COLEMANITE IN CLARK COUNTY, NEVADA.

By L. F. Noble.

INTRODUCTION.

Some deposits of colemanite (hydrous calcium borate, probably $HCa(BO_2)_3+2H_2O$), a mineral that yields borax, have recently been discovered in the Muddy Mountains, Clark County, Nev., in two areas 12 miles apart. One area occupies a part of the mountains that is known locally as White Basin; the other lies near Callville Wash. The White Basin district contains several deposits; the Callville district, so far as known, contains a single deposit, which, however, is by far the largest in the region. The location of the deposits is shown on the accompanying map (fig. 3).

These newly discovered deposits are interesting not only because they are the first economic occurrence of colemanite found outside of California, but because, unlike the California deposits, they occur in rocks whose structure is relatively simple. The large Callville deposit and the inclosing rocks for hundreds of feet above and below it are magnificently exposed, and the deposit itself is regular and persistent over several thousand feet of outcrop. These natural conditions afford an exceptional opportunity to study the origin of the colemanite.

The colemanite in all the deposits occurs in bunchy layers interbedded with whitish shale or thin-bedded limestone that forms part of a series of stratified rocks known as the Horse Spring formation. This formation, which consists of limestone, shale, sandstone, and conglomerate and contains much volcanic ash, is of fresh-water origin and is probably of Miocene age. Some parts of the formation contain deposits of gypsum and magnesite. The colemanite forms bands or zones that are locally called "veins," but these so-called veins are actually beds because they are parallel with the inclosing strata and exhibit bedded structure.

I made a brief examination of the deposits in May, 1921, in company with H. S. Gale, formerly of the United States Geological Survey. The examination was part of a field review of all the important colemanite deposits of California, covering the Ventura, Calico, and Furnace Creek districts.

GEOGRAPHY.

The Muddy Mountains, in which the deposits occur, are a rugged barren desert range which lies near the southern boundary of Nevada not far north of Colorado River. Their highest point, Muddy Peak, is about 5,800 feet above sea level. (See fig. 3.) The mountains occupy an irregular area bounded on the west by Las Vegas Valley, on the east by the valley of Virgin River, on the north by Muddy

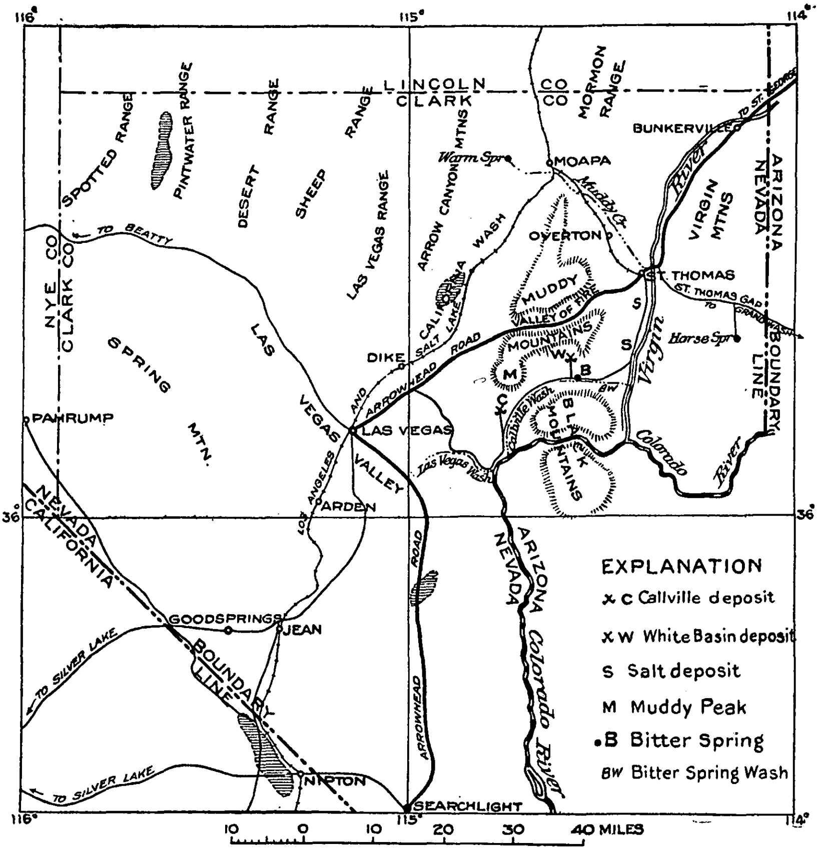


FIGURE 3.—Map showing location of colemanite deposits in Clark County, Nev.

Creek, and on the south by Callville and Bitter Spring washes. Muddy Creek and Bitter Spring Wash are tributaries of Virgin River; Callville Wash is a tributary of the Colorado. Between Las Vegas and Moapa the Los Angeles & Salt Lake Railroad runs northwestward parallel with the west base of the mountains, following California Wash, an arm of Las Vegas Valley.

The mountains are plainly visible from the train. A branch of the railroad runs southeastward along their northern base from Moapa to St. Thomas, following the valley of Muddy Creek. The automobile highway that connects Los Angeles and Salt Lake and is known as the Arrowhead Trail crosses the northern part of the mountains between Las Vegas and St. Thomas, descending eastward from a pass at their crest through an area of brightly colored red sandstone, known to travelers as the Valley of Fire. The colemanite deposits are in the more inaccessible part of the mountains, 10 to 15 miles south of the Arrowhead Trail, and can not be reached directly from this road. The region in which they lie is crossed by an old road that runs from St. Thomas to Las Vegas by way of Virgin River, Bitter Spring Wash, Callville Wash, Colorado River, and Las Vegas Wash. This road runs southward from St. Thomas down Virgin River past a remarkable bed of solid rock salt, exposed in places in cliffs facing the river, ascends Bitter Spring Wash westward to its head, crosses a low divide to the head of Callville Wash, and descends Callville Wash southward to Colorado River. After following the river several miles the road ascends Las Vegas Wash, crosses a divide, and enters Las Vegas Valley, joining the Arrowhead Trail at a point 14 miles from Las Vegas. It is now sandy and rough but was once a well-traveled Government highway. It fell into disuse some time ago but is now utilized in reaching the colemanite deposits, all of which lie within 2 to 5 miles of it and are connected with it by branch roads. The topographic features of the region and the roads just described are shown on figure 3.

