SUBJECT TO REVISION.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Borax-Deposits of the United States.

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(Spokane Meeting, September, 1909.)

CONTENTS.

I. INTRODUCTION.

A COMPLETE transformation has taken place in the borax industry during the year 1908. A most remarkable factor in this radical change in method of producing the crude borates has been its removal from the realm of industrial chemistry to the field of mining. With the development of extensive deposits of borate-minerals interstratified in thick sequences of Tertiary clays and sands, their winning becomes a strictly mining-enterprise, of the same kind and of the same certainty as the digging of coal or iron-ore.

The major supply of the world's production of commercial borax now comes from the United States. While formerly all of the boric salts of commerce were laboriously extracted from the waters of saline lakes of the arid regions, or from the bottom-salts of desiccated ponds, it later was largely slowly leached from ancient desert shales and clays. During these periods the borax industry was a very hazardous and expensive vocation.

The discovery of large deposits of very pure, crystallized borate-minerals in the old Tertiary clays of southern California has enabled the main borax-supplies of the United States to be drawn from a single locality in the Mojave desert, near Daggett. The later finding of immense deposits of the crystallized mineral within easy access to good transportation-facilities promises not only to alter the character of the borax industry for the entire world, but to reduce the cost of production to less than one-third of the present figures.

Some of the extensive bedded deposits of borate-minerals recently discovered and investigated are located in a country that has been always one of the most inaccessible places of our domain. The geology of the region has been wholly unknown. While borates had been recorded from the district, the importance of the deposits has never been determined. The geographic extent of even the shales carrying the borates, or likely to contain them, has only been suggested in the vaguest manner, and then with no association of commercial values. The stratigraphy of the borax-minerals is, therefore, at the present time, of exceptional interest. In the Death Valley district the Tertiary clay-beds, of great extent and thickness, are perhaps as finely displayed as anywhere else. Many of the geological facts associated with the occurrence of the borax are also worthy of more than passing notice.

The present account of the geology of the borax-deposits in the United States originated incidentally in a commercial inquiry regarding the future of certain kinds of borax-supplies, undertaken for one of the chief borax-producing companies.

Later was begun a more personal inquiry of the more strictly geologic features of the occurrence of borate-minerals generally. Extensive investigation into metalliferous mining-properties in the neighborhood of certain of the larger borate-deposits gave opportunity to work out more in detail the geology of the districts in a way which before it was impossible satisfactorily to do. The results of these observations in the Death valley, the Mojave desert, and the Santa Clara valley are given herewith. The more strictly industrial aspects and treatment of the borax-substances for the market will be described in a later paper, after the deposits of other parts of the world have been inspected, and especially those of South America, Turkey, Italy, Germany, and India.

II. Occurrence.

It is now nearly 50 years since borax was first produced in commercial quantities in the United States. Since that time, about 1864, the industry has undergone several distinct changes, and is now entering upon its fourth important stage.

During the early period, soon after the discovery of the presence of boric acid in the waters of Clear lake, in northern California, lake-waters were evaporated and the boric salts extracted from the residues. This method prevailed for the period from 1864 to 1872.

In 1874 it was found that the crusts formed on the surface of certain desert marshes were rich in boric contents. From 1872 to 1890 the chief boric-acid supply of this country was gathered from the bottoms of desiccated ponds in California and Nevada.

A score of years then passed before it was surmised that the marsh-deposits might be possibly naturally leached from the clay-formations which bordered the dry lakes. The clay-beds themselves then began to be exploited. The utilization of the boraciferous Tertiary clays continued from 1890 to 1905. Some boric acid is still obtained from this source.

In the newest period great deposits of very pure borate-minerals have been found imbedded, or interstratified, in old Tertiary sediments; and large mining-operations have been already started which bid fair to control the borax industry of the world.

The Tertiary clays in which borate-minerals are found occur principally in southern California, but partly in Nevada. They extend in a rather broad belt, semicircular in shape, around the southern extremity of the Sierra Nevada and about 60 miles from that range. From Death valley and the Nevada boundary these clays are exposed at intervals through a distance of more than 300 miles, to the Pacific ocean at Santa Barbara, north of Los Angeles. Along the Furnace canyon on the east side of Death valley, in the Amargosa desert, in the low range of mountains north of Daggett, in the Mojave desert, in the Cajon pass of the San Bernardino mountains, and in the Santa Clara valley, which opens eastward from Santa Barbara, fine exposures give insight into the great areal extent of these deposits. For a decade or more Daggett has been the chief source of the borax-supply in the United States, but during the past year the Furnace Canyon and Santa Clara localities have been so extensively developed that the poorer deposits so long worked at Daggett are rapidly being abandoned. Moreover, better and more accessible deposits than any yet mentioned are ready to be developed.

The areal extent and relationships of the principal boraciferous beds are outlined in Fig. 1. In these localities the borate-layers are best exposed in the mountain-sides, where the stratified clay-beds, from 4,000 to 5,000 ft. thick, containing them have been tilted at a high angle and exposed to the erosive processes. Whether or not all of the borate-layers are in the same geologic horizon is not determined. Nor is it known with certainty that the several localities belong in the same geologic province. Presumably the clay-strata are continuous throughout the entire belt.

III. Geology of the Death Valley Borate-Region.

1. *Surface-Relief.*—The principal borate-deposits of the Death Valley region are interbedded with clay and friable sandstone formations of Tertiary age. These beds are best exposed in the Amargosa range, in Death valley, and in the Panamint mountains. This belt of mountain and valley is 125 miles long and

from 30 to 40 miles broad. To the east is the great Amargosa plain, and to the west the Panamint valley.

The district is a part of the Great Basin region, with its myriads of short, lofty mountain ranges, separated from one another by broad plain-like valleys. In this vast region, stretching from the Wasatch range on the east to the Sierra Nevada on the west, are found some of the most remarkable geographic features on the face of the globe.

The Sierra Nevada, rising from 10,000 to 14,000 ft. above mean-tide, constitutes the most conspicuous relief character of

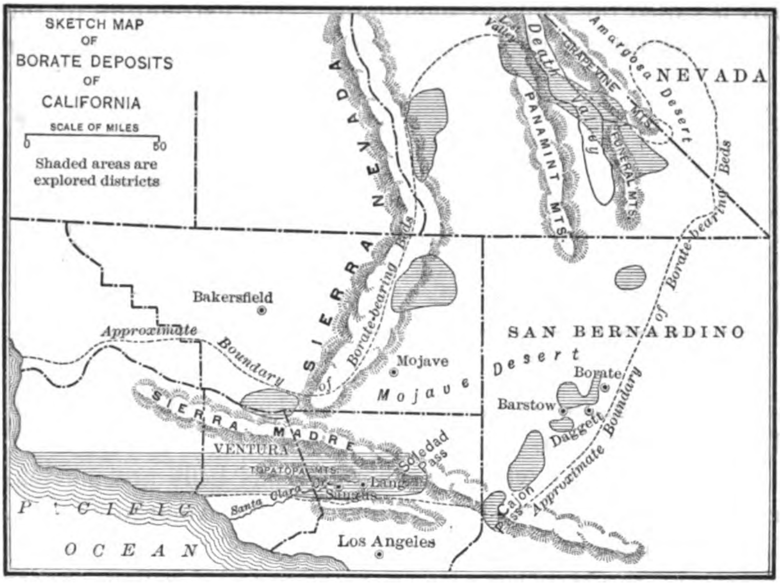

Fig. 1.—Sketch-Map of California Borate-Localities.

the Western United States. Parallel to, and eastward of, this majestic range there are other lesser ridges. The flat-bottomed valleys separating the abrupt mountains from one another are successively lower and lower as the distance increases from the main Sierra until Death valley is reached, which is the lowest depression of all, and the lowest point of any continent. East of the deep valley the intermont plains increase in elevation. The general relief-contrasts thus produced are well shown in profile in Fig. 2.

The immediate area occupied by the soft boraciferous beds is greatly diversified. The great Amargosa range, in which the principal deposits are found, presents to Death valley a very steep slope, which possibly represents a profound fault-scarp now much degraded. The north and south ends of the range are composed of hard clastics and eruptives separated by a belt of soft, infolded clays and friable sandstones, the belt of the latter passing diagonally across the mountain ridge. This slightly-resistant belt has been worn down from 3,000 to 4,000 ft. below the level of the crest of the range, dividing it into two somewhat distinct and nearly equal parts. The northern portion is usually known as the Grapevine mountains, while the southern part is called the Funeral mountains. The extremities of the Amargosa range fade out into the plains in the same manner

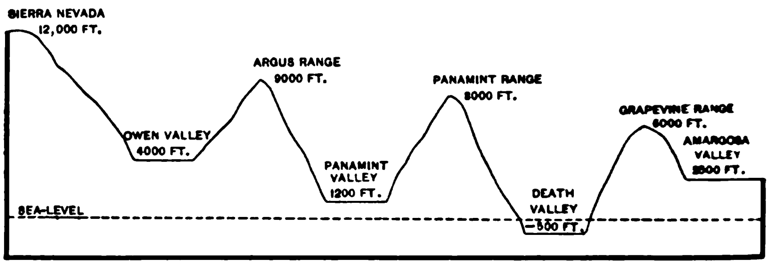

FIG. 2.—PROFILE OF THE DEATH VALLEY BORATE-REGION.

as do the neighboring ranges. It is in the soft middle belt that the chief borate-beds occur. (See Fig. 3.)

