercial source of baryte. The limited baryte content of the outcrops discouraged further exploration and the site was abandoned. The mineralogy of the metasedimentary rocks exposed along the north ridge of Chickencoop Canyon consists of a series of barium minerals which formed during metamorphism of the enclosed sediments at depth. Veins of sanbornite are scattered in the area and host minerals such as fresnoite, titantaramellite, witherite, cerchiarait-(Al), baryte, benitoite, celsian and bazirite. Conspicuously absent from the mineral suite are gillespite and pellyite. A full description of the area including notable minerals is given by Walstrom and Dunning, (2003).

This small deposit lies near the eastern edge of an elongated body of metasedimentary Paleozoic rocks (Bateman and Wahrhaftig, 1966). These host rocks, composed of mica schist and impure quartzites, are part of a roof pendant that has a north-south trend and is surrounded by granodiorite and quartz diorite. The barium minerals occur in a zone composed of quartzite which strikes north-northwest, is about 300 to 500 meters long and less than 2 meters in thickness.

A coarse stratification, parallel to the relict bedding and foliation in the surrounding metasediments, is present in the sanbornite-quartz bed. The lineament of the sanbornite mineralization occurs a little east of center and occupies the southern one-third of the roof pendant.



Figure 3. Locality map for the Baumann Prospect, Chickencoop Canyon, Tulare County.



Figure 4. View north showing the small outcrop along the wollastonite-zoisite rib where ekanite was discovered (after Walstrom and Dunning, 2003).

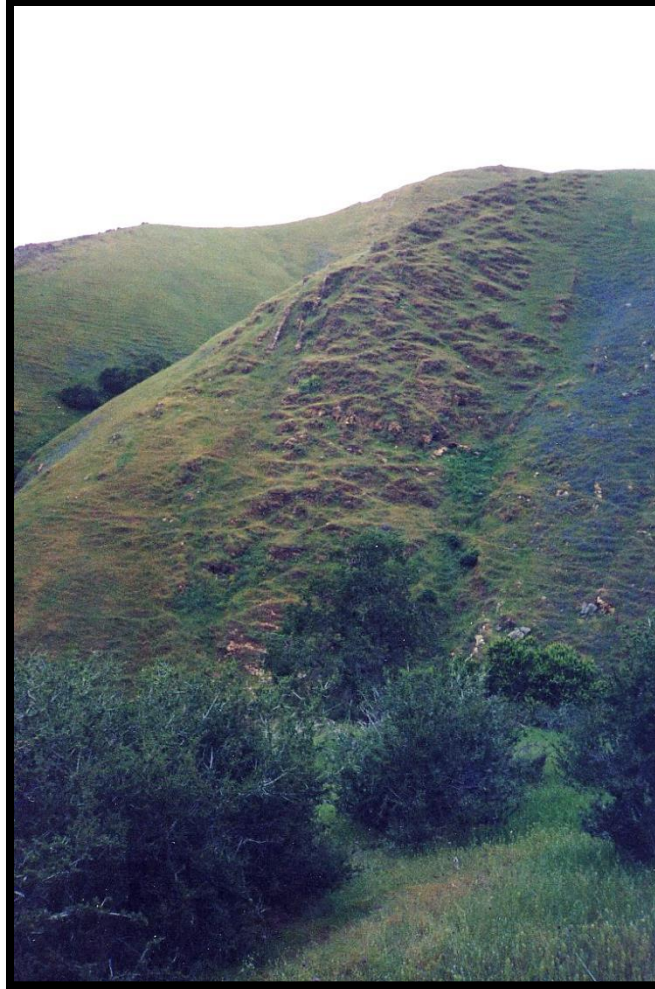


Figure 5. General view north showing bedding on the southern portions of the roof pendant. Site No. 1 is located in the more soil-covered area to left of center. Site No. 2 crops out in the center of the exposed bedding area which runs up the hillside (after Walstrom and Dunning, 2003).



Figure 6. View of outcrop of sanbornite-quartz rock at Site No. 2, showing thinly laminated, broken, fresh and weathered surfaces. Bedding quartzite can be seen at the right margin which encloses the barium mineralization (after Walstrom and Dunning, 2003).

The Big Creek-Rush Creek Barium Silicate Deposits.

The Big Creek-Rush Creek barium silicate deposits represent one of the most diverse and interesting area for rare and unusual barium silicate minerals. A new source for sanbornite was discovered in 1957 by a Mr. Landers after its identification had been made by the California Division of Mines from samples collected at Trumbull Peak, Mariposa County (Rogers, 1932). Also, this sample contained the rare barium-iron silicate gillespite. Mr. Landers could not be located to ascertain the exact locality of this discovery, so a diligent field search was undertaken by one of the authors (REW) to determine the source of the sanbornite sample.

Late in 1961, the source of sanbornite with associated gillespite was located that had been first discovered by M. Landers of North Fork, California. Further prospecting of the general area revealed eight additional outcroppings of sanbornite-bearing rock in the vicinity. Soon after the discovery of sanbornite in the area, small quantities of several unidentified minerals were discovered in debris from the new forest service road construction along Big Creek. This identification of seven new and rare barium silicate minerals (Alfors et al., 1965) initiated a deeper search of the existing outcrops of sanbornite in the surrounding area. In the subsequent years, additional new minerals were discovered and added to the existing literature. A complete history of the barium minerals of the Fresno County sanbornite deposits is given by Walstrom and Leising (2005).

At the Big Creek and Rush Creek sites, 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. 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.

Variable small amounts of calcite and iron sulfides (pyrrhotite and pyrite) are present in the sanbornite-bearing rock, with minor galena, sphalerite and chalcopyrite.

Esquire #7 claim, Big Creek, Fresno County, California (36° 55' N, 119° 14' 42" W).

This claim consists of rock removed from the west bank of Big Creek during the relocation and construction of the new forest service road along Big Creek. Blasting of the metamorphosed sedimentary rock exposed a series of new and rare minerals including fresnoite, muirite, verplanckite, walstromite, bigcreekite, bazirite, ferroericssonite, cerchiaraita-(Fe), devitoite, macdonaldite, anandite, fencooperite, kampfite, gillespite, and benitoite.

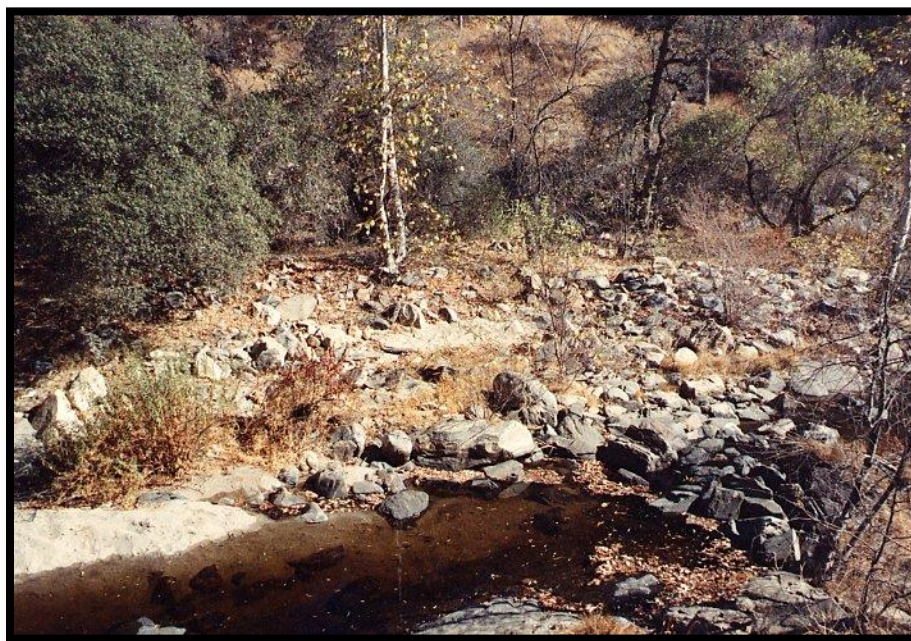


Figure 7. View across Big Creek on the Esquire #7 claim where much of the explosive rock landed during the construction of the new road. Good samples of cerchiaraita-(Fe) were recovered on the far shore area in quartz-sanbornite rock.



Figure 7a. View along Big Creek at the Esquire #7 claim during a mineral collecting trip. Fen Cooper (right center, sitting) watching and directing over the collecting effort.

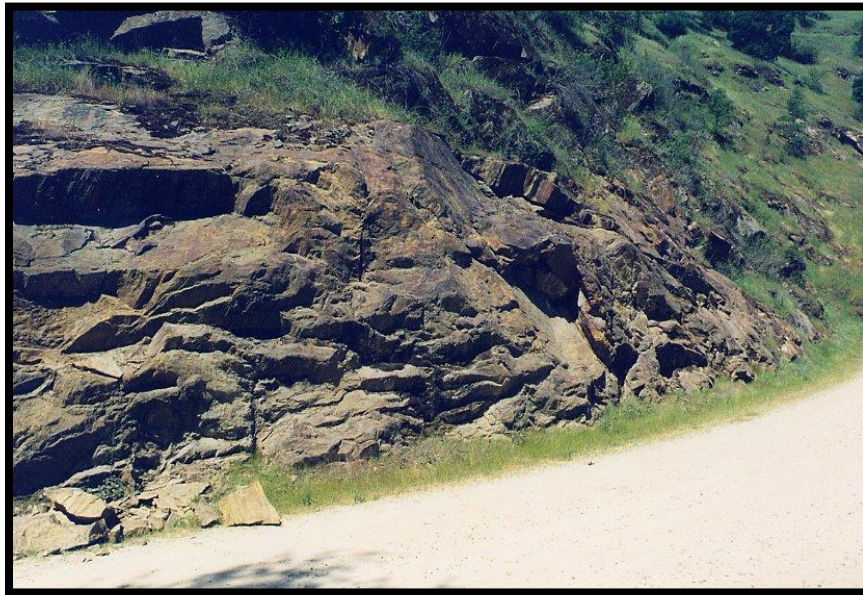


Figure 8. View of the metasedimentary rock of the west end road cut showing the Esquire #7 claim where many of the rare barium silicates were discovered. Samples containing muirite and verplanckite were recovered along the foot of the wall in the ditch.



Figure 9. Another view of the road cut (Esquire #7 claim) where many of the rare barium silicates were discovered.

Esquire #8 claim, Big Creek, Fresno County, California (36° 55' N, 119° 14' 44" W).

The Esquire #8 claim, originally known as Lander's gillespite locality, is located about ¼ mile up the Big Creek road from the Esquire #7 claim. The Ba-silicates are confined to a nearly vertical, foliated vein-like sanbornite body about 1m thick. Banding of the minerals is evident with thin veins of pellyite, celsian containing bazirite, anandite, edingtonite, gillespite, quartz, titantaramellite, walstromite, devitoite, ferroericssonite, and cerchiarait-(Fe).



Figure 10. View up the small ravine where the Esquire #8 claim is located just to the right and up the slope. The original Big Creek forest service road is located up the ravine several hundred feet and curves around just above the vertical vein containing the barium silicates.



Figure 11. View of the vertical barium-containing quartz-sanbornite vein of the Esquire #8 claim where many of the rare barium silicates were discovered. The vein extends up the hill and crosses the old forest service road where excellent dark blue cerchiaraitite-(Fe) occurs.

Esquire #1 claim, Rush Creek, Fresno County, California (36° 55' N, 119° 14' 44" W).

The Esquire #1 claim consists of two rock outcrops along the hillside facing Rush Creek to the west. Sanbornite-rich veins up to 30 cm thick occur against a quartz margin. The sanbornite is quite pure except along the quartz margin where associated minerals occur including titantaramellite, traskite, pyrrhotite, kampfite, cerchiaraitite-(Al), fresnoite, esquireite and macdonaldite. A short distance along the hillside is a meter-sized outcrop that contains a mixture of sanbornite and quartz. Veined in this rock is krauskopfite associated with macdonaldite, both of which are low temperature hydrothermal post sanbornite-quartz mineralization.



Figure 12. View of the single sanbornite rock (center) hosting both macdonaldite and krauskopfite along fracture seams, part of the Esquire #1 claim.



Figure 13. View of the sanbornite vein (Esquire #1 claim) where nearly pure sanbornite (white rock in back-center) is located. Associated rare barium silicate minerals are in a quartz-sanbornite rock just to left center.



Figure 14. View of the nearly pure sanbornite vein (Esquire #1 claim) where many of the rare barium silicate minerals were discovered.

Snow Cap mine, Rush Creek, Fresno County, California (36° 54' N, 119° 14' 44" W).

The Snow Cap mine consists of a short adit driven into a quartz-sanbornite vein just a few meters above Rush Creek. Minerals found here include bazirite, fresnoite, gillespite, krauskopfite, macdonaldite, cerchiarait-(Al), pyrrhotite, quartz, sanbornite and walstromite.



Figure 15. View of several sanbornite-quartz boulders at the Snow Cap mine. Ted Hadley (feet) with sledge hammer after working on large rock.



Figure 16. View of the Snow Cap mine (adit) just above Rush Creek containing sanbornite-quartz vein. Ted Hadley with sledge hammer.

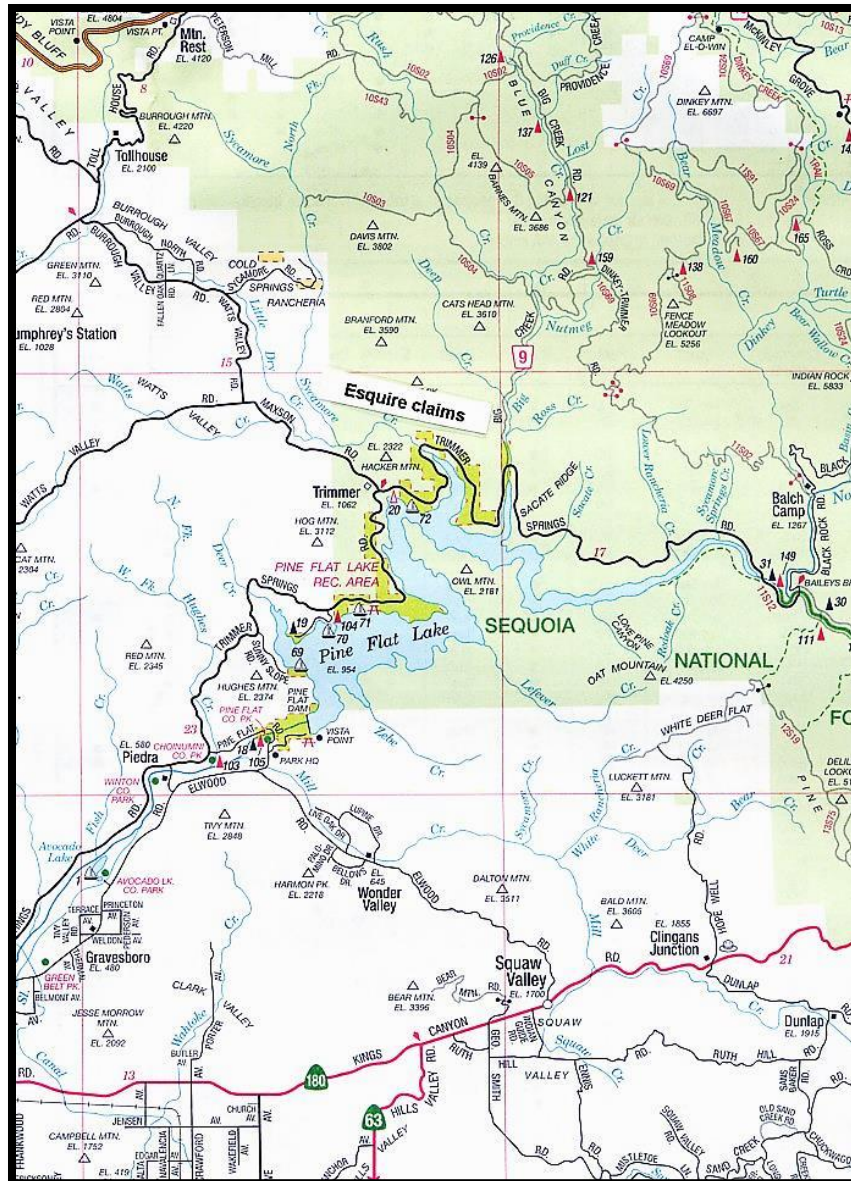


Figure 17. Locality map for the Big Creek and Rush Creek claims, eastern Fresno County.

Trumbull Peak, Mariposa County, California (37° 40' 58" N, 119° 47' 08" W).

The Trumbull Peak barium silicate site is located on the western steep face and consists of three elongated lenses that contain a mixture of sanbornite (TL), gillespite, titantaramellite, benitoite, bigcreekite, fencooperite (TL), alforsite, fresnoite, devitoite, walstromite, kinoshitalite, krauskopfite, cerchiarite-(Fe), ferroericssonite, sanbornite and other associated minerals including diopside, fluorapatite, pyrrhotite, quartz, schorl and vesuvianite. A complete description of the Trumbull Peak locality is given by Dunning and Cooper, (1999).