PREVIOUS GEOLOGIC WORK.

Until recently the geology of the Muddy Mountains has been practically unknown, although a few notes, the result of a brief reconnaissance, were published in a report by Spurr that appeared in 1903.[1] In 1919 C. R. Longwell, a geologist on the faculty of Yale University, made a detailed investigation of the region and prepared a report that will be published by the United States Geological Survey. An abstract of the results of this work has been published in the American Journal of Science,[2] giving the essential facts and conclusions. Longwell's work is one of the most thorough investigations that have been made in geologically unexplored areas of equal size. The Horse Spring formation, in which the colemanite occurs, is carefully described in the published abstract,[3] and the distribution and structure of the formation, not only in the Muddy Mountains but in outlying areas east of Virgin River, are shown on a map accompanied by structural sections,[4] so that the abstract should be of considerable assistance in indicating areas favorable for pros-

[1] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, pp. 136–138, 1903.

[2] Longwell, C. R., Geology of the Muddy Mountains, Nev., with a section to the Grand Wash Cliffs in western Arizona: Am. Jour. Sci., 5th ser., vol. 1, pp. 39–62, January, 1921.

[3] Idem, pp. 52–53.

[4] Idem, pp. 40–41.

pecting, although colemanite was not discovered in the region until after Longwell had completed his work there. The deposits in White Basin lie within the area mapped by Longwell, but the Callville deposit lies a few miles southwest of the area mapped. Much of the general geologic sketch of the region which follows is based on Longwell's work. In my investigation I studied only the areas where the Horse Spring formation is exposed.

GENERAL GEOLOGY.

SEDIMENTARY ROCKS.

The Muddy Mountains consist entirely of stratified rocks, which are divisible into two main groups. The strata of the younger group rest everywhere upon the upturned and eroded edges of those of the older group, so that the groups are separated by a profound unconformity representing a long period of erosion. The strata of the older group are deposits of the Paleozoic and Mesozoic eras; those of the younger group are probably all of Tertiary age.

PALEOZOIC AND MESOZOIC ROCKS.

The Paleozoic and Mesozoic rocks consist of limestone, sandstone, and shale and comprise deposits of the Devonian, Carboniferous, Triassic, and Jurassic periods. The Devonian and Carboniferous strata are chiefly massive limestones which are resistant to erosion, so that they form the higher mountain masses and weather into steep cliffs. Several formations are the westward extensions of those that make the walls of the Grand Canyon. The Triassic and Jurassic strata are chiefly bright-colored sandstones and shales. The Triassic rocks include formations equivalent to those which crop out in the Painted Desert in Arizona, and one formation, which contains petrified wood, is an extension of the formation that underlies the Petrified Forest. The Jurassic rocks are the bright-red sandstones that make the Valley of Fire on the Arrowhead Trail. They are the equivalent of a part of the La Plata sandstone, which covers large areas in southwestern Colorado and in the Navajo region of Arizona. Like the La Plata sandstone, they exhibit cross-bedded structure on a huge scale.

The structure of this older group of rocks is exceedingly complex. The strata are intensely folded and are cut by numerous faults. In places—for example, in Muddy Peak—great masses of Devonian and Carboniferous limestone have been shoved bodily over the Jurassic sandstone which should normally overlie them, so that the geologic section is upside down and the older formations overlie the younger. In general limestone forms practically all the higher part of the Muddy Mountains, and the area is preeminently a limestone region.

TERTIARY SYSTEM.

The Tertiary rocks are divisible into two series of strata, which are separated by an unconformity. The older series, which is probably of Miocene age, includes two formations—the Overton fanglomerate and the Horse Spring formation. The younger series, which is probably of Pliocene age, includes a single formation, here designated the Muddy Creek formation.

MIOCENE (?) SERIES.

OVERTON FANGLOMERATE.

The Miocene (?) series begins with a deposit of coarse conglomerate that rests upon the upturned edges of the Paleozoic and Mesozoic rocks—in most places upon the Jurassic sandstone. The conglomerate consists of fragments derived from the Paleozoic and Mesozoic rocks. Most of the fragments are limestone, are angular in shape, and are of different sizes. Many are large, and some exceed 10 feet in diameter. The conglomerate exhibits wide variations in thickness, ranging from 20 to 3,000 feet, but at most places is less than 30 feet thick. An outcrop of the conglomerate near Horse Spring is shown in Plate I, *A*.

Longwell named this formation the Overton fanglomerate, because it is thickest near the town of Overton, in the valley of Muddy Creek, and because it was evidently deposited in the shape of alluvial cones or fans similar to those that border the slopes of desert mountains to-day. The thicker and coarser deposits of the fanglomerate, as, for example, the deposit near Overton, must lie very near the sites of ancient steep mountain slopes. The mountain ranges must have bordered alluvial basins whose floors were mantled with the thinner deposits. Inasmuch as the component fragments of the fanglomerate and the cement which binds the fragments together are largely carbonate of lime, the mountains from which the material of the fanglomerate were derived must have been composed chiefly of limestone. The underground waters of the basins and the streams carrying material into the basins must therefore have been rich in lime. Doubtless the climate was arid, because alluvial fans are features characteristic of deserts to-day. In the lower parts of these basins, partly in or about playas or "dry lakes," partly on the slopes between the playas and the base of the mountain ranges, the succeeding Horse Spring formation was laid down.

