Geology of the Monte Blanco Borate Deposits, Furnace Creek Wash, Death Valley, California

Open-File Report 2019–1111

U.S. Department of the Interior
U.S. Geological Survey

Cover.
A tabular, white, east-dipping Monte Blanco borate deposit (left skyline) within interbedded sedimentary and volcanic rocks of the Furnace Creek Formation. View to northwest with white playa deposits, Death Valley, California. Photograph by W.M. Pennell

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By S.J. Muessig, W.M. Pennell, J.R. Knott, and J.P. Calzia

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Preface

The geology upon which this report is based was mapped by Siegfried Muessig assisted by Frank M. Byers, Jr., in March and April 1954 for the U.S. Geological Survey's support of the U.S. Navy's "Mojave Project," a program to document the boron resources within the United States.

In the late 1940s and throughout the 1950s, the U.S. military had a very aggressive program to develop, test, produce, and utilize "zip fuels," the name given to "energy-dense" boron-rich fuels. The Navy funded a study of the borate deposit at Monte Blanco, California, among others, as part of a wider effort to ascertain the potential volumes of boron resources in the United States that could be used in boronated fuels to power rockets and jet aircraft.

In 1957, when it became apparent that persistent technical problems made it increasingly unlikely that "zip fuels" were going be utilized in the large volumes originally envisioned, the Navy withdrew its support for the boron resource studies, including funding for publishing the reports from such field programs as Monte Blanco. Before the Navy's withdrawal, Muessig submitted his reports on Monte Blanco's geology and borate resources to the U.S. Geological Survey, but these were never published.

Here, "The Geology of the Monte Blanco borate deposits, Furnace Creek Wash, Death Valley, California," is published as submitted by Muessig and reviewed by the U.S. Geological Survey staff in the 1950s, except for some minor changes and additions. The vast majority of this report is the work of the senior author; the junior authors were involved in preparing this report for publication, researching and making footnoted insertions, substitutions, additions, including an appendix 1 (by J. Knott), which updates some structural details and stratigraphic correlations of the region.

There are few borate deposits worldwide for which geologic details have been published, and even fewer such deposits that crop out, lie within a public park, and provide reasonable accessibility to any sightseer, student, researcher, or other interested visitor. It is the authors' goal to help fill this void by publishing this timeless study.

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Geology of the Monte Blanco Borate Deposits, Furnace Creek Wash, Death Valley, California

By S.J. Muessig,[1] W.M. Pennell,[2] J.R. Knott,[3] and J.P. Calzia[4]

Abstract

The Monte Blanco borate deposits are located along the southern margin of Death Valley's Furnace Creek Wash, south of Twenty Mule Team Canyon road in California. Topographic and geologic mapping by S. Muessig and F.M. Byers, Jr., in 1954 documented these deposits' geologic settings, geometries, mineralogies, and chemical characteristics. They estimated borate resources at the time to be in excess of 550,000 tons B_2O_3.

The borate bodies are composed of predominantly ulexite and colemanite. They lie beneath Monte Blanco itself and along a northwest-trending series of conspicuous, white hills and mounds formed by northeasterly dipping, fine-grained sedimentary beds and basaltic volcanic rocks of the Miocene and Pliocene Furnace Creek Formation.

Steeply dipping beds of ulexite ($NaCaB_2O_3 \cdot 8H_2O$) and interbeds of shale form the main mass of the principal Monte Blanco deposit; colemanite ($Ca_2B_6O_{11} \cdot 5H_2O$) occurs peripherally in tabular masses of limestone that are 10 to 50 feet thick. The deposit is fault-bounded on the north and grades laterally into shales and tuffs on the south.

Satellite borate deposits occur to the northwest of the principal Monte Blanco deposit. They are composed of colemanite and ulexite and are steeply dipping to flat-lying tabular bodies, 10 to 60 feet thick. The bodies pinch out in the shale that forms both their hanging walls and their footwalls. Shale beds occur in both the colemanite and the ulexite masses. Most of the satellite bodies form hogbacks.

Geologic data suggest that in Miocene and Pliocene time, fine-grained sediments, volcanic debris and flows, and volcanically associated, boron-rich fluids gradually filled a fairly flat playa-like environment. At times, thick beds of felty crystals of ulexite developed and were interlayered as lenses in a thick series of mudstones as is seen today at the Eagle Borax works. After burial, the exterior of the ulexite deposit was altered to massive colemanite by ground water, which produced the "shell" of colemanite that typically surrounds the presently outcropping ulexite bodies.

Introduction

The Monte Blanco area of this report is on the southern side of Furnace Creek Wash, Death Valley, California, in NE¼ sec. 17, W¼NW¼ sec. 16, and S½SE ¼, sec. 8, T. 26 N., R. 2 E., San

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Bernardino baseline and meridian. The Twenty Mule Team Canyon road, shown on figure 1 and on the Furnace Creek 7.5' Quadrangle, connects the area with California Highway 190 in Furnace Creek Wash.

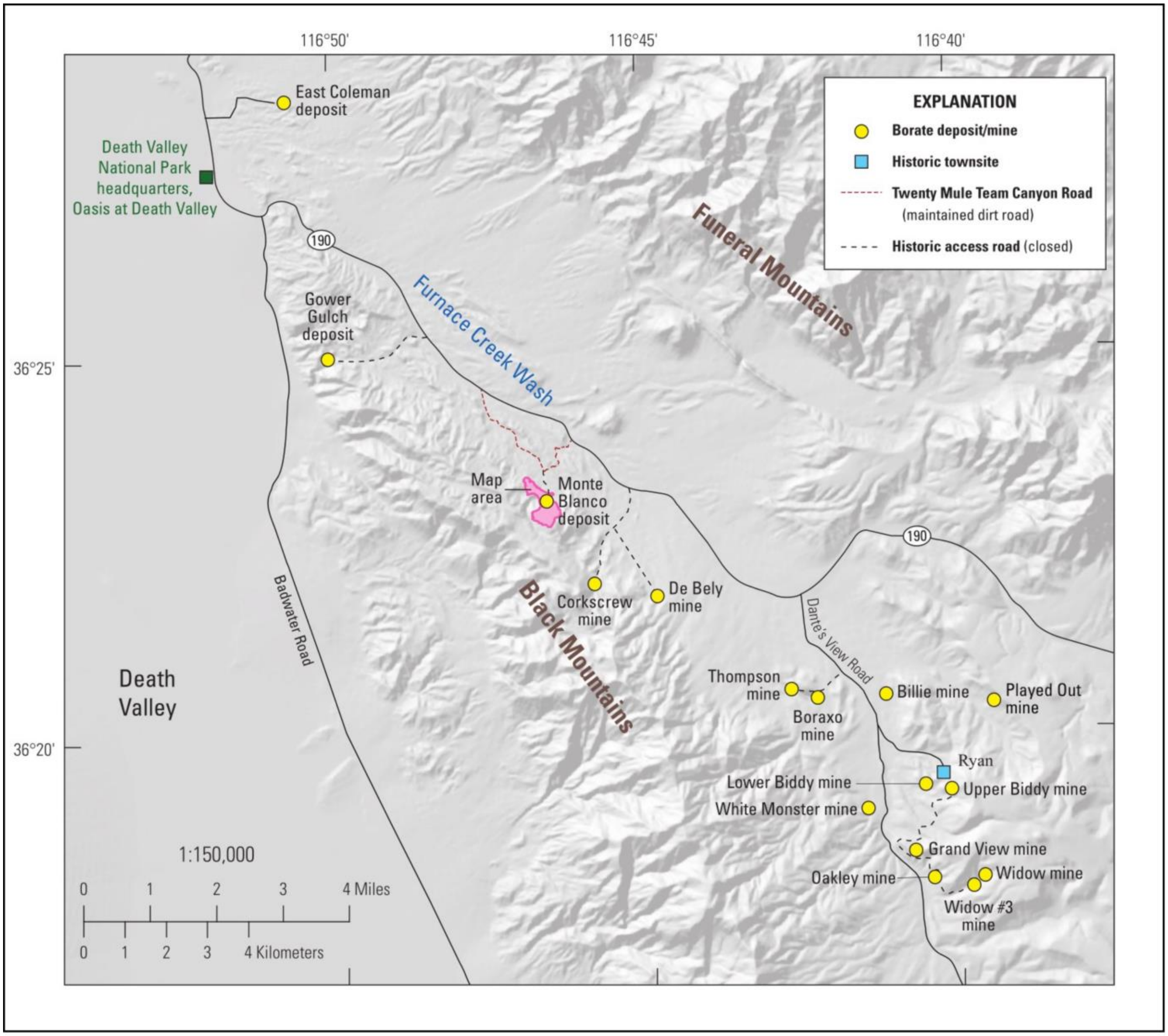

Figure 1. Location map of the Monte Blanco and other borate deposits near Furnace Creek Wash, Death Valley, California.

“Monte Blanco” is the informal local name given to twin, low, conspicuous, white spurs that project northward from the base of a prominent high point on “Mineral Monument hill” (delta 9 on plate 1 and fig. 2) capped by survey marker USMM 40, as shown at the southernmost end of plate 1 and in figure 2A.

The borate minerals ulexite and colemanite form the principal Monte Blanco borate deposit and nearby satellite bodies, which extend northward from Monte Blanco for about 3,000 feet in a single line of hogback ridges. Maximum relief of the area is about 900 feet, and the altitude of the lowest point is about 1,300 feet. The area has a dry climate with almost no vegetation.

Field work was done in 20 days during March and April 1954. All effort was directed toward mapping the borate resources of the deposits in the area; field inquiries not pertinent to the immediate resource were made only when they caused little deviation from this main purpose.

An ore resources report was submitted to the U.S. Geological Survey's Mineral Deposits Branch, Washington, D.C., on August 23, 1954.

This report was drafted by Muessig from memory, from Byers' field notes, and especially from Muessig's detailed field notes on mineral occurrences, types and relations to enclosing rocks and other minerals.

Within this report are many references to "delta" points (for example, "at delta 2"). These are major surveying stations occupied by the plane-table and Muessig during the field work, and they are labeled on plate 1 and figure 2*A* as small blue triangles (for example, Δ2), useful positions from which to locate observations documented herein.