Trumbull Peak is located within a region known as the Western Metamorphic Belt of the Sierra Nevada range, a strongly asymmetric mountain range with a long-gentle western slope and a high, steep eastern escarpment. The rugged peaks and surrounding ridges west of Incline are composed of Paleozoic metasedimentary rocks, principally quartzite and hornfels. The age of

the sediments is not known more precisely than Paleozoic, and the granite composing the Sierra Nevada Batholith several kilometers to the east is supposedly late Jurassic. The sedimentary beds are isoclinally folded and have suffered a low-grade dynamic metamorphism.

Along the northwestern slope of Trumbull Peak several lenses occur, each less than a meter long, which are rich in barium silicates and are surrounded by a hard, dense quartzite. A narrow alpine dike, less than a meter wide, occurs about 50 meters away from the largest lens but according to Alfors and Pabst (1984), appears to have no connection with the barium silicate lenses.

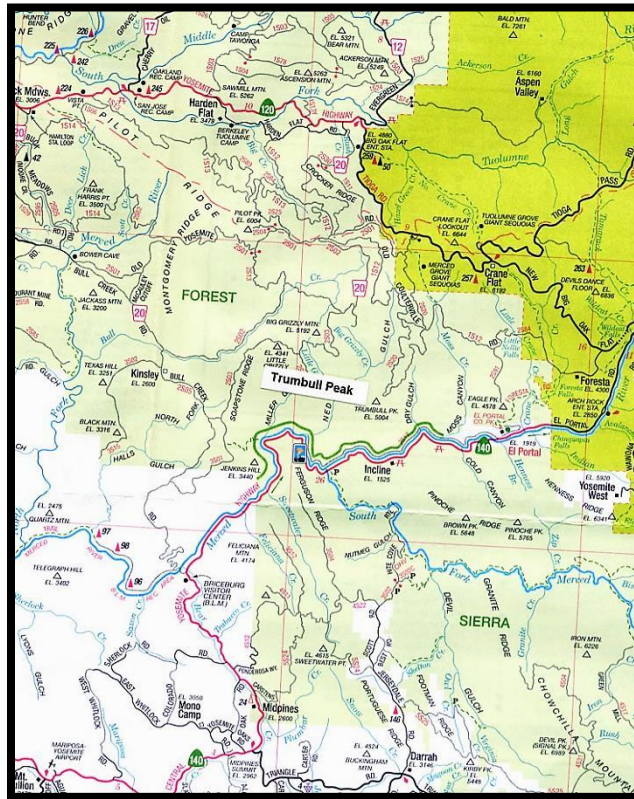


Figure 18. Locality map for the Trumbull Peak barium silicate site, above incline, Mariposa County.



Figure 19. View of the second lens (center-right) hosting many of the barium silicate minerals. The steep slope of the site is shown in the upper part of the photo. A long rope was used to help ascend back up the rocky slope.



Figure 20. View down the steep slope of Trumbull Peak from the Lens above showing the surrounding mountain ranges and deep canyons. White rock fragments down the slope was clue to the source of one lens. We followed the debris up the hill to a locality in the brush to find the lens.

The Southern Diablo Range Group:

The Ba-silicate occurrences identified in the New Idria serpentinite complex (Dallas Gem mine, Victor claim, Mina Numero Uno, Unnamed banalsite occurrence, and Junnila mine) are related to the metamorphism of Franciscan blocks into a hard, compact blue-schist. The single occurrence of benitoite found in the Lost Hills oil field may be related but little is known about the occurrence. Although somewhat removed in distance from the New Idria complex, the isolated occurrence in Franciscan rocks of cymrite along a road cut near Pacheco Pass is included within this group. Pabst (1977) gives an account of some especially dense, hydrous Ca- and Ba-silicates in the Franciscan Formation.

Dallas Gem mine (California State Gem Mine), New Idria District, San Benito County, California (36° 20' 16" N, 120° 36' 19" W).

This famous locality is located near the headwaters of the San Benito River and is noted for the gem-quality mineral benitoite. The locality also hosts several additional rare barium minerals including joaquinite-(Ce), orthojoaquinite-(Ce), jonesite, banalsite, baotite, delindeite, fresnoite, barrio-orthojoaquinite and barioperovskite, which is included within tubes in a single crystal of benitoite associated with fresnoite. Associated minerals include analcime, albite, neptunite and natrolite.

These minerals occur as fracture fillings in a brecciated zone of metamorphosed greywacke and basalt (Franciscan), yielding greenstone and blue-schist that is contained within the serpentinite body. Laurs et al. (1997) describe benitoite from the Dallas Gem mine.

Wise and Gill (1977) and Wilson (2008) give an excellent historical account of the mining activities and mineralogy of this most famous gem mine which was discovered in 1907. The classic paper by George Lauderback (1909) described the three major minerals, benitoite, neptunite, and joaquinite, now joaquinite-(Ce).

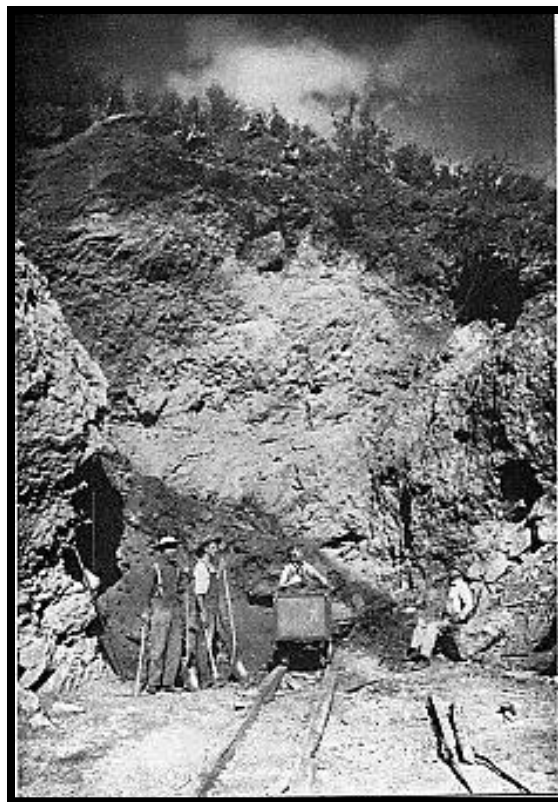
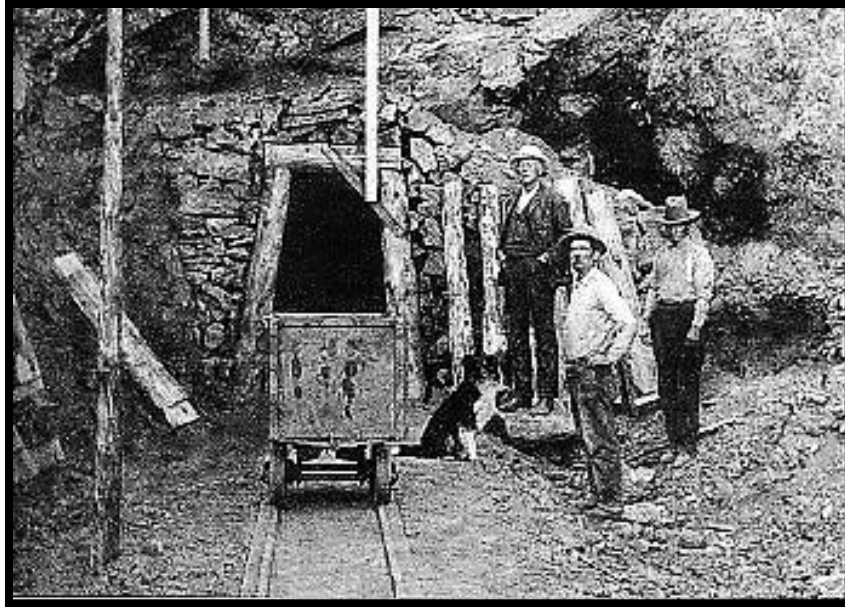


Figure 21. General view of the end of the open pit, Benitoite mine, August, 1908 (after Lauderback, 1909)



**Figure 22. View of the adit entrance to the Dallas Gem mine in 1908.
(Photo courtesy Collector's Edge Minerals)**



Figure 23. View showing the Dallas Gem mine in March, 1972 with extensive excavation. Cisneros photo, 1972.



Figure 24. The Dallas Gem mine area with a mineral collecting trip in progress.



Figure 25. The Dallas Gem mine during 2006 near the end of excavation and gem stone recovery (after Wilson, 2008).

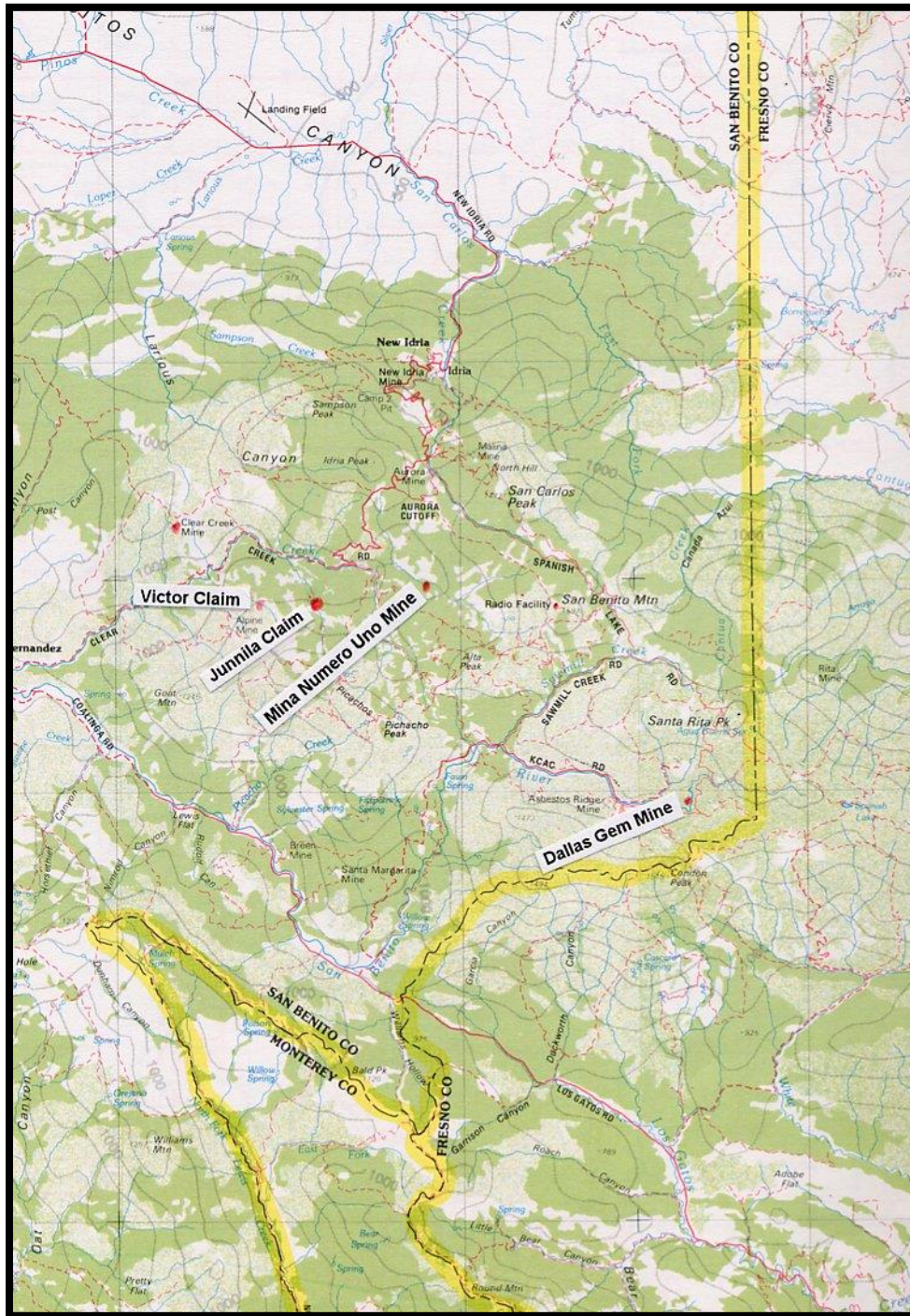


Figure 26. Locality map showing the four barium silicate sites within the New Idria serpentinite complex, San Benito County.

Mina Numero Uno, New Idria District, San Benito County, California (36° 24' N, 120° 40' 30" W).

This claim is located about 8 km northwest of the Dallas Gem mine and represents a small outcrop of 1 to 3 meter-sized rocks of greywacke and basalt (altered Franciscan surrounded by serpentinite) that have been metamorphosed yielding greenstone and blue-schist. Fracture fillings are composed of albite with small crystals of benitoite, joaquinite-(Ce)/orthojoaquinite-(Ce), neptunite and strontiojoaquinite. The general geology of this mine can be comparable to that of the Junnula mine, Victor claim, and the Dallas Gem mine.



Figure 27. Photo showing the large boulders of blue-schist containing thin veins hosting crystals of benitoite, neptunite, strontiojoaquinite and joaquinite-(Ce)/orthojoaquinite-(Ce) with minor albite. Cisneros photo, May, 1970.

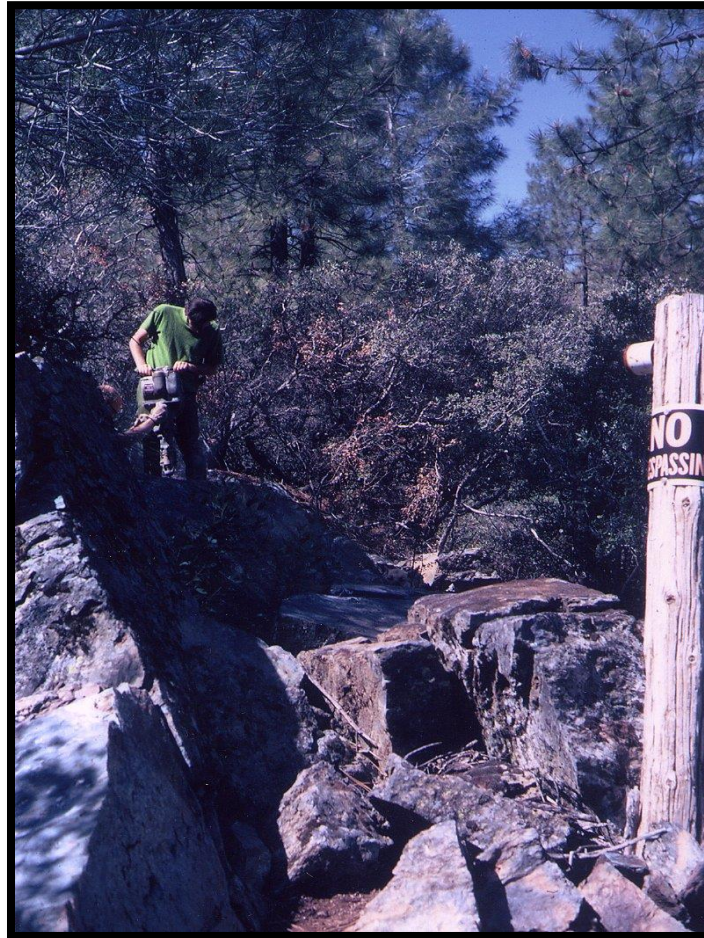


Figure 28. Site photo showing drilling blast holes in the very hard, compact blue-schist rock exposed on the hillside. Cisneros photo, March, 1972.

Unnamed banalsite occurrence, New Idria District, Santa Rita Peak, San Benito County, California (36° 20' N, 120° 36' W?).

Banalsite has been reported to occur at Santa Rita Peak, 1 mile north of the Dallas Gem mine (W.S. Wise, pers. comm., 1981). No information on this reported location has been recorded. Banalsite has also been recorded from the Dallas Gem mine in small amounts.

Junnila mine, New Idria District, San Benito County, California (36° 24' N, 120° 42' 15" W).

The Junnila mine is located west of the Dallas Gem mine and consists of the same outcrop type that is evident at the Mina Numero Uno and Dallas Gem mine. The general area of the Junnila mine is composed of varying grades of serpentinized basalts, contact-metamorphic bodies of Franciscan phyllites and schists (Kleine, 2018). A series of Ba-silicates were discovered here including benitoite, fresnoite, and strontiojoaquinite. The fresnoite crystals are exceptional for the mineral and are the best examples ever found.

Accessory minerals include albite, analcime, andradite, anthophyllite, calcite, copper, chrysocolla, covellite, djurleite, galena, natrolite, neptunite, pyrrhotite and quartz.



Figure 29. View of the Junnila mine, San Benito County in April, 2007 showing the extensive digging for fresnoite. Photo Courtesy of Jim Bean.