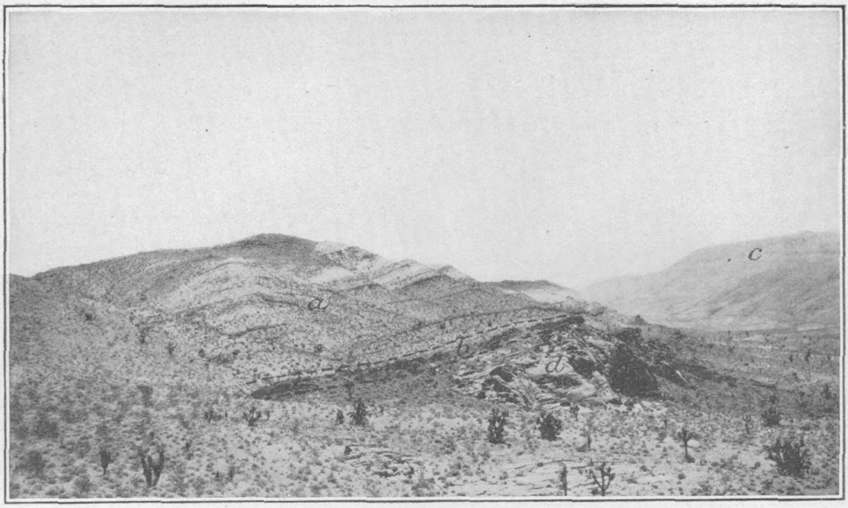
HORSE SPRING FORMATION.

Overlying the Overton conglomerate in conformable sequence are beds of limestone, shale, tuff, gypsum, sandstone, and conglomerate, which together reach a total thickness of over 2,500 feet. Longwell named these beds the Horse Spring formation because they are typically exposed near Horse Spring, east of Virgin River. (See fig. 3 and Pl. I, *A*.) The Horse Spring formation contains the deposits of colemanite described in this paper.

The lower part of the Horse Spring formation consists chiefly of hard limestone, in thick, regular beds. (See Pl. I, *A*, *B*.) Outcrops of the limestone when seen from a distance resemble outcrops of the Paleozoic and Mesozoic limestones, but close inspection shows that much of it has the curious porous and concretionary structure characteristic of deposits of travertine. Moreover, unlike the older limestones, the limestone of the Horse Spring formation contains no marine fossils, so far as known, or other evidence that it was deposited beneath the sea. The thickness of this limestone member is at least 1,000 feet. In places, notably near Kaolin, in the valley of Muddy Creek, deposits of almost pure magnesite (magnesium carbonate) are interbedded with the limestone. At the base of the limestone member, interbedded with the limestone at intervals, and above it are beds of shale and sandstone, many of which are composed essentially of volcanic ash, the finer ash forming shale and the coarser ash forming sandstone. Much of the shale is a very fine calcareous mud that grades into shaly limestone. Many beds of shale contain gypsum. The upper part of the limestone member passes upward by gradual transition into beds of tuff composed wholly of volcanic ash. The deposit of colemanite near Callville Wash occurs near the top of the limestone member just described. Apparently the deposits in White Basin also occur at this horizon, but their exact position in the member can not be determined without careful study, because the strata in White Basin are considerably disturbed by faulting.

The tuff member above the limestone member is at least 500 feet thick and may be thicker. It passes upward into beds of sandy clay, gypsum, sandstone, and conglomerate, the aggregate thickness of which is unknown but is at least 1,000 feet. These beds above the limestone member contain no colemanite, so far as is known, and are disregarded by most prospectors.

Many beds in the Horse Spring formation exhibit changes in composition as the formation is traced from place to place. Consequently sections of the formation at different places are unlikely to correspond closely. In this respect the Horse Spring formation is very different from the Paleozoic and Mesozoic formations, most of which



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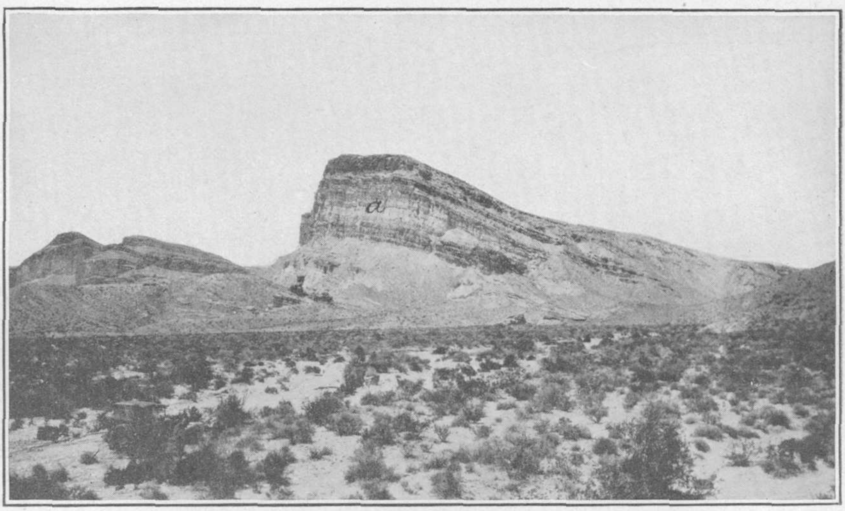
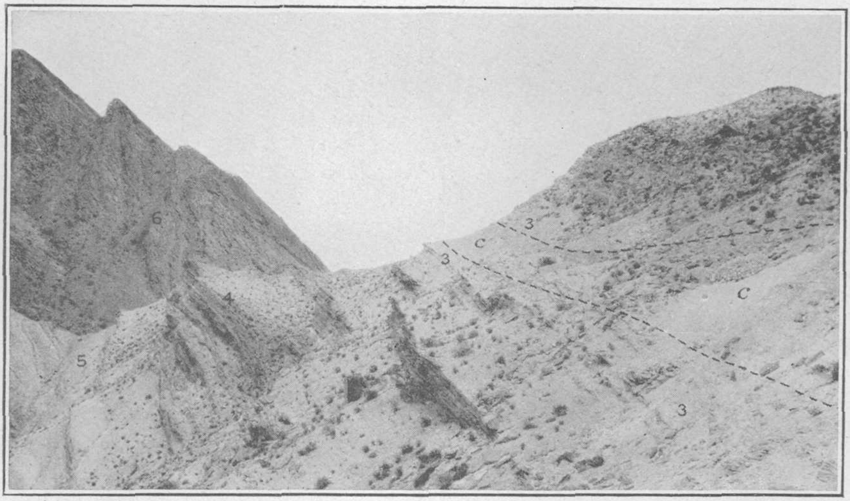