The valleys with which the boraciferous beds are particularly associated are the Death valley and the Amargosa valley. Like the majority of the intermont spaces of the Great Basin region and the Mexican plateau, these so-called valleys appear as vast plains seemingly as level as the sea. From the margins on all sides abruptly rise, without intervening foothills,[1] the lofty mountain ranges.

The most remarkable feature of the plains is the general absence of marked drainage-lines. Most of these basin-plains are true *bolsons*, such as are found farther southward in Mexico,[2] while some are *playas*, as the Spanish term them, having broad shallow sheets of water covering their central portions for a part of the year and at other times forming a bare mud-flat.

[1] *Bulletin of the Geological Society of America*, vol. xix., p. 573 (1907).

[2] *American Journal of Science*, Fourth Series, vol. xv., No. 87, pp. 207 to 210 (Mar., 1903).

Many of the intermont plains of the region have beveled rock floors,[3] and they are now believed to be formed chiefly through deflative erosion instead of tectonically, as they were long thought to be.

The drainage-ways leading into Death valley are many, short, and steep, and are occupied by water only briefly at rare intervals of heavy rain-fall in the neighboring mountains, or during the spring melting of the snows. In the mountains these drainage-ways lie in deep narrow canyons, but as they emerge into the great valley they are represented by shallow etchings on broad alluvial fans.

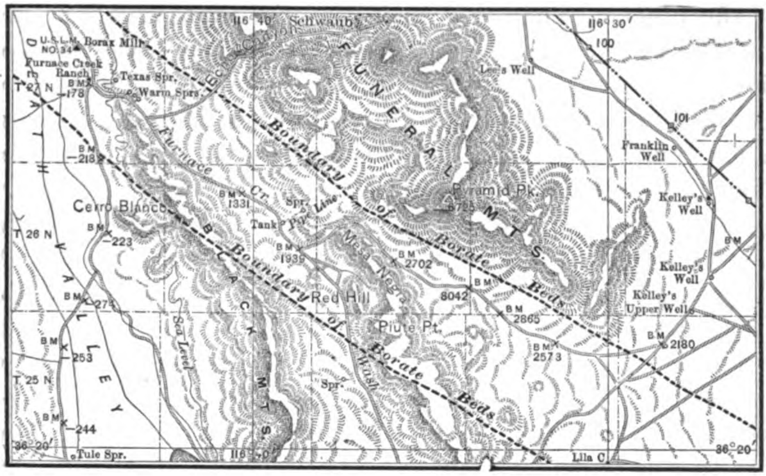

FIG. 3.—MAP OF FURNACE CANYON BORATE-DISTRICT.

Furnace creek has occupied the center of a narrow belt of clays and soft sandstones that traverses diagonally the Amargosa range. This canyon is relatively wide, and of much lower gradient than any of the other drainage-ways of the district. On each side of the main course are numerous deep ramifying canyons, cut in the thick clay-beds, the latter withstanding weathering in a remarkable manner. The crest of the canyon-walls on the east is capped by a thick basalt-flow, which forms a high cliff for a distance of several miles.

2. *Geologic Formations.*—The Death Valley region, which until quite recently has remained one of the least visited portions of

[3] *Bulletin of the Geological Society of America*, vol. xix., p. 67 (1907).

the United States, has never received from travelers more than incidental mention. Aside from a few brief and scattered notes, nothing has yet been published regarding the formations containing the borate-minerals. Altogether the region still remains geologically a veritable *terra incognita.*

The geologic formations of Death valley may be grouped readily into five great classes. The first of these includes certain gneisses and schists, such as appear in the basal part of the Amargosa range north of Furnace canyon, and which are probably of Azoic age. The second group contains hard, and often somewhat metamorphosed, clastics of Palæozoic age; these constitute the foundation of the various mountain ranges of the region. The third class comprises extensive volcanic masses, mainly of Tertiary age, but some of very late extravasation; these are chiefly diorites, rhyolites, andesites, and basalts. To the fourth category belong great deposits of soft clays and sands, commonly regarded as of lacustrine origin, which attain a thickness of more than 4,000 ft., and which often have interbedded extensive basalt sheets. They are largely of Early- and Mid-Tertiary age. With the fifth group may be included all of the more recent clays, sands, and gravels which now mantle the plains and the valleys.

The geologic formations exposed in the vicinity of the Furnace canyon, where the chief borate-deposits are located, represent a total thickness of about 20,000 ft., systematically arranged as shown in Table I.

The fundamental complex, composed of the highly metamorphosed schists and gneisses, is but sparingly displayed in the immediate vicinity of Furnace canyon. The foundation of both the Amargosa and the Panamint ranges comprises mainly quartzites and hard blue limestones of Palæozoic age.

In the neighborhood of the Furnace Canyon pass, at the south end of the Grapevine mountains, the principal part of the mountain ridge appears to be made up principally of Cambrian rocks. A few miles to the north higher beds come in, including peculiar terranes, which seem to be the southward extensions of the Pogonip limestone of King[4] and the Eureka quartzite of Hague.[5]

[4] *Report of the Geological Exploration of the Fortieth Parallel,* vol. i., p. 232 (1878).
[5] *Third Annual Report, U. S. Geological Survey,* p. 254 (1881–82).

TABLE I.—*Geologic Formations About Furnace Canyon.*

	Age.		Thickness.	Rocks.
CENOZOIC.	Quarternary.	Late.	Feet. 500 200	Basaltic flows. Gravels, sands, and clays.
		Early.	1,500	Basaltic flows. Alluvial deposits. Basaltic flows.
	Tertiary.	Late.	1,000	*Playa* deposits.
		Mid.	2,500	Clays and sands with basalt-flows. Clays and marls.
		Early.	4,000	Andesites. Rhyolites. Diorites.
PALÆOZOIC.	Carboniferous.	Mid.	2,500	Limestones.
		Early.	300	Limestones.
	Devonian.	....	100	Limestones.
	Silurian.	....	100 400	Limestones. Quartzites.
	Ordovician.	....	3,000	Limestones.
	Cambrian.	....	2,500	Quartzites.
Az.	Huronian.	....	500	Gneisses and schists.

Besides the Ordovician rocks, there appear to be represented beds of Silurian, Devonian, and Carboniferous limestones. While the first mentioned are known to be entirely absent from the central portions of the Colorado plateau, and are generally regarded as not being present anywhere around its margins, recent inquiries show conclusively that beds of this age certainly occur at many points in the peripheral belt. In the Amargosa range possibly 400 ft. of limestone seems clearly referable to Silurian age. The exact relations of this section to the Lone Mountain limestone of the Eureka district are as yet undetermined, but it is most likely that the two are not coextensive.

At several places in the Amargosa range fossils have been discovered indicating the presence of Devonian beds. At least 100 ft. of strata is thus tentatively referred to this age. Devonian limestones and shales, long thought to be absent around the entire margin of the great dome of the Colorado plateau, have been found recently to be well represented.

Walcott,[6] for instance, has found rocks of this age in the Grand Canyon district, between the Cambrian Tonto formation and the Carboniferous Red Wall terrane. On the south side of the dome the Devonian beds are highly fossiliferous.[7]

The more recent formations of the region under consideration include three main groups of rocks: the early acid volcanics, the clays and friable sandstones and their associated deposits, and the interbedded basic lavas. The latter are to be clearly distinguished from the basaltic surface-flows of Quaternary age. The Mesozoic formations appear to be entirely absent, unless some of the rhyolites and andesites should finally prove to be partly of pre-Tertiary age.

In the immediate vicinity of Furnace canyon the early volcanic rocks find small exposure. To the northward, beyond Boundary canyon, they make up much of the Grapevine range. These rocks appear as numerous and successive flows of what is commonly termed porphyry. The complete sequence of these acidic lavas is at least 4,000 ft. thick, and consists partly of dull grayish and reddish andesites, but mainly of multicolored rhyolites. The first-mentioned flows are much the older, and may be eventually found to be Jurassic in age rather than Tertiary.

South and west of Furnace creek, in that part of the Amargosa range known as the Funeral mountains, the greater part of the mountains is composed of similar andesites and rhyolites, with considerable dioritic and monzonitic masses. The principal volcanics in the Panamint range on the west side of Death valley also appear to be light reddish monzonitic or granitic rocks.

All of these acidic volcanics seem to have been outpoured over more or less level plains, and the mountains partly elevated before the stratified clays and sands were deposited. The latter, of which the Furnace Canyon borate-bearing deposits may be regarded as typical, are widely distributed. They have a thickness, in this district, of probably more than 4,000 ft., and comprise mainly soft, yellowish to brownish sandstones,

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[6] *American Journal of Science*, Third Series, vol. xxvi., No. 156, p. 438 (Dec., 1883).

