

THE ORIGIN OF THE COLEMANITE DEPOSITS OF CALIFORNIA.

WILLIAM F. FOSHAG.¹

INTRODUCTION.

Since the discovery of the calcium borate, colemanite, in the Calico Mountains of California in 1882, it has become the most important source of boric acid and the borates of commerce. Over 50 per cent. of the world's supply is obtained from this mineral, mined in California. So far it has been found in commercial amounts only in California, and, as far as the writer is aware, has not been reported even as specimens from any other locality. The mineral pandermite, formerly classed as a variety of colemanite, is now known to be distinct, and identical with the mineral priceite. The deposits of colemanite are restricted to the southwestern portion of the Great Basin and workable beds are found in Los Angeles, Ventura, San Bernardino and Inyo Counties in California. Borates in the form of borax and ulexite are found in the adjacent parts of Nevada. The waters of Borax and Hachinhama Lakes in Lake County, California, are rich in dissolved borax. The writer has had the opportunity of visiting some of the producing localities as well as a number of the playa lakes of this region, and of studying mineralogical specimens from other localities. The data thus gathered together with that already existing in the literature, have led to the interpretation given below.

THE MINERALS OF THE DEPOSITS.

Colemanite.—This mineral, now the only one used as a source of the borates in the United States, is a calcium borate, the composition of which is expressed by the formula: $\text{Ca}_2\text{B}_6\text{O}_{11} \cdot 5\text{H}_2\text{O}$. It is colorless or white, sometimes gray or brown from included

¹ Published by permission of the Secretary of the Smithsonian Institution.

mud. It crystallizes in clear glassy monoclinic crystals in a great variety of habits. It is easily distinguished from the other borate minerals by its eminent cleavage. When heated in a flame colemanite loses water and falls to a powder. Since the other borates fuse easily but do not decrepitate this gives a simple test for the detection of colemanite.

Ulexite.—At one time ulexite constituted one of the main sources of the borates of commerce. Today its production is restricted to a few localities in South America. It is the double borate of calcium and sodium, $\text{NaCaB}_5\text{O}_9 \cdot 8\text{H}_2\text{O}$. It is abundant in many of the playas of North and South America. It occurs in aggregates of loosely coherent, acicular crystals. These aggregates are popularly called "cotton-balls." They are found in the surface salt crusts of the playa lakes as well as in the mud layers below. At the Lang deposits in California ulexite also occurs in lenticular masses with the colemanite at the foot wall of the beds. In the center of these masses the fibers are oriented in all directions while at their peripheries the fibers are parallel and normal to the surfaces. These masses have the appearance of "cotton-balls" that have been compacted by pressure. Ulexite fuses easily in a flame, coloring the flame intensely yellow.

Inyoite has been found in the Mount Blanco Deposits in Death Valley. Recently it has been found in the gypsum deposits of Nova Scotia. The fresh mineral is in clear glassy monoclinic crystals with eminent cleavage but the mineral at Mount Blanco is almost completely altered to a fibrous crystalline mass of meyerhofferite. In composition inyoite is similar to colemanite but differs in its water content from that mineral. The inyoite contains thirteen molecules of water as shown by its formula, $\text{Ca}_2\text{B}_6\text{O}_{11} \cdot 13\text{H}_2\text{O}$.

Meyerhofferite is a third member of the colemanite series with seven molecules of water, $\text{Ca}_2\text{B}_6\text{O}_{11} \cdot 7\text{H}_2\text{O}$. It has been found only in the Mount Blanco deposits as a dehydration product of the inyoite.

Howlite is a borosilicate of calcium, $\text{H}_5\text{Ca}_2\text{B}_5\text{SiO}_{14}$. It occurs in all the important borate deposits of California in considerable

abundance. It is found in friable masses of monoclinic crystals or in porcelain-like, nodular masses. It is white in color but rarely brown. It fuses in a flame coloring the flame green. Bakerite is a similar if not identical mineral.