Victor claim, New Idria District, San Benito County, California (36° 22' N, 120° 42' 10" W).

The Victor claim is located along a narrow tributary of Clear Creek that cuts friable serpentinite. Large boulders of blue-schist rock derived from metavolcanics protrude through the serpentinite and contain fractures and cavities that host a series of Ba-silicates. These include fresnoite, Bario-orthojoaquinite, joaquinite-(Ce), orthojoaquinite-(Ce), strontiojoaquinite and titantaramellite. Associated minerals include neptunite, pectolite, stilpnomelane, albite, anilite, covellite, brochantite, pseudomalachite, strontio-apatite, fluorapatite and calcite. (Millage, 1981; Cooper, et al., 2006).

The New Idria serpentinite mass is the dominant geologic feature in the area and its emplacement produced the major tectonic forces that have shaped the area. This serpentinite body was emplaced as a result of the hydrothermal alteration of deep-seated mafic rocks and its subsequent volume change produced an upward movement through weaker sedimentary rocks of the Franciscan Formation (Jurassic). The southern margin of the serpentinite body is composed of a mixture of unaltered graywackes and sandstones, conglomerates and shales that have locally been metamorphosed into blue-schists and shales that contain intruded

serpentinite bodies. In the Victor claim area, the metamorphic action was not as intense as that which took place at the Dallas Gem mine, where a relatively pure crossite body was produced.

The blue-schist bodies have been fractured by localized faulting that runs perpendicular to the bedding direction. This fracturing has broken the schist bodies into blocks and has produced many smaller internal fractures. These fractures have acted as channel ways for the barium-rich hydrothermal fluids to enter and form the unusual suite of barium silicates.



Figure 30. View of the upper area of the Victor claim. Photo courtesy of Dan Evanich



Figure 31. Field collecting at the Victor claim, Clear Creek. David Lowe (yellow) and Ted Hadley (red). Photo courtesy of Dan Evanich



**Figure 32. View of the Victor claim showing the area where the neptunite crystals were discovered.
Photo courtesy of Dan Evanich.**

Drill hole in the Lazard area, Lost Hills oil fields, Kern County, California (35° 37' N, 119° 41' W).

Benitoite occurs as detrital grains in heavy mineral fractions associated with piemontite, dumortierite and other minerals from a drill hole in the Lazard area, Lost Hills oil fields (Reed and Bailey, 1927). The underlying sediments consist of Al-rich metamorphosed rocks of the greenschist to amphibolite facies. This locality is just east of the New Idria district and the underlying rock types may have a relation to the altered Franciscan strata (Jurassic). No further information was found on this occurrence of benitoite.

Pacheco Pass road cut, Santa Clara County, California (37° 03' N, 120° 24' 30" W).

In 1967, Essene identified cymrite from a jadeite metagraywacke contact with ultramafic rock (serpentinite) about three miles west of the Pacheco Pass summit on the west side in Santa Clara County. The metagraywacke is bleached and desilicated at the contact, and is veined through with calcite, albite, lawsonite, and more rarely cymrite-containing veins. Veinlets of cymrite-lawsonite may be found, although the coarsely disseminated cymrite shows no signs of reaction. Essene (1967) suggests that the albite-cymrite assemblage in the silica-deficient high-pressure Franciscan rocks compared to the quartz-cymrite assemblage in the lower-pressure greenschist facies of Alaskan rocks, that the albite-cymrite assemblage is stable to higher pressures than quartz-cymrite. Hermes (1973) gives an account of the paragenetic relationships in an amphibolitic tectonic block in the Franciscan terrain, Pacheco Pass, California.

The Coast Range Group:

The Coast Range Group consists of three isolated and geomorphologically distinct Ba-silicate sites located near the Pacific Ocean within the Coast Range. These are the Pacific Coast Limestone Products quarry (Kalkar) located within the city limits of Santa Cruz, California (south site), Coyote Peak, an isolated igneous intrusion (diatreme) just east of the small town of Orick, Humboldt County, California (north site) and the isolated Ash Creek edingtonite locality, a tributary of the Russian River, just north of Cloverdale, Mendocino County. There are no common Ba-silicates between these three sites.

The Coast Range-South Site.

Pacific Coast Limestone Products Quarry (Kalkar), Santa Cruz, Santa Cruz County, California (36° 58' N, 120° 02' W).

The Pacific Coast Limestone Products Quarry, locally known as the Kalkar quarry, represents a deposit hosting a unique assemblage of minerals. Locally, the Kalkar quarry explores a poorly bedded recrystallized limestone containing lens-like strata of calc-silicate rocks which belong to the Sur Series of pre-Cretaceous age (Finch (1931). Lenticular, interbedded layers of calc-silicate rock are most conspicuous in the southwestern part of the quarry where their thickness ranges from about 2 m to 10 m.

Faulting is apparent in the limestone body and exposed in the northern area where intersecting faults are evident. At the junction of these faults the rocks contain a mixture of tremolite and quartz with fine-grained limestone. Ba-silicate minerals identified from the contact zone of two intersecting faults in the recrystallized siliceous limestone include pabstite, celsian and exceptional titanaramellite associated with various silicates, sulfides and sulfosalts, carbonates, sulfates, arsenates, and oxides. Dunning and Cooper (1986) give a comprehensive description of the quarry and its mineralogy.

Gross et al. (1967) have concluded, based on limited evidence from polished section and field relationships, that an overlapping sequence of sulfide formation occurred with molybdenite, cobaltian loellingite and gersdorffite forming earliest at temperature possible above 600° C. Later, arsenopyrite, chalcopyrite, pyrrhotite, pyrite and sphalerite formed, perhaps below 555° C. The sulfosalts formed last at temperatures below 400° C.

The Kalkar quarry differs from other limestone quarries in the Santa Cruz vicinity in the amount and type of impurities in the original sediments and in the degree of metasomatic action that occurred along the transverse faults. These Sur Series limestones generally contain large amounts of silica and iron. Metamorphism by a nearby plutonic body is believed to have formed the forsterite-diopside-phlogopite assemblage and the tremolite-actinolite facies. It is thought that some of the elements were in the existing sediments, most notably Ba, Fe, Zn and Ti, while others, such as Sn, Pb, Sb, As, Mo, Co and Ni were introduced during the metasomatic alteration event. The three barium silicates, pabstite, celsian and titanaramellite, are considered the results of the metasomatic event along the fault zones. Talliaferro (1943) gives an account of the geologic history and structure of the central Coast Ranges of California. Leo (1967) describes the plutonic and metamorphic rocks of the area.



Figure 33. Map showing the location of the quarry within the Santa Cruz city limits boarding the University of California Santa Cruz campus.



Figure 34. Aerial view of Kalkar quarry, Santa Cruz, California. The part of the quarry to the left center was the source of much of the sulfosalts and barium silicates. G. Dunning photo, F. Cooper pilot.



Figure 35. View of the Kalkar quarry during quarry operations removing blocks of limestone for processing.



Figure 36. The view of Kalkar quarry as it is today with housing in the area and park benches and overgrown vegetation.

The Coast Range-North Sites.

Coyote Peak, Bald Hills, Orick, Humboldt County, California (41° 07' 30" N, 124° 10" W).

The alkaline ultramafic diatreme, locally known as Coyote Peak, covers an area of about 260 x 500 meters. Morgan et al. (1985) give an account of the origin and evolution of the alkali ultramafic rocks in the Coyote Peak diatreme. This diatreme penetrates a lithic-wacke sandstone sequence of the Franciscan assemblage (Jurassic). Czamanske and Atkin (1985) described the remarkable history of metasomatism and crystal growth recorded in lithic-wacke fragments that were caught up in, and reacted with, their ultramafic host magma. Small fragments of wacke were totally recrystallized, whereas larger fragments display strong rim-to-core zonation. This isolated mafic alkalic diatreme hosts a variety of minerals, mostly unusually rare alkali copper sulfides. Silicate minerals identified from the diatreme include phlogopite, schorlomite, aegirine, sodalite, cancrinite, pectolite, natrolite, magnetite, several amphiboles and rarely calcite. Sulfides include erdite, orickite, coyoteite, bartonite, djerfisherite, and rasvumite. Very rare fresnoite and barytolamprophyllite occur in clots within the compact alkalic rock. These latter two represent the only Ba minerals thus far identified in the assemblage. Recent studies by Hawthorne et al. (1998) have dealt with the role of Ti in several of the amphiboles that occur there.

Czamanske and Atkin (1985) describe system at Coyote Peak as dynamic, and prograde mineral assemblages were typically "frozen" by reaction kinetics as temperatures fell quickly.

Ash Creek Edingtonite Locality, Mendocino County, California (38° 51' 21" N, 123° 0' 41" W).

Edingtonite was discovered in boulders along Ash Creek, a small tributary of the Russian River, Mendocino County. This zeolite formed as thin seams and veinlets in rocks of the Franciscan Formation at a relatively low temperature, probably less than 200°C. The majority of the edingtonite is massive but where the vein contains voids, minute crystals occur.

Rosenhahnite, a calcium silicate hydroxide, was discovered in boulders along the Russian River near where Ash Creek enters the Russian River. The complete description of this mineral is given by Pabst et al. (1967).

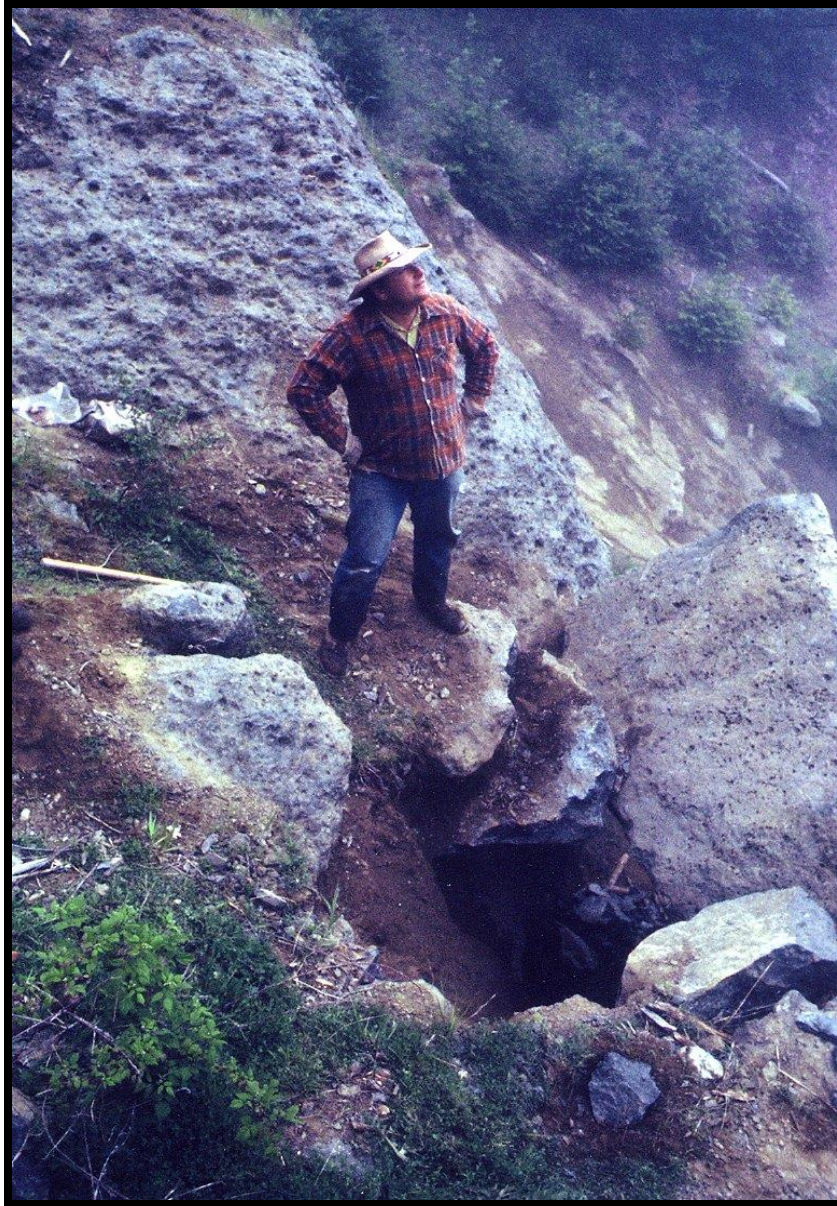


Figure 37. View of the working area of the Coyote Peak diatreme. Fen Cooper resting after a surge of rock hammering with a 12 pound sledge. This attests to the tenacity and size of the rock.



Figure 38. View of the collecting area at Coyote Peak in the fog with a high line to transport material up to the camp. In the foreground are our efforts to reduce a very resistance boulder to smaller sizes by the fresh, dark surfaces exposed. A tired Fen Cooper is seen in the upper right pounding on some hard, unforgiving rock looking for erdite and other phases.



Figure 39. Distant view of Coyote Peak (highest point). The collecting area is to the right center along the western slope of the diatrema.



Figure 40. Map showing the location of Coyote Peak, Humboldt County.

The Northern Group-South Sites.

The Northern Group consists of two distinct geographic localities, the south sites, which are centered in southern Alaska and western British Columbia, and the north sites, located in the Yukon Territory, Canada. The south sites include: Dry Delta, Alaska Range, Greens Creek deposit, Admiralty Island, the Ice River area, and the Galena Prospects. The north sites include Birr claim, the Gun claim and Tom deposit, Wilson Lake mining district, Itsi Mountains, Yukon Territory, Canada.

Greens Creek Mine, Admiralty Island, Skagway-Yakutat-Angoon Borough, Alaska (57° 32' N, 134° 15' W).

The Greens Creek mine is a large massive sulfide deposit (Kuroko Model) consisting of silver-gold-zinc-lead-bearing minerals. This deposit occurs discontinuously along the contact between a structural hanging wall of thinly laminated, quartz-mica-argillie clasts in pyritic massive sulfide ore which are of Late Triassic age (Taylor and Johnson, 2010; Crafford, 1989). The most common sulfides consist of pyrite, sphalerite and galena. The least abundant ore minerals include chalcopyrite, tetrahedrite, freibergite, proustite, and electrum. Very high precious metal values are common in base-metal-rich massive sulfides near the stratigraphic hanging wall contact which include gold.

Barium-bearing minerals identified in the ore include baryte and celsian.

Wigwam Deposit, Akolkolex River area, British Columbia, Canada (50° 30' N, 117° 02' W).

The Wigwam deposit is a metamorphosed Mississippi Valley-type base-metal deposit located in the Akolkolex River area southeast of Revelstoke, British Columbia, Canada. This area is positioned along the transition between the Shuswap metamorphic complex and the Selkirk Mountain fold and thrust belt. It is described by Thompson (1972, 1978) as a structurally complex package of metasediments of Cambrian or Ordovician age. Muraro (1966) describes the metamorphism of the zinc-lead deposits. The Wigwam deposit is contained within the Badshot Formation, which is associated with other occurrences of lead-zinc mineralization locally and throughout the Kootenay Arc (Thompson, 1978; Höy, 1982). The mineralization of the Wigwam deposit, as well as minor mineralization in other parts of the area, is associated with hinge zones of structural folds. The fact that the sulfide layers themselves are folded, and the dominance of pyrrhotite over pyrite, have been taken as indicating that the mineralization pre-dated regional metamorphism and folding (Muraro, 1966; Thompson, 1978).

The three new V-Ba-Si oxide phases, zoltaiite (Bartholomew et al. 2005), greenwoodite (Bartholomew et al. 2012) and batisivite (Armbruster et al., 2008), all occur as fine grains disseminated with quartz, apatite, sphalerite, pyrrhotite and galena. They are best observed in polished sections where their relationships to the surrounding sulfides can be observed.

Unnamed Occurrences (ARDS-EA075, 076) (O'Brien Creek area), Fortymile District, Southeast Fairbanks Borough, Alaska (64° 30' N, 142° 03' W).

These occurrences are located along the Taylor Highway and O'Brien Creek, about 0.8 miles south of the mouth of Columbia Creek. Rocks are predominantly Paleozoic greenschists-facies and black carbonaceous quartzite. Sulfides occur within buff-colored celsian-bearing quartzite. Sulfides include sphalerite, pyrite, galena and chalcopyrite. These occurrences are interpreted to be a sedimentary-exhalative massive sulfide deposit (Dusel-Bacon et al., 1998).

Dry Delta, Yukon-Koyukuk Borough, Alaska Range, Alaska (62° 35' N, 153° 05' W).

This is the type locality for gillespite that was first described by Schaller (1922) from a rock specimen collected by Frank Gillespie from a glacial moraine near the head of Dry Delta, Alaska Range, Alaska. Associated minerals include celsian, hedenbergite and quartz. Based on the minerals identified from the sample, it would seem probable that the source would have been from metamorphosed ferruginous siliceous sediments or contact metamorphic rocks located beneath and along the glacier path. Regional mapping lists the area as Paleozoic-Silurian age. The area is covered by Geological Survey of Canada Map 2159A (Harrison et al., 2011).

