

Primary Borate Mineralogy of the Huntington Lake Region, Kaiser Wilderness, Fresno County, California

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ABSTRACT

The Huntington Lake-Twin Lakes marble hosts a number of primary borate minerals, including the first reported locality for chestermanite, $Mg_2(Fe^{3+}, Mg, Al, Sb^{5+})(BO_3)$. A pathway for the genesis of boron leading to the formation of primary borate minerals and relationships to other similar deposits is discussed and reported in this article.

DEDICATION

This publication is dedicated to Gail E. Dunning (1937 – 2021), long time member of BAM, mentor, prolific author, and recipient of the 2020 Pinch Medal. The project would not have been possible without his inspiration and encouragement.

INTRODUCTION and LOCATION

The Huntington Lake area is hosted in the Sierra Nevada western foothills of California at an elevation of 6950' (2100 m) surrounding 37° 20' N 119° 00' W and lies within the Twin Lakes-Huntington Lake Wilderness area, near the town of Big Creek (not related to the nearby barium silicate locality). State Highway 168 provides access 50 miles (80Km) east of Fresno, CA, in Fresno County. Numerous unimproved forest service roads crisscross the area. The region is drained by Big Creek (not related to the barium silicate locality) which flows into the South Fork of the San Joaquin River.

This location is the discovery site of the primary borate mineral chestermanite and host to a number of other primary borate minerals. Anecdotally, the location of occurrence comprises a volume of less than 10 cubic meters. The exact location is not known as it was kept private and all of those known to have visited the site are now deceased. The material for study was provided from the estate of Charles I. Trantham (2 August 1936 - 16 February 2020). The locality was not visited by the authors.

GEOLOGICAL SETTING

The geology of Huntington Lake area is discussed in detail in Hamilton (1956) and is summarized here. The region is composed of granites, mostly quartz monzonite and granodiorite, overlain by metamorphic rocks in the western part of the Sierra Nevada batholith. The Sierra Nevada batholith extends roughly 400 miles (644 Km) north-south (300 miles, 483 Km, exposed) by 60-70 miles (97-113 Km) east-west. The granites increase in age moving to the west and are composed of hundreds of separate intrusions. The western slope of the mountains is noted for its historical abundance of gold. Tungsten has also been mined as the mineral scheelite in the numerous roof pendant skarns. A band of metamorphic rocks run for most of the western exposed 300 miles (483 Km) and is known for such other places of mineralogical interest as the Big Creek-Rush Creek barium silicate area, the New Melones ferroaxinite location, and the Garnet Hill, Strawberry Mine, Kaiser Peak, and Greenhorn Summit tungsten and molybdenum bearing tactites (provided by MinDat).

The geology began as a shallow sea with limestone, sediments, and lavas deposited approximately 300 ma (Pennsylvanian). The Sierra Nevada batholith formed approximately 200-100 ma (Jurassic-Cretaceous) by the subduction of the Farallones Plate of the eastern Pacific Ocean under the western North American plate (Wallace, 1990). Contact metamorphism took place from 120-100 ma (Cretaceous). Uplift began 50 ma (Eocene) and continues to this day. Sufficient heat was produced to melt the sediments, resulting in schists and hornfels (5%), marbles (25%), and quartzites (75%). Dolomites are common in the marble fraction. Only the marble fraction is of interest for this report. The metamorphic rocks strike N 37 W and dip nearly vertical covering an area of approximately 15 miles east-west by 13 miles north-south and underlying approximately 2 square miles of Huntington Lake.

COLLECTING HISTORY

From 1982 through 2008, a number of trips were made to the chestermanite locality by groups of both professional and amateur mineralogists. Records have shown visits by Charles Chesterman (CDMG), Richard Erd (USGS), and Eugene Foord (USGS). In addition, many amateur mineral collectors visited the site, primarily Charles Trantham and Albert McGuiness.

MINERALOGY

The following description was given by Erd and Foord (1988), "The new mineral occurs in a small lens of brucite marble, about 370 m² in area, encased in a magnetite-forsterite skarn that is surrounded by schists and hornfels. The metamorphosed sediments are transected by dykes and sills of granodiorite. The new mineral, chestermanite, was found as veins 2 to 20 mm thick and as sparse disseminations in the marble along at least 34m of the marble's southwestern contact with the magnetite-forsterite skarn. The most abundant chestermanite was found at the point of original discovery near the base of a thick layer of marble in a 6-cm thick band, colored light green by the mineral, 0.6 m from the marble-skarn contact."