[7] *American Journal of Science*, Fourth Series, vol. xxi., No. 124, pp. 296 to 300 (Apr., 1906).

with numerous clay-layers and greenish-yellow to whitish clays. There are a few calcareous beds. The clayey portions of the deposits contain the borate-minerals. Interbedded with the sands and clays are many sheets of basalt, of which the individual layers often are 100 ft. thick.

The most recent terranes consist of, besides the wash from the mountains, some finer deposits of temporary lakes, and perhaps also *playa*-deposits. These are separable into several distinct formations. Some borate-minerals are found in these beds, but thus far the deposits have proved to be unimportant. Extensive basalt-flows of a very late date cover large areas, and in many cases preserve the underlying soft clays from erosion.

3. *Geotectonics.*—Death valley is not only the lowest part of the Great basin, but the lowest area on the whole continent, being 500 ft. below mean sea-level. Contrary to prevailing opinion, the general tectonics of the Basin region is regarded as quite ancient. The so-called Basin Range type of mountain-structure is thought to be the exception rather than the rule, as an explanation of the rearing of the desert ranges. In the recent treatment of the origin of the Basin ranges the present relief-features were viewed from the stand-point of deflation, or wind-erosion, upon a planed surface composed of alternating belts of hard and soft rocks.[8]

The Death Valley district displays perhaps as well as any other area the distinctive characteristics of the so-called Basin Range structure. As it appears on first glance the geologic structure of the Amargosa range is that of a long, narrow, monoclinal block, tilted towards the east; that of the Panamint range, a huge mountain-block inclined westward; that of Death valley, a key-block 10 miles wide dropped down between, forming what the Germans call a *Graben*-block. The general idea is represented in Fig. 4.

Militating against this explanation is the singular fact that no one has yet been able to point out any direct evidences of recent profound faulting along the sides of the *Graben*. This is a significant fact, also noted by Spurr,[9] as applying to the majority of the desert ranges assumed to represent typical so-called Basin Range structures.

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[8] *Bulletin of the Geological Society of America*, vol. xix., pp. 63 to 92 (1907).

[9] *Bulletin of the Geological Society of America*, vol. xii., pp. 217 to 272 (1900).

The marked flexings, faultings, and unconformities displayed in the region, it may be noted in passing, appear to have little direct influence upon the existing relief expression. It is only to the minor, later deformative effects that attention need be specially called in the present connection. While the strata of the region present notable folding, it is so overshadowed by

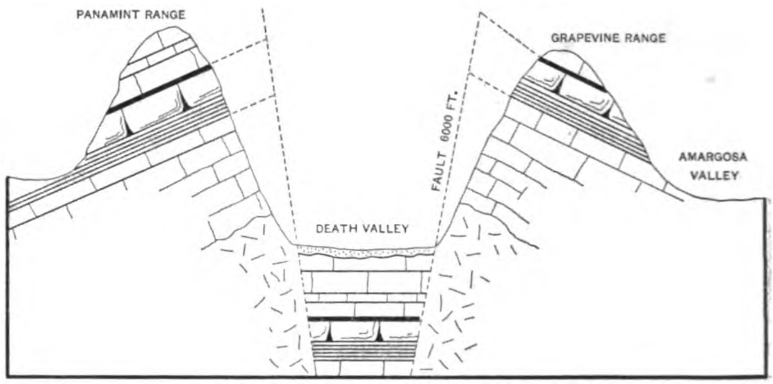

FIG. 4.—GRABEN STRUCTURE OF DEATH VALLEY.

profound and frequent faulting that the phenomenon is not at first glance at all striking.

Some of the more gentle flexures may have been merely attendant or local phenomena of the major faulting. That there is some genetic relationship between the two is further suggested by the fact that the axes of the folds appear to be parallel to the trend of the adjacent mountain ranges. The Tertiary

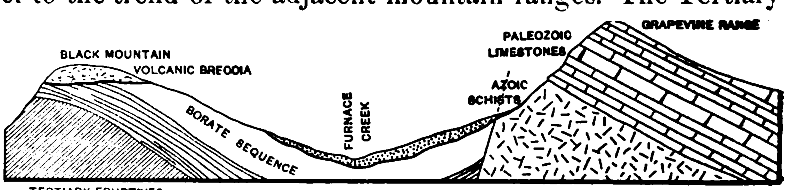

FIG. 5.—CROSS-SECTION OF FURNACE CREEK VALLEY.

clay-strata of the Furnace canyon present the geologic cross-section shown in Fig. 5.

The older major faulting need not be described here, since only the minor faulting has a direct bearing upon the arrangement of the borate-beds. These dislocations have mainly an E–W. trend. They are so recent that in some cases they still impart to the surface-relief a characteristic feature. This is particularly true when the surface is covered by basaltic flows, as, for instance, on the east side of Furnace canyon, and near the north end of the Funeral mountains.

Discordance in sedimentation is of special importance in considering the deposits of borate-minerals, for the reason that it has a direct bearing upon the economic exploration of the boraciferous field. In the section of more than 4,000 ft. of the Tertiary clays there are a number of great planes of unconformity, besides many minor ones. Some of the latter are so inconsequential as easily to escape notice. At the base of the clays-succession there are abundant evidences of profound unconformable relationships between these deposits and the indurated rocks beneath. Also, in the middle of the sequence, there is a very marked plane of like significance. At the top of the same section is a third great plane of discordance.

IV. Geology of the Borate-Beds of Furnace Canyon.

1. *General Features.*—The principal stratified beds carrying borate-deposits lie, as already stated, in a deep valley and canyon between two lofty mountain ranges. These boraciferous beds consist chiefly of soft clays and sands or friable sandstones, while the mountains on either side are composed largely of hard eruptives and metamorphosed clastics. Under conditions of normal humid climate, and in an elevated region, differential weathering alone would enable the weak formations to be eroded deeply within a very short time. In a dry country the same is also true, except that the erosive agent is chiefly wind-scour instead of water-action.

Furnace canyon, which traverses lengthwise the belt of clays trending diagonally across the Amargosa range, has now nearly bisected the great mountain ridge. This *arroyo*, or "dry-creek," has many lateral branches, deep and labyrinthine. The steep sides are produced partly by the undermining of the thick basalt sheet which still covers and protects from erosion many square miles of the soft clay-deposits. The vertical sections of the beds are many and are finely exposed. For the most part the local attitude of the layered deposits is readily made out.

Three rather distinct phases of the soft stratified beds occur. At the base of the section is a coarse conglomerate, which appears to be confined in its areal distribution chiefly to the eastern margin of the belt of finer deposits. It may form a part of the lower beds exposed in the Furnace canyon. It is possible, also, that it long antedates the Miocene terranes. For the present, until more critical evidence is obtained, it may be classed with the borate sequence. This conglomerate forms the south end of the Grapevine mountains, on the east side of the Furnace canyon south of Pyramid peak, where it has a thickness of more than 3,000 ft. It is also extensively exposed at the south end of the Funeral range, at the China ranch, where the Amargosa "river," for a distance of a dozen miles, cuts a deep canyon through the formation. At both of the

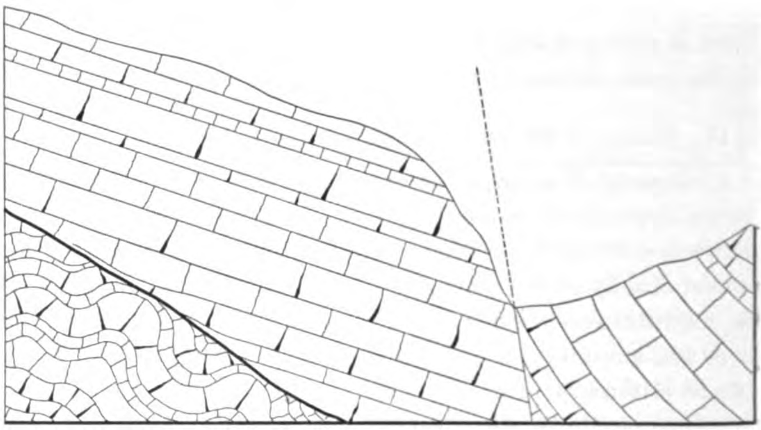

FIG. 6.—SHEARING AT SOUTH END OF FURNACE RANGE.

localities mentioned the terrane is heavily bedded, strongly tilted SE., and nowhere markedly flexed.

The pebbles and boulders comprising the chief portion of the conglomerates are all water-worn and rounded, and are evidently derived mainly from the Palæozoic rocks. The general color is brownish or reddish. There are some fine-grained sandstone-layers. The entire succession of beds is firmly cemented. The exact stratigraphic relationships of the conglomerate with the Palæozoics of the district are not as yet clearly understood. There are marked unconformable relations in some localities, but in one place at least, south of the Pyramid peak, there is a notable shearing, indicated in Fig. 6. Along the thrust-plane the conglomerate-beds contrast sharply with the contorted Ordovician limestones.