Galena Prospect, Nome District, Nome Borough, Alaska (64° 43' 48" N, 165° 49' 10" W).

The Galena prospect is located on the ridge crest along the west side of Washington Creek, an east tributary to Sinuk River. The property consists of nine claims which explore iron oxides. However, a joint-controlled galena-quartz mineralization in crystalline limestone was present on the Sunrise claim; disseminated sphalerite with pyrite and fluorite was present on the Oso claim. The development model consists of iron oxide and some quartz-sulfide veins and replacements in marble and schist with minor silver and gold. Celsian was noted in the mineralized veins but no amount or descriptions were recorded. The barium source is considered a constituent of local sediments. Geology is Paleozoic metasediments, mostly dolomite, graphitic rocks and schists. Area references include: Herreid (1970); Mulligan and Hess (1965); Slack et al. (2014).

Ice River Complex, Golden Mining Division, British Columbia, Canada (51° 10' N, 116° 25' W).

The Ice River alkaline intrusive complex consists of a suite of ijolites, syenites, carbonatites and late-stage pegmatites (Currie 1975). This complex was emplaced into sedimentary rocks of Cambrian and lower Ordovician age. During the mid-Mesozoic, the sedimentary rocks were intensely folded and faulted, but the igneous rocks remained relatively unaltered. Edingtonite occurs in isolated zeolite- and carbonate-rich pockets in nepheline syenite. It is a late-stage mineral. Also occurring in the complex are the barium minerals, banalsite, baryte, barytocalcite with the edingtonite. Rarely occurring are ancylite, catapleiite, acmite, pyrite and galena (Grice and Gault, 1981; Grice et al., 1984). There are 75 reported minerals from this area (Mindat.org).

The Northern Group-North Sites.

The Gun claim, Macmillan Pass area, Watson Lake Mining District, Itsi Mountains, Yukon Territory, Canada (62° 50'50" N, 130° 0' 51" W).

The Gun claim explores a contact metasomatic Ba-rich skarn deposit adjacent to a porphyritic quartz monzonite stock (McNeil et al. 2013). The Ba-silicate minerals occur as a massive crystalline constituent of skarns that have developed in original limestone bodies adjacent to the igneous contact. A pale green sample of fresnoite from this locality showed significant levels of V in an analysis (A. Christy, p.c. 2009).

Ba-silicate minerals identified from this small claim include gillespite, sanbornite, cerchiaraitite-(Fe), cerchiaraitite-(Al), edingtonite, ferrokinoshitalite, suzukiite, walstromite, taramellite, titantaramellite, fresnoite, pellyite, celsian, bavsiiite, itsiite, meierite and muirite. Other minerals reported in the deposit include baryte, hedenbergite, quartz, andradite, chalcopyrite and witherite. Montgomery (1960) and Thompson and Montgomery (1960) give a study of barium minerals from the Yukon Territory. Bojar and Walter (2014) describe the new mineral bavsiiite.

This is the type locality for pellyite named because for its proximity to the headwaters of the Pelly River (Montgomery et al., 1972).



Figure 41. Distance view of the Gun barium silicate claim at the arrow, just to the left of the unnamed lake.



Figure 42. Helicopter making a landing at the Gun claim. This is the best

way to reach this remote site.



Figure 43. View of the Gun claim just to the right of the lake.

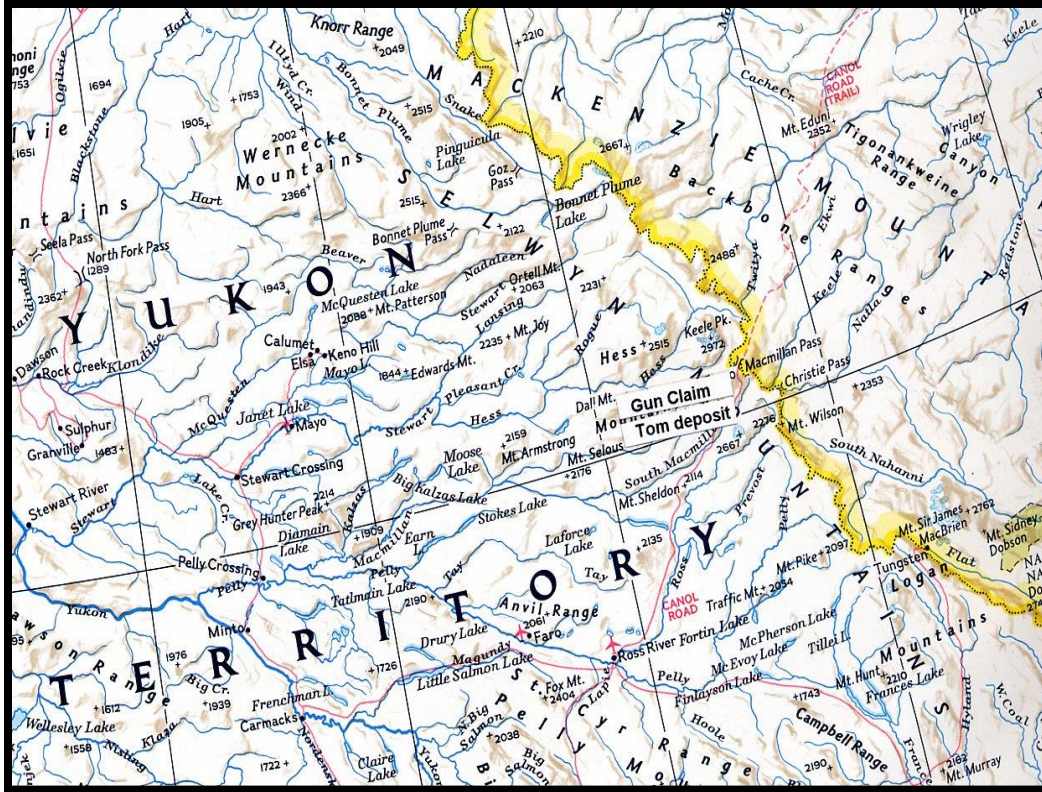


Figure 44. Map of the Yukon Territory showing the location of the Gun Claim, Tom Deposit.

The Birr claim, Macmillan Pass area, Watson Lake Mining District, Itsi Mountains, Yukon Territory, Canada (62° N, 130° W?).

The Birr claim is located about 2 km southeast of the Gun claim and hosts a Cu skarn consisting of pyrrhotite, chalcopyrite, and gillespite developed in Ordovician-Devonian sedimentary rocks at the margin of the quartz monzonite stock. Baryte veins have also been found near the intrusive contact.

Tom deposit, Macmillan Pass area, Watson Lake Mining District, Itsi Mountains, Yukon Territory, Canada (63° 10' N, 130° 12' W).

The Tom deposit explores a small sulfide mineralization consisting of sphalerite, pyrrhotite, pyrite, galena, marcasite and arsenopyrite in a Paleozoic sedimentary setting of Late Devonian-age rocks (Ansdell et al., 1989). The deposit is close to the Gun claim and shares a similar geological setting. Barium mineralization of the sedimentary rocks include baryte, barytocalcite, celsian, cymrite and witherite. The mineral assemblages and paragenesis suggest that early mineral deposition occurred in a sulfur-deficient environment. The temperature of the mineralizing fluids may have been less than 150°C.

The Arctic (Brooks Range) Group:

The Arctic Group consists of a group of claims situated along the southern slope of the Brooks Range. This group of base metal claims has shown significant levels of gold, silver, zinc and lead. No formal mining has been done since the exploratory work was done in the 1970s.

BTcc Prospects, Shungnak District, Northwest Arctic Borough, Brooks Range, Alaska (67° 06' 35" N, 155° 51' 36" W).

This site represents several prospects in a 6-square-mile area about 5 miles northwest of the Mauneluk River. These prospects explore silver-base metal volcanogenic massive sulfide deposits in a sequence of low to medium grade, metamorphosed basaltic and rhyolitic rocks, submarine ash flow tuffs, and pelitic and carbonaceous sedimentary rocks known as the Ambler schist belt. The deposits are Devonian or Mississippian based on fossil evidence and U-Pb radiometric dating. The sulfide minerals consist of chalcopyrite, sphalerite and tennantite. Cymrite, the only Ba-silicate noted, occurs throughout the deposit as seams and isolated grains and was identified from the many drill cores made in the area. Area references include: Hitzman et al. (1986); Hitzman (1978); Grybeck and Nelson (1981) and Harrison et al. (2011).



Figure 45. Location map showing the location of the Bonanza Creek, Ruby Creek, Sun, and Btcc prospects. Brooks Range, Alaska.

Sun Prospect (Picnic Creek, Hot Prospects), Shungnak District, Northwest Arctic Borough, Brooks Range, Alaska (67° 04' 13" N, 155° 02' 34" W).

This site represents several prospects in an approximately 12-square-mile area northeast of Beaver Creek along the southern hills of the Brooks Range. The Sun deposit consists of stratiform, banded, massive to semi-massive sulfides in a series of elongate, southwest-plunging, lenticular bodies along three distinct mineral horizons. The age of the deposit is

Devonian or Mississippian based on radiometric and fossil determinations. Cymrite occurs as isolated seams and grains in the massive sulfides. These sulfides consist of sphalerite, galena, enargite, bornite and arsenopyrite with associated actinolite, baryte, dolomite and quartz. No other Ba-silicates were noted in the core drill samples. No locality or mineral photos were available.

Area references include: Zdepski (1980); Marrs (1978); Grybeck and Nelson (1981).

Ruby Creek Prospects, Shungnak District, Northwest Arctic Borough, Brooks Range, Alaska (67° 05' N, 157° 00' W).

Ruby Creek prospects near the small settlement of Bornite in the Cosmos Hills, Alaska is the site of several drill holes used to explore potential copper reserves. This area has also been listed as in the Ambler district, Yukon-Koyukuk Borough. An examination of the cores by Runnells (1964) revealed the presence of cymrite from near the surface to depths of several hundred feet. Runnells (1969) reports on the mineralogy and sulfur isotopes of the Ruby Creek copper prospect. The cymrite occurs as interlocking anhedral grains with dolomite in a carbonate host rock. The host rock was originally a normal dolomite of marine origin, but it is now mineralized and contains pyrite, chalcopyrite, bornite, chalcocite, sphalerite, galena together with cymrite (Bernstein and Cox, 1986). Cymrite was observed in contact with one or more of the following: dolomite, siderite, ankerite, pyrite, fluorite, quartz and chlorite. Bolotina et al. (2010) reports on the refinement of twinned cymrite from Ruby Creek. It has a twin law corresponding to a six fold axis for the first time. No locality or mineral photos were available.

Bonanza Creek prospects, Shungnak District, North Slope Borough, Brooks Range, Alaska (67° N, 158° W ?).

Cymrite was recognized in the south-central portion of the Brooks Range by Brosgé (1960) in samples collected from a pyritized zone near the head of Bonanza Creek. No other information is available on the site. From its close approximation to the above drill sites at Bornite, it is inferred that the local geological features are identical and are within the Ambler Schist Belt of Devonian or Mississippian age. No locality or mineral photos were available.

STUDY RESULTS:

Table 2. Comparison of mineral abundance (% ratio) and major elements versus locality groups.

MINERAL	RATIO/(%)	LOCALITY GROUP	MAJOR ELEMENTS
Cymrite	4/4 (100%)	A	Ba, Al, Si, O
Baryolamprophyllite	1/1 (100%)	CRN	Ba, Na, Ti, Si, O
Celsian	1/1 (100%)	CRS	Ba, Al, Si, O
Fresnoite	1/1 (100%)	CRN	Ba, Ti, Si, O
Pabstite	1/1 (100%)	CRS	Ba, Sn, Si, O
Titantaramellite	1/1 (100%)	CRS	Ba, Ti, B, Si, O, Cl
Banalsite	1/8 (12.5%)	N	Ba, Na, Al, Si, O
Bavsiite	1/8 (12.5%)	N	Ba, V, Si, O
Celsian	4/8 (50%)	N	Ba, Al, Si, O
Cerchiarait-(Al)	1/8 (12.5%)	N	Ba, Al, Si, O, Cl
Cerchiarait-(Fe)	1/8 (12.5%)	N	Ba, Fe, Si, O, Cl
Cymrite	3/8 (37.5%)	N	Ba, Al, Si, O
Edingtonite	1/8 (12.5%)	N	Ba, Al, Si, O

Ferrokinoshitalite	1/8 (12.5%)	N	Ba, Fe, Si, O
Fresnoite	1/8 (12.5%)	N	Ba, Ti, Si, O
Gillespite	2/8 (25%)	N	Ba, Fe, Si, O
Greenwoodite	1/8 (12.5%)	N	Ba, V, Fe, Si, O
Itsiite	1/8 (12.5%)	N	Ba, Ca, B, Si, O
Meienite	1/8 (12.5%)	N	Ba, Si, Al, O, Cl
Pellyite	1/8 (12.5%)	N	Ba, Ca, Fe, Si, O
Sanbornite	1/8 (12.5%)	N	Ba, Si, O
Suzukiite	1/8 (12.5%)	N	Ba, V, Si, O
Taramellite	1/8 (12.5%)	N	Ba, Fe, B, Si, O, Cl
Zoltaiite	1/8 (12.5%)	N	Ba, V, Si, O
Banalsite	1/6 (16.7%)	SDR	Ba, Na, Al, Si, O
Baotite	1/6 (16.7%)	SDR	Ba, Ti, Si, O, Cl
Bario-orthojoaquinite	2/6 (33.3%)	SDR	Ba, Sr, Fe, Ti, Si, O
Cymrite	1/6 (16.7%)	SDR	Ba, Al, Si, O
Fresnoite	3/6 (50%)	SDR	Ba, Ti, Si, O
Joaquinite-(Ce)	3/6 (50%)	SDR	Ba, Na, Ce, Fe, Ti, Si, O
Jonesite	1/6 (16.7%)	SDR	Ba, K, Ti, Si, O
Orthojoaquinite-(Ce)	2/6 (33.3%)	SDR	Ba, Na, Ce, Fe, Ti, Si, O
Strontiojoaquinite	3/6 (50%)	SDR	Ba, Sr, Na, Ti, Si, O
Titantaramellite	1/6 (16.7%)	SDR	Ba, Ti, B, Si, O, Cl
Anandite	4/8 (50%)	WMB	Ba, Fe, Si, O
Bazirite	5/8 (62.5%)	WMB	Ba, Zr, Si, O
Benitoite	5/8 (62.5%)	WMB	Ba, Ti, Si, O
Bigcreekite	2/8 (25%)	WMB	Ba, Si, O
Celsian	6/8 (75%)	WMB	Ba, Al, Si, O
Cerchiarait-(Al)	5/8 (62.5%)	WMB	Ba, Al, Si, O, Cl
Cerchiarait-(Fe)	4/8 (50%)	WMB	Ba, Fe, Si, O, Cl
Devitoite	3/8 (37.5%)	WMB	Ba, Fe, Si, O, P, C
Edingtonite	1/8 (12.5%)	WMB	Ba, Al, Si, O
Esquireite	1/8(12.5%)	WMB	Ba, Si, O
Fen cooperite	2/8 (25%)	WMB	Ba, Fe, Si, O, C, Cl
Ferroericssonite	3/8 (37.5%)	WMB	Ba, Fe, Si, O
Fresnoite	7/8 (87.5%)	WMB	Ba, Ti, Si, O
Gillespite	6/8 (75%)	WMB	Ba, Fe, Si, O
Kampfite	2/8 (25%)	WMB	Ba, Si, O, C, Cl
Kinoshitalite	2/8 (25%)	WMB	Ba, Mg, Al, Si, O
Krauskopfite	4/8 (50%)	WMB	Ba, Si, O
Macdonaldite	6/8 (75%)	WMB	Ba, Ca, Si, O
Muirite	1/8 (12.5%)	WMB	Ba, Ca, Mn, Ti, Si, O
Pellyite	3/8 (37.5%)	WMB	Ba, Ca, Fe, Si, O
Sanbornite	8/8 (100%)	WMB	Ba, Si, O
Taramellite	2/8 (25%)	WMB	Ba, Fe, B, Si, O, Cl
Titantaramellite	5/8 (62.5%)	WMB	Ba, Ti, B, Si, O, Cl
Traskite	3/8 (37.5%)	WMB	Ba, Ca, Fe, Mn, Ti, Si, O, Cl
Verplanckite	2/8 (25%)	WMB	Ba, Mn, Fe, Ti, Si, O, Cl

A = Arctic Group; CRN = Coast Range Group North; CRS = Coast Range Group South;
N = Northern Group; SDR = Southern Diablo Range Group; WMB = Western Metamorphic Belt Group.