The best way to observe the minerals of this deposit is to dissolve the marble for a short time (1-3 days) in 5% acetic acid (vinegar). This erodes the rock surface slightly and provides relief for the minerals contained within. While other, stronger acids may also work, the borate minerals may be damaged by them.

Borate Mineralogy

Chestermanite $Mg_2(Fe^{3+},Mg,Al,Sb^{5+})(BO_3)$

Chestermanite usually occurs as small aggregates of fine fibers in a mostly parallel arrangement. The habit is distinguished from ludwigite by the fact that ludwigite crystals are of random orientation and not generally parallel. The light green color of the chestermanite is nearly indistinguishable from that of the ludwigite when the fibers are of the same size; however, ludwigite tends to have larger, thicker, and therefore darker crystals (trending toward black), while chestermanite is consistently seen as thin and pale fibers (Fig.1a). Common.



Fig. 1a Asbestiform chestermanite. 3.5mm fov

When chestermanite is sparse, it looks nearly identical to ludwigite. A second habit of chestermanite seen in larger crystals is flat blades of identical color to the fine fibers. This is easily distinguished from ludwigite by its flattened habit and the fact that similar sized ludwigite is nearly black in color (Fig. 1b).



Fig. 1b Chestermanite showing asbestiform habit and individual crystals. 1.8mm fov

Dumortierite $(Al,Fe^{3+})_7(SiO_4)_3(BO_3)O_3$

Dumortierite was identified by Raman Spectroscopy. It is very rare, having been found in a small number of samples. It occurs as roughly hexagonal colorless transparent prisms lying flat upon the matrix approximately 0.5 mm diameter by 1-3 mm long (Fig. 2a, 2b). It exhibits a bright bluish-white fluorescence under short-wave ultraviolet light (Fig. 2c).



Fig. 2a Dumortierite crystal showing elongation and prismatic cleavage. 2.5mm fov.



Fig. 2b Dumortierite crystal showing cleavages. The black inclusions are probably ludwigite. 2.0mm fov.



Fig. 2c Dumortierite crystals showing bright bluish-white fluorescence under shortwave ultraviolet light. 3.5mm fov.

Fluorborite, $Mg_5(BO_3)(F,OH)_3$

Fluorborite was mentioned by Erd and Foord (1988), but, after an extensive search through all available material, none was found. The habit, color, and fluorescence of the dumortierite described herein is very similar in appearance to fluorborite.

Ludwigite, $(Mg,Fe^{2+})_2Fe^{3+}O_2(BO_3)$

Ludwigite occurs as thick (up to 0.5 mm), brittle, dark green to black prisms commonly greater than 2 mm long, and occasionally reaching 6 mm. The crystals have poor terminations with prisms having a generally random orientation. Ludwigite is found throughout the deposit and is sometimes locally abundant enough to give the host rock a dark greenish color (Fig. 3a, 3b, 3c). Common.



Fig. 3a. Ludwigite crystal approximately 5.0mm tall

Ludwigite $(\text{Mg,Fe}^{2+})_2\text{Fe}^{3+}\text{O}_2(\text{BO}_3)$



Fig. 3b Two ludwigite crystals (not a twin) with chondrodite and individual chestermanite crystals. 3mm fov.



Fig. 3c Ludwigite with chondrodite (clear) and chestermanite (green). 2.0mm fov

Accessory Mineralogy

Brucite, $Mg(OH)_2$

Brucite was identified using Raman spectroscopy as small anhedral grains from 0.5-3 mm diameter in the marble. The mineral is cream-white, pale pink, or pale yellow. While not common, it is found locally as an abundant constituent of the matrix. It is soluble in vinegar, so care must be exercised when etching samples (Fig. 4a, 4b).