B.

TYPICAL EXPOSURES OF LIMESTONE MEMBER OF HORSE SPRING FORMATION IN CLARK COUNTY, NEV.

A, Near Horse Spring; *B*, near Bitter Spring. *a*, Limestone member of Horse Spring formation; *b*, Overton conglomerate; *c*, Paleozoic limestone; *d*, La Plata sandstone.



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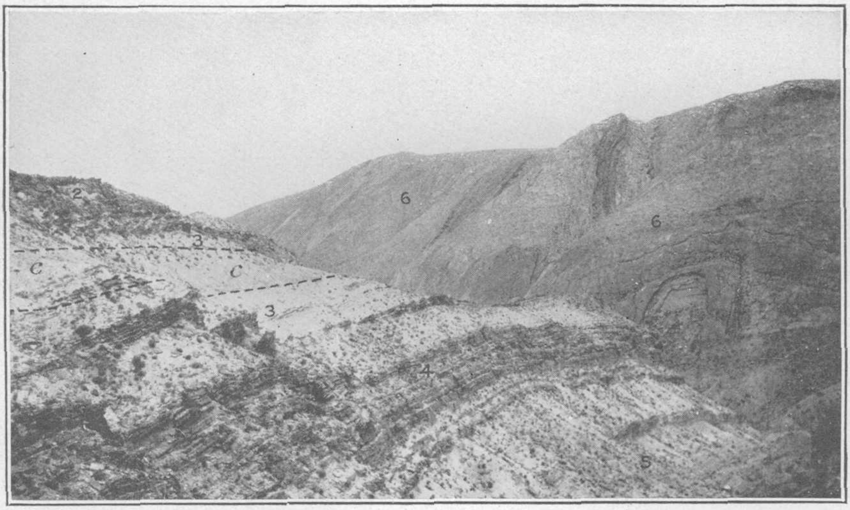


B.

COLEMANITE DEPOSIT NEAR CALLVILLE WASH, NEV.

A, Looking east along outcrop of colemanite bed; *B*, looking west along outcrop of colemanite bed. See section on pages 36–37 for explanation of numbers. *c*, Colemanite bed.

preserve their distinctive character and appearance over wide areas, being recognizable from their appearance alone at places hundreds of miles east of the Muddy Mountain region.

STRUCTURE AND DISTRIBUTION.

The structure of the Overton and Horse Spring beds is not nearly so complex as that of the Paleozoic and Mesozoic rocks, yet they have been considerably disturbed since they were laid down. In most places they are bent into anticlines and synclines, and in some places they are considerably faulted. Consequently they do not generally lie in their original horizontal position but are inclined at various angles. (See Pls. I and II.) Commonly the limestones make high cliffs and form ridges or "hogbacks," whereas the tuffs, sands, and clays are carved into badlands.

The largest area in which the Horse Spring formation is exposed covers more than 150 square miles in the southern part of the Muddy Mountains, but the exposures are not continuous throughout the area, being interrupted at many places by outcrops of the older rocks. Moreover, only a part of the exposures include the limestone member, in which the colemanite deposits occur. White Basin, in the northern part of the area, is in the limestone member, as is the deposit near Callville Wash, in the southwestern part of the area. Bitter Spring Wash flows through the eastern part of the area, and Virgin River crosses an extreme eastern extension of it at the mouth of Bitter Spring Wash. The beds at the mouth of Bitter Spring Wash, however, are not the limestone member but higher beds. West of Muddy Peak the Arrowhead Trail crosses outcrops of the limestone member near the point where the road is joined by the road up Las Vegas Wash. These outcrops are an extreme western extension of the limestone.

The formation is also exposed in and along the valley of Muddy Creek, at the north end of the Muddy Mountains, where it occupies an elongated area of perhaps 10 square miles that trends southeastward 8 miles or more along the base of the range. Muddy Creek and the road that connects St. Thomas and Moapa cross the northern part of this area about 6 miles above Overton. The area is about 2 miles wide at the north end and tapers gradually to the vanishing point at the south end.

East of Virgin River, in the region betwen the valley of the Virgin and Grand Wash, several exposures form elongated areas a mile or more wide and several miles long that trend north and south. Two of these areas lie in St. Thomas Gap, in Nevada, and are crossed by the road that runs through the gap from St. Thomas to Grand Wash. Horse Spring lies in the eastern of these two areas and is about 6 miles south of the road. Another area lies in Arizona, just west of Grand Wash and about 6 miles east of the Horse Spring area.

The area on Muddy Creek, the two areas in St. Thomas Gap, and the area near Grand Wash are in the limestone member.