Table 3. Comparison of percent abundance within the WMB group of barium silicate minerals. (Barium non-silicates are included for comparison)

WESTERN METAMORPHIC BELT GROUP MINERALS	RANKING
Sanbornite	100%
Fresnoite	87.5%
Gillespite, Celsian, Macdonaldite	75%
Bazirite, Benitoite, Cerchiarait-(Al), Titanaramellite	62.5%
Anandite, Cerchiarait-(Fe), Krauskopfite	50%
Devitoite, Ferroericssonite, Pellyite, Traskite	37.5%
Bigcreekite, Fencooperite, Kampfite, Kinoshitalite, Taramellite	25%
Edingtonite, Esquireite, Muirite	12.5%
Alforsite, Baryte, Witherite	n/a

Table 4. Comparison of percent abundance within the SDR group of barium silicate minerals. (Close associated non-Barium minerals include)

SOUTHERN DIABLO RANGE GROUP MINERALS	RANKING
Fresnoite, Strontiojoaquinite, Joaquinite-(Ce),	50%
Orthojoaquinite-(Ce), Bario-orthojoaquinite	33.3%
Baotite, Banalsite, Cymrite, Jonesite, Titanaramellite	16.7%
Neptunite, Natrolite	n/a

Table 5. Comparison of percent abundance of minerals within the CRG SOUTH

COAST RANGE GROUP MINERALS (SOUTH)	RANKING
Celsian, Pabstite, Titanaramellite	100%

Table 6. Comparison of percent abundance of minerals within the CRG NORTH

COAST RANGE GROUP MINERALS (NORTH)	RANKING
Barytolamprophyllite, Fresnoite, Edingtonite	100%

Table 7. Comparison of percent abundance of minerals within the NG

NORTHERN GROUP MINERALS	RANKING
Celsian	50%
Cymrite	37.5%
Gillespite	25%
Bavsiite, Banalsite, Cerchiarait-(Al), Cerchiarait-(Fe), Edingtonite, Ferrokinoshitalite, Fresnoite, Greenwoodite, Itsiite, Meinenite, Pellyite, Sanbornite, Suzukiite, Taramellite, Zoltaiite	12.5%
Alforsite, Baryte, Witherite, Barytocalcite	n/a

Table 8. Comparison of percent abundance of minerals within the AG

ARTIC (BROOKS RANGE) GROUP MINERALS	RANKING
Cymrite	100%

Table 9. Comparison of site groups with host rock, type of deposit, age and cations.

GROUP	HOST ROCK	TYPE OF DEPOSIT	AGE	ELEMENTS CATIONS
Arctic	Metasediments	Metamorphic	Paleozoic-Devonian or Mississippi	Ba,Al,Si
Northern-South Sites	Metasediments	Contact Metasomatic	Paleozoic-Ordovician-Devonian	Ba,Al,Fe,Ca,Ti, V,Ca,B
Northern-North Sites	Metasediments	Contact Metasomatic	Paleozoic-Mississippi-Valley	Ba,Al,Fe,Ca,Ti,B
Coast Range North Site	Mafic alkali intrusion	Contact Metasomatic	Mesozoic-Jurassic-Franciscan	Ba,Na,Ti,Si
Coast Range South Site	Recrystallized Limestone	Contact Metamorphic	Mesozoic-Pre-Cretaceous-Sur Series	Ba,Sn,Al,Si,B,Ti
Southern Diablo Range	Metamorphosed greywacke, blueschist	Metamorphic	Mesozoic-Jurassic-Franciscan	Ba,Na,Al,Si,Fe, Ti,Sr,Ce,B
Western Metamorphic Belt	Metasediments	Metamorphic	Mesozoic-Jurassic-Franciscan	Ba,Mn,Fe,Ti,Si,C, B,Mg,Al,Zr

Table 10. Approximate paragenetic timeline and formation temperatures for the barium silicates from Baja California Norte in the south to Alaska in the north with some associated minerals.

MINERAL	EARLY													LATE	
	1400°C	1300	1200	1100	1000	900	800	700	600	500	400	300	200	100	50°C
Anandite										X					
Banalsite			X?												
Baotite															X?
Barytolamprophyllite						X									
Bario-orthojoaquinite															X _{>95°C}
Batisivite										X>		<X			
Bavsiite												X			
Bazirite										X _{635°C}	X _{500°C}				
Benitoite										X _{600°C}		X _{300°C}			X _{>95°C}
Bigcreekite														X	
Celsian							X?								
Cerchiarait-(Al)								X							
Cerchiarait-(Fe)								X							
Cymrite										X					
Delindeite														X?	
Devitoite										X					
Edingtonite															X
Esquireite															X
Fencooperite						X									
Ferroericssonite											X				
Ferrokioshitalite										X					
Fresnoite											X _{450°C}	X _{300°C}			
Gillespite									X						
Greenwoodite											X>	<X			
Itsiite						X									
Joaquinite-(Ce)															X _{>95°C}
Orthojoaquinite-(Ce)															X _{>95°C}
Jonesite															X _{>95°C}
Kampfite							X								
Kinoshitalite											X				
Krauskopfite														X>	
Macdonaldite														X>	
Meierite										X?					
Muirite					X										
Pabstite									X _{680°C}			X _{430°C}			
Pellyite								X?							
Sanbornite									X _{600°C}			X _{400°C}			
Strontiojoaquinite															X _{>95°C}
Suzukiite					X?										
Taramellite						X									
Titantaramellite							X								
Traskite					X										
Verplanckite						X									
Walstromite									X _{670°C}			<X _{425°C}			
Zoltaiite										X>		<X			
Opal														X	
Witherite															X
Baryte		<X													
Pyrrhotite												X			
Neptunite															X _{>95°C}
Barioperovskite															X _{>95°C}
Quartz												<X>			

Temperatures in red from Wise and Gill (1977)

Temperature ranges in green from Hinthorne (1974)

Table 11. Paragenetic timeline for the Western Metamorphic Belt Group of Ba-silicates compared to the Gun claim, Yukon, Canada. (1) = Gun claim; (2) = WMB Ba-silicates

<u>MINERAL</u>	<u>EARLY</u>	<u>LATE</u>
Anandite ⁽²⁾		_____
Bavsiite ⁽¹⁾		_____
Bazirite ⁽²⁾	_____	
Benitoite ⁽²⁾		_____
Bigcreekite ⁽²⁾		_____
Celsian ⁽¹⁾⁽²⁾	_____	
Cerchiarait-(Al) ⁽¹⁾⁽²⁾		_____
Cerchiarait-(Fe) ⁽¹⁾⁽²⁾		_____
Devitoite ⁽²⁾		_____
Edingtonite ⁽¹⁾⁽²⁾		_____
Esquireite ⁽²⁾		_____
Fen Cooperite ⁽²⁾		_____
Ferroericssonite ⁽²⁾		_____
Ferrokinoshitalite ⁽¹⁾		_____
Fresnoite ⁽¹⁾⁽²⁾	_____	
Gillespite ⁽¹⁾⁽²⁾		_____
Itsiite ⁽¹⁾		_____
Kampfite ⁽²⁾		_____
Kinoshitalite ⁽²⁾		_____
Krauskopfite ⁽²⁾		_____
Macdonaldite ⁽²⁾		_____
Meierite ⁽¹⁾		_____
Muirite ⁽¹⁾⁽²⁾		_____
Pellyite ⁽¹⁾⁽²⁾		_____
Sanbornite ⁽¹⁾⁽²⁾		_____
Suzukiite ⁽¹⁾		_____
Taramellite ⁽¹⁾	_____	
Titantaramellite ⁽¹⁾⁽²⁾	_____	
Traskite ⁽²⁾	_____	
Verplanckite ⁽²⁾	_____	
Walstromite ⁽¹⁾⁽²⁾		_____
Alforsite ⁽²⁾		_____
Baryte ⁽¹⁾⁽²⁾	_____	
Witherite ⁽¹⁾⁽²⁾		_____
Pyrrhotite ⁽²⁾	_____	
Quartz ⁽¹⁾⁽²⁾		_____
Barian tobermorite ⁽²⁾		_____
Opal ⁽²⁾		_____

Table 12. Paragenetic timeline for the Southern Diablo Range Group. (1) = Dallas Gem mine; (2) = Mina Numero Uno; (3) = Victor claim; (4) = Junnila mine; (5) = Santa Rita Peak locality.

<u>MINERAL</u>	<u>EARLY</u>	<u>LATE</u> <u><100°C</u>
Banalsite ⁽⁵⁾	———?	
Baotite ⁽¹⁾		———
Bario-orthojoaquinite ⁽¹⁾		———
Benitoite ⁽¹⁾⁽²⁾⁽³⁾⁽⁴⁾		———
Delindeite ⁽¹⁾		———
Fresnoite ⁽¹⁾⁽³⁾⁽⁴⁾	——— ?	———
Joaquinite-(Ce) ⁽¹⁾⁽³⁾		———
Orthojoaquinite-(Ce) ⁽¹⁾⁽³⁾		———
Jonesite ⁽¹⁾		———
Strontiojoaquinite ⁽²⁾		———
Titantaramellite ⁽³⁾	———?	
Neptunite ⁽¹⁾⁽²⁾⁽³⁾⁽⁴⁾		———

Table 13. Paragenetic timeline for the Coast Range Group. (1) = Kalkar quarry, Santa Cruz County; (2) = Coyote Peak, Humboldt County; (3) Ash Creek, Mendocino County.

<u>MINERAL</u>	<u>EARLY</u>	<u>LATE</u>
Barytolamprophyllite ⁽²⁾	———?	
Celsian ⁽¹⁾		———
Edingtonite ⁽³⁾		———
Fresnoite ⁽²⁾	———?	
Pabstite ⁽¹⁾		———
Titantaramellite ⁽¹⁾		———

Table 14. Paragenetic timeline for the Northern Group-South Sites. (1) = Greens Creek mine; (2) = Wigwam Deposit; (3) Unnamed Occurrences; (4) Dry Delta; (5) = Galena Prospect; (6) Ice River.

<u>MINERAL</u>	<u>EARLY</u>	<u>LATE</u>
Banalsite ⁽⁶⁾		———
Baryte ⁽¹⁾⁽⁶⁾	———	
Barytocalcite ⁽⁶⁾		———
Batisivite ⁽²⁾		———
Celsian ⁽¹⁾⁽³⁾⁽⁴⁾⁽⁵⁾		———
Edingtonite ⁽⁶⁾		———
Gillespite ⁽⁴⁾		———
Greenwoodite ⁽²⁾		———
Zoltaiite ⁽²⁾		———

COMPARATIVE ANALYSIS:

Comparison of group barium silicate sites with known geological age:

Table 1 compares the known barium silicate localities along the western margin of North America with the geological ages determined for the host rocks. The Western Metamorphic Belt group of mineral occurrences show a consistency of geological age for the metamorphosed sediments that hosted the elements that, when combined under favorable conditions, resulted in the wide array of barium silicates identified. Basically, these barium silicates are the product of metamorphism of sediments during hydrothermal activity and pressure during the Mesozoic era of Late Cretaceous Period. In all cases, these sediments were influenced by plutonic rocks consisting of granodiorite and quartz monzonite.

The barium silicate bearing sites of the Southern Diablo Range, located within the confines of a massive serpentinite body of San Benito County, have a consistent geological history. The majority of the barium silicate minerals occurs as fracture fillings of brecciated zones of metamorphosed greywacke and basalts of the Franciscan Formation of Jurassic age (Mesozoic). Within this group of mineral sites, the elements Ba, Na, Al, Si, Fe, Ti, Sr, Ce, and B are evident.

The mineral assemblage of the Coast Range, South Site (Kalkar Quarry, Santa Cruz), is unique in mineralogy because the host rock, recrystallized limestone, host not only three barium silicates but a range of sulfides and sulfosalts. The local geology consists of bedded recrystallized limestone with calc-silicate rocks of the Sur Series, pre-Cretaceous (Mesozoic). Fault-induced-contact metamorphism is responsible for the minerals pabstite, titantaramellite and celsian. Elements, Ba, Sn, Al, Si, B, and Ti occur in the barium silicate minerals.

A general comparison of the Western Metamorphic Belt mineralogy shows a strong relationship to the mineralogy of the Gun claim, Itsi Mountains, Yukon Territory, Canada. The geological features of each group show very similar rock types and history. The total number of barium silicates noted in the WMB group is 26 when compared to those of the N group of 16. There are 8 minerals that are common to both localities which would suggest similar fluid composition and conditions (Eh, pH, temperature and pressure). Of the several localities in the Northern Group, one locality is favored with identical species, namely the Gun claim. These species include celsian, cerchiaraita-(Al), cerchiaraita-(Fe), fresnoite, gillespite, pellyite, sanbornite, and taramellite. Non-barium silicate minerals common to both groups, include alforsite, baryte, witherite, diopside, pyrite, quartz, and sphalerite.

Within specific groups, mineral abundance trends are evident. The Southern Diablo Range Group of mines illustrates this data. The Dallas Gem mine contains major benitoite and neptunite with minor joaquinite-(Ce)/orthojoaquinite-(Ce), jonesite and fresnoite. The Victor claim has major benitoite and neptunite with minor fresnoite and strontiojoaquinite. The Junnila mine has major fresnoite with minor strontiojoaquinite, neptunite and benitoite. Mina Numero Uno has major strontiojoaquinite with minor joaquinite-(Ce)/orthojoaquinite-(Ce), benitoite and neptunite. The single occurrence of banalsite near Santa Rita Peak does not relate to the above occurrences. It is well to note that this group of mines has the joaquinite family as a uniform thread mineral in addition to fresnoite. Neptunite also is evident across this zone.

Comparison of mineral abundance (% Ratio) and major elements versus Locality Group:

Table 2 is a comparison of the known barium silicates over the entire study area versus the percent ratio per each locality with the major elements present. For the Arctic Group, there are four mineral sites, all contain only one barium silicate, cymrite. This is consistent with the local geology and core mineralogy of a base metal locality.

The single site of the Coast Range Group-North (Coyote Peak) consists of only two barium silicates, fresnoite and baryolamprophyllite. These two silicates of barium are contained within the intruded mafic alkali diatreme (igneous plug) which intruded the surrounding Franciscan Formation (Jurassic). Fresnoite is unusual for this type of formation and no explanation is given for its occurrence in this environment.

The single site of the Coast Range Group-South (Kalkar Quarry) consists of three barium silicates, celsian, titantaramellite and pabstite. Again, this represents an unusual locality based on its closeness to the Pacific Ocean and removed from other barium silicate localities in the state. The sulfosalt and sulfide content of the calc-silicate rocks is unique for the area. Here, pabstite, the tin analogue of benitoite, occurs in close association with titantaramellite and celsian. Additional barium silicate minerals were expected but after many searches, none were found. The tin in the pabstite is presumed to have come from either stannite or franckeite during the fault-induced contact metamorphism of the limestone with the introduction of silica.

The Northern Group contains mineral sites both in Alaska, British Columbia, and the Yukon Territory. Of the 16 barium silicate minerals identified in this locality group, only celsian (4/8), cymrite (3/8) and gillespite (2/8) occur in multiple localities. The remainder of these minerals occur as single sites over the entire region. This attests to the degree of rareness in the region. Unusual in the field of barium silicates, vanadium plays an important role in four such minerals, bavsiiite, greenwoodite, suzukiite, and zoltaiite, three of which occur in intimate contact with fine-grained base metal sulfides. The majority of the remaining minerals occur at one claim, the Gun claim, in a contact metasomatic deposit within sedimentary rocks.

The Southern Diablo Range Group exhibits a wider range of barium silicate minerals, although somewhat lesser in content. This group of mines occurs in metamorphosed rocks of the greywacke and basalt type. Of the seven barium silicate occurrences in this group, two are outside the localized zone of consistent mineralization, the Kern County drill hole (benitoite) and the Santa Clara County Pacheco Pass (cymrite) road cut.

Comparison of percent abundance of barium silicate minerals between the seven groups:

Tables 3 through 8 rank the barium silicate minerals as percentages over the entire groups studied. As an example, the suite of Ba-silicate minerals in the Western Metamorphic Belt rank sanbornite as 100% occurring in the known sites. Fresnoite is second at 87.5% with gillespite, celsian and macdonaldite at 75%. Bazirite, benitoite, cerchiaraitite-(Al) and titantaramellite are at 62.5%. Anandite, cerchiaraitite-(Fe), and krauskopfite rank at 50%. Devitoite, ferroericssonite, pellyite and traskite at 37.5%. Following these are bigcreekite, fencooperrite, kampfite, kinoshitalite and taramellite at 25%. Lastly, edingtonite, esquireite and muirite at 12.5%. This ranking trend is followed in the remaining groups.

Comparison of site groups with host rock, deposit type, age and cations:

Table 9 compares each group with respect to the host rock containing the barium silicates, type of deposit, geological age and important cations which formed the individual silicates. The Arctic, Northern South sites and the Northern North sites are all Paleozoic (Devonian/Ordovician or Mississippi-Valley) in age, with metasediments as host rock in a metamorphic or contact metasomatic deposit type. The remaining groups are all Mesozoic (Jurassic-Franciscan) except the Kalkar quarry site, which is Pre-Cretaceous-Sur series. The specific cations are listed that constitute the various barium silicates occurring in these sites.