Gypsum is present in all the deposits. It is always secondary with respect to the beds in which it is found. It occurs in clear glassy monoclinic crystals, as selenite, or as satin spar. No chemically precipitated gypsum appears in any of the deposits as far as the writer has been able to observe.

Calcite-aragonite.—Calcium carbonate appears in two forms in the deposits. As calcite it is present in the clays, perhaps as an original chemical precipitate. As aragonite it very rarely occurs as buff colored, acicular crystals perched upon and perhaps derived from colemanite.

Celestite.—Strontium sulphate, SrSO_4 , is as far as known found only in the Calico beds. Here it occurs in colorless or blue, long orthorhombic crystals in the geodes of colemanite.

THE PLAYA LAKES.

In order to understand what has taken place in the Tertiary lakes it will be well to observe what is taking place in similar basins of today.

Borax Lake, in Lake County, California, was the first borax-producing locality in the United States. It is situated in a triangular valley surrounded by hills of basalt. A basalt ridge separates the lake from the larger, fresh water Clear Lake. Formerly Borax Lake shrunk to a small volume in the summer but it is now fed by an artesian well in the lake floor and is essentially a permanent body of water. The dissolved solids carried borax to the extent of 18 per cent., with about 62 per cent. of sodium carbonate and 20 per cent. of sodium chloride. In the mud of this lake were numerous crystals of sodium borate, a rather peculiar feature, since the lake waters were not saturated with salts. About the edge of the lake were numerous small spires of calcareous tufa ranging up to a foot in height. A small solfatara.

known as the Little Sulphur Banks, is not far distant from the shores. Across the ridge that separates Borax Lake from Clear Lake is a solfatara of large dimensions, known as Sulphur Banks. The springs and waters emanating from this solfatara are highly boriferous. The boron in Borax Lake is without doubt derived from the adjacent solfataras.

Searles Lake in San Bernardino County offers a somewhat different type of playa lake. This is a concentration basin receiving its salines from the drainage of a considerable area. The area now drained is restricted to the Argus and Slate Ranges, but at some earlier period Owens Lake overflowed into the Searles Basin by way of Indian Wells and Salt Wells Valleys and it was these waters that contributed most of the salts now covering the floor of Searles Basin. In the winter a few inches of water covers the lake bed, but in summer the water level falls to a few inches below the salt crust. The crust is a mere efflorescence at the outer edge but acquires a thickness of about 50-75 feet in the center. Beneath this salt crust are beds of fine mud with embedded crystals of halite, hanksite, gay-lussite and others. These salts, especially the hanksite and pirssonite, are in sufficient abundance to form definite solid layers or strata. Many of these muds are rich in precipitated calcium carbonate, in the form of calcite. The minerals occurring here are chiefly sulphates and carbonates of calcium and sodium, chlorides of sodium and potassium, and borax. Ulexite, if present at all, is very rare, and no colemanite occurs.

Danby Lake covers a large area near the town of Amboy in San Bernardino County. Although it presents some unusual features, it has never been studied in detail. Near the western edge of the lake a small cone of basalt arises and some of the flows cover a portion of the lake bed. The surface is covered with gypsum and mud. The mud is rich in small crystals of glauberite and the brines carry a large amount of calcium chloride as well as sodium chloride. A stratum of salt underlies the mud but its extent and thickness are undetermined. No ulexite or colemanite have been reported from here.

Rhodes Marsh is one of the types of playa lake that formerly produced considerable quantities of borax before the discovery of the colemanite beds. It is situated in Esmeralda County, Nevada. According to the description of LeConte,² common salt occupies the center of the flat. Around this to the margin, the deposits differ from place to place. In some parts borates occur as borax or "tincal," in others the borate is ulexite. Common salt is found nearly everywhere, more or less mingled with the other salts. Sodium carbonate and sulphate are present in considerable amounts. The well known ulexite "balls" occur in a semicircular area surrounding the central salt area on the north. They are embedded in a stiff, wet clay. If the loose earth is removed to the depth of a foot or more, until the stiff clay is reached, the "cotton balls" are found. In places the beds of ulexite reach a thickness of six to eight feet. This concentration of the ulexite into patches seems to be a common feature of both western deposits and the South American lakes. In some of the later deposits the ulexite occurs in considerable quantities and of great purity.