The exposures of the Horse Spring formation have been extensively prospected since the time when colemanite was discovered at White Basin and near Callville Wash, but no new deposits have been brought to light. Yet because the exposures are in the aggregate of considerable extent and because the beds at many places are similar in lithologic character to those that contain the colemanite at White Basin and near Callville Wash, it seems unlikely that all the colemanite in the region has been found.

Little is known of the occurrence and distribution of the Horse Spring formation outside the Muddy Mountain region. Strata that crop out at several places south of Colorado River in Arizona not far from the Muddy Mountains may represent the Horse Spring beds. Possibly the formation occurs in some of the neighboring ranges in Nevada, as, for example, the Spring Mountain (Charleston) Range, whose detailed geologic features are little known.

AGE.

No fossils have been found in the Horse Spring beds or in the Overton fanglomerate, so that the exact age of these formations is unknown. Because they rest unconformably upon Jurassic strata and are overlain unconformably by beds that are probably Pliocene they may be of any age from Jurassic to Pliocene. However, the unconformity between the Overton fanglomerate and the Jurassic sandstone is so profound and obviously represents so long an interval of time that its existence creates a strong presumption that the Overton and Horse Spring beds are Tertiary. Because they resemble in lithology and in degree of deformation the Siebert and Esmeralda formations of Nevada, which are of probable late Miocene age, Longwell assigned them provisionally to the Miocene.

Many beds in the Horse Spring formation resemble beds in which colemanite occurs in the Calico and Furnace Creek districts in California. All the evidence available indicates that the Overton and Horse Spring beds, in common with the Siebert and Esmeralda beds and those in the Calico and Furnace Creek districts, were deposited in desert basins similar to those existing at the present day.

PLIOCENE (?) SERIES.

MUDDY CREEK FORMATION.

Overlying the Horse Spring formation is a series of loosely consolidated beds of sandy clay, sand, and gravel that at most places are horizontal or nearly horizontal but at some places are moderately tilted and folded. These beds are exposed typically along Virgin River and Muddy Creek and have been named the Muddy Creek beds by Stock.[5] Some beds contain much saline material. Many beds contain gypsum, and one or more beds consist of solid rock salt. At several places in the valley of Muddy Creek I obtained reactions for nitrate in loose clay soil that covers the outcrops of some beds.

The Muddy Creek beds lie nearly in the attitude in which they were originally deposited and occupy the present topographic basins of the region, whereas the Overton and Horse Spring beds have been considerably disturbed, and the topography of the basins in which they were deposited has been almost completely obliterated by deformation and erosion. Wherever the Muddy Creek formation rests upon the Overton and Horse Spring formations it is separated from them by an unconformity, the subjacent strata being upturned and eroded. The Muddy Creek formation is interesting because it contains in places along Virgin River deposits of rock salt and because it has recently yielded fossils, largely the remains of camels. No colemanite has been found in it.

Longwell assigned the Muddy Creek formation tentatively to the Pliocene because of its resemblance to deposits of that age near Panaca, 100 miles north of Muddy Creek. The fossils found in the Muddy Creek beds differ somewhat from those found in the Pliocene (?) Panaca beds of Stock[5] and may be older. Therefore the fossils do not establish definitely the age of the Muddy Creek formation as Pliocene, but they suggest that the beds are not younger than Pliocene.

IGNEOUS ROCKS.

The only igneous rocks in the Muddy Mountain area are thin flows of basaltic lava interbedded with the Muddy Creek sediments, of supposed Pliocene age, along Virgin River, but the Black Mountains, which lie southeast of the Muddy Range and just east of Callville Wash (see fig. 3), consist largely of Tertiary or later volcanic rocks. No igneous rocks are associated with the Horse Spring formation in the vicinity of the colemanite deposits, although the volcanic ash which forms a large part of the Horse Spring beds in that vicinity affords evidence that volcanic activity prevailed in the general region while the beds were being deposited.

[5] Stock, Chester, Late Cenozoic mammalian remains from the Meadow Valley region, southeastern Nevada: Geol. Soc. America Bull., vol. 32, pp. 146, 147, March, 1921.

THE COLEMANITE DEPOSITS.

DEPOSITS IN WHITE BASIN.

HISTORY OF DISCOVERY.

Colemanite was first discovered in this region in White Basin, an area 8 to 10 miles wide that lies just east of Muddy Peak and is bordered on the west, north, and east by high ridges of the Muddy Range. The basin is underlain by beds of the limestone member of the Horse Spring formation, from whose prevailingly whitish outcrops it derives its name. White Basin is about 15 miles due southwest of St. Thomas, but the road that connects it with St. Thomas is at least 25 miles in length. (See fig. 3.) The first locations were made by John Perkins, of St. Thomas, late in the fall of 1920. The discovery was soon brought to the attention of the Pacific Coast Borax Co., which promptly bought out Mr. Perkins's entire interest, the group of locations finally contracted for covering about a dozen claims. Subsequently other claims were located in the district, some of which passed into the possession of the American Borax Co., which is now developing them for an independent production.

CHARACTER.

The colemanite in White Basin occurs in bunchy lenticular layers interbedded with whitish shale. The typical shale contains a considerable amount of carbonate of lime and effervesces with acid. Qualitative tests indicate that it contains an appreciable amount of borate. It is essentially a consolidated mud, for fragments of it soften and dissolve to mud when moistened with water. Much of the shale contains gypsum, and here and there it contains beds of volcanic ash, some of which is light and pumiceous. The association of these beds of ash with the shale suggests that much of the shale may be composed largely of very fine volcanic ash. Tiny hexagonal flakes of black mica occur both in the shale and in the associated beds of ash or tuff. In places the shale contains thin interbedded layers of limestone. Commonly the laminae of the limestone are as thin as cardboard, and many laminae are as thin as paper. This interbedded limestone is called "paper shale" or "paper limestone" by the prospectors. Much of it exhibits concretionary structure and weathers into globular forms which shell in concentric layers like an onion (see Pl. II) and are called "goose eggs" by the prospectors. The "goose eggs" litter the ground near many outcrops of colemanite and are regarded by many prospectors as the most favorable clue to the presence of colemanite. Two samples of the typical "goose egg" material, one from White Basin and the other from the Callville deposit, which I submitted to the chemical laboratory of the Geological Survey for qualitative tests, are reported to consist "chiefly of carbonate of lime, with an appreciable amount of borate, probably ulexite."