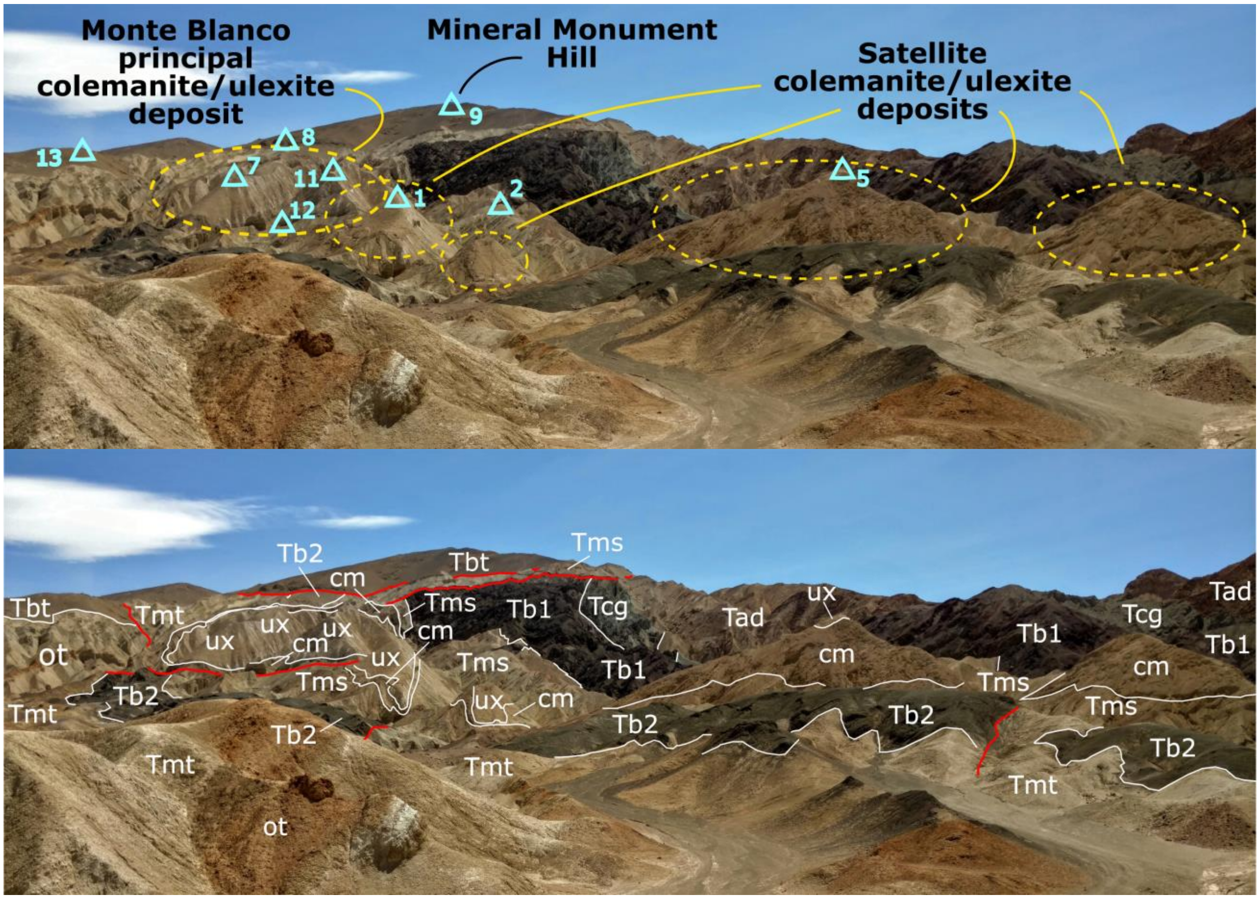

Figure 2. Photographs looking south toward location of the principal Monte Blanco Deposit. In *A*, photograph is annotated with the borate deposits in the Monte Blanco area and the delta point locations (shown in light blue). In *B*, same photograph as part *A*, photos is annotated to show generalized geology of the Monte Blanco area. Sedimentary contacts in thin white lines; faults in red lines. Stratigraphic units: Tad, Artists Drive Formation; units in the Furnace Creek Formation are Tcg, conglomerate; Tb1, lower basalt; Tms, lower mudstone; Tb2, upper basalt; Tmt, upper mudstones and tuffs; ot, orange tuff marker bed in Tmt; Tbt, basaltic tuff. Borate minerals: cm, colemanite; ux, ulexite. Photograph by W. Pennell, 2017.

Descriptive Geology[5]

The rocks exposed and mapped in the greater Monte Blanco area of plate 1 and figure 2 are probably Miocene and Pliocene (see Noble, 1941, p. 956, and appendix 1) and have an aggregate thickness of about 2,100 feet. They comprise mudstones, tuffs, conglomerates, basalts, and lenticular lenses or beds of the borate minerals ulexite and colemanite; they contain much volcanic material and are all terrestrial.

Two formations are recognized in the mapped area: the Artist Drive Formation, whose base is not exposed; and conformably (?) above it, the Furnace Creek Formation, which contains the borates. The formations both crop out as northeastward-dipping beds that are cut by high-angle faults of northeast, west, and northwest trend. Two apparently low-angle thrust faults in the southwestern part of the map area modify the otherwise simple structure.

Unit `Tad`, Artist Drive Formation

The Artist Drive Formation (Noble, 1941, p. 955–956), unit `Tad`, crops out on the northwest flank of “Mineral Monument hill” (see plate 1 and fig. 2) and extends to the northwest beyond the mapped area. It underlies the Furnace Creek Formation with apparent conformity and is faulted off by low- and high-angle faults on the southeast. Only the upper 400 feet of the unit is exposed near Monte Blanco; here it consists of interbedded, well stratified, light yellowish-brown siltstone and sandstone.

Unit `Tfc`, Furnace Creek Formation

The Furnace Creek Formation (Noble, 1941, p. 955–956), unit `Tfc`, includes all the rocks that overlie the Artist Drive Formation. The upper part of the Furnace Creek Formation is not exposed in the area mapped. The part that is exposed and mapped is about 2,000 feet thick and was divided into six major mappable stratigraphic units. These will be treated as “units” in this report. As the field work was concentrated on the borate lenses and bodies, descriptions of the stratigraphic units are only briefly summarized in the stratigraphic column of figure 3 and in the sections on plate 1.

Unit `Tcg`, Conglomerate

In the Monte Blanco area the lowest unit of the Furnace Creek Formation consists of interlayered, poorly sorted greenish conglomerate and sandstone beds, which overlie the sandstones of the Artist Drive Formation conformably or at least with parallelism (see plate 1 cross section B–B’). Conglomerate beds predominate over sandstone. In the coarse beds, the fragments range in size from pebbles to boulders, are well rounded to subangular, and consist chiefly of Paleozoic limestone, as well as some granitic and Tertiary volcanic rocks. The matrix appears to be tuffaceous throughout the unit. Some beds are composed of well-rounded boulders that are broken by healed fractures and lie in a poorly consolidated tuffaceous matrix. The unit is about 200 feet thick in this area and extends northwestward to the mouth of Gower Gulch (fig. 1).

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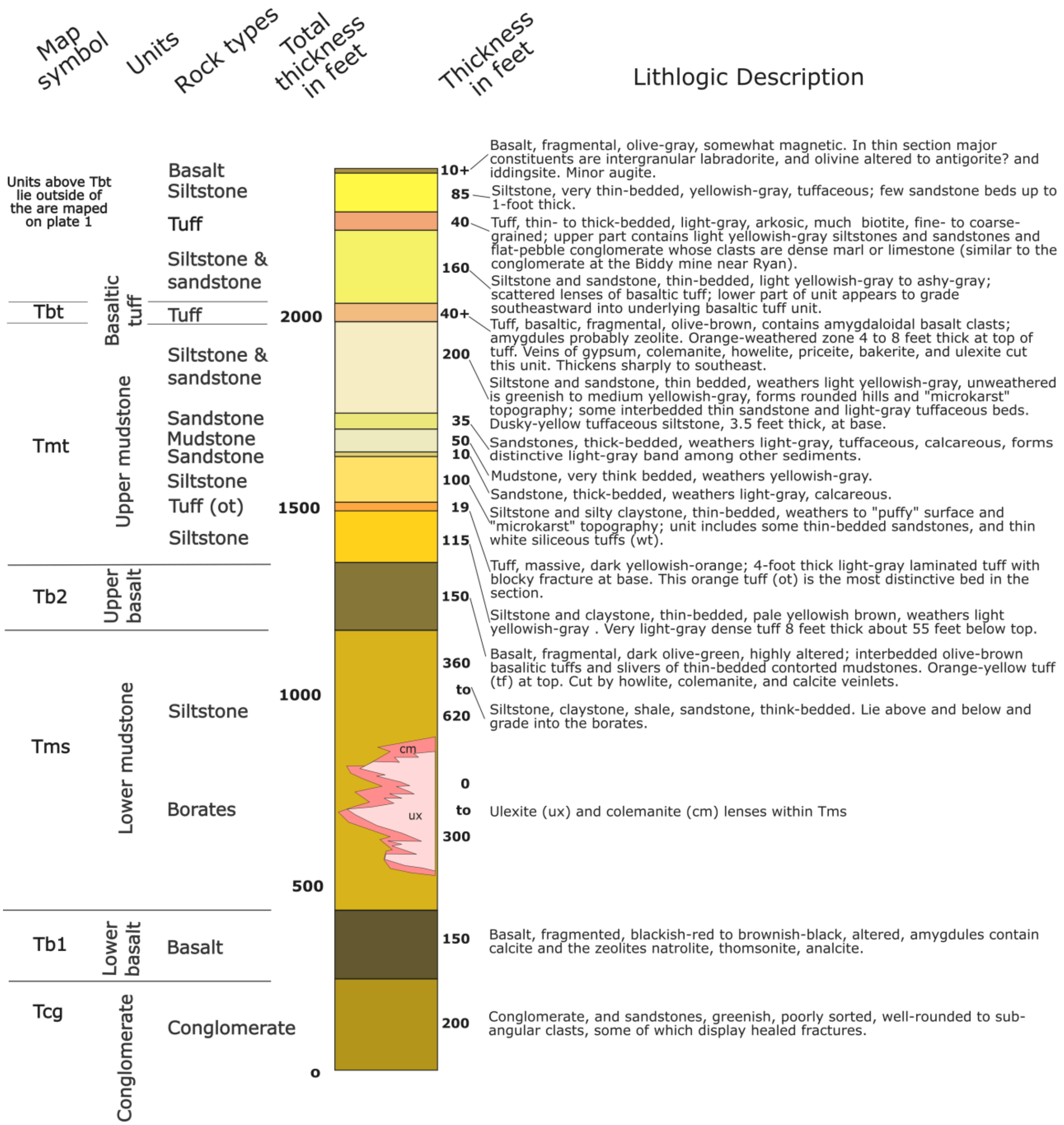
[5] See appendix 1 for the current understanding of ages of the formations and the faults in the Death Valley region.



Basalt, fragmental, olive-gray, somewhat magnetic. In thin section major constituents are intergranular labradorite, and olivine altered to antigorite? and iddingsite. Minor augite.

Siltstone, very thin-bedded, yellowish-gray, tuffaceous; few sandstone beds up to 1-foot thick.

Tuff, thin- to thick-bedded, light-gray, arkosic, much biotite, fine- to coarse-grained; upper part contains light yellowish-gray siltstones and sandstones and flat-pebble conglomerate whose clasts are dense marl or limestone (similar to the conglomerate at the Biddy mine near Ryan).

Siltstone and sandstone, thin-bedded, light yellowish-gray to ashy-gray; scattered lenses of basaltic tuff; lower part of unit appears to grade southeastward into underlying basaltic tuff unit.

Tuff, basaltic, fragmental, olive-brown, contains amygdaloidal basalt clasts; amygdules probably zeolite. Orange-weathered zone 4 to 8 feet thick at top of tuff. Veins of gypsum, colemanite, howelite, priceite, bakerite, and ulexite cut this unit. Thickens sharply to southeast.

Siltstone and sandstone, thin bedded, weathers light yellowish-gray, unweathered is greenish to medium yellowish-gray, forms rounded hills and "microkarst" topography; some interbedded thin sandstone and light-gray tuffaceous beds. Dusky-yellow tuffaceous siltstone, 3.5 feet thick, at base.

Sandstones, thick-bedded, weathers light-gray, tuffaceous, calcareous, forms distinctive light-gray band among other sediments.

Mudstone, very think bedded, weathers yellowish-gray.

Sandstone, thick-bedded, weathers light-gray, calcareous.

Siltstone and silty claystone, thin-bedded, weathers to "puffy" surface and "microkarst" topography; unit includes some thin-bedded sandstones, and thin white siliceous tuffs (wt).

Tuff, massive, dark yellowish-orange; 4-foot thick light-gray laminated tuff with blocky fracture at base. This orange tuff (ot) is the most distinctive bed in the section.

Siltstone and claystone, thin-bedded, pale yellowish brown, weathers light yellowish-gray . Very light-gray dense tuff 8 feet thick about 55 feet below top.