GEOLOGY OF THE DEPOSITS.

General Geology.—The colemanite deposits are found interstratified with lake bed deposits of Tertiary age. These lake bed deposits are for the most part volcanic ash or material derived from volcanic rocks laid down under shallow water conditions in closed basins. The beds in direct association with the colemanite are fine-grained, thin-bedded shales of various colors. Lavas of rhyolitic, andesitic or basaltic character are often present in the boron-bearing series. For the most part they appear to be surface flows.

The borate beds themselves follow the bedding of the series but are somewhat irregular in form. They do not form continuous, well-defined beds but rather represent shale beds in which the borates are more or less irregularly distributed. They are, however, restricted to a definite member of the series.

² Third Ann. Rept. Calif. State Min. Bur., p. 51, 1883.

The borate-bearing beds have all undergone some movement. They range from beds almost perpendicular to beds but slightly tilted. There is also evidence of movement within the beds themselves.

Lang.—The sedimentary rocks in the region about Lang are coarsely stratified sandstones of a light buff color. These sandstones grade into conglomerates. In the immediate vicinity of the colemanite deposits they are fine, thin-bedded shales. The borate-bearing beds have an east-west trend and dip at an angle of about 70° to the south.

The commercial product is colemanite, in cleavage masses and very often in columnar bands. There is evidence of movement and pressure in the ore-bearing strata, but hardly sufficient to account for the large masses of cleavable colemanite. Much of the colemanite is of gray color, due to included mud, but secondary colemanite is of a pure white color. Crystals are rare. Howlite is present in considerable abundance as botryoidal concretions which sometimes are several feet in diameter. The howlite nodules are imbedded in the colemanite and form "augen" in the strata. Rarely howlite and colemanite are intergrown, and still more rarely the howlite is later than the colemanite.

The mineral of greatest significance is ulexite, which occurs in abundance in some of the workings. At the 250-foot level the footwall is composed largely of ulexite. It is not the ordinary "cotton-ball" type but is massive and fibrous. It has the appearance of cotton balls that have been consolidated by pressure. That it is typical ulexite is shown by the following analysis:

CaO	14.14
H ₂ O	35.68
B ₂ O ₃	43.12
Na ₂ O	(7.05) (by difference)
	<hr/> 100.00

The ulexite occurs in irregular masses, more or less lens-like and surrounded by thin layers of clay. In structure these lenses are compact-fibrous, the fibers oriented in all directions in the centers, and parallel at the peripheries.

Calcite is rare in the deposits and none was observed in direct association with the colemanite. Aragonite occurs sparingly and is always secondary.

Borate.—The borate deposits are situated in the Calico Mountains not far from the old silver camp of Calico. The nearest town is Yermo on the Salt Lake Railroad, eight miles distant by wagon road. At the time of the writer's visit (May, 1920) a small amount of work in the nature of "gophering" was being done. Since the mines have been idle for a number of years the extensive old workings are no longer accessible, so that the only data obtainable was from the dumps and shallow workings.

The sediments here are sandstones and shales. The borate beds are in thin-bedded shales similar to those at Lang. The beds have an east-west trend and dip to the south. South of the deposits rises the main rhyolite mass that forms the core of the Calico Mountains. Storms³ states that "the rocks have not suffered, in the region about the borax deposits, the slightest metamorphism." The surface exposures are unaltered, loosely coherent, shales. The colemanite beds outcrop along the hill for a distance of about one-half mile and show, beside colemanite, occasional bands of howlite and numerous veins of satin spar gypsum. Storms describes the beds as being much mixed with sandy sediments and gypsum at their western end, giving the appearance of having formed "near the shore line of a basin."