Alteration products of primary barium silicates:

An examination of the primary barium silicates over the study area exhibit a number of phases which have resulted from the hydrothermal alteration of several primary barium silicate minerals.

First, sanbornite has been observed altering to macdonaldite, krauskopfite, bigcreekite, esquireite, witherite, and opal. These secondary barium silicate phases have resulted from the moderate to low temperature and pressure fluid conditions of the primary phase, sanbornite. These products occur primarily in the sanbornite-quartz deposits of eastern Fresno County, but also have been noted at both Trumbull Peak and the Baumann prospect, California.

Gillespite has also been noted as altering to several secondary barium silicate minerals confined to the sanbornite-quartz deposits along Big Creek and at Trumbull Peak. These alteration products include, devitoite, anandite, and ferroericssonite. There is a modest level of chloride in the structure of ferroericssonite.

Although gillespite is closely related to sanbornite in composition and occurrence in addition to possessing a silicate sheet structure, Douglass (1958) states that the two structures have important differences. Gillespite is tetragonal with two double sheets per unit cell made up of linked, four-membered rings of SiO₄ tetrahedra. The barium ions in gillespite, as in sanbornite, lie between the sheets and are associated with oxygen ions of both adjacent sheets, but each ferrous ion in gillespite is associated with oxygen ions of only one sheet.

It has been demonstrated that both iron and barium can be completely leached out of gillespite with hydrochloric acid without complete physical disintegration of the structure (Schaller, 1929; Pabst, 1943; 1955). The optical character and outward shape of the mineral are retained and that the essential silicate sheet structure remains. Sanbornite, however, quickly swells up when treated with dilute hydrochloric acid and results in X-ray amorphous shreds (Douglass, 1958). When the individual plates of leached gillespite are examined under the microscope, they remain intact.

Douglass (1958) states that the greater stability of the gillespite sheet structure on leaching may arise from its having two cations, beside silicon, which are differently linked to the silicate sheets. These double sheets of four-membered rings of tetrahedra in gillespite are mechanically more rigid than the single sheets of six-membered rings in sanbornite.

At the Esquire #7 claim along Big Creek, the gillespite layers are nearly black and contain thin flakes of ferroericssonite. The red color of the gillespite has completely gone as the hydrothermal conversion to the ferroericssonite is accomplished.

Barium silicate thread minerals across groups:

A thread mineral phase is one that occurs over a specific range of localities, either in a given locality grouping or along a trend of several groupings of mineralization. These occurrences can imply that specific fluid content and hydrothermal conditions were present over the region of interest. Specifically, the following barium silicates may be considered a thread mineral.

Cymrite occurs exclusively in the base metal claims along the southern region of the Brooks Range, Alaska. An isolated occurrence of cymrite occurs in Santa Clara County, California along Highway 152 near Pacheco Pass in the Franciscan Formation (Jurassic). Benitoite, surprisingly occurs in many mines in the WMB and also in the SDR group. Celsian, the high temperature feldspar, occurs across the NG, WMBG and the CRSG occurrences. Fresnoite, occurs over a wide range of sites from the NG (Gun claim) through most of the sites in the WMB and SDRG and a single site in Humboldt County (Coyote Peak). Gillespite, like sanbornite, occurs across all of the WMBG sites and one in the NG site (Gun claim). Sanbornite occurs across all of the WMBG sites, generally associated with gillespite. Titanantaramellite occurs across the entire WMB sites, one in the SDRG and one in the CRS site. The zeolite, edingtonite, has been recorded from eastern Fresno County in the south to the Gun claim in the north.

Barium silicate thread minerals within groups:

Certain mineral families are seen grouping within a specific area of mineralization. Specifically, the joaquinite family consistently is seen across the SDR group of sites, which

include the Dallas Gem mine, Mina Numero Uno, the Victor claim, and the Junnila mine. These individual minerals have different chemistry, which is a function of the fluid chemistry and available anions present in those fluids.

Major barium silicate and accessory minerals per group:

The SDR group shows a number of interesting relationships between major and minor minerals within each mineral site. The Dallas Gem mine: Benitoite and neptunite are major minerals whereas joaquinite-(Ce)/orthojoaquinite-(Ce), fresnoite and jonesite can be considered minor in amount. At the Victor claim, benitoite and neptunite are major while fresnoite, strontiojoaquinite are minor. At the Junnila mine, fresnoite is major but strontiojoaquinite, neptunite and benitoite are minor. At Mina Numero Uno, benitoite is major followed by strontiojoaquinite and joaquinite-(Ce)/orthojoaquinite-(Ce), while neptunite is minor.

Synthesis of major barium silicate minerals:

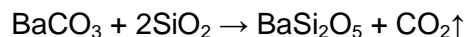
Hinthorne (1974) presents data for the synthesis of six of the major barium silicate minerals found in specific localities of the Western Metamorphic Belt, located in Baja California, Norte (La Madrelena) and California (Chicken Coop Canyon, Trumbull Peak, Big Creek-Rush Creek, Kalkar quarry). These phases include sanbornite, walstromite, fresnoite, benitoite, pabstite and bazirite.

The natural chemical system can be represented by the components BaO and SiO₂. Other components in the system represented by the mineralogy of the Western Metamorphic Belt include CaO, TiO₂, Al₂O₃, FeO, SnO₂, H₂O, and CO₂. However, when the total mineralogy of the Western Margin, North American Continent is examined in detail, additional components have been identified, including MnO₂, SrO, MgO, ZrO₂, Ce₂O₃, Na₂O, K₂O, V₂O₅, Cl⁻, S²⁻, P₂O₅, and Nb₂O₅.

In his initial experimental work, Hinthorne (1974) considered three systems: (1) BaO-SiO₂-CO₂, (2) BaO-CaO-SiO₂, and (3) BaO-TiO₂-SiO₂ to better understand the natural geochemical systems forming sanbornite, walstromite and fresnoite identified in the diverse group of barium silicate minerals in the field localities.

Sanbornite:

Results of the first system show that stoichiometric mixtures of BaCO₃ plus SiO₂ yielded BaSi₂O₅ plus CO₂ according to the equation:



This reaction produced sanbornite plus CO₂ vapor from witherite and silica. The temperature range for this reaction was from 440°C to 600°C at a minimum of 2.0 kilobar pressure to a maximum of 3.9 kilobars. Stoichiometric mixtures of silica + baryte failed to react at temperatures up to 750°C at 2000 bars of water pressure. Virtually no baryte broke down at these temperatures. These results would appear to eliminate baryte as a direct source of the barium for the formation of sanbornite during metamorphism.

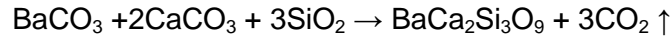
The reaction of barium carbonate and silica to form sanbornite and carbon dioxide is analogous to the well-known reaction of calcite and silica forming wollastonite and carbon dioxide.

Walstromite:

Walstromite is the only barium silicate found with sanbornite which contains calcium as a major constituent. It was synthesized from the oxides by the equation:



The temperature range using the oxide mixture was selected between 315°C and 752°C. Also, walstromite was synthesized from a mixture of barium carbonate, calcium carbonate and silica by the equation:



In the assemblages containing a carbonate and quartz, 425°C appeared to be the minimum temperature for the formation of walstromite and 669°C the maximum.

Fresnoite:

The third phase studied is the formation of fresnoite using a mixture of barium hydroxide, titanium dioxide and silica by the equation:



Fresnoite was found to be stable over a range of pressures and temperatures and that the bulk composition and crystal chemistry are responsible for its unusual structure. Fresnoite grows very slowly at 300°C but it was readily synthesized above 450°C.

Benitoite-Pabstite-Bazirite Isomorphous Series:

The next set of phases investigated by Hinthorne (1974) was the formation conditions for the triad of barium silicate phases, benitoite, pabstite and bazirite.

Benitoite:

Benitoite was formed from a mixture of barium hydroxide, titanium dioxide and silica according to the equation:



Runs were made from 299°C to 682°C and pressures from 1.0 kilobar to 2.0 kilobars. Benitoite was formed from 650°C to 752°C at 1.0 kb pressure and from 299°C to 682°C at 2.0 kb pressure. From the data, the stability fields of benitoite and fresnoite overlap completely. Temperatures below 680°C and more accurately, below 600°C, benitoite is metastable and slowly breaks down into fresnoite.

Pabstite:

Four runs were made in the syntheses of pabstite at a pressure of 2.0 kilobars. Two runs were conducted using the following starting materials according to the equation:



Two additional runs used the following starting materials according to the equation:



All four runs consisted of more than 90% BaSnSi₃O₉.

Pabstite was formed using both starting materials. In the two lower temperature runs, 546°C and 571°C, the other phases present were cassiterite, quartz and sanbornite. In the two higher temperature runs, at 635°C and 685°C, only cassiterite was present as an impurity. The purest product was obtained at a temperature of 635°C.

Bazirite:

The third phase, bazirite, was formed using a mixture of BaZrO₃ and SiO₂ according to the equation:



Three temperatures were used, 546°C, 584°C and 635°C at a pressure of 2.0 kilobars. The results were very similar to the synthesis of pabstite. The two higher temperature runs contained fewer impurities. The temperature that gave the best result was 584°C.

Stability of mineral assemblages-field versus laboratory:

Hinthorne (1974) reports experimental results that suggest a reaction temperature of 343°C at 2 kb and 460°C at 1 kb for the reaction:



The common occurrences of fresnoite + quartz, rather than benitoite + sanbornite in the Big Creek and Rush Creek sanbornite deposits indicates a temperature and pressure of formation for the sanbornite-quartz rocks in the high temperature range, between 600°C and 700°C and 1 to 2 kilobars pressures.

Thin section results indicate that the following assemblages are possibly present in the Big Creek-Rush Creek sanbornite deposits:

- (1) Walstromite + quartz
- (2) Walstromite + sanbornite + quartz
- (3) Walstromite + wollastonite + quartz

The reaction below can be used to account for all the naturally observed assemblages above:



Experimental studies in the BaTiSi₃O₉ -- BaSnSi₃O₉ -- BaZrSi₃O₉ system:

Hinthorne (1974) conducted a series of experiments to understand the possibility of extensive solid solution between these three end members of the benitoite family. Naturally occurring examples of this ternary system exist as benitoite, pabstite, and bazirite. Benitoite occurs as nearly pure BaTiSi₃O₉ from the Dallas Gem mine, San Benito County. Pabstite, Ba(Sn_{0.77}Ti_{0.23})Si₃O₉, the titanian member of the series, occurs from the Kalkar quarry, Santa Cruz County, and bazirite, Ba(Ti_{0.18}Sn_{0.40}Zr_{0.42})Si₃O₉, the stannian-titanian member, occurs at the Madrelena mine, Baja California Norte, Mexico. Both benitoite and bazirite also occur in the quartz-sanbornite deposits of eastern Fresno County and at Trumbull Peak, Mariposa County.

Gross et al. (1965) report that pure barium tin silicate has been synthesized from a mixture of stoichiometric composition in a simple hydrothermal apparatus at 330°C and saturated water vapor pressure. Large crystals of sanbornite were produced at the same time; however, the crystals of BaSnSi₃O₉ were not of suitable size for single-crystal examination. Synthesis was also successfully carried out at 500°C and 15,000 psi, again, sanbornite was present.

Hinthorne (1974) was able to synthesize all three members of the ternary system with the benitoite-type structure, which suggests the possibility of extensive solid solution between these end members. The temperatures used ranged from 496°C to 635°C at 2 kilobars pressure.

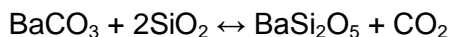
The results show that the three end members form benitoite structures readily and the ternary composition can be crystallized. Of the binary series, only the Ti-Sn composition appears to form a solid solution series. The Ti-Zr compositions appear to have a compositional gap from $\text{Ba}(\text{Ti}_{0.3}\text{Zr}_{0.7})\text{Si}_3\text{O}_9$ to nearly the $\text{BaTiSi}_3\text{O}_9$ end member. The data for the Sn-Zr series is not definitive, but suggests that compositions containing from 10 to >50 mole% $\text{BaSnSi}_3\text{O}_9$ are unstable in the temperature-pressure region tested.

Summary of the experimental, field and petrographic evidence for the occurrence of barium silicates known in the study areas:

In summary, Hinthorne (1974) presents his field, petrographic and experiment evidence which substantiate a complex series of events leading to the formation of several rare barium silicate minerals, namely sanbornite, walstromite, fresnoite, benitoite, pabstite and bazirite. One of these minerals, sanbornite, comprises up to 95% of parts of the barium-rich thin metasedimentary sequences, whereas, the other barium silicates occur mostly as scattered grains and fracture fillings.

The following sequence of events leading to the formation of the four similar occurrences of these unique rocks appears to account for all of the observed relations.

1. Sedimentary baryte, or witherite, precipitated locally as part of an abyssal sedimentary sequence in a possibly continuous narrow basin off the west coast of Mexico and California within the late Paleozoic to Early Jurassic time period.
2. Diagenetic activity then dissolved the baryte and re-precipitated the barium as witherite. The deposition of witherite may have taken place directly, without baryte as an intermediate phase, but no marine analog of direct witherite deposition is known.
3. Burial of the sediments to depths was followed by one or more periods of severe deformation, probably caused by subduction along a continental margin and thermal metamorphism attributable to the intrusion of large granitic plutons. The temperature of metamorphism was between 400°C and 600°C, as determined by the reactions:



The pressure during the formation of the barium silicates was at least 1.0 kilobar and probably greater than 2.0 kilobars. An upper limit for the pressure during metamorphism can be placed at 3.9 kilobars from the common andalusite-sillimanite association found in metamorphosed pelitic rocks throughout the Sierra Nevada and the fact that kyanite is lacking.

4. Several minerals such as the poorly crystallized witherite and the hydrated barium silicates krauskopfite and macdonaldite appear to have formed relatively recently by low temperature ground water action in the pores and joints of the quartz-sanbornite and adjacent rocks. Also, the alteration of gillespite by fluids other than ground water formed anandite, ferroericssonite and devitoite. Fluid chemistry contained chloride, phosphate and carbonate as evidence by the chemical composition of the three alteration products of gillespite.

COMPARATIVE RESULTS:

1. The geologic eras for this trend of Ba-silicates occurrences range from the Mesozoic Era south of the Coast Range Group to the Paleozoic Era north to the Arctic (Brooks Range) Group.
2. Predominant geological Period in the southern groups is the Jurassic-Franciscan Formation with one pre-Cretaceous-Sur Series.
3. Predominant Periods in the Northern Group consist of Devonian, Mississippian, or Ordovician, all Paleozoic.
4. The majority of Ba-silicate minerals occur predominantly in the mines within the Western Metamorphic Belt, with the next abundance divided between the Southern Diablo Range and one single group in the Northern Group.
5. The barium silicate mineralogy of the Western Metamorphic Belt shows a close resemblance to that of the Gun claim of the Northern Group.
6. The majority of barium silicates identified in this study are of primary origin. Several are enclosed in base metal ore deposits, specifically in the Northern Group.
7. Metamorphic action on residual sediments rich in barium and other elements is the major reason for the majority of barium silicate occurrences over the studied trend.
8. Fresnoite, titanitaramellite, benitoite, sanbornite, gillespite, celsian, and cymrite have been recognized as trace minerals, both across groups or within specific groups.
9. The secondary alteration of sanbornite during low temperature hydrothermal activity has produced macdonaldite, krauskopfite, bigcreekite, esquireite, witherite and opal.
10. The secondary alteration of gillespite during low temperature hydrothermal activity has produced anandite, devitoite, and ferroericssonite.
11. Secondary Ba-silicate formation (low temperature hydrothermal action) is confined to the claims along Big Creek/Rush Creek, Trumbull Peak, and the Baumann prospect.
12. Strontium is very rare in the barium silicate occurrences studied and is confined to the Southern Diablo Range Group of mines, namely the Victor claim, Mina Numero Uno, and the Junnila mine.

DISCUSSION:

Tables 10 through 14 illustrate, to the best of our ability, the apparent paragenetic timeline and temperature of formation for the barium silicates examined herein. The range of samples identified ranged from Baja California Norte, Mexico in the south to the Brooks Range, Alaska in the north. This extended trend of barium silicate localities offered the opportunity to examine the geology, origin, and paragenesis.

Approximate paragenesis and temperatures of formation for the known barium silicates in the total study region are illustrated in Table 10. Several barium and non-barium phases are included at the end for comparison, as they comprise accessory minerals found with the barium silicates under study. Based on mineral associations and known mineral stability temperatures of several phases given in the available literature, certain time-temperature values can be estimated for those phases that no data exists.

Each of the six area study groups will be examined separately to determine the most probable mineral paragenesis and temperature of formation.

