

STRONTIANITE DEPOSITS NEAR BARSTOW, CALIFORNIA.

By ADOLPH KNOPF.

LOCATION AND DISCOVERY.

Strontianite in economically important quantity has recently been found near Barstow, San Bernardino County, Cal. The deposits occur 10 miles north of the town, in a group of hills known locally as the Mud Hills, because occasional desert storms convert the clay beds, of which the hills are largely composed, to masses of mud, but this designation is likely to be supplanted by the name Strontium Hills. The deposits lie at altitudes between 3,000 and 4,000 feet and are readily accessible over fairly good roads, the grade of which is mainly downhill to Barstow.

The strontianite was discovered by Henry Hart and T. G. Nicklin, who were prospecting for borax. In 1915 they found masses of a fibrous mineral of resinous color and luster, which they thought might be either "needle borax" or "rosin jack" (zinc blende). At Barstow the mineral was provisionally determined as witherite (barium carbonate), but later, doubts being felt as to the validity of the determination, specimens were sent to Prof. Charles Palache, of Harvard University, who established the identity of the mineral as strontianite (strontium carbonate).

The first claims for strontianite, known as the Needles group, were staked in October, 1916, and since then nearly 40 claims have been located. The whole area in which strontianite occurs had been staked for oil during the boom that culminated in 1913, and the oil claims had been marked by monuments, some of which were built partly of solid lumps of strontianite.

The strontianite deposits were briefly examined by me in February, 1917, and it gives me pleasure to acknowledge my indebtedness to Messrs. L. G. Henderson, T. G. Nicklin, and A. A. Turner for facilitating the examination.

GENERAL GEOLOGY.

The Strontium Hills are underlain by a series of lake and terrestrial deposits which have been folded into a syncline. (See Pl. XI.)

These beds have been partly described by Baker¹ under the name "Rosamond series," and later more fully by Pack.²

The syncline into which the beds have been bent is referred to by Baker and Pack as the Barstow syncline. A monograph on the fauna of the beds is in preparation by Prof. J. C. Merriam,³ who discusses also the age and correlation of the beds. The term "Barstow formation" is used by Merriam for the deposits containing the upper Miocene fauna and comprising the uppermost beds of the Barstow syncline, but it is recognized that this fauna may occur in all of the strata of the syncline.⁴ The fauna includes about 30 species, among which horses of at least four species and camels are most abundantly represented, for it is the bones of these animals that are usually found.⁵

A threefold subdivision of the beds in the Strontium Hills may easily be recognized, as Pack has pointed out. The lowest member consists largely of granitic detritus, remarkably fresh in composition and consisting of angular boulders, some of which are as much as 5 feet in diameter. It is without more than a trace of bedding and is clearly an ancient alluvial deposit, a "fanglomerate." Some rhyolite tuff occurs with it.

The middle subdivision, which contains the strontium, is made up chiefly of grayish-green clay in thick beds. The erosion of the clay beds has produced a badland topography which is highly characteristic of the middle member of the Barstow syncline. At the surface the clay is loosely coherent, but in places it grades into shale, which is fairly well bedded. Crystals of gypsum half an inch or so in diameter are common throughout the clay beds. Moreover, the clay yields calcium sulphate on extraction with water, and it effervesces freely in hydrochloric acid; it is therefore a gypsiferous, calcareous clay. Calcareous concretions of odd and peculiar patterns are of widespread occurrence in the clay beds; they are locally called "fossils."

Above the clays come more highly indurated beds, consisting of calcareous tuffs, white rhyolite tuff, sandstone, and limestone in persistent beds 4 to 6 feet thick. Many of these limestones are clearly of algal origin, as shown by the concentric circular patterns on their weathered surfaces. Some of the limestones have an apparently brecciated structure—that is, they carry angular fragments of limestone embedded in a dense matrix of somewhat different color. However, as there are all gradations between such seemingly brecciated