Basalt, fragmental, dark olive-green, highly altered; interbedded olive-brown basalitic tuffs and slivers of thin-bedded contorted mudstones. Orange-yellow tuff (tf) at top. Cut by howlite, colemanite, and calcite veinlets.

Siltstone, claystone, shale, sandstone, think-bedded. Lie above and below and grade into the borates.

Ulexite (ux) and colemanite (cm) lenses within Tms

Basalt, fragmented, blackish-red to brownish-black, altered, amygdules contain calcite and the zeolites natrolite, thomsonite, analcite.

Conglomerate, and sandstones, greenish, poorly sorted, well-rounded to sub-angular clasts, some of which display healed fractures.

Figure 3. Stratigraphic column of the Furnace Creek Formation, Monte Blanco area of Death Valley, California.

Unit Tb1, Lower Basalt.

Overlying unit Tcg, the conglomerate unit, is unit Tb1, the lower basalt unit, which is about 150 feet thick (fig. 2*B*). The lower basalt is blackish red to brownish black, somewhat fragmental, and appears to be highly altered. None of its constituent minerals, other than those in amygdules, were determined. The amygdules, which are fairly abundant in the basalt, contain natrolite, thomsonite, and analcite, as well as calcite. The fragmental texture and abundant amygdules suggest that the basalt is a flow or series of flows rather than an intrusive body. So far as could be determined, this basalt is likely the same flow(s) that underlies the borate beds in Corkscrew Canyon (fig. 1).

Unit `Tms`, Lower Mudstone

Unit `Tms`, the lower mudstone unit, lies between the lower basalt (unit `Tb1`) and the upper basalt (unit `Tb2`) of the Furnace Creek Formation. It hosts all the area's borate bodies, and it crops out in a band that extends northwestward from Monte Blanco (see plate 1 cross section A–A' and cross section C–C'). It also crops out along the 1,800-foot contour on the north slope of the "Mineral Monument hill" (delta 9, fig. 2, and plate 1). The borate deposits themselves are treated as separate units of the Furnace Creek Formation.

There are light dusky yellow sandstones and siltstones in the lower part of the unit. They are well bedded, and many of the sandstone bedding surfaces display ripple marks. Three-toed footprints were found on the surface of one of the sandstone beds. The upper and thicker portion of the unit is comprised of light olive-green to grayish-green calcareous siltstones, claystones, and shales, which are very thinly bedded and laminated. Abundant thin gypsum veinlets are both parallel to and cut across the bedding of these strata.

The thickness of the lower mudstone unit was measured in five places. The total thickness of unit is approximately 380 feet along cross-section A–A'; 500 feet in the area approximately 800 feet to the southwest of A–A'; 620 feet just southeast of the northeast-trending fault near delta 2; and 550 feet immediately northwest of delta 12. The thickness of the lower mudstone unit from the top of the borate units to the base of the overlying upper basalt unit is more uniform, ranging from approximately 100 feet thick along the lines of cross-sections A–A' and B–B' to 70 feet thick east of delta 1. The sedimentary rocks below the borates are much more variable in thickness than those above, ranging from a maximum of 200 feet along cross section A–A' to approximately 60 feet at cross section B–B', to a minimum of about 50 feet at the flat-lying beds on the north shoulder of "Mineral Monument hill."

These measurements of the lower mudstone seem to show that the thickness of the unit as a whole increases to the southeast, and that the thickness of this unit's sedimentary strata below the borates decreases in the same direction. The significance of these thickness changes is discussed below under the heading, "Stratigraphic and Structural Control of the Deposits."

Borate Unit Within the Lower Mudstone Unit

The borate bodies are composed of mineralized lenses or beds contained within (and described as part of) the lower mudstone unit in the sections that follow (see the cross sections on plate 1, which show the relationships of the borate minerals to the enclosing stratigraphy), and plate 1, which shows the areal distribution of the borate minerals. Later sections of this report deal with the mineralogy and genesis of these borate bodies.

Distribution.—As shown on plate 1 and fig. 2*B*, the borate minerals, ulexite and colemanite (units `ux` and `cm`, respectively, on plate 1), occur in stratiform bodies that have much the same northwest-trending outcrop pattern as the surrounding sediments. Topographically, they crop out in a line of disconnected northwest-trending hogbacks. The colemanite bodies along the north shoulder of "Mineral Monument hill" are an exception to this pattern.

Lithology.—Simplistically, the borate bodies are composed of lenses of ulexite and mudstone interbeds enclosed by peripheral, tabular, colemanite-rich, limestone masses. In detail, ulexite occurs as massive white lenses as thick as 30 feet, interbedded with greenish, laminated, calcareous claystone and shale beds that are as much as 15 feet thick (fig. 4). Partings of claystone are spaced at irregular intervals throughout the ulexite. The ulexite is fibrous, dense, and massive and has columnar structure that is not continuous across the claystone partings. Fragmented chips of laminated, cream-colored marl and limestone occur throughout the ulexite in discontinuous beds and irregularly spaced clusters. The content of ulexite within these mineralized intervals ranges up to 75 percent, and cross-cutting colemanite veins occur throughout. The ulexite lenses weather to smooth, rounded hills that have a dirty white crust that is underlain by 2 feet, or less, of a white powdery efflorescence of ulexite, borax, and (or) thenardite. Small white “puffs” of ulexite (which we call “cottonballs”) are of recent origin and occur in the shale and claystone interbeds near the surface.

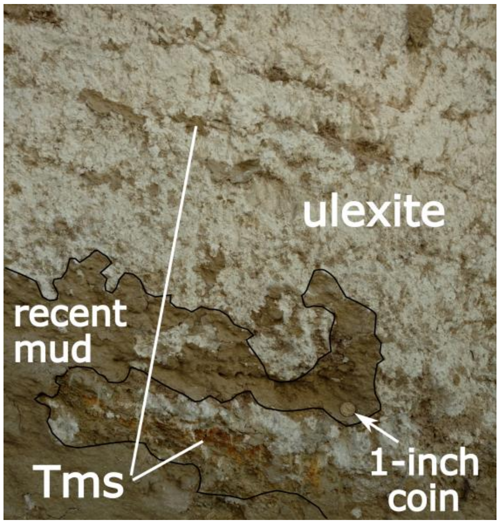


Figure 4. Photo of ulexite at Monte Blanco. This occurrence is approximately 100 feet due east of locality delta 7 (plate 1). Notice the difference in appearance of ulexite that occurs within the Tms mudstones in the bottom part of photo where the ulexite is more massive, compared to the upper part of the photo, where Tms mudstones form gently dipping, thin interbeds within the ulexite. The “recent mud” was deposited on the canyon wall during flooding, probably in the late 20th century. Photograph by W. Pennell, 2017.

Most of the colemanite occurs peripherally to the ulexite; the detailed relations between the two borate minerals are subtle, but the mineral bodies appear to grade into, and interfinger with, each other. The peripheral colemanite always occurs in, or with, yellowish-gray limestone or marlstone and forms three broad types of rock.

The most common occurrence of colemanite is as coarsely crystalline masses that fill the interstices between oriented and unoriented limestone chips and fragments, some of which have primary bedding features. In some places, a single crystal mass having a common crystallographic orientation over the entire thickness of a limey bed was seen.

Most of the colemanite is clear to white, but some of it has color much like that of the limestone. Most of these beds have irregular tops and bottoms and are as much as 1 or 2 feet thick. The limestone fragments commonly have angular irregular outlines, many have embayments of colemanite, and some have minute to large fractures that are filled with colemanite. The colemanite content of these beds ranges from a few percent, in beds that are chiefly limestone, to nearly 100 percent, in sporadically occurring, white, crystal masses that occur in similar beds that have an overall lower borate mineral content. Thin beds of greenish shale and claystone are interbedded with, or form partings within, the colemanite-rich limey beds.

The colemanite-rich limey beds are best developed in an occurrence of several beds under the ulexite in the borate body at delta 1 (fig. 2; plate 1; fig. 5), and are the principal type of borate mineralization cut by the adits accessing the northwest-trending group of satellite borate bodies. (This colemanite-rich limestone also forms the borate bodies on the northwestern shoulder of “Mineral Monument hill.” At the principal Monte Blanco deposit, the colemanite beds on the southwestern and western side, as well as some of those that crop out along the eastern side, are of this type.

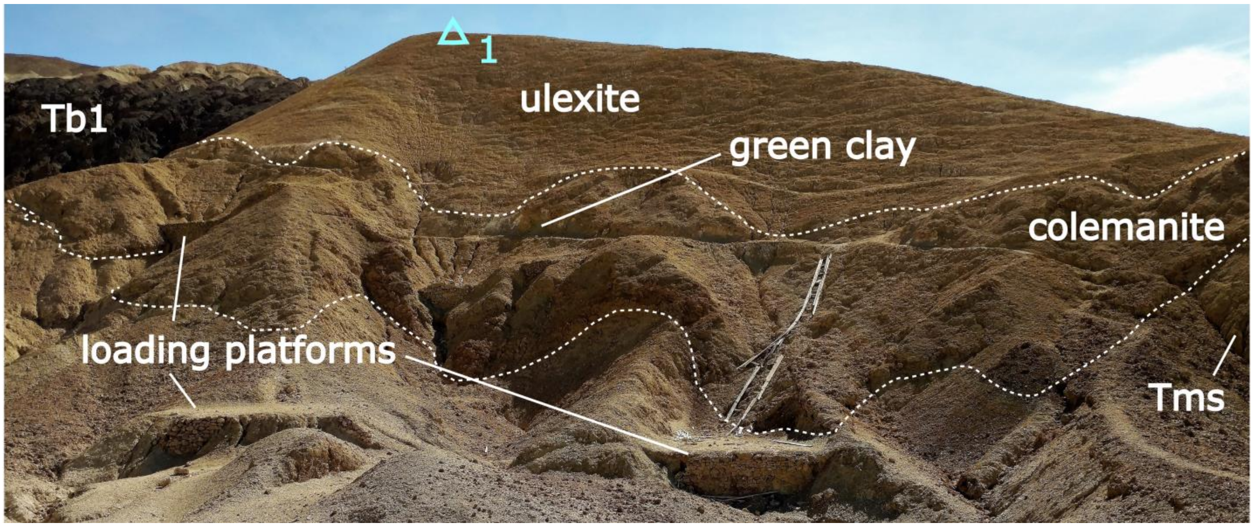


Figure 5. Photograph looking southwest of the borate body underlying the delta 1 hogback (see plate 1 for map location). The ulexite core of the borate body is recognized by its relatively smooth surface expression. The ulexite is bordered by the rougher-surfaced, massive, colemanite-rich limey beds along the lower part (stratigraphic top) of the hill's northeastern-facing dip-slope (note dip on unit Tms). Greenish clay and siltstone interbeds within the colemanite are apparent along the access road in the middle of the photo. The loading platforms are composed of colemanite blocks; the mined colemanite ore was lowered down the wooden decline, pieces of which are scattered down-slope at photo's right center, to the main loading platform in the lower left-center of the photo. Photograph by W. Pennell, 2017.

The second type of colemanite occurrence, which we call "drusy colemanite," is confined to the principal Monte Blanco borate deposit (fig. 6). It occurs along its northern boundary fault, is somewhat like the colemanite in the lime-rich beds in that it forms the matrix for, and apparently has replaced, limestone and marlstone. This drusy colemanite, however, is characterized by having very many irregularly shaped cavities lined with tiny, sugary, colemanite crystals, or druses, some of which are large enough for a man to walk into (for example, in the adit at delta 12 [fig. 2; plate 1]). Most of the druses have two long dimensions relative to the third one, many are inter-connected, and in many places their long dimensions are crudely parallel to what appears to be bedding. Probably much of the drusy colemanite-rich rock contains about 70 percent colemanite.