A peculiarity of the colemanite occurring here is the large number of geodal nodules lined with excellent crystals of colemanite with sometimes celestite and selenite. In some parts of the deposit they occur in great numbers imbedded in the shales, much after the fashion of the ulexite nodules described by LeConte at Rhodes Marsh.⁴ The geodes often show two generations of colemanite crystals. In certain other portions of the deposits colemanite gives way to cavities containing clear and brilliant selenite crystals. The shale containing these selenites has a decidedly honeycombed structure, and the cavities now con-

³ Calif. State Min. Bur., 11th Ann. Rep., p. 346.

⁴ See above, under Rhodes Marsh.

taining the selenite crystals were undoubtedly formed by the removal of some previous mineral. Associated with both the colemanite and the selenite are small nodules of howlite. The colemanite crystals of many of the geodes, especially those near the surface, are partially or wholly altered to calcium carbonate, in many cases still retaining the external form of the colemanite crystals.

Ventura.—The Ventura deposits have been described by Gale⁵ and were not visited by the writer. They are situated on the south flank of Mt. Pinos, near the San Emigdio Range, in Ventura County. The general trend of the borate-bearing beds is northeast and southwest and they dip to the southeast. These beds have been extensively folded and faulted. The colemanite occurs in shales and limestones intercalated with flows of basalt.

The colemanite is typical of the mineral as it occurs elsewhere. It is crystalline with excellent cleavage, white in color, but in places gray from included mud. The masses follow the bedding of the sedimentary strata with which they are associated but appear to be very irregular in form. The mineral is often radiated and in places crystallized in open cavities. The colemanite appears to have been developed in immediate association with a bed of limestone included within the shales. The limestone is massive or of a roughly porous character. The outcrops rarely show any colemanite but are indicated by an abundance of gypsum. This gypsum is in the form of selenite and is of vein character.

Death Valley.—The geology of the Death Valley deposits has been described by Keyes.⁶ He characterizes the borate-bearing beds as fine olive green clays that weather pale green or white. Numerous basalt sheets from ten to a hundred feet thick are interbedded. In the upper part of the sequence much selenite gypsum, beds of colemanite and thin layers of limestone of probable chemical origin, occur. Underneath these beds are strata of sandstone and conglomerate.

⁵ U. S. Geol. Survey Prof. Paper 85, p. 5.

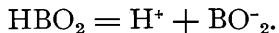
⁶ Trans. Am. Inst. Min. Eng. Bul. 34, p. 870, 1910.

The richer borate beds are from a few inches to fifty feet thick. In the unweathered portions they consist of bluish clays interspersed with milk-white layers, nodular bands and nodules of colemanite. Through the strata carrying the coarsely crystallized colemanite the clays are more or less highly impregnated with fine particles of the borate mineral, and yield upon leaching ten to twenty-five per cent. of anhydrous boric acid. Mingled with the coarse colemanite are often found large amounts of crystallized gypsum. In some places the gypsum is so abundant that the borate minerals are all but completely obscured. Frequently there are present large amounts of pure limestone. Howlite, although not mentioned in any of the published descriptions, is abundant in many of the colemanite specimens examined from this locality by the writer. In appearance it is very similar to the Calico howlite.

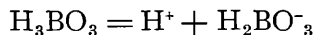
CHEMISTRY OF THE MINERALS.

Boric acid is one of the weakest of inorganic acids, dissociating to a less extent than carbonic or hydrosulphuric acids. The dissociating constant for boric acid is 1.7×10^{-9} at 18° as compared with carbonic, (H_2CO_3) , 3.04×10^{-7} and hydrosulphuric (H_2S) , 0.91×10^{-7} . Besides orthoboric acid there exist in the form of salts metaboric acid, HBO_2 , tetraboric acid, $\text{H}_2\text{B}_4\text{O}_7$, and a number of poly acids. In respect to its formation of poly acids, boric acid is similar to silicic acid.