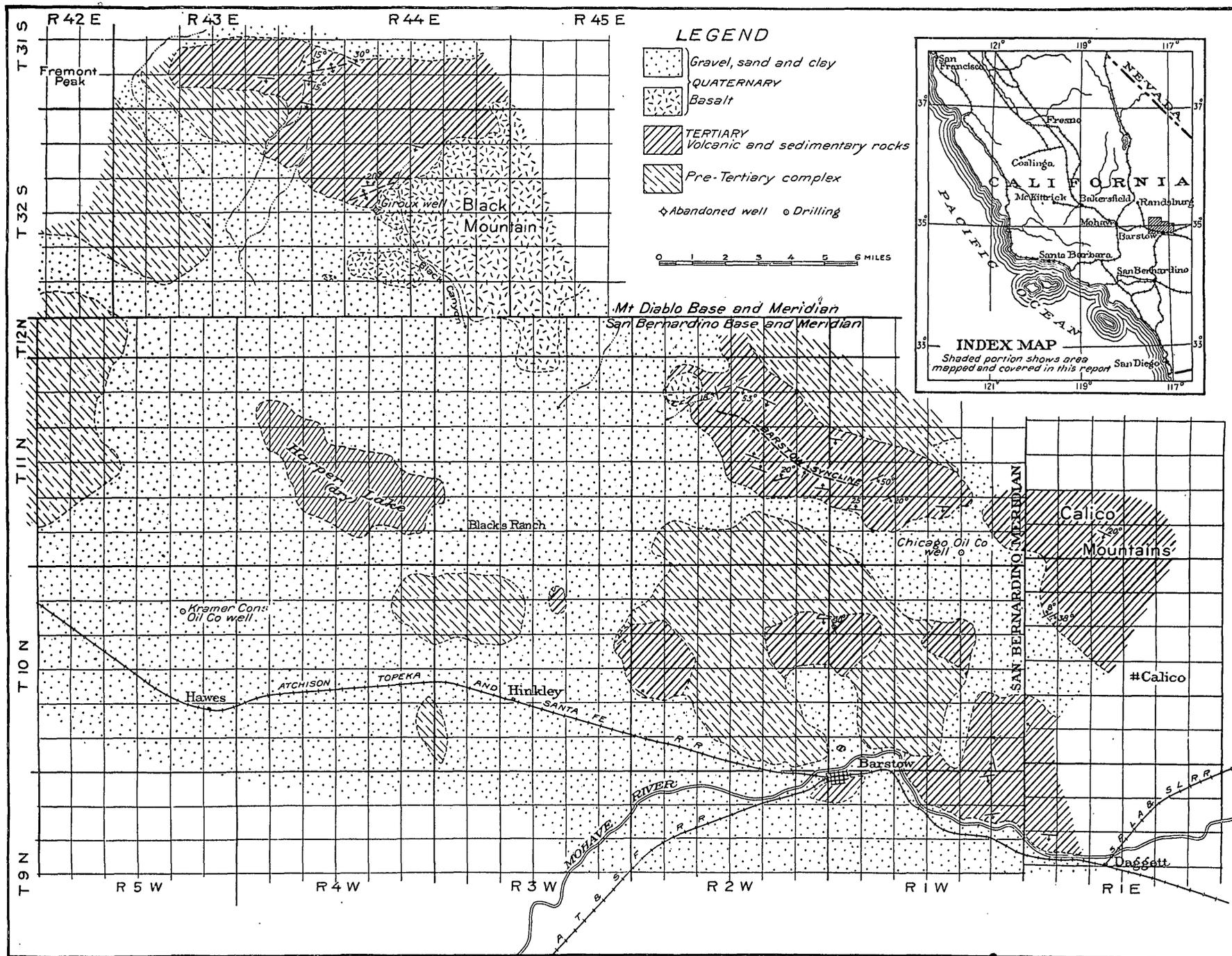
¹ Baker, C. A., Notes on the later Cenozoic history of the Mohave Desert region in southeastern California: California Univ. Dept. Geology Bull., vol. 6, pp. 342-347, 1911.

² Pack, R. W., Reconnaissance of the Barstow-Kramer region, Cal.: U. S. Geol. Survey Bull. 541, pp. 141-151, 1913.

³ Oral communication.

⁴ Merriam, J. C., unpublished MS.

⁵ Merriam, J. C., Extinct faunas of the Mohave Desert, their significance in a study of the origin and evolution of life in America: Pop. Sci. Monthly, vol. 86, p. 255, 1915.