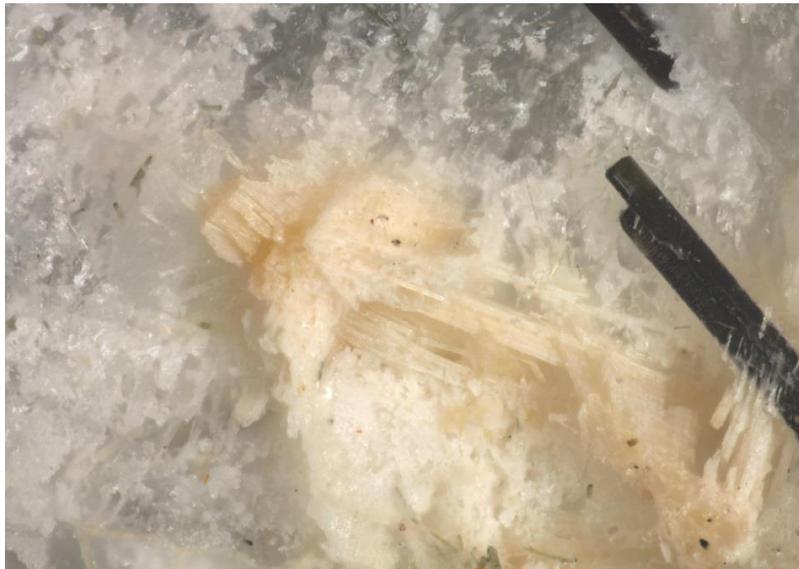


Fig. 4a Slightly etched brucite bleb associated with ludwigite. 1.2mm fov



Fig. 4b Slightly etched cream-white color brucite blebs in matrix. 2.0mm fov

Brucite, $\text{Mg}(\text{OH})_2$

Brucite readily weathers out of the marble to form small voids. These voids are often filled, partially to completely, with a powdery calcite which is weakly fluorescent under ultraviolet light. The voids are common, indicating the brucite was at one time a common mineral (Fig. 4c).



Fig. 4c Slightly etched cream-white color brucite blebs in marble. 4.0mm fov

Calcite, CaCO_3

Calcite forms the bulk of the matrix rock as anhedral crystalline grains 0.5-3 mm across, usually milky white and with typical calcite cleavage faces. It is not fluorescent. Common.

Dolomite, $\text{CaMg}(\text{CO}_3)_2$

Dolomite is mentioned by Erd and Foord (1988) but has not been specifically noticed by the authors. It is assumed to be a common constituent of the marble, especially because of the presence of brucite.

Chondrodite, $(\text{Mg,Fe}^{2+})_5(\text{SiO}_4)_2(\text{F,OH})_2$

Chondrodite was identified by Raman spectroscopy. It occurs as anhedral, small, < 0.5 mm, transparent colorless lenticular spherules scattered through the marble matrix. It is very difficult to see without light etching of the matrix. The mineral seems to be abundant (Fig. 5a, 5b).



Fig. 5a Chondrodite clear crystal group with ludwigite. 1.2mm fov



Fig. 5b Chondrodite crystal group with minor chestermanite. 1.4mm fov

Hydromagnesite, $Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$

Hydromagnesite, identified using RAMAN spectroscopy, occurs as a massive, white, powdery, clay-like material partially surrounding meionite crystals. The mineral is most easily noticed when a sample is soaked in vinegar leaving a wet, clayey mass under and around the meionite. It is presumed to be common, but due to its occurrence under the meionite crystals, it is rarely visible.

Magnetite, $Fe^{2+}Fe^{3+}_2O_4$

Magnetite was identified as black grains and as thin black coatings on individual spinel grains. It is so thin that it does not exhibit noticeable magnetic attraction (Fig. 6a, 6b). Common.



Fig. 6a Magnetite rounded grains in matrix. 1.2mm fov



Fig. 6b Magnetite flattened grains in matrix. 2.0mm fov

Meionite, $\text{Ca}_4\text{Al}_6\text{Si}_6\text{O}_{24}\text{CO}_3$

Erd and Foord (1988) stated that wightmanite was an accessory borate mineral in the Huntington Lakes marble. The present authors found an abundance of material which is nearly identical in appearance to the wightmanite from the type locality of Crestmore, Riverside County, California. Upon analysis, the wightmanite-looking material proved not to be wightmanite. Upon further analyses, the mineral was settled to be meionite. No wightmanite was found during this study.

Meionite crystals occur as semi-radial groups of parallel elongated fibers (Fig. 7a). The color is white with varying amounts of opacity, which may be due to weathering. The individual fibers reach up to 5 mm in length. Characteristic of the fibers is what appear to be cracks or lines at right angles to the elongation (Fig. 7b, 7c, 7d). There is no pattern to the lines and their spacing appears to be random.