At some places the colemanite forms balls or lumpy bunches in the shale, but at most places it forms irregular interbedded layers that are continuous for considerable distances. Material that resembles ulexite ("cottonball," a hydrous borate of soda and lime, probably $NaCaB_5O_9.8H_2O$) is associated with the colemanite in some of the deposits. Commonly this material forms lumpy masses in which the supposed ulexite is intimately mixed with colemanite. The structure of the masses suggests that they consisted originally of ulexite, which has partly or wholly altered to colemanite. I did not determine the composition of this material in the White Basin deposits, but similar material collected from the Callville deposit was tested in the chemical laboratory of the Geological Survey and reported to consist partly of ulexite.

EXTENT.

As exposed in the natural outcrops in White Basin the layers of colemanite are small, varying in width from a fraction of an inch to a maximum of 2½ feet, and the district as a whole is considerably disturbed by faulting and folding, which interrupts the continuity of the deposits, but there seems to be no doubt that the district contains a considerable quantity of commercially valuable material. At the time of writing a carload of colemanite taken out by the American Borax Co. was standing at the railroad station at St. Thomas.

ORIGIN.

The fact that the colemanite deposits contain lumpy masses that appear to have consisted originally of ulexite suggests that the deposits were originally formed as ulexite in mud, just as ulexite is being formed in the dry lakes or playas of desert basins to-day, and that percolating waters highly charged with lime may have afterward changed the ulexite to colemanite.

The structure of the "goose egg" limestone suggests spring deposits built up layer upon layer by evaporating waters highly charged with lime. Volcanic activity in this general region, which is proved by the presence of volcanic ash in many beds, suggests the ultimate source of the boron that formed the ulexite, and the great masses of Paleozoic limestone in the Muddy Mountains were doubtless the source of the lime.

DEPOSIT NEAR CALLVILLE WASH.

HISTORY OF DISCOVERY.

In December, 1920, F. M. Lovell and George Hartman started from St. Thomas on a prospecting trip to discover, if possible, any extensions of the White Basin deposits. After a stay of two weeks in White Basin, where they studied the mode of occurrence of the colemanite, they worked slowly southwestward along the outcrops of the Horse Spring formation and finally, late in January, 1921, came upon a huge deposit of colemanite in the canyon of one of the tributaries of Callville Wash about 12 miles southwest of White Basin. This discovery is considered by all familiar with the situation to be a most clever piece of scientific prospecting. Almost as soon as the discovery was announced, which was not until the prospectors had covered the entire deposit with claim locations, a sale was effected to F. M. Smith for $250,000. Mr. Smith, familiarly known as "Borax Smith," was the pioneer in establishing the borax industry in the United States and is undoubtedly the foremost figure in the industry. Although he founded the industry in the United States, he had lost control of the larger producing properties and had for some years been endeavoring to procure another hold. The present acquisition gives him an opportunity to enter the field as a competitor of the Pacific Coast Borax Co. in the production of borax and boric acid. As might be expected, the strike made by Messrs. Lovell and Hartman aroused local interest to fever heat, and the country became alive with prospectors.

LOCATION AND ACCESS.

The deposit lies at an elevation of about 2,000 feet 6 miles south of Muddy Peak and 8 miles north of the junction of Callville Wash with Colorado River. (See fig. 3.) It is about 24 miles east of Las Vegas, from which it is reached at present by the old Callville road. The distance from Las Vegas to the deposit by this road is 45 miles. At the time of my visit a camp had been established at the property and a crew of men were employed in opening up the deposit and in constructing a road due west from the deposit to Dike, a station on the Los Angeles & Salt Lake Railroad. The distance from the deposit to the railroad over this road will be about 20 miles. When the road is completed the ore will be hauled out over it by caterpillar tractors.

STRUCTURE AND EXTENT.

The deposit lies in the northern limb of a downward fold or syncline (see fig. 4) whose axis trends east and determines a troughlike depression over a mile long and nearly a mile wide. The relatively soft beds of tuff and ash of the tuff member of the Horse Spring formation lie in the axis of the trough, and the underlying hard limestones of the limestone member of the formation crop out all around the rim in high hogback ridges whose gentler slopes are toward the center of the trough. The west end of the trough has the canoe form characteristic of a plunging syncline, but the east end is open and irregular owing to faulting.

At a point about 2 miles west of Callville Wash a deep tributary canyon cuts entirely across the canoe end of the syncline from north to south, at right angles to the strike of the beds, exposing in cross section all the strata involved in the syncline. The colemanite deposit was discovered at the point where this canyon cuts through the innermost hogback ridge of hard limestone on the northern limb of the syncline. The bed of colemanite, or "vein," as it is called, dips everywhere as a regular part of the stratigraphic section and crops out along the steep outer slope of the hogback ridge. (See Pl. II and fig. 4.) So clearly is it exposed that from certain viewpoints the outcrop is plainly visible for its entire length. The length of outcrop of the bed is at least 3,000 feet. The minimum thickness in this distance is 10 feet, and the maximum thickness 18 feet. In form, therefore, the bed is a great lens. Everywhere along its outcrop the bed dips 45°–60° S., toward the axis of the syncline.