The second marked phase of the Tertiary stratified deposits has been called the older sand-series. The section is composed chiefly of yellow to reddish sandstones, rather massively bedded. These sandstones, so far as observed, nowhere merge into the underlying conglomerates; neither are there within them any conglomeratic facies. There are interstratified some minor clay-layers. The upper surface of the sandstones is very uneven and is apparently sub-aërially eroded. The higher clays seem to lie upon them unconformably. The sandstones are well displayed in the Furnace canyon, about 15 miles above its mouth. The thickness of the beds probably exceeds 1,000 ft. Neither in the sandstones nor in the conglomerates beneath are there any indications of the presence of borate-minerals.

The third, and uppermost lithologic, phase consists of fine, alkaline, olive-green clays, which weather to pale yellow or white. Numerous olivine-basalt sheets, from 10 to 100 ft. thick, are interbedded. In the upper part of the sequence is much crystalline gypsum (selenite), thick beds of crystallized calcium borate (colemanite), and thin layers of limestone, probably of chemical origin. Thick beds of rock-salt are also reported to occur in several localities. So far as known, no fossils are found in any of the formations within the area under consideration.

2. *Geologic Structure.*—The strata in the Furnace canyon are all more or less disturbed. The tilting of the beds appears to be chiefly the result of late flexing. The main lines of dislocation, if such they be, blocking out the clay-deposits, strike nearly NW–SE. The main anticlinal flexure trends more nearly E–W. The axis runs nearly parallel to the north branch of the Furnace creek, or Black canyon, and 4 or 5 miles from it. A line drawn from the Lila C. mine to the Cerro Blanco, a distance of 25 miles, nearly coincides with this axis. It crosses the canyon obliquely, making a noteworthy feature of the local topography. The geologic cross-section, SW. from Pyramid peak, is represented in Fig. 7.

From the central core of the older sandstones, as displayed in the Furnace canyon, the younger succession of deposits containing the principal borate-beds dip on either side of the axis in opposite directions. On the east side of the canyon, basaltic lava-flows cover the soft clays, and rest upon their evenly-beveled edges. The principal borate-beds have been cut through by the excavation of the canyon. Towards the crest of the Funeral mountains they are steeply upturned.

Near the summit of the older axis, where it passes beneath the basalt-sheet at Piute point, the beds are so beveled that the

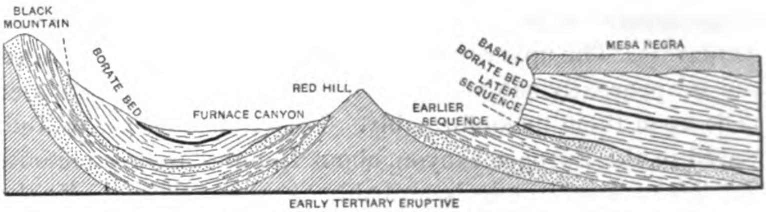

FIG. 7.—CROSS-SECTION OF FURNACE CANYON BORATE-DEPOSITS.

separated ends of the main borate-ledge on either side of the fold are 2 miles apart. The details are shown in Fig. 8.

Two miles to the north of the last-mentioned locality, under the Black mesa, where, near the top of the escarpment, the borate-beds again appear, the latter are sloping to the NE., as shown in Fig. 9.

In the Cerro Blanco, at the north end of the Funeral mountains, the succession of the borate-beds is finely displayed. An E-W. cross-section of the tilted strata is shown in the sub-

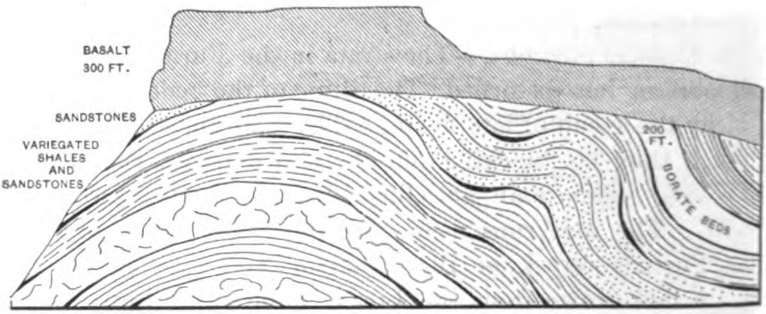

FIG. 8.—ANTICLINAL STRUCTURE AT PIUTE POINT. HEIGHT OF SECTION, 1,000 FEET.

joined diagram, Fig. 10. A notable feature of this sequence is the interbedded basalt-flows. The total thickness represented exceeds 3,000 ft. for the stratified clays alone. There are besides extensive deposits of old gravels, clays, and eruptives in thick sheets. The clay-deposits and sandstones present an alternation of soft and hard layers, which, with their present attitudes, form a series of sharp parallel ridges separated by deep valleys. In this section also there appear at least two marked planes of unconformity.

3. *Ores.*—The richer borate-beds are from a few inches to

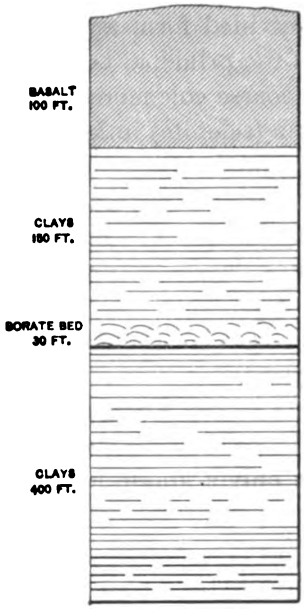

FIG. 9.—FACE OF BORATE-BEDS UNDER THE BLACK MESA.

50 ft. thick. In the unweathered portions they consist of bluish clays thickly interspersed with milk-white layers, nodular bands, and nodules of crystallized colemanite, or calcium borate, which is termed locally "high-grade ore."

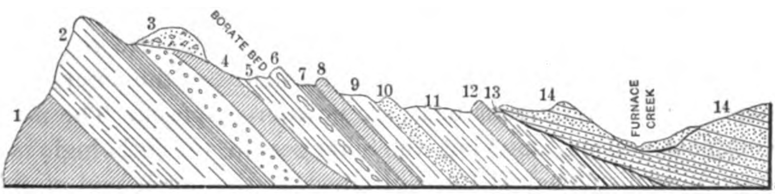

FIG. 10.—TILTED BORATE-BEDS AT CERRO BLANCO, FURNACE VALLEY. SECTION 2 MILES LONG.

Through the strata carrying the coarse, crystallized colemanite, the clays are more or less highly impregnated with fine particles of the borate-mineral, and yield, upon leaching, from 10 to 25 per cent. of anhydrous boric acid. This material is called by the miners "low-grade ore." While there are large quantities of this low-grade material in the Furnace Canyon district, it cannot be utilized to advantage in competition with the richer layers adjacent to it. At Daggett, however, similar clays carrying as low as from 6 to 12 per cent. of boric-acid content in a finely-divided form are exclusively mined on a large scale by two of the principal borax-producers.

Mingled with the coarse colemanite are often large amounts of crystallized gypsum (selenite) in large plates. In places the gypsum becomes so abundant that the borate-minerals are all but completely obscured. Frequently, also, there are present large amounts of very pure lime, which sometimes forms compact bands resembling layers of ordinary limestone. There are to a greater or less extent associated in the borate-beds other alkaline salts. Special attention will be called to some of these in another place.

There appear to be in the Furnace canyon several distinct horizons at which the colemanite was deposited, but, so far as now known, there is only a single level at which the mineral was formed in large quantities. This horizon is exposed on both sides of the Furnace valley. Large quantities of the mineral have been already removed through the excavation of the canyon.

The clays associated with the borate-beds are all very fine and are entirely free from coarse material, the crystallizations excepted. These clays, when freshly exposed, are blue in color, but on weathering soon become olive-green, then yellowish, and finally nearly white. They seem to be of typical *playa* origin, very much the same kind as are being formed at the present day in many inclosed basins throughout the arid region.

4. *Typical Section.*—In their full thickness the later clay-deposits, or boraciferous beds, are nowhere exposed. The most complete section, showing the changes in the lithologic sequence, is displayed at Cerro Blanco, at the north end of the Funeral mountains. The relationships of the various beds are indicated in Fig. 10. The details of the stratigraphic succession are as follows:

Section of Borate-Beds at Cerro Blanco.