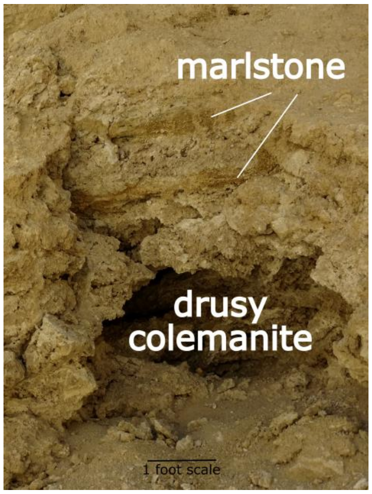


Figure 6. Photograph of a typical drusy colemanite-lined cavity. This occurrence is approximately 100 feet east of delta 7 (see plate 1 for location). Photograph by W. Pennell, 2017

The third type of colemanite occurrence in the map area is called “fragmental colemanite.” This rock consists of fragmental cream-colored limestone that contains colemanite as fine fracture fillings, crystal-lined cavities, or as finely crystalline mineral disseminated throughout the rock. The mineralized rock is loosely consolidated and is very porous. This fragmental colemanite forms the broad cap of the hill south of delta 7 (plate 1). It also occurs along approximately 30 feet of the adit whose portal is 500 southwest of delta 14 where it appears to be a down-dip “facies” of the ulexite mineralization that crops out on the surface above.

Stratigraphic relations.—Exposures of the borate unit, specifically in the canyon just west of delta 6 (plate 1) and in the canyon about 340 feet N 60° E from delta 3, show that the colemanite beds, and hence the borate unit as a whole, pinch out down-dip and along the strike. At these places, near the thinnest parts of the lenses, the limestone host rock contains less colemanite than where it is thicker. Most of this limestone, in turn, pinches out into claystones and shales just a few feet downdip from where it contains abundant colemanite, and virtually all limestone host beds that extend into the claystones contain some borate minerals. Elsewhere, away from the margins of the borate bodies, many thick limestone beds within the lower mudstone unit contain no borate minerals.

Colemanite lenses occur as sharply defined interbeds within the enclosing mudstones. Wherever reliable attitudes of the bedding in the borates host rocks can be measured, the mineralized beds are parallel to the bedding of the enclosing mudstones. The attitude of the contact between the overall borate unit and the lower mudstone unit, however, is different from the attitude of the beds themselves. This is obvious, for example, southeast of delta 1 (plate 1) and about W 20° S of delta 11, where the contact dips about 30 degrees, but the underlying beds dip about 45 degrees. (The dip of the contact was determined using three surveyed altitudes on the contact). This contact is gradational, as the individual borate-bearing beds actually tongue out into the enclosing sediments, and some colemanite-rich beds lie beneath the contact, (for example, under the colemanite body at delta 10).

Although treated as more-or-less separate entities above, the individual borate bodies—or, what remains of them—can reasonably be considered to have been a part of a single borate deposit within the lower mudstone unit. From the outcrop pattern, it appears that this original deposit had one long dimension, which is oriented parallel to the strike of the enclosing beds. Because the top of the original deposit is eroded away, not much is known of its dimension normal to strike, but in the third dimension, normal to strike and dip, measurements at many places demonstrate that the original deposit thickened sharply up section, from its thinnest “roots” to its maximum thickness apparent today.

Extreme thickening of the borate deposit is exposed at two locations. The borate body that lies under the delta 1 hill has a thickness of about 150 feet in the stream wash that transects its southeastern part. It pinches out at its northwestern end, which is 90 feet lower in altitude. The largest borate deposit underlying Monte Blanco is shown in cross-section B–B’ (see plate 1). Its thickness, as measured normal to strike south of delta 7, is about 300 feet, and its down-dip thickness, as measured on its faulted-off down-dip extension just west of delta 6, is about 10 feet.

This up-dip thickening of the borate unit is also reflected in the up-dip thinning of the mudstones below the borate bodies. It might appear, moreover, that because the mudstones above the smaller satellite borate bodies, northwest of the principle Monte Blanco deposit, are of fairly constant thickness, this thickening of the borate unit takes place by the successive up-dip occurrence of additional borate lenses at the base of the lower mudstone unit.

Unfortunately, this simplified deduction is probably either too simplistic or regionally incorrect, as the mudstones above the principal Monte Blanco borate deposit, especially due west of delta 13, are much thicker than those overlying the smaller satellite bodies to the northwest. Moreover, the principal deposit appears to grade into a basaltic tuff (northeast of delta 8) that is tentatively identified as the upper basalt unit. If the basaltic tuff is indeed the upper basalt unit, whose base normally lies 70 to 100 feet above the borate unit, then the borates occur progressively higher in the stratigraphic section to the southwest. Evidence indicating that this upward transgression of the borates does take place, at least locally, is also seen just southeast of delta 6, where, south of a west-striking fault, the borate unit lies in fault contact against the upper basalt unit, north of the fault. The borate block is downthrown with respect to the basalts, indicating that the borate beds that occur next to the basalt are stratigraphically younger than the basalt at that place.

Unit Tb2, Upper Basalt

The upper basalt unit lies above the lower mudstone unit with apparent conformity and, in the lower part of the map area, crops out in a northwest-trending band (see fig. 2*B* and cross sections on plate 1). It is faulted off at the foot of the principle Monte Blanco deposit, approximately 150 feet northeast of delta 7. The upper basalt unit is about 150 feet thick at delta 15.

Dark olive-green basalts, which are highly altered and fragmental, make up the major part of the unit. These basalts are aphanitic: there are no megascopically identifiable minerals. In thin section, the rock is intergranular. Labradorite and augite, in laths, are the dominate minerals, and olivine (altered to antigorite? and iddingsite) is a minor constituent (R.D. Allen, written commun., 1954). No flow structures were seen in thin section. Colemanite, howlite, and calcite veins cut the basalt in some places. The aphanitic texture, as often apparent in shallow intrusive rocks and surface flows, suggests that the basaltic magma was quickly cooled, but the lack of amygdules is more typical of intrusive sill emplacement. It is the fragmental and altered nature of the rock which makes its mode of emplacement difficult to deduce.

Interbedded with the basalts are olive-brown basaltic tuffs that are well bedded at some places. Howlite veins cut them near delta 15. Slivers of contorted thin-bedded mudstones occur throughout the unit. At the top of the unit is a distinctive yellowish-brown tuff that is a darker yellowish-orange in its upper part.

Olive-brown basaltic tuffs, containing slivers of contorted thin-bedded mudstones and marlstones, crop out on the northern and northwestern shoulder of “Mineral Monument hill” and are thought to be correlative with the upper basalt unit. The basaltic tuff that is about 200 feet northwest of delta 8 is about 140 feet thick and is lithologically similar to basaltic tuffs in the upper basalt near deltas 14 and 15, including the characteristic orange-brown tuff at its top. Some 560 feet west of delta 13, these basaltic tuffs seem to interfinger progressively westward with very thinly bedded mudstones and limestones into the principal Monte Blanco borate deposit; moreover, the uppermost orange-brown tuff also appears in lenses in the colemanite-rich beds.

Unit Tmt, Upper Mudstone

The upper mudstone unit of the Furnace Creek Formation lies conformably above the Upper Basalt and is comprised of a 500-foot sequence of thin-bedded siltstones, claystones, sandstones, tuffs, and shales (see fig. 3). Within this unit, there is a distinctive yellowish-orange tuff (unit ot on plate 1 and fig. 2*B*) that lies about 100 feet above the top of the upper basalt unit. Southeastward from the B–B’ cross section, this orange tuff is cut by a northwest-trending fault, but does not reappear, as might be expected, among the mudstones that overlie the upper basalt southwest of delta 13, near the principal Monte Blanco deposit. It is unknown whether unmapped faults, subsurface thinning of the tuff, or some other explanation accounts for this absence.

South of delta 10, the lowest bed of the upper mudstone unit is a white tuff, several feet thick, that lies directly above the orange-yellow tuff of the upper basalt. A white tuff also lies above the upper basalt west of delta 13 but, for some reason, no similar tuff occurs above this basalt at delta 15.

Unit Tbt, Basaltic Tuff

The basaltic tuff unit is the youngest stratigraphic unit mapped at Monte Blanco. In the section northeast of delta 15 it crops out about 500 feet above the top of the upper basalt unit and has a minimum thickness of 10 feet. A reconnaissance indicated that this basaltic tuff unit thickens to the southeast, toward delta 13, and forms the cap of “Mineral Monument hill.” On “Mineral Monument hill,” the unit appears to have been cut by a low-angle fault.

The unit consists of bedded, olive-brown basaltic tuff that contains angular to rounded basalt clasts that range from sand to boulder size and whose matrix is chiefly volcanic glass with an index of refraction of 1.51 to 1.52 (R.D. Allen, written commun., 1954).The clasts contain amygdules of analcite, natrolite, thomsonite, and calcite. At delta 13, priceite, howlite, and colemanite are disseminated in the matrix, possibly as fillings, replacements, and (or) detrital material. Close by, priceite, howlite, colemanite, bakerite, ulexite, calcite, and gypsum veins cut the tuff. At one place, an ulexite vein that is rimmed by colemanite grades, within 1 foot, into a borate that looks like priceite. The veins within the tuff are of such diverse types that their study could give some answers regarding the general question of borate mineral genesis.

Above the basaltic tuff unit are a sequence of sediments, tuffs and basalts to the northeast of the mapped area; they are included in the stratigraphic column of figure 3, but are outside the limit of the geologic map (plate 1).

Unit Qal, Alluvium

The Quaternary and Holocene deposits that are found unconsolidated in the stream washes are mapped as alluvium. Other post-Tertiary bodies of rock, such as talus, landslide debris, and so on were not mapped.

Structure

As shown on the geologic map (plate 1), the Furnace Creek and Artist Drive Formations in the northern part of the Monte Blanco area dip 40 to 60 degrees, homoclinally, to the northeast and strike fairly uniformly northwest-southeast. High-angle transverse faults displace some of the beds, but otherwise the area is structurally simple.

In the southern part of the area, the strike of the beds is more north-south, and the dips are generally less steep. The beds that crop out in the northern part of the area and extend into its southeastern part are cut by west-trending normal faults. Several low-angle faults complicate the briefly outlined structural setting, but do not greatly modify it.

Because the structures were mapped over such a small area, their regional significance and relations are not known. Hence, the following section is chiefly descriptive. The order in which the faults are treated has no particular significance.

Northeast-Trending Faults

Faults of northeast trend cut beds of the Furnace Creek Formation transversely in the northern lowland northwest of delta 6. Wherever their attitudes could be determined, they are relatively high-angle faults. Most of these faults are confined to the lower mudstone unit, but some of them also cut overlying and underlying beds. Displacement along them is not more than 100 feet in the mapped area. There are probably many more such faults than those few mapped, but a lack of stratigraphic markers makes their recognition difficult. The small faults at the base of the upper basalt unit, such as those immediately west of delta 15, are probably of this class. Their greater number is due to the fact that they cut a prominent stratigraphic interface and are thus easily recognizable.

East-West Trending Fault Along Northern Side of Principal Monte Blanco Borate Deposit

The principal Monte Blanco borate deposit is bounded along its northern side by a sharply defined, east-west-trending normal fault that dips from 45°to 60° degrees south. The southern block, which contains the majority of Monte Blanco's borate resources, is, relatively, down-dropped by this fault. At the fault's eastern end, the orange tuff is only slightly displaced by the fault, but the fault's apparent right-lateral offset of the stratigraphy increases westward to a measured maximum of about 85 feet. The contact between the lower mudstone and lower basalt units, located about 240 feet southwest of delta 11, is also laterally displaced 85 feet across this fault immediately south of delta 2.