The dissociation of metaboric acid takes place as follows:



Theoretically orthoboric can give three hydrogen ions, but the dissociation



takes place to such a very slight extent that further ionization is not measurable. The orthoborates in nature are accordingly of the type $\text{R}'\text{H}_2\text{BO}_3$, *e.g.*, pinnoite, $\text{Mg}(\text{H}_2\text{BO}_3)_2 \cdot \text{H}_2\text{O}$; and such salts as $\text{Mg}_3\text{B}_2\text{O}_6$ do not form from solution.

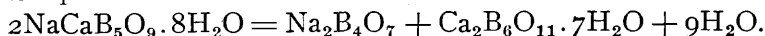
Orthoboric acid upon heating loses water and passes over into metaboric acid. Further heating converts it to the oxide, B_2O_3 . The oxide is volatile only at high temperatures. The orthoboric acid, however, is volatile in steam and this explains its presence in fumaroles and volcanic exhalations.

Although orthoboric acid is weaker than carbonic it may possibly replace the latter to some extent in hot concentrated solutions. This would be due to the greater volatility of the carbonic acid. The reaction, however, has never been studied in any detail. The writer subjected sections of calcite to the action of boric acid for a period of several months without any change of the carbonate to the borate.

When boric acid dissolves it tends to form complex molecules with the formation of meta, ortho, tetra and poly acids, so that a solution of boric acid does not contain the orthoboric acid ion alone but the others in equilibrium with each other.

Borax solutions in the presence of sodium chloride attack colemanite to form ulexite and calcium chloride. Ulexite is the common occurring borate in the playa lakes where it is found with borax and salt. Ulexite has been synthesized by Van't Hoff⁷ by the action of a borax and sodium chloride solution on $Ca_2B_6O_{11} \cdot 9H_2O$, one of the members of the colemanite series.

At 83° ulexite splits into its component borates according to the equation



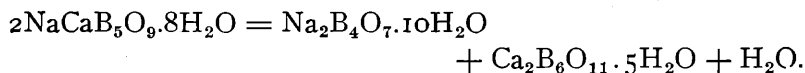
This splitting takes places at lower temperatures in the presence of sodium chloride. It will be noticed that one of the products of the above reaction is the mineral meyerhofferite, one of the colemanite series. Kraut⁸ obtained another member of the colemanite series, $Ca_2B_6O_{11} \cdot 6H_2O$, by simple leaching of ulexite.

Van't Hoff found further that the pentahydrate, colemanite, was less soluble in sodium chloride solutions than the heptahydrate, meyerhofferite. By treating the heptahydrate with a sodium chloride solution he obtained the pentahydrate, cole-

⁷ *Sitzb. Acad. Wiss. Berlin*, p. 566, 1906.

⁸ *Arch. Pharm.*, 2, 112.

manite. By leaching ulexite with sodium chloride solutions instead of pure water he obtained colemanite in place of meyerhofferite. The reaction



is completely reversible and by varying the amounts of borax the reaction can go in either direction—colemanite and borax may result from ulexite or ulexite from colemanite and borax. If an excess of borax is present any colemanite is converted into ulexite while if the borax is removed as fast as it is formed the ulexite will break down completely, leaving the mineral meyerhofferite if no sodium chloride is present but giving colemanite if the solutions are salt-bearing ones.

ORIGIN OF THE BORON.

Three hypotheses have been put forward to explain the source of the boron in the various borate deposits: (1) origin from sea water, (2) from the decomposition of borosilicate minerals, and (3) volcanic exhalations.

1. In such deposits as those at Stassfurt the source of the boron is without doubt from sea waters. The amount of boric acid in the waters of the ocean is sufficient to account for the relatively small amounts of borates in these salt beds. For the California deposits, however, all evidence points to an origin other than the evaporation of sea water, so that this possible source may be dismissed.