		Feet.
14.	Clays and gravels, pale reddish-brown and purple,	500
	Unconformity, very marked.	
13.	Clay, shaly, argillaceous, yellowish,	200
12.	Basalt, black, surface-flow,	30
11.	Clay, shaly, pale yellow,	500
10.	Sandstone, friable, red in color,	25
9.	Clay, shaly, yellow to green,	150
8.	Basalt, surface-flow,	100
7.	Clay, shaly, olive-green to yellow,	60
6.	Clay, shaly, colemanite in large nodules and nodular layers,	50
5.	Shale, argillaceous and sandy, buff,	300
	Unconformity.	
4.	Basalt,	200
3.	Gravels, coarse, little or no clay,	300
2.	Clay-shale, blue above, yellowish below,	1,000
1.	Andesite (exposed),	500

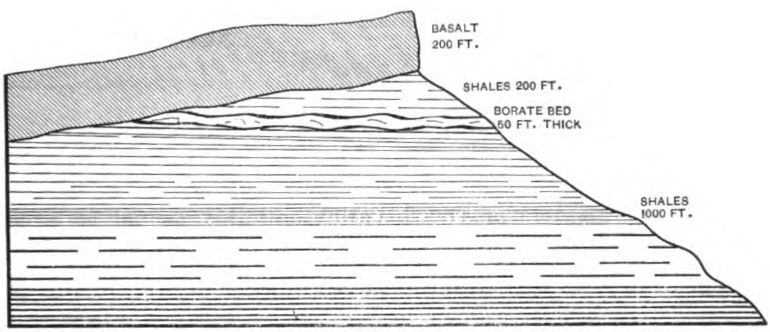

FIG. 11.—BORATE-BEDS UNDER MESA NEGRA, FURNACE CANYON.

On the opposite side of the Furnace valley, and 5 miles SE., under the Mesa Negra, the beds are inclined as shown in Fig. 11. While the thickness of the boraciferous bed is very clearly displayed, the subdivisions of the clay sequence are not so well shown as at the Cerro Blanco.

Two miles south of the last-mentioned locality, under the Black mesa, at a high sharp promontory called Piute point, the section is finely presented, as shown in Fig. 12.

At a mine-opening, 10 miles SE. of the Piute point, on the edge of the Amargosa plain, the clays are inclined about 20° E. In the sides of a low hill, where the borate-bed has been drifted upon, the richer colemanite-bearing stratum is 4 ft. thick, as illustrated in Fig. 13. Although the surface of the ground is obscured by the soil mantle, it is quite evident that the workable stratum is thicker. The full section is well exposed near the mine-entrance.

V. Borate-Deposits of Lost Valley.

The great belt of yellow Tertiary clays traverses not only the Amargosa range but also the Death valley, and extends

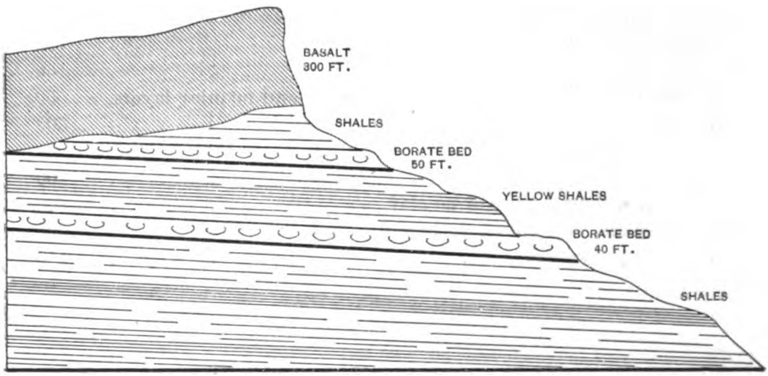

Fig. 12.—Details of Borate-Beds at Piute Point.

into the northern end of the Panamint range. On a spur of the latter, in an arm of Death valley called Lost valley, these clays are finely developed. At a point 25 miles from Cerro Blanco, in a NW. direction, borate-minerals occur. Thus far

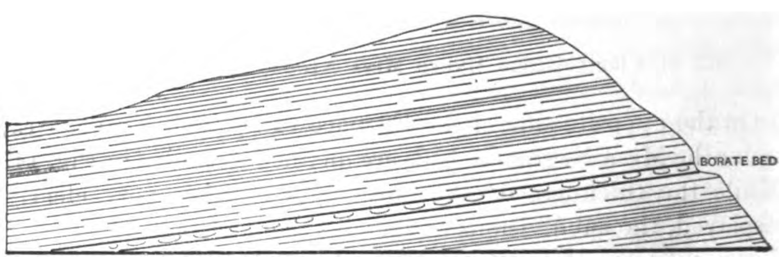

Fig. 13.—Drift on Inclined Borate-Bed at Lila C.

the deposits discovered consist mainly of low-grade material similar to the disseminated beds at Daggett. On account of the inaccessibility of the region at present little systematic exploratory work has been done.

VI. Borate-Deposits in Mojave Desert.

1. *Distribution.*—The peculiar yellow clays and sands, with which the borate-minerals are particularly associated, are widely

distributed in the Mojave Desert region. Only in the vicinity of Daggett, a station on the Atchison, Topeka & Santa Fé railroad, have the borate-minerals been carefully explored and opened up. It is this locality which has furnished, for a period of more than a dozen years, practically all of the borax obtained in this country.

From the crest of the Sierra Madre, at the Cajon and Soledad passes north of San Bernardino, Cal., to the Furnace canyon, in Death valley, the yellow clays are exposed at frequent intervals in the low mountains which protrude above the broad expanse of the Mojave desert. Along the Mojave river, from the Cajon pass north to beyond Daggett, a distance of 75 miles, the outcrops of the formations in question are almost unbroken. They also occur on the opposite side of the desert-basin, on the flanks of the Sierra Nevada, 100 miles north of the Cajon pass. Since on the plains the yellow deposits are often found a few feet beneath the surface-mantle of wind-drifted soils, it is very probable that the same beds underlie the greater portion of the Mojave desert, especially the belt 100 miles wide extending from Daggett to Death valley and beyond.

The borate-bearing deposits are usually spoken of as lake-beds. Upon what grounds I do not know. Lithologically, they appear to be the same from Death valley to the Pacific ocean. Only in the western part of the Mojave plain have fossils been found, and these are marine Eocene and Miocene types. It seems probable that if strictly marine beds extend this far from the Pacific into the Mojave area, the Death Valley beds are also deposits of the sea rather than of extensive lakes in the process of desiccation.

The yellow clays of the Mojave region also contain inter-bedded basalt-flows similar to those occurring in Death valley.

2. *Geologic Structure.*—As admirably shown in the low mountains north of Daggett, the borate-beds are somewhat flexed and frequently infolded with the old volcanic sheets which once were surface lava-flows. The axes of the flexures are mainly E–W., and parallel to the trend of the great Sierra Madre line of uplift on the south.

At the mining-camp of Borate, 12 miles north of Daggett, the inclination of the strata varies from 15° to 50° southward. As shown in Fig. 14, the soft clays have not been deposited around the foot of the mountains as recent lake-beds, but dip at a high angle directly into them near their summits. The crest of the range is formed by a thick sheet of eruptive rock, which constitutes a protecting cap for the weak clays beneath. The peculiarities of desert eolation permit differential erosion to go

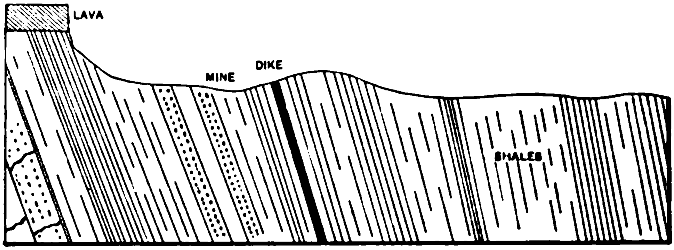

FIG. 14.—VERTICAL TERTIARY BORATE-BEDS NEAR DAGGETT, CAL.

on more rapidly in the arid country than in a normal moist climate.[10] It is estimated that under conditions of aridity erosion of soft rock-masses proceeds ten times as fast in a dry country as it does in a moist one; while under similar climatic circumstances the wasting away of hard rock-masses goes on only one-tenth as rapidly.

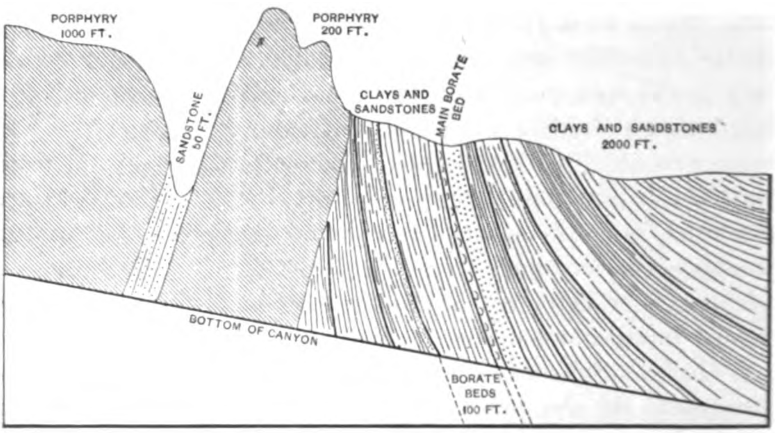

FIG. 15.—BORATE-DEPOSITS AT LANG, CAL.

The surface of the broad valley west of Borate and Calico and 10 miles NE. of Barstow, is over many square miles a true rock floor but thinly veneered by soil. The strata are highly tilted and evenly beveled. Wherever the more-indurated layers

[10] *Bulletin of the Geological Society of America*, vol. xix., pp. 63 to 92 (1907).

occur long ridges are found. At the mines of the American Borax Co. the section is finely displayed, as shown in Fig. 15. The beds dip 75° N. The yellow clays and sands are here more than a mile thick. There appear to be two well-defined borate-horizons separated by about 80 ft. of sandy shale; 15 ft. above the superior bed is a thin andesitic sheet scarcely 2 ft. thick. A short distance south of the mines is a high flat-topped hill. This is composed of the soft clays and sands standing on edge, evenly truncated and covered by a basalt-sheet.