The Western Metamorphic Belt Group:

The Western Metamorphic Belt Group represents the most consistent set of eight barium silicate occurrences in the study region which host at least 24 individual barium silicates in addition to baryte and witherite. The barium silicate mineralogy of this group is directly related

to the metamorphic effects on deep-seated oceanic sediments containing a varied host of elements which formed the diverse barium silicate mineralogy.

The principal host for these barium silicates is described as a mixture of sanbornite and quartz. Hinthorne (1974) gives a probable scenario for the formation of sanbornite. He postulated the sanbornite formed from a mixture of witherite and quartz at a temperature between 440°C and 600°C and at pressures from 1.0 to 3.9 kilobars.

Specifically, there are a number of included phases contained in the host mineral, sanbornite. These are: fresnoite, muirite, verplanckite, benitoite, bazirite, kampfite, traskite, gillespite, titantaramellite, cerchiaraita-(Al), cerchiaraita-(Fe), fencooperite and celsian. These all occur as grains or clots within sanbornite, and/or quartz, showing that they formed first in the liquid barium silicate at temperatures well below 1350°C, the melting temperature of fresnoite. The formation temperature range for these phases appears to be lower than 960°C but above 670°C. After cooling, sanbornite formed, trapping the higher temperature phases. Moore and Louisnathan (1969) state that the mineral assemblage at Big Creek is typically a high-temperature type as inferred from the melting points of the minerals, and fresnoite has a high melting point relative to a number of other minerals with which it is associated.

Geologically, the occurrence of fresnoite is in the migmatite zone. It is postulated that fresnoite was one of the early products to crystallize out of the magmatic fluid, crystallizing almost immediately after coming into contact with the walls of the plutonic host rocks. Robbins (1970) conducted melting experiments using high purity barium carbonate, titanium oxide and silica in a furnace in air to near 1425°C for 1 hour, held for 1 hour and then cooled at 3 degrees per hour to 1000°C and then at 10°C per hour to 20°C. The final product was identified as Ba₂TiOSi₂O₇, identical to natural fresnoite.

Gillespite, a layered mineral like sanbornite, occurs in seven of the eight localities in this group of localities and is thought to have formed at a slightly higher temperature than sanbornite because it has been observed being surrounded by sanbornite. This observance is well noted in the veins at Trumbull Peak where grains and masses of gillespite are completely surrounded by sanbornite.

Both sanbornite and gillespite have been altered in part by low temperature hydrothermal fluids in most of the recorded localities in this group. Gillespite has altered to devitoite, anandite and ferroericssonite by hydrothermal fluids specifically at the Esquire #7 and #8 claims along Big Creek and to a lesser extent at Trumbull Peak. The fact that devitoite contains a carbonate group in the structure would require that the fluid pH would be near neutral or slightly higher. Also, this is the only secondary phase that has a phosphate group in it. Samples containing anandite, ferroericssonite and devitoite at the Esquire #7 claim show all three phases in close contact with each other. However, at the Esquire #8 claim, devitoite has been observed isolated but close to leached gillespite.

Gillespite is unusually absent in the sanbornite-rich rocks at the Baumann prospect, Chickencoop Canyon, even after diligent searching. No formal explanation is given by any author familiar with barium silicate deposits. It is postulated that the geochemical conditions did not favor the formation of gillespite, although there is sufficient iron in the deposit.

The low temperature hydrothermal alteration of sanbornite may have occurred below 150°C and formed bigcreekite, krauskopfite, macdonaldite, opal and witherite along fractures, cleavage planes and perpendicular to these planes. Cerchiaraita-(Al) and cerchiaraita-(Fe) appear to have formed well below 900°C as individual grains and vein fillings, at times surrounding grains of pyrrhotite.

The Gun claim, Itsi Mountains, Yukon Territory, Canada comprises a barium silicate mineralogy quite similar to that of the Western Metamorphic Belt Group. Again, metamorphism of sediments rich in barium and other elements has resulted in several barium silicates identical to those of the eastern Fresno County sites. The Gun claim has 35.5% of Ba-silicates in

common with the total 31 for both sites. Also, it has 19.4% unique phases compared to the total number between the two sites.

The principal Ba-silicate mineralogy of the eastern Fresno County sanbornite deposits is quite simple and can be expressed as the assemblage of the ternary system BaO-SiO₂-H₂O. Additional components can exist such as Al₂O₃ forming celsian, CaO forming walstromite, TiO₂ forming fresnoite and FeO forming gillespite. Owing to the low volume of witherite in the sanbornite deposits, a different source for the barium is postulated. Among known Ba-containing geologic units accompanied by siliceous rocks, the most extensive one is occurring in baryte beds of sea floor origin. Matsubara (1985) suggests that such baryte beds are regionally or contact metamorphosed up to the grade allowing for the formation of wollastonite. Under reducing and higher temperature conditions, decomposition of baryte takes place, leaving the reactive compound, BaS, which could be a source of Ba silicates together with the siliceous rocks associated in the system. The release of sulfur could be the source of pyrite and pyrrhotite, which is extensively distributed throughout the sanbornite deposit.

In the Ba silicates found in the Big Creek-Rush Creek deposits, there are some evidences with crystallochemical implications. One is the coexistence of walstromite and wollastonite. The chemical composition of the former is derived from that of the latter by substitution Ba for Ca to obtain the ratio Ca:Ba = 2:1. While the crystal structure of walstromite corresponds to that of the high pressure form of wollastonite, we see that the presence of Ba plays a role of stabilization of the high-pressure Ca₃Si₃O₉ structure.

Another crystallochemical characteristic of the Big Creek-Rush Creek Ba-silicates is the appearance of diverse crystal structures. The following are some examples of diverse silicate structures found as primary minerals: sanbornite and gillespite (sheet structure), celsian (four-membered ring structure), fresnoite (independent radical structure), and bazirite and walstromite (ring structure). In the case of the younger hydrous Ba silicates: muirite, verplanckite and titantaramellite (ring structure), krauskopfite (chain structure), and macdonaldite (sheet structure). Although Ba-silicates show a diverse series of crystal structures under the same or similar geological conditions, the form of the silicate structure reflects the chemical environment rather than the physical one.

The Southern Diablo Range Group:

The Southern Diablo Range Group consists of four closely grouped mines/claims in San Benito County and two remotely single mineral occurrences in Santa Clara and Kern Counties.

Wise and Gill (1977) present an extensive study of the Dallas Gem mine and give a sequence of crystallization for the local mineralogy. The meta-basalt near the fractures has been converted to albite, crossite, and actinolite before any vein filling, because the amphiboles are the same, whether forming vein walls or inclusions in the later minerals. Albite, apatite, and the serandite and silica pseudomorphs after serandite having grown on the vein walls, occur as inclusions in neptunite and benitoite. Djurleite occurs included in or covered by neptunite and benitoite as well as in the reverse relationship. Benitoite, neptunite, and joaquinite-(Ce) grew nearly simultaneously because joaquinite-(Ce) has been found embedded in benitoite and neptunite, as well as growing on the surfaces of these minerals, and neptunite is commonly included in benitoite, though the reverse is rare. The close association of djurleite and digenite with benitoite and neptunite indicates that all these minerals formed at about the same time and under the same geothermal conditions.

Wise and Gill (1977) present data showing that benitoite, neptunite and members of the joaquinite family formed at temperatures below 95°C. This rather low temperature of formation is based on the fact that djurleite is not stable at temperatures above 95°C (Potter, 1974). Both djurleite and digenite occur in close association with benitoite and neptunite at the Dallas Gem mine. Based on the above temperature of formation information, we imply that benitoite, neptunite and fresnoite collectively formed at a temperature below 95°C from fluids containing

the basic elements constituting the final barium silicate minerals. Rare jonesite has been observed only on veins walls or on neptunite, and is probably the last to form, again below 95°C.

The formation temperature for the majority of Ba silicates found at the Dallas Gem mine of less than 95°C (Wise and Gill, 1977) is in stark contrast to the values determined by Hinthorne (1974) of near 600°C. No pressure of formation was estimated for the Dallas Gem mine mineralization by Wise and Gill (1977). Geothermal factors of the mineralizing fluids such as pressure, pH and Eh may have contributed to this difference. Although Hinthorne (1974) used water in the synthesis of the silicate products, none of the natural phases under consideration contain water, so H₂O is not directly involved in the formation or breakdown of any important phases.

The mineralizing fluid which entered the fracture system contained sufficient ions such as Ba²⁺, Sr²⁺, Ti⁴⁺, Si⁴⁺, K⁺, Na⁺, Li⁺, Fe²⁺, Al³⁺, Ce³⁺, and OH⁻. This combination of ions in the proper concentration, over time, resulted in the formation of benitoite, neptunite, joaquinite-(Ce), jonesite and the copper sulfides, djurleite, digenite and covellite. The vein filling mineral, natrolite, formed after the barium silicate deposition, also at a temperature below the formation temperature of the barium silicates, as the copper sulfides have remained unaltered.

At the Victor claim along a small tributary of Clear Creek, benitoite occurs as tabular, colorless crystals associated with neptunite, fresnoite, strontiojoaquinite and joaquinite-(Ce) (Cooper et al. 2006). The geology is assumed to be identical to that of the Dallas Gem mine, the Junnila mine and Mina Numero Uno. Although no specific temperatures of formation are given for the Ba-silicate mineralogy of this claim, it is proposed that the temperature of formation is identical or close to that given by Wise and Gill (1977).

The Junnila mine is unique in the area for the best and largest fresnoite crystals ever discovered in the world. No data on the paragenesis of the deposit was given by Kleine (2018) for the abundance of fresnoite over both benitoite and neptunite, in contrast to the Dallas Gem mine, the Mina Numero Uno and the Victor claim where a similar Ba-silicate mineralogy occurs.

In his study of the source of barium and strontium in silicates, Matsubara (1985) concludes that there are two major geneses of barium and strontium silicate minerals: (1) later stage products of deep-seated alkali magma or their metamorphic equivalents and (2) constituents of metamorphosed bedded manganese and baryte ores deposited in the sea floor. With respect to the single strontium-bearing silicate identified from three closely group occurrences within the New Idria serpentinite mass, it is postulated that Matsubara's first geneses would be responsible for the source of strontium that occurs in the three mines, namely the Victor, Mina Numero Uno and Junnila, where strontiojoaquinite occurs. An optical examination of the strontiojoaquinite shows that the strontiojoaquinite actually has replaced in part joaquinite-(Ce) crystal, leaving a central core of joaquinite-(Ce). This would suggest that a second fluid influx, richer in strontium, entered the system and selectively replaced the cerium in the joaquinite-(Ce) structure.

The crystal structure of joaquinite (now joaquinite-(Ce)) was determined by Dowty (1975). His results showed that joaquinite has monoclinic symmetry with space group C2. This new independent structure determination largely confirms a previous one by Cannillo et al. (1972), but with important differences, including the space group and several additional atoms found in the present study, namely (Na, OH, H₂O). The existence of the monoclinic cell as well as an orthorhombic cell had been noted by Laird and Albee (1972) and Cannillo et al. (1972). Their X-ray studies have disclosed that these orthorhombic cells usually consist of finely twined or disordered monoclinic joaquinite-(Ce) intermixed with orthorhombic joaquinite-(Ce), giving the whole crystal simulating orthorhombic symmetry. The space group of the orthorhombic cell was determined to be Cc2m.

Wise (1982) described two new minerals from San Benito County, strontiojoaquinite, the Sr analogue of joaquinite-(Ce) and barrio-orthojoaquinite, the Ba analogue of orthojoaquinite-(Ce). Strontiojoaquinite has been identified from samples collected from the Mina Numero Uno,

Junnila and Victor localities, a group of barium silicate occurrences west of the Dallas Gem mine. Barrio-orthojoaquinite has only been identified from a single block of rock at the Dallas Gem mine.

To date, the Sr analogue of orthojoaquinite-(Ce) has not been identified from the barium silicate localities of San Benito County. The first recorded reference of strontio-orthojoaquinite is from Ohmi, Niigata Prefecture, Japan by Chihara et al. (1974). It can be speculated that this mineral may occur in one of the three above barium silicate occurrence because based on the fact that crystals of strontiojoaquinite contain segments of the orthorhombic phase in the crystal structure of joaquinite-(Ce) where the cerium has been replaced by strontium. Careful X-ray and microprobe analysis may reveal this phase previously known only from Japan.

The Coast Range Group-South and North Sites:

The Coast Range Group consists of two isolated localities which are geomorphologically different. The south site, the Pacific Limestone Products quarry, Santa Cruz County, host three barium silicate minerals in an impure, recrystallized limestone containing a variety of sulfides and sulfosalts of lead, copper, iron, tin and antimony. Pabstite, celsian and titanaramellite occur in a fine-grained altered limestone at the junction of two intersecting faults. The three barium silicates are in close contact with each other. Both titanaramellite and celsian may have formed between 900°C and 950°C while the pabstite may have formed between 400°C and 600°C. The formation temperature for pabstite is much higher than for its titanium analogue, benitoite and bazirite, the zirconium analogue. No explanation is given for the wide spread of formation temperatures.

The north site, Coyote Peak, Humboldt County, consists of an isolated intruded igneous rock mass (diatreme) within the surrounding Franciscan Formation that hosts a series of alkaline sulfides. The two barium silicates identified from this diatreme are fresnoite and barytolamprophyllite. During the formal description of erdite, Czamanske et al. (1980) noted the occurrence of barytolamprophyllite associated with phlogopite, schorlomite, clinopyroxene, nepheline, natrolite, sodalite, vishnevite, acmite, and apatite. At that time fresnoite had not been reported. During our study of samples collected from the diatreme, dull yellow grains were noted which gave a yellow fluorescence under SWUV light. This phase was subsequently identified as fresnoite by PXRD. Although no formation temperature has been given for the diatreme, it is assumed that the initial maximum temperature was greater than 1000°C, near the melting point of fresnoite.

Czamanske and Atkin (1985) interpret the present exposures of the diatreme were within 1 km of the surface at the time of dynamic eruption of a gas-charged, highly fluidized silicate melt. Their challenge in studying the lithic-wacke inclusions in this diatreme was to interpret mineral relations that have developed at less than 0.1 GPa pressure during exposure to an extremely high temperature event of minimal duration.

Also included in this group is the single edingtonite locality along Ash Creek, Mendocino County. It is assumed that the formation temperature would be similar to other known occurrences for edingtonite, which would be lower than 200°C and formed very late in the mineral sequence.

The Northern Group-South and North Sites:

Six independent sites are covered in the Northern Group-South sites. These include (1) Green Creek mine (celsian), (2) Wigwam deposit (zoltaiite, greenwoodite, and batisivite), (3) Unnamed occurrence along O'Brien Creek (celsian), (4) Dry Delta (gillespite, celsian), (5) Galena prospect (celsian) and (5) Ice River Complex (edingtonite, banalsite, baryte and barytocalcite).

At the Green Creek base metal deposit, celsian is the only barium silicate noted. Based on available data, the celsian probably formed at a temperature below 1000°C.

The Wigwam mine, also a base metal deposit, host three rare barium-vanadium silicates, zoltaiite, greenwoodite and batisivite. Bartholomew et al. (2005) based their conclusion of the formation temperature on the fact that no biotite was found in pelites near the Wigwam deposit which indicates that the metamorphic conditions were at temperatures below the biotite stability temperature. This allows the formation temperature range for the three Ba minerals to be between 300 to 425°C.

The unnamed occurrences along O'Brien Creek contain only celsian in a base metal deposit within a buff-colored celsian-bearing quartzite. Sulfides include sphalerite, pyrite, galena and chalcopyrite. These occurrences are interpreted to be a sedimentary-exhalative massive sulfide deposit (Dusel-Bacon et al., 1998).

Three sites are included in the Northern Group-North sites. These include (1) the Gun claim (18 Ba-silicates), (2) the Birr claim (gillespite, baryte), and (3) the Tom deposit (celsian, cymrite, baryte, barytocalcite, witherite).

The Gun claim, a series of shallow trenches, is characteristically very similar in barium mineralogy to that of the Western Metamorphic Belt, especially to that of the Esquire claims along Big Creek and Rush Creek. The host rock consists of metasediments and shows a very close relationship to the geochemistry and mineralogy of the Western Metamorphic Belt Group.

Little is known about the Birr claim except that it is described as a copper skarn deposit hosting pyrrhotite and chalcopyrite.

The Tom deposit is a low temperature sulfide deposit near the Gun claim. It is stated that the deposit formed at temperatures below 150°C.

The Arctic (Brooks Range) Group:

There are four sites in this group which consist of drill holes that explore base metal mineralization. Cymrite has been identified in all four locations as thin seams and isolated grains closely associated with the sulfides. It is estimated that the deposits formed between 500°C and 600°C. Runnells (1964) states that the host rock was originally a normal dolomite of marine origin, but is now mineralized and contains pyrite, chalcopyrite, bornite, chalcopyrite, sphalerite, galena and cymrite. The cymrite was observed in contact with one or more of the following minerals: dolomite, siderite, ankerite, pyrite, fluorite, quartz and chlorite. Runnells (1964) states that the cymrite appears to be an early mineral in the paragenetic sequence and is closely associated in space with the sulfides and seems to be a product of solution alteration of the impure carbonate host-rock. Brosgé (1960) gives an account of the metasedimentary rocks in the south-central Brooks Range.