Fig. 7a Meionite showing elongated crystal groups in matrix. 4.5mm fov

Meionite, $\text{Ca}_4\text{Al}_6\text{Si}_6\text{O}_{24}\text{CO}_3$



Fig. 7b Meionite showing elongated crystals with what appear to be cracks crossing the crystals at right angles. 1.4mm fov



Fig. 7c Meionite showing single elongated crystal. 3.5mm fov



Fig. 7d Meionite in matrix. 2.5mm fov

Löllingite, FeAs_2

Safflorite, CoAs_2

Individual grains of safflorite and löllingite were identified in the vein system containing chestermanite by Erd and Foord (1988). The present authors have not noticed these species.

Spinel, $MgAl_2O_4$

Individual complex crystals of spinel are dispersed throughout the vein containing the chestermanite and other borates. Their size ranges from 0.2 – 1 mm and their color ranges from a light green to greenish-yellow. The habit is primarily dodecahedral, unusual for the species (Fig. 8a, 8b, 8c). A single crystal has been noticed that appears to be a twin, but its twin geometry has not been proven (Fig. 8d).



Fig. 8a Nearly transparent green spinel crystal showing the dodecahedral habit common for this locality. 2.0mm fov



Fig. 8b Spinel crystal showing a slightly distorted dodecahedral form. 3.0mm fov

Spinel, MgAl_2O_4



Fig. 8c Spinel showing an intermediate between dodecahedral and octahedral habits. 2.5mm fov

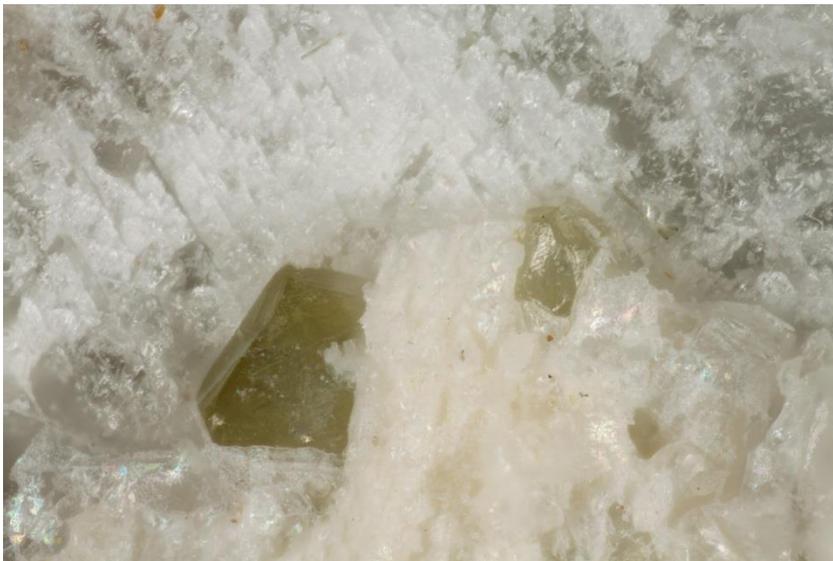


Fig. 8d Flattened spinel crystal. While not proven, this form appears to be a flattened spinel twin similar in form to the "mackle" habit of diamonds. 1.8mm fov

Taramite, $\{Na\}\{CaNa\}\{Mg_3Al_2\}(Al_2Si_6O_{22})(OH)_2$

An amphibole, possibly taramite, was found using Raman spectroscopy. Due to limitations of Raman for mineral identification, the exact species is not known. Only one crystal fragment was observed. It is black and slightly elongated like most amphiboles.

Indeterminate Phases

Erd and Foord (1988) mention four minerals as present which have not been noticed in the current study. These minerals are fluoborite, wightmanite, and two unknowns, suggested to be borates. Fluoborite looks very similar in appearance to the dumortierite in the study material and meionite looks virtually identical to wightmanite, but is not. (<https://www.mindat.org/photo-367057.html>). No data in the 1988 paper for the description or appearance of the unknowns is given.

PARAGENESIS and DISCUSSION

The general paragenesis for the minerals is quite simple. A boron bearing solution reacted with fluorine- and magnesium-bearing host rocks during intense contact metamorphism. Marble containing spinel and other common contact metamorphic minerals formed alongside the primary borates. No secondary enrichment and very little weathering are evident.