It is not known whether movement on this fault occurred before or after the colemanite in the block above was formed (see section called "Colemanite"). In the adit southeast of delta 6, the fault is a sharp break, and the colemanite in the hanging wall abruptly terminates against it. On seeing the relation there, the strong impression is that the colemanite was faulted after it had formed; however, there are colemanite veins within basalt in the fault's footwall. Clearly all that can be said at this present state of knowledge is that this fault is post-mineralization.

West-Trending Faults on the Northern Slope of "Mineral Monument Hill"[6]

Steeply Dipping Faults

On the north slope of "Mineral Monument hill" the borate lenses, as well as the over- and underlying rocks, are truncated by several west-trending, high-angle faults whose net effect is to offset all the hanging wall beds to the west in right-lateral sense.

The topographically lowest of such faults, and the one with the least effect on the outcrop pattern of the rocks, is about 400 feet west of delta 13 and forms part of the boundary of the principal Monte Blanco deposit on its southeastern side. This eastern fault is approximately 300 feet long. The downward displacement of the southern block increases to the east. The fault is hinged at its western end, where there is no observable displacement, and seems to die out in the mudstones to the east. The fault forms a low scarp and sharply truncates the principal Monte Blanco colemanite lenses. Maximum vertical displacement along this fault is probably less than 100 feet.

To the west of the eastern fault, northeast of delta 10, is a prominent, steeply dipping, normal fault that sharply truncates the lower basalt unit, but its vertical throw, down to the south, is probably less than 50 feet. Eastward, this fault appears to die out in colemanite of the principal Monte Blanco deposit. Proceeding westward (260 feet northeast of delta 10), it cuts a subparallel, low-angle fault and then, 300 feet further to the west, it flattens out and apparently joins this low-angle fault.

The southernmost west-trending normal fault of the Monte Blanco area runs subparallel to the E-W fault northeast of delta 10 and some 150–200 feet to its south up the slope of "Mineral Monument hill." The contact between the upper basalt unit and the overlying upper mudstone unit, where the characteristic tuff and white tuff (tf and wt, respectively, on plate 1) were mapped, the fault's southern hanging wall is laterally displaced by this fault some 900 feet eastward on the northern footwall side of

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[6] See appendix 1 for current understanding of faults in the Death Valley region.

the fault. To the west, this fault bifurcates and the displacement across the two fault splay, as determined by the outcrops of the tuff and white tuff, diminishes to approximately 150 feet. Displacement may much greater to the west where the bifurcated segments join, however, as colemanite and ulexite lenses, which may be the faulted extensions of the original Monte Blanco deposit, occur 1,000 to 3,000 feet west of the mapped area. The position of the lower mudstone unit and the borate bodies between the westerly trending faults along the northern flank of "Mineral Monument hill" is probably due as much to up-dip flattening of dip of these beds as from the displacements along the faults. The colemanite beds near delta 10 are flat lying, as are the mudstones to the east; the steeper dips in this area are probably attributable to contortion of beds along the faults rather than to larger-scale folding.

Gently Dipping Low-Angle Fault

The low-angle fault north of delta 10 separates the nearly flat-lying lower mudstone unit and small colemanite bodies from the steeply dipping conglomerate unit of the Furnace Creek Formation and the upper part of the Artist Drive Formation. The maximum lateral stratigraphic displacement, measured about 280 feet W 15° S from delta 10, is about 500 feet, but displacement decreases to less than 150 feet toward the east. The low-angle fault is truncated at both of its ends by high-angle faults and is clearly older than they are, but it is probably somewhat younger than the folding that tilted the beds.

Low-Angle Fault at Base of Basaltic Tuff Unit on Mineral Monument Hill

There appears to be a north-trending low-angle fault between the basaltic tuff unit and upper mudstone unit on northwest side of "Mineral Monument hill". The mudstones directly beneath this low-angle fault are very much contorted, and some beds appear to be truncated by the fault. Away from this low-angle fault, bedding in the mudstones is regular and undeformed. Bedding in the basaltic tuff unit above the low-angle fault appears to be fairly regular, and the dips are shallower than in the mudstones below. All this evidence points toward the low-angle fault being a reverse fault, but neither the fault's displacement nor its dip are known. This low-angle fault is cut at its northern end by the southern splay of the bifurcated east-west trending steeply dipping normal fault which runs across the northern face of "Mineral Monument hill."

Northwest-Southeast-Trending Fault on the East Side of the Principal Monte Blanco Borate Deposit

A northwest-trending, high-angle, normal fault cuts the upper mudstone unit and the colemanite along the eastern side of the principal Monte Blanco borate deposit. The fault dips to the northeast, and the northeastern block is downthrown. At its northwestern end, the fault terminates at the west-trending fault that truncates the principal borate deposit. Lateral apparent stratigraphic displacement along the fault at this northern terminus is approximately 100 feet, where an orange tuff in the Upper Mudstone unit is faulted against the colemanite. Farther to the southeast, the basaltic tuff unit lies on the northeastern side of the fault; such displacement here may be over 500 feet.

Relative Ages of the Faults

Little can be said with certainly regarding the relative ages of the faults. All faults appear to have occurred after the rocks were folded. The relations on the shoulder of the Mineral Monument hill seem to show that the low-angle faults are earlier, perhaps only slightly so, than the high-angle faults.

Mineralogy

Borate and gangue minerals of the Monte Blanco area are listed in Table 1.

Table 1. Mineralogy of rocks mapped in the Monte Blanco area, Death Valley, California.
[Common rock-forming minerals are not listed]

Species	Formula
Analcite, Natrolite, and Thomsonite	zeolites: hydrous, Na, Al and silicates: thomsonite with Ca
Gypsum	$CaSO_4 \cdot 2H_20$
Thenardite	Na_2SO_4
Calcite	$CaCO_3$
Celestite	$SrSO_4$
Ulexite	$Na_2O \cdot 2CaO \cdot 5B_20_3 \cdot 16H_20$
Colemanite	$2CaO \cdot 3B_20_3 \cdot 5H_2O$
Meyerhofferite	$2CaO \cdot 3B_2O_3 \cdot 7 H_2O$
(Inyoite)	$2CaO \cdot 3B_2O_3 \cdot 13H_2O$
Probertite	$Na_2O \cdot 2CaO\ 5B_20_3 \cdot 10H_2O$
Howlite	$4CaO \cdot 5B_2O_3 \cdot 2SiO_2 \cdot 5H_2O$
Bakerite	$8CaO \cdot 5B_2O_3 \cdot 6SiO_2 \cdot 5H_2O$
Priceite	$9CaO \cdot 11B_2O_3 \cdot 16\ H_2O$
Borax	$Na_2O \cdot 2B_2O_3 \cdot 10H_2O$

Zeolites

Three zeolites, analcite, natrolite and thomsonite, were identified in amygdules in the lower basalt unit of the Furnace Creek Formation and in basalt fragments from the basaltic tuff unit near delta 13 (plate 1) using the mineral grains' index of refraction and birefringence (R.D. Allen, written commun., 1956).

Gypsum

Gypsum at Monte Blanco most commonly occurs as thin fibrous veinlets in the mudstones of the area. The veinlets are predominately parallel to bedding but also cross cut it. Gypsum of this type is found as an abundant constituent of the mudstones interrelated with the borates, especially ulexite mineralization. White gypsum veins as much as several feet thick, cutting the basaltic tuff unit, are common near delta 13. Northeast of delta 15 some of the vein gypsum as selenite has irregular masses of colemanite within it. In this locality there are also veins of gypsum that contain fragments of crystalline colemanite. No clear selenite, such as that which fills vugs in crystalline colemanite at the Grand View mine (see fig. 1), was seen at Monte Blanco.

Thenardite

Thenardite occurs as an efflorescent white powder on and below the surface of the ulexite outcrops in the area. It is intimately associated with powdery efflorescent ulexite and borax, and is as much as 1 or 2 feet thick in many places.

Calcite

Calcite veins that cross cut bedding are common in the upper basalt and basaltic tuff units. The calcite is mostly opaque, earthy, and in some places displays irregular crustified banding with openings parallel to the vein. An unusual calcite occurrence is 190 feet northwest of delta 10, where large well-formed crystals of clear colemanite display deeply etched crystal faces and contain rough-surface, acicular, calcite masses. The somewhat reticulated calcite masses lie directly upon the irregularly etched colemanite surfaces and, on one specimen, at least, do not project outward beyond the original colemanite crystal faces. The calcite is clearly an alteration product of colemanite.

Celestite

Celestite was found at only two places in the Monte Blanco area. Light-yellowish-gray nodules of celestite, some botryoidal and up to several inches in diameter, occur in the mudstones that grade into colemanite, about 390 feet N 45° W from delta 8. The nodules are very dense and have no apparent internal structure. Several well-formed, tabular crystals were found on the weathered surface of the colemanite that crops out 190 feet northwest of delta 10. No clear crystals growing on colemanite, such as are common at other colemanite localities in Death Valley, were found.

Ulexite

Quantitatively, ulexite is the most abundant borate mineral at Monte Blanco. The ulexite is both primary and secondary and occurs in this area in five ways:

1. **Columnar ulexite**, as noted in the "Descriptive Geology" section, occurs as thick and thin lenses interbedded with mudstones. Associated with the ulexite are thin, fragmented beds of cream-colored, laminated limestone or marlstone that are of sedimentary origin.
   It would seem most likely that the lenses of columnar ulexite represent syngenetic deposits of initially massive beds of mottled felty crystals, such as are found at the Eagle Borax Works located 5.8 miles west-southwest of Badwater (36°12′02.5″ N, 116°52′01.38″ W). Because the ulexite beds at the Eagle borax locality have a bulk specific gravity of perhaps 1.67 whereas the columnar ulexite of the Monte Blanco deposits has a bulk specific gravity of about 2, compaction and loss of sedimentary volume must have resulted from the alteration of the primary "playa-type" deposit to that seen today. The columnar structure and recrystallization of the ulexite, fragmentation of the marlstone and mudstone interbeds, as well as other contortions of bedding, all could have partly resulted from this lithogenesis. The mudstones and marlstones also would compact during lithification, but the ratio of their compaction to that of ulexite is probably not unity; thus differential compaction would result.
2. **Thin fibrous veins of translucent ulexite** occur in the mudstones interbedded with the columnar ulexite of the principal Monte Blanco borate deposit. The veins are as much as 1 inch thick and are chiefly parallel to bedding, but some of them cut the beds. They are clearly of secondary origin.
3. **Other ulexite veins** occur in the basaltic tuff unit overlying the borate deposits. This ulexite, in the only vein studied, occurs as a porous, drusy, central mass as much as 1 inch thick coated on both sides of the vein by coarsely crystalline colemanite that is as thick as 1/8 inch. The ulexite hard and dense. Along the vein, the ulexite portion grades imperceptibly to massive opaque priceite. A clear understanding of the relations of these vein minerals might provide insight into the genesis of various borate minerals in this area.
4. **Efflorescent ulexite** is a common widespread constituent of the white powder mantle that lies on the ulexite bedrock outcrops of the area. Its associate minerals are thenardite and borax. It is distinguishable from them by its characteristic silky luster.

5. **Round “cottonball” ulexite** occurs in colluvium and near the surface in mudstones associated with the borate deposits, and along some fault zones near delta 13 (plate 1). These small cottonball-like masses in the colluvium and mudstones were apparently formed by the introduction, by capillary action, of borate-rich water and (or) perhaps by physical transport of finely divided ulexite that later accretes around centers to form the cottonball masses. This type of ulexite is still being formed in the area. Ulexite cottonballs were found along some of the fault zones near delta 13. They occur as more or less tightly packed balls, as large as 1/4 inch in diameter, in the fault zone. The zone of their occurrence is as much as several inches wide. Several shallow holes were hand dug along faults near delta 13 and the cottonballs found to extend to the bottom of each hole. They undoubtedly extend deeper. The origin of this type of ulexite is probably related to borate-rich waters migrating along faults.