RECONNAISSANCE MAP OF THE BARSTOW-KRAMER REGION, SAN BERNARDINO COUNTY, CAL.

limestone and that in which the algæ are preserved unbroken, it is probable that the brecciation is an original structure—that is, that the angular fragments are broken algal growths which were incorporated in the limestone at the time the limestone was formed.

A large specimen of the best-preserved algal limestone was forwarded to Dr. Charles D. Walcott, who reports as follows:

I had the specimen cut through vertically, also three thin sections made of a portion of it. The microscopic section shows essentially the same general structure that occurs in recent fresh-water calcareous algal deposits, and they are also very similar to deposits that occur in the supposed fresh-water beds in the Algonkian Belt limestones of Montana.

The thin sections show the same type of lamination and structure as the thin sections of the similar forms from the Algonkian and the Cambrian limestones. From the character of the limestone I do not think it is probable that the algal cells will be found, but from the general resemblance of the structure in the specimen received from Mr. Knopf, it is exceedingly probable that the lime in the specimen was deposited through the agency of the blue-green alga.

The section described in the preceding paragraphs is that near the east end of the Barstow syncline, near the discovery group of claims, where only the north limb of the syncline is exposed. Farther west the strontium deposits occur in the south limb of the syncline. The beds here resemble those of the middle subdivision already described, but the interbedded algal limestones are especially conspicuous. They weather out in relief, forming ledges 300 to 400 feet long. Their greatest thickness is 6 feet, and they gradually pinch out along the strike. As seen from a distance the ledges roughly resemble aggregates of cauliflower heads. Branching, arborescent forms also occur, in which the separate branches are about 3 inches in diameter.

STRONTIANITE DEPOSITS.

Strontianite and strontium-bearing rock have been found at a large number of places in a belt about 2 miles long. They occur as layers that lie parallel to the bedding of the inclosing clays and are distributed at intervals through a thickness of several hundred feet.

The strontianite occurs in two forms—as fibrous masses of resinous color and luster (locally spoken of as “rosin strontianite”) and as dense, exceedingly fine grained (aphanitic) gray or drab material, which resembles limestone. The fibrous variety, because of its weight and evident purity, is obviously of high grade; the grade of the aphanitic variety, of course, can not be determined without chemical examination, except very roughly by its high specific gravity. The two varieties occur separately, as a rule, but in some deposits they are intermingled, spherulites of coarse resinous strontianite being irregularly scattered through aphanitic gray strontianite rock.

The thickest body of pure spherulitic strontianite that had been found at the time of visit is 14 inches thick; this body is lenticular and pinches out within a few feet along the strike, but other bodies of strontianite appear farther along at the same stratigraphic level.

The gray aphanitic strontianite occurs in layers as much as 3 feet thick. In all respects these layers simulate ordinary beds of limestone interstratified with the predominant clays, and it is only after the supposed limestone has been handled that its abnormal character is suspected. Some of the gray strontianite rock contains angular glassy particles of feldspar and quartz and more rarely small fragments of brown vitrophyre. Under the microscope the gray strontianite rock is found to consist almost wholly of minute spherulites of strontianite, the different spherulites interfering and forming a mosaic of polygonal grains.

The general dip of the strontianite deposits in the discovery claims is 10° - 30° S. In places, however, the beds are faulted and for short distances lie horizontal or even dip to the north.

Strontianite rock obtained near the main workings on the Needles group was analyzed in the laboratory of the Geological Survey. It is a faintly banded, aphanitic rock resembling a drab limestone; under the microscope it is seen to be composed chiefly of extremely small obscure spherulites of strontianite.

Partial analysis of strontianite rock from the Strontium Hills, Cal.

[R. C. Wells, analyst.]

SrO	55.20
CaO	5.19
BaO	None.
CO ₂	28.18
SO ₃28
SiO ₂	5.59
Al ₂ O ₃	1.17

Computation of the analysis shows that the strontianite rock contains 78.6 per cent of strontium carbonate. The ratio of strontia to lime is approximately the same as in the pure, coarsely crystallized strontianite whose analysis is given on page 262, where it is pointed out that the lime, as calcium carbonate, is an isomorphous constituent of the strontianite. Using the composition of the strontianite there given, computation of the analysis shows that the strontianite rock consists of 87.8 per cent of strontianite.