REFERENCES:

ALFORS, J.T. and PABST, A. (1984) Titanian taramellites in western North America. *American Mineralogist*, **69**, 358-373.

ALFORS, J.T., STINSON, M.C., MATTHEWS, R.A, and PABST, A. (1965) Seven new barium minerals from eastern Fresno County, California. *American Mineralogist*, **50**, 314-340.

ANSDELL, K.M., NESBITT, B.E. and LONGSTAFFE, F.J. (1989) A fluid inclusion and stable-isotope study of the Tom Ba-Pb-Zn deposit, Yukon territory, Canada. *Economic Geology*, **84** (4), 841-856.

ARMBRUSTER, T., MADIYSKI, M., REZNITSKY, L.Z., SKLYAROV, E.V. and GALUSKIN, E.V. (2008) Batisivite, the first silicate related to the derbylite-hemloite group. *European Journal of Mineralogy*, **20**, 975-981.

BARTHOLOMEW, P.R., MANCINI, F., CAHILL, C., HARLOW, G.E., and BERNHARDT, HEINZ-JUERGEN. (2005) Zoltaiite, a new barium-vanadium neosubsilicate mineral from British Columbia: Description and crystal structure. *American Mineralogist*, **90**, 1655-1660.

BARTHOLOMEW, P.R., MANCINI, F., HARLOW, DEIFEL, N., CAHILL, C. and BERNHARDT, H. –J. (2012) Greenwoodite, a new neosilicate from British Columbia with a Ba-VOH coupled substitution and tetrahedral Fe: Description and structure. *Canadian Mineralogist*, **50**, 1233-1242.

BATEMAN, P.C. and WAHRHAFTIG, C. (1966) Geology of the Sierra Nevada. In *Geology of Northern California*, ed. E.H. Bailey, *California Division of Mines and Geology Bulletin* **190**, 107-172.

BERNSTEIN, L.R., and COX, D.P. (1986) Geology and sulfide mineralogy of the Number One ore body, Ruby creek copper deposit, Alaska. *Economic Geology*, **81**, 1675-1689.

BOJAR, H.-P. and WALTER, F. (2014) Bavsiite, IMA 2014-019. CNMNC Newsletter No. 21, August 2014, page 800; *Mineralogical Magazine*, **78**, 797-804.

BOLOTINA, N.B., RASTSVETAeva, R.K. and KASHAEV, A.A. (2010) Refinement of the twinned structure of cymrite from the Ruby Creek deposit (Alaska). *Crystallography Reports*, **55**, 569-574.

BROSGÉ, W.F. (1960) Metasedimentary rocks in the south-central Brooks Range, Alaska. *U.S. Geological Survey Professional Paper* **400-B**, 351-352.

CHIHARA, K., KOMATSU, M. and MIZOTA, T. (1974) A joaquinite-like mineral from Ohmi, Niigata Prefecture, Central Japan. *Mineralogical Journal*, **7**, 395-399.

COOPER, J.F., JR., DUNNING, G.E. and HADLEY, T.A. (2006) Mineralogy of the Victor Claim, Clear Creek Area, New Idria District, San Benito County, California. *Baymin Journal*, **7**, www.baymin.org.

CRAFFORD, T.C. (1989) The Greens Creek Ag-Au-Pb-Zn massive sulfide deposit, Admiralty Island, southeast Alaska: Alaska Miners Association, Juneau, April 20-21, 1989, Program with Abstracts: 27-29.

CURRIE, K.L. (1975) The geology and petrology of the Ice River alkaline complex, British Columbia. *Geological Survey of Canada Bulletin* **245**.

CZAMANSKE, G.K., LEONARD, B.F. and CLARK, J.R. Erdite, a new hydrated sodium iron sulfide mineral. *American Mineralogist*, **65**, 509-515.

CZAMANSKE, G.K. and ATKIN, S.A. (1985) Metasomatism, titanian acmite, and alkali amphiboles in lithic-wacke inclusions within the Coyote Peak diatreme, Humboldt County, California. *American Mineralogist*, **70**, 499-516.

DUNNING, G.E. and COOPER, J.F., JR. (1986) Mineralogy of the Kalkar quarry, Santa Cruz, California. *Mineralogical Record*, **17**, 315-326.

- DUNNING, G.E. and COOPER, J.F., JR. (1999) Barium silicate minerals from Trumbull Peak, Mariposa County, California. *Mineralogical Record*, **30**, 411-417.
- DOWTY, E. (1975) Crystal structure of joaquinite. *American Mineralogist*, **60**, 872-878.
- DUSEL-BACON, C., BRASSLER, J.R., TAKAOKA, H., MORTENSEN, J.K. OLIVER, D.H., LEVENTHAL, J.S., NEWBERRY, R.J., and BUNDTZEN, T.K. (1998) Stratiform zinc-lead mineralization in Nasina assemblage rocks of the Yukon-Tanana Upland in east-central Alaska. *U.S. Geological Survey Open-File Report* **98-340**, 26p.
- DOUGLASS, R.M. (1958) The crystal structure of sanbornite, BaSi₂O₅. *American Mineralogist*, **43**, 517-536.
- ESSENE, E.J. (1967) An occurrence of cymrite in the Franciscan Formation, California. *American Mineralogist*, **52**, 1885-1890.
- FINCH, A.A. (1931) The geology of the Ben Lomond Mountain. *University of California, Department of Geology Publications*, **12**, 1-13.
- GRICE, J.D. and GAULT, R.A. (1981) Edingtonite and natrolite from Ice River, British Columbia. *Mineralogical Record*, **12**, 221-226.
- GRICE, J.D. and GAULT, R.A. (1984) Edingtonite: the first two Canadian occurrences. *Canadian Mineralogist*, **22**, 253-258.
- GROSS, E.B., CHESTERMAN, C.W., DUNNING, G. and COOPER, J.F., JR. (1967) Mineralogy of the Kalkar quarry, Santa Cruz, California. *California Division of Mines Special Report* **92**, 3-10.
- GRYBECK, D.J. and NELSON, S.W. (1981) Mineral deposit map of the Survey Pass quadrangle, Brooks Range, Alaska. U.S. Geological Survey Miscellaneous Field Studies Map MF-1176-F, scale 1:250,000.
- HARRISON, J.C., ST-ONGE, M.R., PETROV, O.V., STRELNIKOV, S.I., LOPATIN, B.G., WILSON, F.H., TELLA, S., PAUL, D., LYNDY, T., SHOLALSKY, S.P., HULTS, C.K., BERGMAN, S., JEPSEN, H.F. and SOLLI, A. (2011) Geological map of the Arctic. Doi:10.4095/287868. *Geological Survey of Canada Map* 2159A.
- HAWTHORNE, F.C., OBERTI, R., ZANETTI, A. and CZAMANSKE, G.K. (1998) The role of Ti in hydrogen-deficient amphiboles: sodic-calcic and sodic amphiboles from Coyote Peak, California. *Canadian Mineralogist*, **36**, 1253-1265.
- HERMES, O.D. (1973) Paragenetic Relationships in an Amphibolitic Tectonic Block in the Franciscan Terrain, Pacheco Pass, California. *Journal of Petrology*, **14**(1), 1-32.
- HERREID, G.H. (1970) Geology and geochemistry of the Sinuk area, Seward Peninsula, Alaska. *Alaska Division of Mines and Minerals Geologic Report* **36**, 61 p. 3 sheets, scale 1:42,000.
- HINTHORNE, J.R. (1974) The origin of sanbornite and related minerals. Ph.D. thesis, University of California, Santa Barbara, California.

HITZMAN, M.W. (1978) Geology of the BT claim group, southwestern Brooks Range, Alaska. Seattle, University of Washington, M.Sc. thesis, 80 p.

HITZMAN, M.W., PROFETT, J.M., Jr. SCHMIDT, J.M. and SMITH, T.E. (1986) Geology and mineralization of the Ambler district, northwestern Alaska. *Economic Geology*, **81**, 1592-1618.

HÖY, T. (1982) Stratigraphic and structural setting of strata bound lead-zinc deposits in southeastern B.C. *CIM Bulletin*, **75**, 1140134.

KAMPF, A.R., ROSSMAN, G.R., STEELE, I.M., PLUTH, J.J., DUNNING G.E., and WALSTROM, R.E. (2010) Devitoite, a new heterophyllosilicate mineral with astrophyllite-like layers from eastern Fresno County, California. *Canadian Mineralogist*, **48**, 29-40.

KAMPF, A.R., ROBERTS, A.C., VENANCE, K.E., DUNNING, G.E. and WALSTROM, R.E. (2011) Ferroericssonite, the Fe²⁺ analogue of ericssonite, from eastern Fresno County, California, U.S.A. *Canadian Mineralogist*, **49**, 587-594.

KLEINE, S. (2018) The Junnila Mine, San Benito County, California. *Mineralogical Record*, **49**, 577-596.

LAIRD, J. and ALBEE, A.L. (1972) Chemical composition and physical, optical, and structural properties of benitoite, neptunite, and joaquinite. *American Mineralogist*, **57**, 85-102.

LARSEN, E.S., Jr. (1948) Batholith and associated rocks of Corona, Elsinore and San Luis Rey Quadrangles Southern California. *Geological Society of America Memoir* **29**.

LAUDERBACK, G.D. (1909) Benitoite, its paragenesis and mode of occurrence. *University of California, Department of Geology Bulletin* **5**, 331-380.

LAURS, B.M., ROHTERT, W.R. and GRAY, M. (1997) Benitoite from the New Idria District, San Benito County, California. *Gems and Gemology*, **33** (3), 166-187.

LEO, G.W. (1967) The plutonic and metamorphic rocks of Ben Lomond Mountain, Santa Cruz County, California. *California Division of Mines and Geology Special Report* **91**, 27-43.

MARRS, C.D. (1978) Geology of the Sun massive sulfide deposit, Ambler district, Alaska [abs.]. Northwest Mining Association, 84th Annual Convention, Spokane, Washington, Nov. 29-Dec. 2, 1978.

MATSUBARA, S., KATO, A. and YUI, S. (1982) Suzukiite, Ba₂V⁴⁺₂(O₂)(Si₄O₁₂), a new mineral from the Mogurazawa mine, Gumma Prefecture, Japan. *Mineralogical Journal Japan*, **11**, 15-20.

MATSUBARA, S. (1985) The mineralogical implication of barium and strontium silicates. *Bulletin of the national Science Museum, Series C*, **11**,(2), Tokyo, Japan.

MCNEIL, L.A., PETERSON, R.C., FARBER, G. GROAT, L. and WITZKE, T. (2013) Mineralogical studies a low-temperature barium-rich skarn deposit, Gunn claim, Yukon Territory. *Abstract with Program, Mineral Associate of Canada Annual Meeting, Winnipeg, May 2013*.

- MILLAGE, A.H. (1981) Mineralogy of the Victor claim, New Idria District, San Benito County, California. M.S. thesis, Stanford University.
- MONTGOMERY, J.H. (1960) A study of barium minerals from the Yukon Territory. B.Sc. thesis, University of British Columbia, Vancouver, British Columbia, Canada.
- MONTGOMERY, J.H., THOMPSON, R.M., and MEAGHER, E.P. (1972) Pellyite, a new barium silicate mineral from the Yukon Territory. *Canadian Mineralogist*, **11**, 444-447.
- MORGAN, J.W., CZAMANSKE, G.K. and WANDLESS, G.A. (1985) Origin and evolution of the alkalic ultramafic rocks in the Coyote Peak diatreme, Humboldt County, California. *Geochimica et Cosmochimica Acta*, **49**, 749-760.
- MULLIGAN, J.J. and HESS, H.D. (1965) Examination of the Sinuk iron deposits, Seward Peninsula, Alaska. *U.S. Bureau of Mines Open-File Report 8-65*, 34 p.
- MURARO, T.W. (1966) Metamorphism of zinc-lead deposits in southeastern British Columbia. *CIM Special Volume*, **8**, 239-247.
- PABST, A. (1943) Crystal structure of gillespite, $\text{BaFeSi}_4\text{O}_{10}$. *American Mineralogist*, **28**, 372-390.
- PABST, A. (1955) The structure of leached gillespite, a sheet silicate. *American Crystallographical Association, Program and Abstracts, Summer Meeting, 1955*, 15.
- PABST, A., GROSS, E.B. and ALFORS, J.T. (1967) Rosenhahnite, a new hydrous calcium silicate from Mendocino County, California. *American Mineralogist*, **52**, 336-351.
- PABST, A. (1977) On some especially dense, hydrous Ca- and Ba-silicates from the Franciscan Formation, California. *Neues Jahrbuch Für Mineralogie, Abhandlungen*, **129**, 1-14.
- POTTER, R.W., II (1974) The low temperature phase relations in the system Cu—S derived from an electrochemical investigation. *Geological Society of America Abstracts with Programs, Annual Meetings, 1974*, **6**, 915-916.
- REED, R.D. and BAILEY, J.P. (1927) Subsurface correlation by means of heavy minerals. *American Association of Petroleum Geologists*, **11**, 359-372.
- ROGERS, A.F. (1932) Sanbornite, a new barium silicate mineral from mariposa County, California. *American Mineralogist*, **17**, 161-172.
- RUNNELLS, D.D. (1964) Cymrite in a copper deposit, Brooks Range, Alaska. *American Mineralogist*, **49**, 158-165.
- RUNNELLS, D.D. (1969) The mineralogy and sulfur isotopes of the Ruby Creek copper prospect, Bornite, Alaska. *Economic Geology*, **64**, p. 75-90.
- SEKI, Y. and KENNEDY, G.C. (1964) Phase relations between cymrite, $\text{BaAlSi}_3\text{O}_8(\text{OH})$, and celsian, $\text{BaAl}_2\text{Si}_2\text{O}_8$. *American Mineralogist*, **49**, 1407-1426.

SCHALLER, W.T. (1922) Gillespite, a new mineral. *Journal of the Washington Academy of Science*, **123**, 7-8.

SCHALLER, W.T. (1929) The properties and associated minerals of gillespite: *American Mineralogist*, **14**, 319-322.

SLACK, J.F., TILL, A.B., BELKIN, H.E. and SHANKS III, W.P. (2014) Late Devonian-Mississippian Zn-Pb (-Ag-Au-Ba-F) deposits and related aluminous alteration zones in the Nome Complex, Seward Peninsula, Alaska. *Geological Society of American Special Papers*, **506**, 173-212.

TALLIAFERRO, N.L. (1943) Geologic history and structure of the central Coast Ranges of California. *California Division of Mines Bulletin*, **118**, 119-163.

TAYLOR, D.C. and JOHNSON, C.A., editors (2010), Geology, geochemistry and genesis of the Greens Creek massive sulfide deposit, Admiralty Island, southeastern Alaska: *USGS Professional Paper 1763*, 429.

THOMPSON, R. M. and MONTGOMERY, G. H. (1960): Barium silicates from the Yukon Territory. *Bulletin of the Canadian Institute of Mining and Metallurgy*, **53**, 200.

THOMPSON, R.I. (1972) Geology of the Akolkolex River area near Revelstoke, British Columbia. Ph.D. thesis, Queen's University, Kingston, Ontario, 125 p.

THOMPSON, R.I. (1978) Geology of the Akolkolex River area. *British Columbia Ministry of Energy, Mines and Petroleum Resources Bulletin*, **60**, 84p.

WALSTROM, R.E. and DUNNING, G.E. (2003) The Baumann prospect, Chickencoop Canyon, Tulare County, California. *Mineralogical Record*, **34**, 159-166.

WALSTROM, R.E. and LEISING, J.F. (2005) Barium minerals of the sanbornite deposits, Fresno County, California. *Axis* Vol. **1**, No. 8, 1-18.

WEILER, C.T., MATHEWS, R.A. and ALFORS, J.T. (1964) Investigations of the Rush Creek sanbornite deposit, Fresno County, California. *United States Bureau of Mines Open-File Report*, 21p.

WERNER, S.S. (1980) Geology of the Baja California sanbornite deposit. B.Sc. thesis, San Diego State University.

WILSON, W.E. (2008) The 100-year history of the Benitoite Gem Mine, San Benito County, California. *Mineralogical Record*, **39**, 13-42.

WISE, W.S. and GILL, R.H. (1977) Minerals of the Benitoite Gem mine. *Mineralogical Record*, **8**, 442-452.

WISE, W.S. (1982) Strontiojoaquinite and barrio-orthojoaquinite: two new members of the joaquinite group. *American Mineralogist*, **67**, 809-816.

ZDEPSKI, J.M. (1980) Stratigraphy, mineralogy and zonal relations of the Sun massive-sulfide deposit, Ambler district, northwest Alaska. Fairbanks, University of Alaska, M.Sc. thesis, 93 p.