The horizon of the colemanite deposit can be traced all around the inner rim of the syncline for several miles along the outcrop, but colemanite is not visible in considerable amount except along the northern rim in the great lens already mentioned. The entire outcrop has been covered by the claim locations. The extension of the deposit underground down the dip of the strata and underneath the axis of the syncline is unknown. Probably it extends considerably more than 500 feet and less than 5,000 feet. If it extended much more than 5,000 feet it would appear in the southern rim of the syncline.

The remarkable feature of the deposit is its continuity and regularity. It is not as thick as some of the enormous deposits at Furnace Creek, but at Furnace Creek and in all the other producing districts in California the deposits are bunchy and broken, lie in brecciated and intensely folded portions of the inclosing rocks, and appear to have been more or less recrystallized by outside influences, whereas the Callville deposit has suffered only minor structural distortion and therefore appears to afford unusual facilities for efficient and economical mining.

CHARACTER OF INCLOSING STRATA.

The Horse Spring beds are magnificently exposed for many hundreds of feet above and below the deposit and lie in unbroken succession. Their sequence is shown in detail below. (See also fig. 4.) The thicknesses given are approximate.

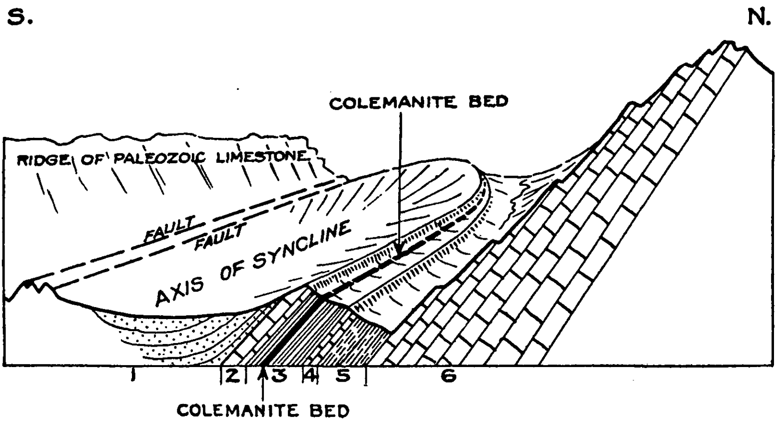


FIGURE 4.—Diagrammatic sketch showing mode of occurrence of colemanite deposit near Callville Wash, Clark County, Nev. Numbers correspond to those in section below.

Section of colemanite deposit and accompanying beds near Callville Wash.

	Feet.
1. Tuff	400
2. Cliff-making limestone forming crest of hogback ridge. Some layers massive, others thinly laminated. Many massive layers exhibit form structure characteristic of travertine; contain impressions resembling plant stems; in places the structure suggests deposition by algae. Some thinly laminated layers exhibit concretionary wavy structure ("goose eggs," "eggshells"); others are evenly bedded and the laminae are as thin as paper	100
3. (*a*) Light-gray shale exhibiting paper-thin lamination and "goose egg" structure	40
(*b*) Hard, travertine-like limestone with interbedded laminae of evenly bedded "paper" shale and wavy, concretionary "eggshell" shale or limestone	8
(*c*) Whitish paper shale exhibiting "goose egg" structure on a magnificent scale	10
(*d*) Colemanite "vein"; pale-yellowish bed consisting of bunchy layers of crystalline colemanite alternating with layers of paper shale, some of which exhibits "goose egg" structure. This and all other paper "shales" in the section are probably composed of limy mud containing more or less volcanic dust	18
(*e*) Wavy pinkish "eggshell" shale, full of small veins of gypsum	10
(*f*) Fine-grained yellowish-brown volcanic ash	½

	Feet.
(g) Wavy pinkish "eggshell" shale; many laminae as thin as paper	10
(h) Fine-grained yellowish-brown volcanic ash, variable in thickness	1–4
(i) Wavy "eggshell" shale; many laminae as thin as paper	15
(j) Hard limestone, like No. 4	4
(k) Pinkish "eggshell" shale; many laminae as thin as paper	25
4. Hard limestone, forming cliffs. Pinkish, thinly laminated beds characterized in part by "goose egg" structure alternate with massive, travertine-like beds resembling the massive beds in No. 2. Contains interbedded ash toward the base	75
5. Pinkish, yellowish, and greenish shale overlying bright-red shale containing gypsum	200
6. Massive limestone	600?

The colemanite deposit lies near the middle of a set of shaly beds consisting chiefly of thin-bedded concretionary limestone, which are at least 150 feet thick. The limestone is characterized by exceedingly thin, papery lamination and by the curious "goose egg" structure already described. (See Pl. III.) It breaks up into fragments that resemble pieces of eggshells, and in the Callville district it is called "eggshell limestone" or "paper limestone" by the prospectors. Wavy beds characterized by "goose egg" structure alternate with beds composed of even, level laminae and with beds of more massive limestone whose structure resembles that of travertine. Much calcareous shale is interbedded with the limestone, and gypsum occurs sparingly in the shale. Some beds of shale exhibit mud cracks. Thin beds of fine volcanic ash occur at several horizons.

Above these shaly limestones are beds of massive limestone composed largely of travertine. These massive limestones form the crest of the hogback ridge in which the colemanite occurs (see fig. 4) and are about 100 feet thick. They pass upward into alternating beds of limestone and tuff and finally into the beds composed almost wholly of tuff or ash which lie in the axis of the syncline.