2. The average boron trioxide content of igneous rocks is very small but may reach an appreciable amount in such rocks as tourmaline granites. These rocks, upon decomposition, may give up their boron, which may then be leached out and concentrated in suitable basins. But borosilicates such as tourmaline are resistant minerals and no accumulations of borates are known that can be definitely traced to this source.

3. The volcanic origin of the boron has much evidence to favor it. Boron has been detected in the vapors of many volcanoes. It

is one of the important mineralizers of igneous rocks. But most important of all is the actual accumulation of boron in the craters of certain volcanoes and in the hot springs and solfataras of volcanic regions. Thus sassolite, $B(OH)_3$, is sometimes found at Vesuvius; while at Volcano, borates were at one time present in such quantities that it became profitable to work them in the very crater.

At Steamboat Springs, Nevada, a hot spring connected with rhyolitic rocks, the boron content of the dissolved solids is as high as 9 per cent. B_2O_3 . At Sulphur Banks, in Lake County, California, there is a solfataras of large dimensions discharging highly boriferous waters and close by are borax deposits of actual commercial importance. The waters of the hot springs carry over 25 per cent. of B_2O_3 (of the dissolved salts) while waters collected in the old Parrot Shaft contained solids with over 40 per cent. boric oxide. Thus in the case of Sulphur Banks a large quantity of borax is discharged yearly into the waters of Clear Lake. These springs are connected with fairly recent basalt flows and have a direct genetic connection with the sulphur and cinnabar deposits from which they issue.

The Tuscany soffioni have long been cited as an example of the volcanic origin of the boron, although the evidence here is not conclusive, since the waters pass through strata of sandstone and other sedimentary rocks, and a possible source of the boron in these rocks is not entirely precluded.

It is significant that all deposits of borax and other borates are situated in regions of past or present volcanic activity. The Borax Lake in California is adjacent to the solfataras of the district, the deposits of the desert region are connected with numerous volcanic flows. The borate deposits of South America are, according to Chamberlain⁹ largely confined to those lakes which lie close to the volcanoes of the western Cordillera. Away from these volcanoes the borates rapidly disappear. The original source of the boron in our Western deposits is most probably to be found in the hot springs and solfataras connected with the

⁹ *Jour. Geol.*, 20, 763, 1912.

tremendous volcanic activity that characterized the Tertiary Period when these deposits first accumulated.

PREVIOUS THEORIES.

To account for these accumulations of calcium borate two theories have been proposed. The older, and the one accepted for many years, is that of the chemical precipitation of the colemanite from the waters of inclosed basins during periods of great desiccation. This theory was first put forward by W. H. Storms¹⁰ and later supported by Campbell,¹¹ Keyes,¹² Baker,¹³ and others.

It fails, however, to explain the reaction by which such masses of colemanite might form. In order to produce beds of any thickness the amount of water would have to have been very great, because of the slight solubility of the colemanite. Since the borate-bearing beds have all the appearance of shallow-water deposits, it is difficult to conceive any means whereby such masses could be deposited by simple evaporation. In the playa lakes of today no precipitation of colemanite is evident. In fact, under ordinary playa conditions, where there are large amounts of borax present, the formation of colemanite seems impossible; for under these conditions any simple calcium borates are prevented from forming, any calcium in solution separating as the double sodium calcium borate, ulexite. Colemanite forms only from solutions free of sodium borate, a condition which is apparently never reached in the playa lakes. These relations have been discussed under the separate minerals.

The second theory is one put forth by H. S. Gale.¹⁴ From his studies of the Ventura deposits he reached the conclusion that the colemanite was formed by metasomatic replacement of limestone beds intercalated with beds of shale between basalt flows.

¹⁰ Calif. State Min. Bureau, 11th Ann. Rep., p. 346, 1893.

¹¹ U. S. Geol. Survey Bull. 200, p. 8, 1902.

¹² Am. Inst. Min. Eng. Bull. 34, 1909.