Chestermanite is presumed to be related to the presence of antimony in the mineral solutions, though antimony is only a trace element and of unknown origin. In the absence of antimony, ludwigite might have been produced.

The presence of boron in the marbles presents a problem. If it were a result of the precursor volcanic rocks, why is there only miniscule silicon in the marbles? The lack of silicon implies that the lavas were not a part of the specific sediments which became the marbles of interest here. If the boron were a component of the limestones, why did the boron remain, especially in areas of high concentration, since it is highly soluble and mobile and should have washed away during deposition (Palmer, 2017)? The only remaining source is from the granites which intruded and caused the metamorphism.

Possible Origin of Boron

As an alternative to the conventional wisdom thinking of the past, the authors wish to share another theory on the possible origin of boron found at this locality. Boron (as well as lithium and beryllium) on earth derives from cosmic ray spallation (Vangioni-Flam et al., 2000). This is different from the majority of the other elements, which derive from fusion nucleosynthesis during the hot formation of the earth. In the spallation process, cosmic rays bombard carbon atoms (atomic number 6) in the atmosphere and the uppermost 3 meters of the crust, essentially blasting molecular fragments off. The result of this spallation is the creation of both boron (atomic number 5) and hydrogen (atomic number 1).

Possible Origin of Boron (con't.)

Four side effects of this process are:

- 1) It is inefficient. The production of boron is slow.
- 2) As a result of (1), the concentration of boron in the crust is low, roughly 3-4 orders of magnitude less than predicted by the concentrations of neighboring elements (see WebElements).
- 3) As a result of (2), boron minerals are relatively scarce, since a long period of time is needed to build an amount sufficient to produce minerals in sufficient quantities to be noticed.
- 4) The spallation process continually creates boron. It is one of the only elements whose concentration is increasing with time.

Boron accumulates on land and in the oceans. The oceanic concentration is larger (4.5 ppm vs. < 0.1 ppm on land) because of boron's high solubility (Palmer, 2017). Boron is transported in the H_3BO_3 and $B(OH)_4^-$ forms (Deverel et al., 2012), which prefer a pH < 9. The resulting boron-rich oceanic sediments and fluids are later subducted. The boron they contain is combined as a substitution for aluminum and silicon in common rock forming silicate minerals and silicate rocks as shown below.

vesuvianite	up to 8000 ppm
plagioclase	up to 2000 ppm
granite (simple)	20 to 80 ppm average
granite (tourmalinized)	900 ppm average
granodiorite	50 ppm average
greisen	1300 ppm average (up to 5% recorded)
aplite	550 ppm average

(Data from Christ and Harder, 1969)

These boron-containing silicates become incorporated in the reformed crustal rocks and uplifted as granite and related plutonic rocks (Palmer, 2017). Evidence of significant boron inclusion in granites can be seen by the presence of tourmalines, which are borosilicate minerals. These plutonic rocks intrude, and contact metamorphose, the overlying limestone rocks, releasing some of their boron in the process. The result is small, localized pods rich in primary borate minerals. Perhaps not coincidentally the form the boron takes in the resulting minerals is BO_3^{-3} , which is the same form exhibited in its transportation.

Note that lithium and beryllium are produced in the same manner as boron (Vangioni-Flam et al., 2000) and also are known to accumulate in granite pegmatites.

Similarity to Other Deposits

The nearby Twin Lakes area has ludwigite reported. It is a part of the same marble stock discussed here.

Crestmore Quarries, Riverside Co., CA, show many similarities to the Huntington Lake deposit. Mississippian age magnesium-rich limestones were contact metamorphosed by pegmatite-rich quartz monzonites and diorites in the early Triassic (Woodford et al., 1941). The resulting marbles contain a rich assemblage of minerals, including several small pods of ludwigite, fluoborite, and wightmanite. The pegmatites present in the quartz monzonites are famous among mineral collectors for their tourmalines (see MinDat for Jensen Quarry, Riverside Co., CA, <https://www.mindat.org/loc-3525.html>).

An interesting coincidence is the occurrence of wiluite at the Bill Waley mine in Tulare Co., CA, some 50 miles (80 km) due south of this locality. Wiluite is a boron dominant member of the vesuvianite group and the Bill Waley mine is a Sierra Nevada roof (Krauskopf, 1983; MinDat <https://www.mindat.org/loc-40675.html>).

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