Colemanite

The predominate types of colemanite that make up the massive and drusy colemanite bodies were briefly described above. They, together with less common types, are described below in more detail. The following six types of colemanite are present at Monte Blanco:

1. **Massive colemanite rock** forms the bulk of the colemanite bodies at Monte Blanco and is described above in the discussion of the minerals of the Furnace Creek Formation’s borate unit of the lower mudstone unit. The relations of massive colemanite to ulexite and the genetic significance of the colemanite are discussed below.
2. **Drusy colemanite** is also discussed above in the borate unit’s descriptive section. A distinctive feature of the drusy colemanite is that most of it occurs as intergrown crystal rosettes whose average diameter is about 1/4 of an inch, as contrasted with the coarsely crystalline massive colemanite. The significance of this rosette crystal habit is not understood but it probably points to a genesis for the drusy colemanite that may be somewhat different—at least in its end stages or modifications—from that of the massive colemanite.

Regardless of their differences, the massive and drusy colemanite bodies are much alike in three gross aspects:

1. Both types have abundant, associated, massive limestone.
2. Both types show much replacement of the limestone by colemanite.
3. Both types occur in beds as a halo around the massive bodies of ulexite and are probably an alteration of the ulexite. The detailed relations at the colemanite-ulexite contacts have not been studied, but the two mineral bodies appear to grade into and interfinger with each other.

In any consideration of the formation of colemanite from ulexite, the starting point probably must be the hydrolysis of ulexite, which could proceed according to the following reaction (Schaller, 1936, p. 104):

Ulexite + **water** →
$Na_2O \cdot 2CaO \cdot 5B_2O_3 \cdot 16H_2O$ + H_2O →

Borax + **Colemanite** + **water**
$Na_2O \cdot 2B_2O_3 \cdot 10H_2O$ + $2CaO \cdot 3B_2O_3 \cdot 5H_2O$ + H_2O

The hydrolysis does not directly produce colemanite; rather, at temperatures below 55 °C the 9-hydrate of the colemanite series is formed, which then dehydrates to colemanite. (The 9-hydrate has been synthesized by Schaller). Assuming that the above reaction did take place in nature, it does not appear that the borax, so formed, left the system. If it had, 40 percent of the original B_2O_3 of the ulexite would be flushed out during the metamorphosis, and the field observations do not indicate that this happened. (The colemanite is generally of higher boron grade than the ulexite, and there is no evidence that any given prism of colemanite rock—even though it may be internally drusy—has appreciably less volume than that of the ulexite from which it was derived). Because both types of colemanite have much associated limestone, the borax could react with colemanite as soon as it formed to produce more ulexite, which in turn would again hydrolyze to form more colemanite and borax, and so on. The reaction of calcite and borax to produce ulexite was demonstrated at room temperature in the laboratory (W.T. Schaller, oral commun., ca. 1956). If the above series of reactions reflect a natural process, then little or no additional calcium was needed in the system; the calcium was already present in the form of limestone associated with the beds of ulexite. Moreover, the replacement features so common in the colemanite beds are explained as resulting from the reaction of borax with limestone to produce ulexite, which hydrolyzes to give colemanite. Colemanite, then ulexite and borax, are all much more soluble than calcite (in distilled water at room temperature; for example, Godlevsky, 1937, p. 364; Hodgman, 1951) so that the reaction may not go to completion and some boron could leave the system.

When scrutinized in the light of the distribution and form of the colemanite at Monte Blanco, the chain-reaction mechanism considered above poses two questions. First, why does the colemanite occur above, below, and down-dip from the ulexite (the “halo” effect)? Second, what accounts for the presence of drusy colemanite, with its characteristic crystal habit in one place, and massive colemanite, with a distinctly different crystal habit, in other places?

The answers to these questions might consider the following lines of thought:

1. At Monte Blanco the “halo” effect is real (see plate 1 and the discussions of ulexite and colemanite in the section “Borate Unit Within the Lower Mudstone Unit”) and is present as mineralized bodies whose constituents are chiefly massive colemanite rock. The drusy colemanite appears to be predominately localized along the northernmost fault that cuts the principal borate deposit.
2. The massive colemanite contains significantly greater amounts and thicker beds of limestone than does the ulexite from which it must have come. Perhaps the original ulexite deposit, if considered as a lens, had thicker beds of limestone (or marlstone) at its margins than internally - in other words, had a limy marginal facies. The action of groundwater, then, whether charged with calcium or not, could change this shell of calcium-rich ulexite to colemanite. Modifications of this process could take place, of course. If the groundwater were highly charged with calcium, and much time were allowed for it to react with the ulexite lens, perhaps the whole lens would eventually be changed to colemanite. Or, if the lens was thin and contained limy interbeds—this seems to be the case for most of the Tertiary ulexite bodies in Death Valley—hydrolyzing waters would change it to colemanite very easily. It can be seen that various combinations of process can be invoked to create the change, depending upon the calcium content of the original ulexite beds and the later waters. The permeability of the ulexite mass could affect the amount and rate of change to colemanite. For example, if the ulexite is buried and soaked with water before it changes from the “playa type” to the columnar type, porosity would be greater and the change to colemanite would probably be enhanced and be more complete than if it were acted upon by water when in the relatively dense, columnar form.
3. At the principal Monte Blanco deposit, drusy colemanite appears to be concentrated along the northernmost fault. It appears to have less associated limestone than does the massive colemanite, and contains many interconnected caverns that seem to be parallel to bedding and look like watercourses, similar to those of limestone caves. It seems reasonable that the drusy colemanite was originally the massive type and that later reaction with the invading waters,

along the fault, caused the recrystallization of the colemanite and removal of some material, perhaps chiefly limestone, forming “caves”. A plausible alternative to this recrystallization process is that the drusy colemanite was formed directly from ulexite (following the reaction already suggested), and later circulating waters formed the watercourses and introduced the required calcium.

4. Fragmental colemanite occurs as a thick hill cap south of delta 7. Its role in the borate genetic story is unclear.
5. “Punky” colemanite is light-brown calcareous colemanite rock that looks like the crushed remnants of a calcified sponge; it is very loosely consolidated. It occurs at an altitude of 1,295 feet along about 30 feet of the adit whose portal is 505 feet southwest of delta 14. It is sandwiched in between two thin beds of massive colemanite and contains about 15 percent B_2O_3. Up dip on the surface, this “punky” colemanite is represented by columnar ulexite. Along strike 40 feet to the northwest, and 10 feet higher, it is represented also by columnar ulexite. The characteristics of this colemanite type attest to a removal of material from the beds.
6. Vein colemanite occurs within the borate bodies and also in the volcanic rocks above them. The veins within the borate bodies appear to be generally localized along fractures. Those within the ulexite bodies (as in the adit 225 feet southwest of delta 6) appear to be due to alteration—possibly from ground water along the fractures—rather than to actual filling of open spaces. Colemanite veins also occur in the upper basalt and basaltic tuff units. Those in the upper basalt unit are composed of coarsely crystalline colemanite and appear to be fillings. The colemanite veins in the basaltic tuff unit northeast of delta 15 are coarsely crystalline, and some of them have crustified banding and very sharp boundaries. In one ulexite/priceite vein (see discussion under “Ulexite” section, type 3), the crystalline colemanite occurs next to the vein’s bounding wall rock. Abundant calcite occurs in some colemanite veins, as well. In other colemanite veins white gypsum occurs along the outside of the vein; its contacts with the colemanite are clear-cut and intricately sutured in some places, but gradational in other places. The field relations suggest that the gypsum is an alteration product of the colemanite. Another colemanite vein shows large selenite crystals that contain “islands” and embayments of coarsely crystalline colemanite, which may suggest that colemanite is here replacing gypsum. All the colemanite veins in rocks above the main borate bodies appear to be fillings rather than replacements.
7. Colemanite pseudomorphs, after ulexite and meyerhofferite, occur at the principal deposit at Monte Blanco. Small colemanite crystal geodes, which have the external form and size of secondary ulexite of the “cottonball" type (described under “Ulexite” section, type 5), occur in a 6-inch-thick bed 430 feet due west of delta 13. The bed is at the base of the massive colemanite that here overlies columnar ulexite. Colemanite pseudomorphs after meyerhofferite occur in the adit at delta 12. Here the meyerhofferite commonly has the form of clear to white prismatic crystals arranged in reticulate masses. At some places among the meyerhofferite crystals are clear crystals of the same form but they have the indices and hardness of colemanite. This may be the first reported occurrence of colemanite pseudomorphs after mayerhofferite.

Meyerhofferite and Inyoite

Meyerhofferite of the form described above was found in the adit at delta 12, and in thin beds at the colemanite-ulexite contact 285 feet S 10° W of delta 7, 390 feet S 35° W of delta 7, and in the adit at delta 6. Intergrown fibrous aggregates of meyerhofferite embedded in columnar ulexite occurs 225 feet southwest of delta 6 above the adit portal. This form of meyerhofferite is very easily mistaken for one common form of probertite. Large rhombs of white meyerhofferite pseudomorphs after inyoite occur in the adit at delta 12; however, unaltered inyoite, whose type locality is in this adit (Schaller, 1916), was sought but not found among any of the specimens collected here.

Probertite

Isolated irregular masses of fibrous probertite enclosed in columnar ulexite were found in the adits at delta 12 and 225 feet southwest of delta 6. The position and occurrences of the probertite masses could not be related to any observable structural, stratigraphic, or mineralogical features within the ulexite. The mode of genesis of the probertite is therefore unknown, but it must have formed by dehydration from the ulexite.

Howlite

Veins of howlite thicker than 1 foot are found in abundance in the upper basalt unit as at delta 15 (where they were prospected), and in the basaltic tuff unit northeast of delta 15, near delta 13, and on "Mineral Monument hill." At delta 13, and probably at other localities, the howlite is intimately associated with gypsum, priceite, and colemanite.

The howlite commonly occurs as a white mineral that has a satiny micaceous sheen on fresh surfaces. It has roughly columnar structure developed perpendicular to the veins and mammillary and botryoidal outer surfaces. The howlite strongly resembles priceite in the field; some of the veins shown as howlite on the map may actually be priceite.

Bakerite

Bakerite was found 435 feet NNE of delta 9 on the north-facing slope of "Mineral Monument hill". It forms a hard, greenish-white, porcelainous vein that has unoriented fragments of basaltic tuff in it. Clear crystalline calcite is irregularly distributed in part of the vein. No zeolites, which accompany the other known occurrences of bakerite, have been found as an associate of the bakerite here.

Priceite

Veins of fairly pure priceite, some of them as much as 1 foot thick, are found in marlstones of the lower mudstone unit about 400 feet northwest of delta 8. Some of the white borate veins near delta 10 may be priceite. The mineral also occurs as veins in the basaltic tuff unit near delta 13, on "Mineral Monument hill," and northeast of delta 15.

At all of these places, the priceite is intimately associated with howlite, colemanite, calcite, and gypsum. One vein northeast of delta 15 has massive priceite that grades into porous, dense ulexite along the vein; there is a suggestion that the ulexite is an alteration product of the priceite.

About 420 feet S 30° to 35° W of delta 7 is massive calcareous colemanite that is altered to a dense, white, opaque mineral that looks like priceite. The mineral was not identified microscopically, but material from the Thompson mine to the east in Furnace Creek (see fig. 1), which has similar megascopic physical properties and appears to be an alteration of colemanite, has been tentatively identified as priceite (J.F. McAllister, oral commun., 1954).