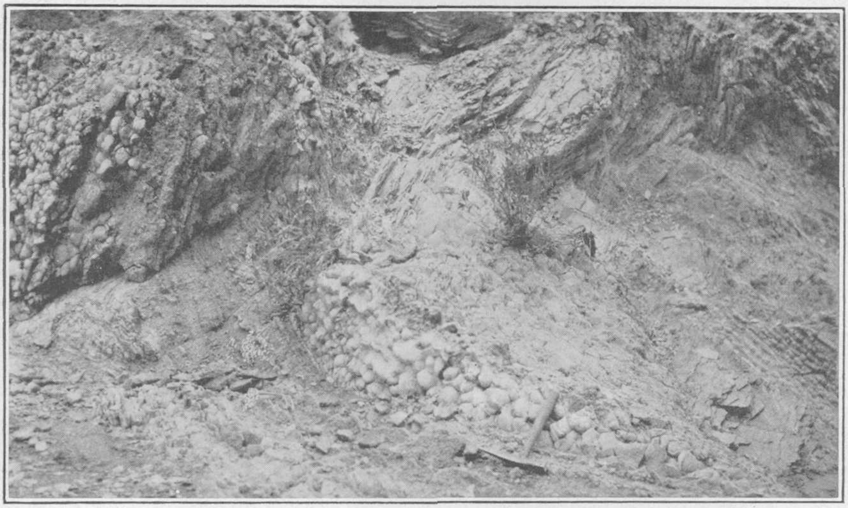
Below the shaly limestones are beds of massive limestone like that which lies above them. These limestones are about 75 feet thick. Below them are yellowish, greenish, and pinkish shales, overlying bright-red shales which contain large amounts of gypsum; these variously colored shales are about 200 feet thick. Below the shales are great thicknesses of massive limestone which form the bulk of the limestone member of the Horse Spring formation. These massive limestones form a high mountainous ridge on the outer northern rim of the syncline. (See fig. 4.)

CHARACTER OF DEPOSIT.

The colemanite deposit is simply a lenticular bed that consists largely of colemanite, lies in the shaly "eggshell" or "paper" limestones, and is clearly interbedded with them. It consists essentially of solid layers of colemanite alternating with layers of the paper shale or limestone. Some of the shale within the deposit exhibits the typical "goose egg" structure and is wavy; some of it is in level, parallel laminae. As seen in two open cuts that have already been made at places about 800 feet apart across the deposit, massive crystalline colemanite constitutes a large part of the material in the deposit. Most of the colemanite occurs in bunchy layers that lie parallel with the bedding of the shale, but some of it occurs in lumps that bulge the laminae of the shale around their borders. Some of these lumps are composed partly of ulexite. Commonly the deposit is distinguishable from the inclosing beds by faint shades of yellow, green, and pink exhibited by the shale interbedded with the colemanite—strange delicate tints similar to those of the shales associated with the borate deposits in the Calico and Furnace Creek districts of California. The outcrop of the deposit consists of loose, spongy weathered material that resembles gypsite and at first sight might not be recognized as colemanite even by the most experienced prospector. Unlike gypsite, however, it grates harshly when scraped by the point of a pick. The deposit appears to pass into gypsiferous beds at both ends of its 3,000 feet of outcrop, but I saw no gypsum within the deposit itself in the openings already dug across it. In some places gypsum occurs in stringers in beds just under the deposit.

CHARACTER OF ORE.

Although a large portion of the deposit is massive crystalline colemanite, the colemanite is interbedded with considerable shaly material, so that any ordinary method of mining will yield solid masses of crystalline colemanite, mixed with shaly material, which it will probably be desirable to concentrate by the usual method of roasting. So far as can be judged from the two open cuts already made across it, at least one-third of the deposit or bed may be expected to consist of pure colemanite. An averaged sample representing a strip 10 feet in length cut across the upper part of the bed at right angles to the strike was analyzed in the chemical laboratory of the Geological Survey and found to contain 22.65 per cent of anhydrous boric acid (B_2O_3). This result indicates that at least one-third of the sample consists of colemanite. At the point where the sample was taken the total thickness of the bed is 18 feet, but the 8 feet not sampled does not differ conspicuously in appearance from the 10 feet



A.

B.

"GOOSE EGG" STRUCTURE IN LIMESTONE BEDS ASSOCIATED WITH COLEMANITE DEPOSIT NEAR CALLVILLE WASH, NEV.

sampled. The open cut where the sample was taken is near the extreme east end of the colemanite bed, not far from the point where the bed disappears, so that it is at least as fair to conclude that the sample represents a leaner part of the bed as that it represents a richer part. However, any estimate based on an examination of two open cuts spaced 800 feet apart on an outcrop 3,000 feet long and one sample from the outcrop is little more than a guess.

ORIGIN OF DEPOSIT.

In origin the Callville deposit is apparently similar to those in White Basin, although it is on a vastly greater scale. More study is needed to reach a definite conclusion as to the origin of the deposits in both districts. The Callville material appears to be essentially a huge spring deposit formed in or about a playa by the evaporation of waters rich in boron and lime. All the colemanite may have been deposited originally as ulexite, but it is conceivable that the great abundance of lime in the waters of the district, which is shown by the enormous development of the "goose egg" and travertine limestones, was sufficient to form most of the colemanite directly, provided the spring waters also contained boron, although some ulexite may also have been deposited, as is shown by the presence of ulexite in the deposit.

The Callville deposit may represent an earlier stage in the formation of colemanite than the deposits in the California districts. Some of the colemanite in California is in veins that cut across the bedding of the associated shales, although much of it is in beds somewhat similar to the Callville deposit, but more bunchy and irregular. The colemanite in the crosscutting veins in the California deposits is probably secondary. It may have been formed from deposits originally like the Callville deposit, through the agency of hot waters accompanying the igneous invasions, intense structural deformation, and brecciation which took place in the California districts after the strata were laid down. These waters might dissolve part of the boron minerals in the original bedded deposits and redeposit them in veins. The Callville deposit did not experience this later violent igneous activity and intense deformation, so that it is preserved more nearly in its original condition.

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