South of Daggett and Barstow, a distance of from 8 to 10 miles, the yellow clays and sands appear in force in several prominent E–W. ridges. These deposits have been prospected for borate-minerals, but have not as yet yielded workable bodies. The strata are only slightly inclined, seldom more than 5° or 10°. The soft yellow formations have interbedded numerous sheets of basaltic and andesitic lavas. In the tilted condition these faulted and resistant layers lying over weak deposits give rise to the long, sharp ridges. To the west these pronounced relief-features gradually melt away into the general surface of the immediate valley of the Mojave river, indicating that the lava-flows do not extend far in that direction.

3. *Ores.*—At the mines of the American Borax Co., NW. of Daggett, there are, as already noted (Fig. 15), in the yellow-clays section two distinct horizons from which the borate-materials are obtained. Both beds are about 5 ft. thick. The mineral is in a finely-divided state, the blue clay of the beds worked containing 10 or 12 per cent. of anhydrous boric acid. The 80 ft. of clays separating the two productive layers contain some borate-material, but not enough to make it profitable at the present time to remove. Near the old Calico gold-mine, 6 miles east, another borax-refinery is obtaining its crude material from similar deposits. There are doubtless other horizons in the general section which are borate-bearing.

At the mining-camp of Borate there are also two workable beds, about 50 ft. apart. Whether or not these two levels are the same as those worked at the American mine is not at the present time known. The high-grade borate here is mainly the calcium salt occurring in nodular crystallized masses scattered through the blue clays. This nodular colemanite is now mined at depths of from 400 to 500 ft., and is treated at the refinery near Daggett. The associated low-grade material out of which the crystallized colemanite is separated is not at present utilized, although elsewhere it is the low-grade boraciferous clays that are leached.

A photographic view of the borax-mines at Borate is given in Fig. 16; the refinery and the evaporation-racks of the American Borax Co., at Daggett, in Figs. 17 and 18, respectively; and Fig. 19 shows the general type of concentrating-vats used in the Mojave valley.

VII. Borate-Deposits of Santa Clara Valley.

1. *Distribution.*—Yellow sands and clays of Tertiary age are extensively involved in the foldings of the Sierra Madre extending from the Cajon pass to the Pacific ocean. The Santa Clara valley follows the southern foot of the Sierra, and eastward separates it from the western end of the San Gabriel range. On the north side of the valley the nearest range of the Sierra Madre is known as the Topatopa mountains. Near the eastern extremity of the latter, a few miles NE. of the junction of the two branches of the Southern Pacific railroad at Saugus, and 5 or 6 miles NW. of Lang station, important borate-deposits have been recently discovered.

The boraciferous formation is one of great thickness, variously estimated at different places at from 5,000 to 8,000 ft. It comprises mainly fine gravel-beds, more or less indurated, yellow sandstones, and yellow clays. These are traversed by intrusive masses. Judging from the outcrops at the south end of the railroad-tunnel under the Fernando pass, in the San Gabriel range, the beds immediately inclosing the borate-deposits near Lang appear to belong to the Vaqueros terrane, lately described by Eldridge.[11] This is of early Miocene age. Other parts of the Lang section may belong to the Pliocene Fernando formation of the same writer.[12] The geologic structure of the Santa Clara valley is complicated. The strata are profoundly disturbed, so that the detailed relationships of the formations in different parts of the region are not easily grasped without extensive investigations.

Compared with the yellow boraciferous clays of the Mojave desert and Death valley, the Santa Clara section contains much

[11] *Bulletin No.* 309, *U. S. Geological Survey*, p. 12 (1907). [12] *Ibid.*, p. 22.

Fig. 16.—Borax-Mines at Borate, Cal.

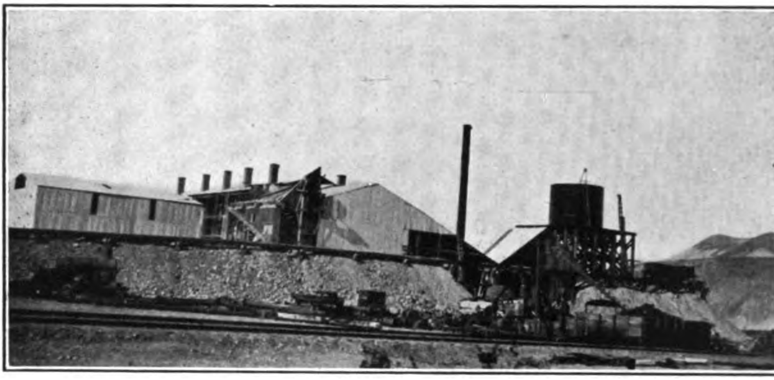

FIG. 17.—REFINERY OF THE AMERICAN BORAX CO., AT DAGGETT, CAL.

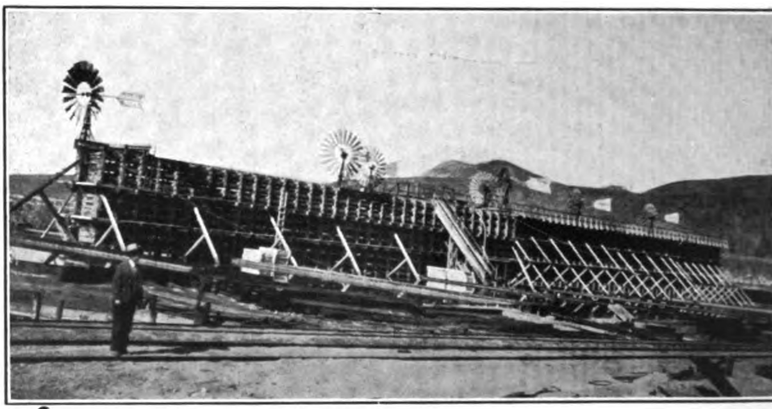

FIG. 18.—EVAPORATING-RACKS AT THE REFINERY OF THE AMERICAN BORAX CO., DAGGETT, CAL.

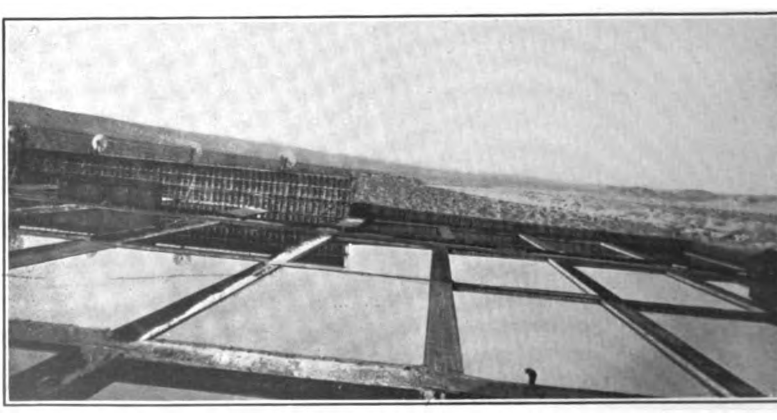

FIG. 19.—CONCENTRATING-VATS IN THE MOJAVE VALLEY.

more sandstone and conglomerate, which suggests that the borate-deposits of the latter district may be of somewhat later geologic age than the former.

2. *Geologic Structure.*—Notwithstanding the recency of formation and the great thickness of the yellow clay and sands in the Santa Clara district, the strata have been severely flexed and profoundly faulted. Several great unconformities tend also to vastly increase the complexity of the stratigraphy. The general tectonics of the Topatopa range, a few miles west of the borate-producing locality, is well displayed in the cross-section near Piru, modified from Eldridge, Fig. 20.

A short distance north of the Lang borate-belt volcanic rocks abruptly take the place of the soft clays and friable sandstones.

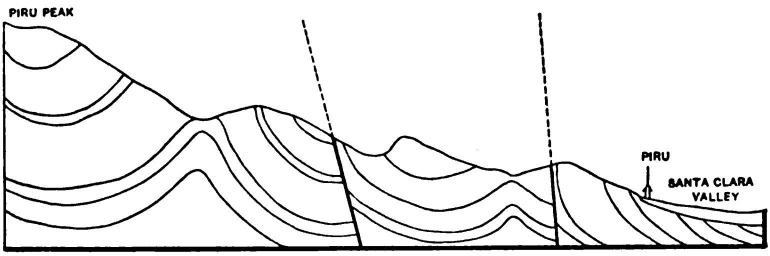

FIG. 20.—GENERAL STRUCTURE OF THE SANTA CLARA VALLEY, CAL.

In these porphyries considerable metal-mining is carried on. The strike of the strata is nearly E–W., but at the borate-mines there is repeated off-setting of the borate-stratum by faulting, having a trend NE–SW., and of several hundreds of feet lateral displacement in each case.