Borax

An efflorescent powder as much as 2 feet thick overlies the massive ulexite bodies nearly everywhere at Monte Blanco. The efflorescence consists of ulexite, thenardite, and borax in unknown proportions and distribution. At least 10 shallow pits were dug into the efflorescent powder on the principle borate deposit, and in at least half of them borax was found.

As discussed above, the hydrolysis of ulexite yields borax as one of its products; the efflorescent borax may have originated in this way. If so, calcium borate should lie somewhere below this surficial powder. The colemanite veins in the ulexite (see discussion under “Colemanite”) are probably not related to this borax because they were probably formed much earlier; the borax is related to the present erosion cycle.

Genesis of Borate Veins in Rocks above the Borates in the Lower Mudstone Unit

Cross-cutting borate veins of various types occur in the basaltic rocks that lie stratigraphically above the borate bodies. They have been found neither in the intervening mudstones nor in rocks below the borates, except those very close to the borates on the shoulder of “Mineral Monument hill.”

The borate in these veins may have come from hydrothermal solutions associated with the volcanism that produced the younger volcanic rocks of the Furnace Creek Formation. Little is known about the stability, and nothing is known about the temperatures of formation of the vein-forming borates other than the fact that at 1 atmosphere pressure, priceite starts to lose water around 250 °C and colemanite at about 320 °C (R.B. Allen, written commun., 1950s). Hence, these minerals, and probably the borosilicates also, are evidently stable enough to exist at elevated temperatures and, thus, could have formed veins in a hydrothermal setting. Furthermore, the fact that zeolites accompany bakerite veins might suggest that these veins, and those of the other borates, may also have a hydrothermal origin. If so, such hydrothermal veins might be expected to occur cross cutting the strata below the borate unit, but none have been observed in these lower units.

A hypothesis more compelling for the origin of the vein borates than that outlined above is that the vein borates came from the bedded borates. Although no direct evidence for this is at hand, the close association of abundant borate veins with the massive borate bodies is probably more than fortuitous. The veins seem to have a stratigraphic preference for basaltic rocks, because they have been found in no other hosts, with the two exceptions noted above. This stratigraphic control may be chemical or structural, or both, but if the boron source for the vein borates is from the massive bodies, there should be some reflection of this in the number and distribution of veins in one or both of the basaltic units along their outcrops.

It may be that the borates now fixed in the veins represent the residuum of the hydrolysis of ulexite to form borax and the colemanite that now occurs as a crust around the ulexite bodies. As discussed above, if the ulexite + water yielding borax + colemanite reaction did not go to completion, the resulting excess borax would be available to migrate from the massive borates and be concentrated as veins in nearby favorable host rocks.

The timing of borate emplacement is critical. If the veins occurred only above the borate bodies, suggesting that the boron migrated upward (toward region of lower pressure and temperature), then the veins might have formed while the massive borates were still undeformed. Further, if the vein borates resulted from the same process that formed colemanite (hence, happened at the same time), then the colemanite would have been formed while the enclosing strata were still undeformed. Observational data bearing on the time of major colemanite formation are sketchy and inconclusive at best, but the idea that colemanite formed early is certainly tenable.

Lithium Geochemically Associated with Borates

Lithium, in amounts ranging from 0.08 percent to 0.14 percent Li_2O as weight percent, was found in samples of mixed clay and borate minerals at Monte Blanco. Lithium has also been found as a constituent of the mudstones at other borate localities in Death Valley.

Borate Deposits

Borate Resources

The Monte Blanco deposits were, at the time of the mapping in the 1950s, covered by the Meridian claims, which were purchased in 1884 by the Meridian Mining Company (William T. Coleman, principal), and subsequently passed into the ownership of Borax Consolidated, Limited. The property is one of the groups of mines or deposits in the Furnace Creek Wash area, all, or most of which, were owned or controlled by Borax Consolidated Limited, or its subsidiary, Pacific Coast Borax Company. At the time of mapping, there were adits and some tunnels that accessed many of the borate bodies, but very little tonnage had been extracted.

The borate bodies were split into lettered blocks, starting with block A at the northwest and continuing, on sections drawn perpendicular to the strike of the enclosing sediments, to the southeast to block K, which is the location of the principal Monte Blanco deposit.

Ulexite resources in the Monte Blanco area contain impurities of shale and thin fragmental limestone layers. Discrete ulexite beds or groups of beds as thick as 25 feet have grades up to 35 percent B_2O_3, but the overall grade of the ulexite resources is much less.

Colemanite resources are contained in veins, fracture fillings, coarse crystal masses, and drusy cavity linings in brecciated limestone. In most places the colemanite resource has a high percentage of cavities. At the principal Monte Blanco deposit, a little shale is intercalated with the colemanite-bearing limestone, and some of the cavities are large enough to walk into. At the smaller bodies, there is more shale as interbeds and the lenses are less cavernous.

The grade of the colemanite resource is more variable than that of the ulexite resource. Some single lenses contain in excess of 35 percent B_2O_3, but in groups of lenses, the interbedded shale, or limestone with less colemanite, dilutes this high grade.

For Monte Blanco, *indicated resources* (tables 2 and 3) include that material for which tonnage and grade are computed partly from specific measurements and partly from projection for a reasonable distance on geologic evidence. *Inferred resources* (table 2) use quantitative estimates based largely on broad knowledge of the geologic character of the deposits and for which there are few, if any, samples or measurements and may contain material that is completely concealed if there is specific geologic evidence of their presence.

A tonnage factor of 15 cubic feet per ton of colemanite or ulexite in place was used for all the estimates. This factor was agreed upon by Mojave Project staff members who were doing similar studies on other borate deposits in the region.

Two standard methods were used to estimate the volume of the deposits:

1. the average thickness and area method, for the thin gently-dipping satellite bodies, and
2. the cross-section method, for the thicker, more steeply dipping bodies.

The borate resources for the principal Monte Blanco borate deposit are tabulated in table 2. Borate resources for the satellite bodies, those extending to the northwest from the principal Monte Blanco borate deposit, are summarized in table 3.

Table 2. Mineral resource estimates for the principal Monte Blanco borate deposit.

Indicated resource minerals	Tons	Percent B_2O_3	Tons B_2O_3
Ulexite	1,900,000	18	350,000
Colemanite	600,000	22	130,000
Subtotals	2,500,000	19	480,000
Inferred resource minerals			
Ulexite and colemanite	>300,000	20	70,000
Totals	2,800,000	19	550,000

Table 3. Borate resource estimates for the satellite bodies, Monte Blanco borate deposi.t

Indicated resource minerals	Tons	Percent B_2O_3	Tons B_2O_3
Ulexite	90,000	20	18,000
Colemanite	350,000	>18	65,000
Totals	440,000	19	83,000

Shape of the Deposits

Previous discussion has pointed out that the borate bodies are lenticular along strike and also down dip. As now exposed in outcrop, they comprise several discrete bodies, but originally these were probably all part of one large borate deposit. All the satellite bodies to the northwest of the principal Monte Blanco deposit seem to pinch out down dip at about the same attitude. Thus, when the initial deposit was horizontal, its northeastern edge probably described essentially a straight line. These data and considerations suggest that the original deposit had one long dimension, parallel to the current present outcrop strike of the individual bodies.

We infer that the principle Monte Blanco deposit is a down-faulted remnant of a once larger deposit whose roots are represented by the smaller satellite bodies that extend to its northwest. If this is so, the down dip shape of the principle deposit can be expected to be somewhat like that of the satellite bodies to the northwest.

Stratigraphic and Structural Control of the Deposits

The borate lenses seem to occupy predominately one stratigraphic zone in the lower mudstone unit at Monte Blanco. In other words, its original position was controlled stratigraphically. At the Corkscrew deposit (2.2 miles southeast of Monte Blanco; see fig. 1), the borates occupy essentially the same zone.

Present position and extent of the borate bodies is largely a function of the structure that has been superimposed on them. The smaller satellite bodies crop out in a line of hogbacks that are underlain by the remnants of the original borate deposit. Because they are not flat lying—they lie in a northeastward-dipping homocline—only their roots remain. The observed faults, having very minor normal movement, had little influence on the position or extent of these satellite bodies.

Structure, as well as the favorable high topographic relief, are together responsible for the preservation of the principal Monte Blanco deposit. Downward movement of the deposit along its northern boundary fault removed at least a part of the borate mass from the headward erosion of the ephemeral streams whose valleys now incise it.

The smaller borate bodies on the shoulder of the Mineral Monument hill are, evidently, down-faulted remnants of the basal part of the larger deposit. The borate body near delta 10 is faulted off on the south so that only a part of the original deposit remains.

Possible Extensions of Exposed Deposits

Evidence that the satellite hogback bodies pinch out down dip is strong (see for example, north of delta 1) and indicates that major downward extensions are unlikely down dip along their northeastern margins. The principal Monte Blanco deposit's downward extent is not well known and can only be inferred. New drill holes to the west and southwest of delta 13, as well as several in the deposit east of delta 7, would give adequate control for the extension of the borates down dip. Drill holes southwest of delta 13 would likewise clarify the interfingering relations of the borates and the basaltic tuff unit at that place.

Several colemanite and ulexite outcrops do lie to the west of "Mineral Monument hill;" they occur south of the west-striking fault that lies on the shoulder of the hill and may very well be evidence of faulted extensions of the original Monte Blanco deposit.

There are additional possible extensions of the known Monte Blanco borate mineralization which were covered in an October 27, 1954 Memorandum with the subject "Speculation about blind ore bodies under Furnace Creek Wash, Death Valley, California," and that memo is included as appendix 2 of this report.

Physical History of the Deposits

Our vague present knowledge of the genesis of borate bodies precludes the making of many definitive statements regarding them. The following section, therefore, is brief and is intended merely to give some of the senior writer's ideas.

During the early deposition of the Furnace Creek Formation, the Monte Blanco area was probably the site of a fairly flat basin (or trough, as used above) of westerly trend that likely contained a water body at some times and was playa-like at others. The Monte Blanco site was probably near the southwestern margin of this basin. To the southwest was probably a volcano highland that stood higher than the basin because of its constructional nature; faults might also have contributed to the delineation of highland and basin. Lava flows and other volcanic debris piled up around the volcanic centers while streams, mudflows, and debris avalanches carried some of the volcanic products out into the basin, where they were deposited as the sediments of the Furnace Creek Formation. Some flows extended out into the basin and were interlayered with the sediments.

Thick beds of felty crystals of ulexite interlayered as a lens in a thick series of mudstones look as though they were deposited in quiet shallow water; the source of the boron for the ulexite was probably hot springs or other emanations associated with the volcanism in the area. Marginal layers of limestone and ulexite were probably deposited around more massive ulexite beds. The site of deposition might have looked like the Boratera de Coyahuaima (Los Andes, Argentina), which is a calcareous tufa and ulexite spring deposit (Catalano, 1930). This comparison is not strictly correct, however, because the stratigraphic evidence at Monte Blanco demonstrates that the borates were deposited on a surface of little or no relief, even though the hills probably were not far away. It would perhaps be more nearly correct to say that the mechanism of ulexite deposition was something like that shown at the Argentinian deposit but that the depositional surface was flat rather than hilly. These speculations could lead, then, to a picture like that presented at the Eagle borax deposit on the Death Valley floor, but no limestone beds were observed there.

How the ulexite actually formed is a moot question. It certainly did not form as a desiccation product of saline water. There may have been shallow water containing borate as borax; both surface and groundwater from alluvial fans of the neighboring hills may have brought calcium as $Ca(HCO_3)_2$ into the system and, by reaction with the borax, precipitated ulexite. (This may well be the operative mechanism at the Eagle deposit, as well).