¹³ Univ. Calif. Pub. Dept. Geol. Bull., vol. 6, No. 15, 1911.

¹⁴ Prof. Paper 85, U. S. Geol. Survey, p. 3, 1914.

In support of this hypothesis he calls attention to the irregular character of the deposits and the vein character of the associated gypsum. Furthermore he states that "certain specimens collected on the ore dumps and in the mines show that at least a part of the colemanite is a replacement deposit. Irregular portions of the limestone are surrounded by white crystalline colemanite and minute fractures which traverse the limestone throughout are also filled with this mineral. These veinlets are observed to have been enlarged irregularly within the limestone. Small rounded masses of limestone are also included within the solid portions of the colemanite, indicating that in places the same enlargement of the intersecting veinlets has been carried to a further stage and the separated portions of the limestone are residual within the deposited colemanite." These reactions are possible, for, although boric acid is a much weaker acid than carbonic, the greater volatility of the latter may allow replacement to take place in concentrated and hot solutions of boric acid. The reverse reaction takes place in nature, however, to a great extent and colemanite crystals altered to calcium carbonate are common in the borate deposits. It is doubtful if the boric acid emanations from the neighboring basalts were of sufficient volume and of long enough duration to effect the replacement of such large amounts of limestones. Being surface flows, their period of activity must have been short. What replacement of limestone has taken place is more probably due to borate solutions of vadose origin.

Eakle¹⁵ arrived at a similar hypothesis to the above. He considered the Lang deposits as probably derived from marls by the action of boric acid solutions.

ORIGIN OF THE DEPOSITS.

Van't Hoff's work clearly demonstrates that, under the conditions existing in playa lakes, ulexite forms instead of colemanite, and in order to accomplish the splitting of the ulexite into

¹⁵ Univ. Calif. Pub. Dept. Geol., vol. 6, No. 9, 1911.

its component calcium borate and sodium borate the sodium borate must be removed as fast as it is formed. In the closed basins of the playa lakes with their clay floors this removal of the sodium borate cannot take place to any large extent either by surface or underground drainage, so that the borate accumulations consist wholly of ulexite and borax. When these deposits are later covered over and uplifted sufficiently to allow free drainage from the beds, the percolation of chloride solutions gradually converts the ulexite to colemanite and other members of the colemanite series.

The evidence to support this hypothesis is:

1. The total absence of colemanite or any member of the colemanite series in any of the playa lake deposits.
2. The occurrence of ulexite in large quantities in the borate beds at Lang, where it lies for the most part near the foot wall.
3. The bedded character of the deposits.
4. The structural features of the deposits, especially the nodular and geodal character of a large part of the colemanite.

The first three points have already been treated. The fourth item will now be discussed briefly. It has been pointed out that nodular and geodal masses are common in the deposits, in fact at the Calico beds and presumably at those at Death Valley a large proportion of the ore consists of nodular geodes embedded in the clays. This suggests strongly LeConte's description of the occurrence of the "cotton-balls" in the clays of Rhodes Marsh. If the theory of the derivation of colemanite from ulexite be accepted, there is a ready explanation of this type of ore. The ulexite embedded in the clays is acted upon by salt solutions. The light, fluffy "cotton-balls" are converted into the more compact colemanite, giving rise to the more or less spherical geodes and allowing the free crystallization of the colemanite in the center. It is inconceivable that the cavities were original in the shales and that they were later filled in with the colemanite. Where ulexite was aggregated in more compact masses the colemanite took a more massive form but the contraction of volume still allowed for a large number of drusy cavities such as are so

abundant in the deposits. In some deposits, as at Lang, the pressure exerted was sufficient to close the cavities and compact the mass. The selenite gypsum and perhaps some of the limestone also, resulted from the action of sulphated and carbonated waters upon the colemanite.

SMITHSONIAN INSTITUTION,
U. S. NATIONAL MUSEUM,
WASHINGTON, D. C.