3. *Ores.*—At the point at which the borate-mines are opened the rocks are very much disturbed. The strata are abruptly upturned against a great basic dike, Fig. 15. As observed along the base of the canyon cutting the deposits transversely, the succession of layers is as follows:

Borate-Section at Lang.

	Feet.
6. Sandstone, hard, drab,	25
5. Clays, yellowish, with thin limestone-lenses, and several arenaceous layers,	100
4. Clay, bluish, carrying abundant colemanite nodules and layers,	4
3. Clays and sandstones, yellowish, often calcareous,	200
2. Porphyry dike,	200
1. Sandstone, indurated, brown (exposed),	50

As yet mining is not carried on by means of shafts, as in the cases of the Daggett and Borate localities. In a deep narrow canyon which cuts across the almost vertically-disposed boraciferous bed, and near the bottom, tunnels are driven into the canyon-walls on either side. The mineral is then stoped down, just as the larger ore-bodies are removed in metal-mining. The exceptionally good transportation-facilities, and the high-grade of the material, well combine to make this locality, for many years to come, the principal source of borax in the United States.

VIII. Borate-Deposits in Ventura County, Cal.

On the north side of the Sierra Madre, in the extreme corner of Ventura county, Cal., there occur extensive beds of the yellow clays and sands, similar in all respects to those found on the south slope of the same mountain system and in the Mojave desert. The strata are all highly inclined, and the colemanite is scattered through the blue clay in small nodular crystallizations. The locality has been worked for a number of years, and has furnished a considerable amount of material for the manufacture of boric acid. Since this point is 75 miles from the railroad, the operation of the mines has been conducted under great difficulties, but these in large measure are soon to be removed.

IX. General Geologic Occurrence of Borax.

1. *Original Sources.*—As a title in commerce the name borax is usually applied not only to the substance borax, $Na_2B_4O_7$, itself, but to the several boron compounds which are capable of being readily converted into the sodium tetraborate.

The element boron is widely distributed through the earth's crust. Commonly, however, it is found in such small quantities as to be almost inappreciable. As all of the boron salts, from which the article of commerce is derived, are quite soluble under ordinary climatic conditions, no valuable deposits of these salts occur in normally moist lands. As geological deposits the salts of boron are possible only under climatic conditions of extreme aridity.

Sea-water is known to contain minute amounts of borax. According to Forchhammer,[13] boron is one of the 27 elements the presence of which he detected in the waters of the ocean.

[13] *Philosophical Transactions of the Royal Society*, vol. clv., p. 208 (1865).

Certain of the rock-forming minerals have boron as an essential constituent. Its vapors are regarded as highly important mineralizers in the metamorphism of rocks and in connection with the formation of many ore-deposits.

Boric acid is a common exhalation accompanying volcanic eruptions. Vulcano, Stromboli, Etna, Vesuvius, and other active volcanoes in different parts of the globe give it forth in notable amount.

Many warm and brine springs give forth waters carrying in solution very appreciable quantities. The waters from the great Ash Meadows springs, in SW. Nevada, contain so much borax as to be noticeable to the touch. Roth,[14] especially, has called particular attention to the presence of borates in some of the brine-springs of Germany.

In the drier regions of the globe many of the bitter-lake waters contain considerable amounts of borax. This has been concentrated through long-continued evaporation. In some of these shallow lakes the borax forms in well-defined but scattered crystals in the muds of the bottom. In the old Tertiary clays of the West borates appear to have originated in large deposits in this way.

Geologically, deposits of borax derived from four of the five original sources just enumerated are unimportant. While formerly most of the borax of commerce was obtained from solfataric vapors and from the evaporation of strongly saline waters, little from these sources is now collected. At the present time the greater part of the world's supply of borax comes from the arid regions, where alkaline lakes in the last stages of desiccation yield either borax direct or borates from which it may be artificially derived.

2. *Solfataric Borax.*—Boric acid occurs as a sublimate in lava-cavities and cracks around active volcanoes. Acidic magmas in cooling give off such appreciable amounts of boric vapors that these, together with those of fluorine, chlorine, etc., become important "mineralizers" of the rocks through which they pass. So early as 1846, Élie de Beaumont, the famous French geologist, emphasized the activity which must be displayed by such vapors as those of boron, phosphorus, and fluorine in being

[14] *Allegemeine und chemische Geologie*, vol. i., p. 442 *et seq.* (1879).

expelled from consolidating granite magmas.[15] Since that time others have expressed similar views.

It is now a well-established fact that the borate-producing localities of the world are also districts in which volcanic activity has not yet ceased. The extent to which boron compounds occur at these places may be judged from the statement that the vapors in some situations are collected in commercial quantities, as in the Maremma of Tuscany. The vapors, as they issue from the *saffioni*, are passed through vats of water, which eventually become charged to the extent of 2 per cent. with boric acid, when the waters are drawn off and the process repeated.

3. *Lacustrine Borax.*—Lake-waters containing small percentages of boric acid have yielded some of the principal borax-supplies. In the United States the most noteworthy of such occurrences are at Clear lake, in northern California, and at Ragtown lake and Sand springs, in Churchill county, Nev.

At the Clear Lake locality the crystals of boric acid occur abundantly in the muds of the bottom of the lake. These muds are pumped out, washed, and sent to the refining-plant. The waters are also boiled in small vats and the boric acid finally crystallized. In Nevada the lake-waters were pumped out upon a plain and allowed to evaporate in the dry air.

4. *Marsh Borax.*—From the *playas* of the arid regions the major part of the borax-supply was formerly obtained. The bottoms of desiccated lakes are often, for a part of the year, covered by a few inches of water. The alkaline crusts which gather upon the floors upon complete evaporation of the waters are harvested and sent to the refinery. The material thus obtained is usually the native borax, $Na_2B_4O_7$, mixed with a number of other salines.

Half a century ago, when the principal portion of the world's supply of borax came from Thibet, in central Asia, it was from such lake-floors that the unrefined material was chiefly gathered. In the United States the main supply was for many years obtained in a similar way. Searle marsh, in the NW. corner of San Bernardino county, Cal., has long been noted for this class of borax.

[15] *Bulletin de la Société géologique de France*, Second Series, vol. iv., p. 1249 *et seq.* (1846–47).

It is generally assumed that such salinas as Searle marsh are the final remnants of former extensive lakes. According to the latest observations and deductions concerning the evolution of desert relief-features, it seems more probable that the majority of such salinas are due directly to the fact that eolian erosion has encountered ground-water level, permitting their constant evaporation just at the surface of the ground without forming open bodies of water.[16]

5. *Terranal Borax.*—Borates forming old geological deposits are now known to occur in a number of places in the arid regions. The layers, imbedded with shales and sandstones, are associated with gypsum, rock-salt, and other salines deposited from desiccating bodies of water. The bedded borates of California are the most important deposits of the kind known. They form geologic terranes in the strictest sense of the word. It is from this source that the world's supply in the future may be expected mainly to come. The laborious harvesting of lake-muds and thin surface-crusts will soon be a thing of the past. Borax-gathering now becomes a strictly mining industry.

As more fully stated in another place, large bodies of water are known to have existed in very recent geologic times in many parts of what are now eastern California and western Nevada. The smaller of these inland seas, for some of them were cut off from the ocean, soon became bitter-lakes, and finally dried up altogether.

As such bodies of water pass from the stage of saline lakes to that of complete desiccation many interesting precipitations take place. According to the most recent investigations on the subject, ordinary gypsum begins to be deposited on the lake-floor when about 37 per cent. of the water has evaporated. Then as the water progressively reaches the point of saturation for other salts they are thrown down in turn. Finally, when 93 per cent. of the water has passed off, common salt is deposited.

The most frequent succession of salts thrown down by progressive evaporation of saline waters of inland seas is: 1, boracite; 2, anhydrite; 3, gypsum; 4, sylvite; 5, halite, 6, kieserite; 7, polyhalite; 8, kainite; 9, carnallite; 10, tachyhydrite.

Contrary to long-accepted opinion, the various salts in saline

[16] *Bulletin of the Geological Society of America,* vol. xix., p. 90 (1907).

waters under conditions of arid climate are not precipitated in inverse order of their solubilities. The relative amount of the several elements in solution has a prime influence. This differs widely in different basins, so that under the same climatic conditions the same succession of salts does not always appear. Time is a noteworthy determining element. Temperature also plays an important rôle; and pressure has some influence.

The notable factor to be taken into account in considering the general sequence of the salts thrown down in bitter-lakes is the early appearance of the borates.

X. Chemistry of Natural Borates.

1. *General Considerations.*—Since the borates which supply commerce with most of the raw materials for conversion into borax as it is used in the arts now come from old lake-beds of inland-sea deposits, their chemical relations and development are quite like those of saline deposits generally. While a general sequence of salts in the precipitations from complex saline waters has been commonly regarded as established, it is now known that this succession is not everywhere invariably the same. Neither is the sequence in inverse order of solubility, as it was long thought to be.