Mudstones, tuffs, and basalts were laid down above the ulexite to a thickness of several thousand feet. Sometime after burial, part of the ulexite could have been altered to massive colemanite by interaction with ground water. If any borate left the system at this time, borate veins might have been formed both within and above the borate deposit.

The rocks were then folded and faulted. Ground water that moved along faults perhaps altered some of the massive colemanite to drusy colemanite—there is some evidence that the drusy colemanite of the principle borate deposit is localized along the northern boundary fault that cuts it. All the colemanite could have formed after folding and faulting; the borate veins would then logically have formed at about the same time. During the time after burial, inyoite, meyerhofferite, and probertite were formed. Efflorescent ulexite, thenardite, and borax were, and are, being formed during the present erosional cycle.

Acknowledgments

At Ohio State University, Dr. Edmund M. Spieker taught Muessig the skills of plane table surveying. In as much as this paper may be the last U.S. Geological Survey publication that uses the plane table and alidade as the primary tools to document both its topographic and geologic data and observations, the authors would like to acknowledge the passion with which Dr. Spieker taught. We include as plate 2 a copy of Muessig's original plane-table map and a photo (fig. 7) of Muessig at work at Monte Blanco.

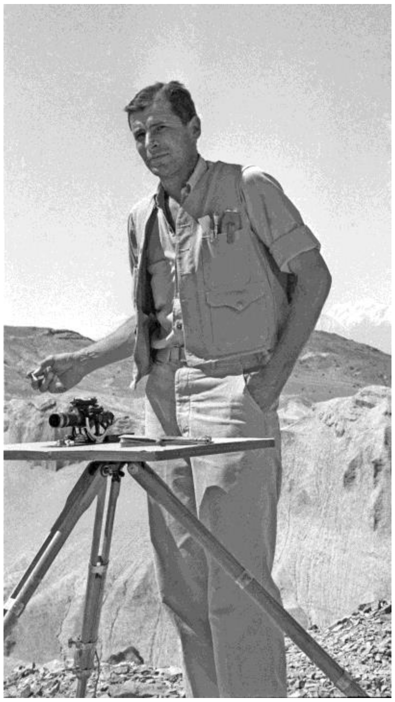

Figure 7. Siegfried Muessig mapping the topography and geology of the Monte Blanco area using plane table and alidade in March and April 1954.

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Appendix 1. Furnace Creek Wash Structure and Stratigraphic Correlations, 1954 to Present

By J.R. Knott

The purpose of this appendix is to correlate the stratigraphic units in this Monte Blanco report, mapped and drafted in the 1950s, to those of later studies throughout the Furnace Creek Wash area and to discuss the current understanding of faults in the Death Valley region.

Stratigraphy

Correlating the stratigraphy established by Muessig in the Twenty Mule Team Canyon area during his 1954 mapping is complicated by poor exposure, faulting, and inconsistencies between his stratigraphic units and those of later studies. In some cases, the outlines of Muessig's original map units resemble those of McAllister (1970). In other cases, the map unit shapes and positions resemble those of Greene (1997). Under these circumstances, the following correlations may justifiably be considered speculative; nevertheless, they are useful to provide a framework for future mapping and studies.

Muessig mapped ulexite and colemanite cropping out in a northwest trend from Monte Blanco. The shape and location of this zone is similar to McAllister's (1970) borate-bearing unit within the lower Furnace Creek Formation (his unit Tf) and is a key correlation of the stratigraphy between those studies.

The deposits mapped by Muessig are Pliocene, but the numerical age is uncertain. There are two K-Ar dates that directly apply to the area mapped on plate 1; these are listed in table 1.1. McAllister (1970) mapped several basalt flows intercalated with the lower Furnace Creek Formation mudstone and sandstone that are stratigraphically below the borate mineralization. Although multiple basalt flows are shown on the map and cross section, McAllister (1970) designated all of these basalt flows with one map-unit symbol, Tfb. Based on stratigraphic position, McAllister's basalt flows are stratigraphically below the borate mineralization. McAllister (1970) mapped this sequence of older basalt flows 4 to 5 kilometers northwest to the mouth of Gower Gulch where a K-Ar date of 5.72±0.22 Ma (table 4) was determined on the basalt.

McAllister (1970) mapped another basalt flow, also part of his map unit Tfb, which is stratigraphically above the borate mineralization zone. Based on the outcrop pattern and stratigraphic position, this younger basalt flow of McAllister (1970) is Muessig's upper basalt Tb2 (plate 1). Based on the original coordinates, a basalt sample was collected by U.S. Borax for K-Ar dating (table 1.1) about 150 meters northeast of the area mapped by Muessig. According to McAllister's mapping, the outcrop at the coordinates given in table 1.1 is mudstone and sandstone and not basalt. On the basis of proximity to the original coordinates, it's likely that this basalt sample is from Muessig's upper basalt unit Tb2 on plate 1. This sample yielded a K-Ar date of 5.87±0.12 Ma.

Table 1.1. K-Ar dates of Furnace Creek Formation that crop out near the map area in Death Valley, California.

[All samples are basalt flow(s) intercalated with the Furnace Creek Formation. JM13A was analyzed by USGS K-Ar lab in Menlo Park, Calif.; DVG-20 and DVMM were analyzed by Univ of Arizona Isotope Geochemistry Lab. Ages were calculated using the following constants: λε=0.585x10-10 year-1, λß=4.78x10-10 year-1, 40K/K=1.19x10-4 atom percent]

Spl no.	Lat	Long	Age (Ma)	Mineral	K_2O (percent)	$^{40}Ar^*$ (x10^{-11} mole/gm)	Percent $^{40}Ar^*$	Reference	Notes
JM13A	36°19'53"	116°44'17"	5.89±0.18	Biotite	8.07	7.039	52	J.F. McAllister, wc, 1959	
DVG-20	36°25.0’	116°49.17’	5.72±0.22	Groundmass	0.59	0.585	75.4	U.S Borax, wc, 1990	
DVMM-52	36°23.25’	116°45.55’	5.87±0.12	Groundmass	0.833	0.848	51	"	

Although not in stratigraphic order, these K-Ar dates overlap within the analytical error reported. There is some confusion related to previous publication of these K-Ar dates. The 5.87±0.12 Ma date was reported by Wright and others (1999, p. 109) as the sample within the subordinate basalt flows in the lower Furnace Creek Formation at Gower Gulch. Wright and others (1999, p. 109) cited “R. B. Kistler, cited in Cemen and others, (1985)” for this date. Based on a reading of the original documents, the date in the lower Furnace Creek Formation at Gower Gulch is actually the 5.72±0.22 Ma date. This transposition of dates does not significantly change the age of the lower Furnace Creek Formation, but it seems appropriate to rectify the record here. An age of 5.87–5.72 Ma for the lower Furnace Creek Formation is consistent with the findings of Knott and others (2016) who used tephrochronology, $^{40}Ar/^{39}Ar$ dating and magnetostratigraphy to determine that the lower Furnace Creek Formation was at least 4.1 Ma.

Muessig mapped several tuff beds within the upper mudstone unit of the Furnace Creek Formation (his unit Tmt). South (near delta 8) and southwest (near delta 10) of Monte Blanco are two relatively thick tuff beds (Muessig’s units tf and wt) at the base of the upper mudstone unit (Tmt) that lie in nonconformity over the Muessig’s upper basalt, Tb2. North of Monte Blanco (near delta 15), one of these tuffs (tf) is, again, in nonconformity with the Tb2 unit and with the thick orange tuff (ot) higher in the section. East of Monte Blanco, the orange tuff is in nonconformity with unit Tb2, and the other tuffs (tf and wt) are absent. Although Knott and others (2016) identified six tuffs that range in age from approximately 3.54 Ma to 3.30 Ma in the upper Furnace Creek Formation (unit Tfu of McAllister, 1970) about 4 km northwest and along strike of Muessig’s mapping, faulting and discontinuous exposure do not allow correlation of the tuffs in Knott and others (2016) with those mapped by Muessig. The tuffs mapped by Muessig are apparently older than those identified by Knott and others (2016) based on the K-Ar dates on basalts Tb1 and Tb2.

In summary, Muessig’s upper basalt unit, Tb2, is very likely 5.87±0.12 Ma, and the ulexite and colemanite beds are probably slightly older. The tf, ot, and wt tuffs described by Muessig in the lower part of the Furnace Creek Formation are older than tuffs subsequently identified in the area.

Faults

The gently dipping low-angle faults described by Muessig in the main body of this report are most likely normal faults. In 1954, the paradigm was that all the low-angle faults in Death Valley were thrust faults (Noble, 1941). It would be nearly 20 years before Wright and Troxel (1973) published their observations about low-angle normal faults in the Basin and Range Province. Since that time, Neogene faults in Death Valley that display vertical displacement have been almost universally recognized as normal faults (Wright, 1976).

Appendix 2. 1954 Memorandum to Smith from Muessig about Blind Borate Deposits

October 27, 1954

MEMORANDUM
To: Ward C. Smith [chief of the Mojave Borate Project]
From: Siegfried Muessig
Subject: Speculation about blind ore bodies under Furnace Creek Wash, Death Valley, California

Any geologic investigation involving economically important deposits always has as one of its aspects—whether by intent or not—the question: are there more? An answer as the result of the present investigations would be premature, but brief speculations can be made, which are exciting and perhaps not without merit.

Results of the present work suggest that the original borate deposit was a linear lens whose long axis trended northwestward. The lens crops out along the southwestern edge of the Furnace Creek trough where the Furnace Creek Formation dips away from the edges of the trough. The borate bodies to the northwest—to the eastern edge of Death Valley—likewise lie along the margin of the trough rather than near its center. The distribution of the Furnace Creek Formation suggests that its sediments were localized in a structural trough whose form and position closely corresponds to the present one. If this were so, the position and shape of the borate deposits could indicate that they were localized along the margin of the trough and their present exposure is just lucky happenstance. Further then, if these speculative deductions from too-few data are in the right direction, there may not be many more deposits farther out in the basin to the northeast. However, other data and different reasoning result in more favorable prospects.

The linear outcrop of the borates in Furnace Creek from Death Valley to the Ryan area and beyond (see fig. 1) has been noticed by many who have worked in the area. Consider the strike length of this outcrop versus the strike length of the enclosing Furnace Creek strata. A surprisingly high percentage of the strike length of the beds consists of borates. From the Corkscrew to the Gower Gulch deposits (see fig. 1), in which interval the outcrops are continuous, the borate beds comprise about 20 percent of the strike length of the Furnace Creek beds. The following are the data in support of this percentage:

Table 2.1 Estimated length of mineralized outcrops in the Furnace Creek Formation.

Deposits	Outcrop length (in feet)
Corkscrew	2,000
Monte Blanco	4,000
Gower Gulch	2,500
Total	8,500 feet = 1.6 miles

The Furnace Creek outcrop length of about 6.3 miles (measured on a topographic, not geologic, map) does not take into account duplication by faulting; it is probably closer to 8 miles. Hence, 1.6 / 8 = 20 percent.

Now, if the deposits are not all linear and concentrated along the trough margins but have more or less random distribution in the trough, the 20 percent outcrop length may approach a valid cross-sectional sample of the areal percentage of the favorable Furnace Creek stratigraphic zone that contains borates. Regional geologic mapping should furnish data that will shed light on these speculations. If, after further work, they still seem reasonable, drilling will be needed to test them. (It might be pointed out that the borates of the Played Out mine (see fig. 1), and others in the Ryan area, probably lay along the margins of the Furnace Creek trough).

Menlo Park Publishing Service Center, California
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