The experiments on evaporating large quantities of sea-water carried on many years ago by the celebrated Italian scientist, Usiglio,[17] are well known. The results obtained by this chemist have been widely accepted; but more recent tests prove that they are not of so wide application as was at first supposed. Careful comparisons show that the artificial processes do not correspond exactly to the natural ones. This fact recently led the German chemists, Van't Hoff, Meyerhoffer, Hindrichsen, and Weigat,[18] to conduct exhaustive researches on the salt-formations in nature. Very interesting results were obtained, which throw a flood of light upon the subject, and offer satisfactory explanations to many hitherto little understood phenomena.

Among the important factors which Usiglio, and others who have been especially interested in similar experimentation, did not take into consideration were: 1, the composition of the

[17] *Annales de Chimie et de Physique*, Third Series, vol. xxvii., pp. 92 to 107 (1849).

[18] *Sitzungsbericht der königlich preussischen Akademie der Wissenschaften*, 1897.

saline waters; 2, the solubility of the compounds present; 3, the time allowed for concentration; 4, the temperature at which saturation for a given salt took place; and 5, pressure under which crystallization began. Since the recent chemical results have such a direct bearing upon the saline deposits under consideration, they may be briefly summed up here.

In the great salt-deposits of Stassfurt, Germany, which were chiefly investigated, it was found that in the succession of strata four very distinct zones were recognizable. These, beginning at the bottom and named after the principal salt found in them, were the anhydrite zone, the polyhalite zone, the kieserite zone, and the carnallite zone. In all of these zones rock-salt is found. There are also other salts present which are regarded as of secondary formation.

The desiccated inland-sea deposits of the Great Basin region of western America have not been as yet investigated in detail to determine the full variety of salts and their relationships. However, sufficient is known in the case of the borate-deposits of the Death Valley district to state something regarding the peculiar conditions existing at the time at which the salts belonging to the first or lowest zone were precipitated. This zone is the one containing, besides anhydrite, the borates, gypsum, calcite, and some other salts in which lime is an important constituent.

2. *Composition of Saline Waters.*—Were it merely oceanic waters with which we had to deal the chemistry of natural salines would be very simple. By not taking into account the calcium salts the composition would be identical the world over. The composition of the waters of bitter-lakes is very much more complex and varied. Many new conditions are introduced. Inclosed bodies of water, especially those of the very dry regions of the earth, receive compounds in solution from the surrounding elevations that vary greatly in every case, and according to the composition of the rocks, or geologic terranes. In every known instance some one salt greatly predominates.

Instead of the various salts being precipitated in inverse order of solubility, it appears that in a given solution the component which is greatly in excess is the one that is most likely to reach the point of saturation first, and hence will be the first to crystallize out. As Van't Hoff has recently clearly shown, concentration will continue until the water reaches the point of saturation for a second salt, when that also will commence to be precipitated. If for the moment we can neglect the other salts, in order to give the problem its simplest form, it is from this point onward that the water remains with the composition unchanged. The water gradually evaporates and the salts continue to fall until complete desiccation has taken place.

3. *Solubility of Components.*—There is a widespread opinion among scientists that the salts which crystallize out of saline waters in the arid regions of the globe are merely in solution, and that merely the proper point of concentration is required to be reached in order to precipitate a given salt. Such, it has been already intimated, is not really the case.

Recent observation has conclusively shown that in the desiccation of some saline waters certain salts which naturally would be expected to be found do not appear at all. In other cases compounds entirely unexpected are actually deposited. Under one set of physical conditions the waters of bitter-lakes as they evaporate may throw down a certain series of salts, while under slightly different conditions the same saline waters may deposit an entirely distinct series of compounds.

The first-mentioned results are rather unduly emphasized on account of their being the outcome of laboratory-experimentation also. Here the physical conditions are always very nearly uniform, and the methods of chemical procedure fixed. In nature there is no such uniformity of conditions as is found in the laboratory. In consequence there are many departures from the artificially-conducted tests. Solubility is also a function of temperature, and varies in degree very greatly, as all laboratory-work shows.

4. *Time-Element in Water-Concentrations.*—In nature the time-factor in the determination of precipitates in solution is probably very much more important than is commonly assumed. In the chemical laboratory time is of necessity practically eliminated in all experimentation, and as a consequence very erroneous conclusions are often drawn regarding the chemical processes at work in the earth's crust and the results attained.

The unexpected chemical reactions in nature are as noteworthy in the desiccation of saline waters as they are among the rock-magmas in the process of solidification. Among the last mentioned granite alone may be cited out of the many known examples. It is shown that an acidic magma, owing to the presence of aqueous vapor, the high pressures under which alone granite can form, and the long time that must manifestly pass, may cool down considerably below the temperature required to crystallize out certain minerals under ordinary dry-fusion conditions. Thus quartz, which should be formed quite early in the normal sequence, can be the last to crystallize, solidifying the whole mass into solid rock. This principle was long ago formulated by Scheerer,[19] who later advocated it at greater length and in greater detail.[20] It was subsequently confirmed experimentally by Èlie de Beaumont, Daubrèe and others, as well as by some more recent investigators.

In the case of similar retardations in crystallization of salts in saline waters under much simpler conditions than those existing among molten materials, recent inquiry has clearly indicated that such phenomena occur very much more frequently than was ever surmised. Length of time, however, is not the only determining factor in these cases.

In the formation of natural salts in desiccating lake-waters the time-factor must be regarded as of prime importance. To it must be ascribed the presence in the sequence of saline deposits of certain salts which never appear in the laboratory-trials. Concerning the saline deposits of the old inland seas of the Great Basin region, this time-factor explains much that previously was very obscure.

5. *Effect of Temperature.*—The general influence of temperature in effecting the crystallizations in saline solutions need not be dwelt upon at length here. Effects of the high temperatures are now well known. Effects of slight changes of a few degrees, within the limits of the ordinary temperatures as they are known in saline waters of the arid regions, have not been so well understood or considered.

At normal temperatures saline waters of the desert basins may deposit a certain number of salts and in a certain sequence. Under conditions of 20° or 30° increase waters of identical composition in the process of desiccation may give rise to some

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[19] *Poggendorff's Annalen der Physik und Chemie*, vol. lvi., pp. 479 to 505 (1842).

[20] *Bulletin de la Société géologique de France*, Second Series, vol. iv., p. 468 *et seq.* (1846-47).

entirely new minerals. At the same time, at the higher temperature, some of the salts which commonly appear at lower degrees of heat do not form at all. Within certain limits the salts derived from evaporation of the waters of saline or bitter-lakes may be regarded as indices of the temperatures of the waters at the time the deposits took place. Hence, it is possible to use deposits of this kind as factors in the determination of geologic climate.

Temperature of saline waters has also a very important bearing upon the paragenesis of many of the minerals which are commonly associated in old lake-beds or deposits of inland seas. The gathering of winter and summer sodas in some of the alkaline ponds of Wyoming and elsewhere forms a good illustration. Just what part temperature has played in the formation of the borate-deposits of California has not yet been definitely determined, but it is thought to be highly influential.

6. *Effect of Pressure.*—The effect of pressure in the formation of saline materials in saline lake-waters can hardly be so great as it is in the cases of many other geologic deposits. Variations in pressure must be quite negligible, because the bodies of water of this kind are comparatively shallow when the salts begin to form. In laboratory-experimentation pressure is usually eliminated altogether.

XI. Occurrence of Other Commercial Salines.

The Tertiary boraciferous formations of southern California are the most remarkable and most extensive in the world. They were formed under conditions of an arid climate in a great shallow arm of the Pacific ocean that had been cut off by the upheaval of the mountain ranges along the coast. The inland sea was long in drying up, and perhaps had frequent connection with the ocean, as is shown by the enormous thickness of the terranes carrying the borates. The disappearance of the water may have been more rapid than the thickness of the deposits suggests at first thought, for the reason that as an accompaniment of the evaporation of the waters in an excessively dry climate there may have been a filling-up of the basin by the prodigious quantities of wind-borne dust derived from the neighboring deserts. It is not to be inferred that, since the

Tertiary clays and sands are between 5,000 and 8,000 ft. thick, the waters in the beginning were at least of the same depth, but rather that the arm of the ocean and afterwards the inland sea was always very shallow, and that as the area was filling up the waters continued to rest on the surface, rising with the rise of the bottom. This postulates a gradual sinking of the foundations of the region, and the truth of this is indicated by the general tectonics of the region.

The entire field of the Tertiary clays in southern California is capable of great results from systematic prospecting and exploration for commercial salines other than calcium borate. The inferences to be drawn from the modern conceptions of the deposition of salines are that with proper inquiry a large series of natural salts may be discovered. The calcium borate-beds are easily passed over unnoticed unless special care be taken to look for them. Other borates are found even more valuable than the colemanite. Extensive rock-salt deposits are already known, as are those of purest gypsum, anhydrite, and calcite. In some of the bitter-lakes immense bodies of soda and magnesia of the kind known mineralogically as blœdite, are among the most wonderful deposits recently found. In one small lakelet scarcely a mile across it is estimated that more than 1,000,000 tons of this mineral is readily available.