In the western part of the district the geologic features differ somewhat from those already described. The strontium-bearing beds occur on the south limb of the Barstow syncline and dip 70° N. They consist largely of brownish calcite, with subordinate celestite and less strontianite. They are consequently of low grade, and none of the material shown to me has proved on laboratory examination to be of commercial value. An analysis of supposedly high-grade material from the ledge known as the Upper Brown was made in the laboratory of the Geological Survey; the preliminary microscopic examination showed it to be composed of calcite, celestite, and strontianite.

Partial analysis of strontium-bearing rock from the Strontium Hills, Cal.

[R. C. Wells, analyst.]

SrO -----	12.9
CaO -----	39.5

A remarkable feature of the western part of the strontium-bearing belt is the abundant occurrence of fibrous spherulitic, resinous-colored calcite exactly resembling the "rosin strontianite" found on the Needles group of claims. This calcite occurs in veinlets and as deposits formed by replacement of limestone beds. Unless supposed strontium-bearing material is subjected to quantitative chemical analysis, the presence of this deceptive calcite is certain to cause much disappointment.

The work done in opening the prospects in the strontium-bearing belt was small at the time of visit, and exposures of strontianite were, in the main, the natural outcrops. The output in 1917 was 500 tons of strontianite rock.

MINERALOGY OF THE DEPOSITS.

STRONTIANITE.

The purest strontianite, as already mentioned, occurs in compact masses of thin fibers or needles. The fibers average about 1 inch in length but exceptionally are as much as 3 inches long. They radiate from centers, thus forming either fan-shaped aggregates or completely spherical masses. In the dense aphanitic variety the strontianite, as shown by the microscope, occurs also in spherulites, which, however, are very minute and the fibers of which are not as sharply individualized as in the larger aggregates.

The mineral strontianite, as shown by over 30 analyses on material from many localities in different parts of the world, never contains 100 per cent of strontium carbonate but invariably carries some isomorphous calcium carbonate, generally from 4 to 6 per cent.¹ The strontianite from the Westphalian deposits, whose homogeneity was tested microscopically, carries from 6 to 11 per cent of isomorphous calcium carbonate.² In view of these facts it appeared advisable to determine the chemical composition of the strontianite from Barstow, Cal. The following partial analysis was made in the laboratory of the Geological Survey by R. C. Wells. On examination in thin section and in oils the strontianite taken for analysis was found to be homogeneous and free from inclusions or intergrowths of calcite or aragonite. The refractive indices, γ and α , as determined by the immersion method, are respectively 1.67 and 1.52. Consequently the strontianite shows the strong difference in relief characteristic of calcite and aragonite. The color is pale brownish yellow, the intensity of which varies strongly according to the direction in which the mineral is viewed under the microscope.

¹ Doelter, C., *Handbuch der Mineralchemie*, vol. 1, pp. 481-483, 1912.

² Beykirch, J., *Ueber den Strontianite des Münstérlandes: Neues Jahrb., Bellage Band 13*, pp. 396-407, 1901.

Partial analysis of strontianite from Strontium Hills, Cal.

[R. C. Wells, analyst.]

SrO	-----	60.99
CaO	-----	6.40
BaO	-----	None.
SO ₃	-----	.05
CO ₂ (computed)	-----	29.86
		97.30

Computation of the analysis shows that the strontianite consists of 87 per cent of strontium carbonate and 10.25 per cent of calcium carbonate.

As the calcium carbonate present in the strontianite is an isomorphous constituent of the mineral and not a mechanical admixture, it can not be separated and removed mechanically by vanning tables or similar means. Further, it is unlikely that strontium-bearing material carrying more than 87 per cent of strontium carbonate can be obtained; in fact, only by the most careful sorting of the "rosin strontianite" will it be possible to obtain a commercial product running as high as 87 per cent strontium carbonate.

Minerals believed to be strontianite were tested at Barstow by those prospecting the district as follows: The mineral was placed in acid, alcohol was added and ignited, and the color of the flame was noted in a darkened room. The intensity of the redness of the flame was used as a measure of the amount of strontium present in the mineral examined. This test is very unsatisfactory, inasmuch as the purest strontianite of the district, which, as the preceding analysis shows, contains 10 per cent of calcium carbonate, gives to the alcohol flame a yellowish-red color not appreciably different from that imparted by pure calcite. More reliable results can be obtained by removing, by means of a small loop in the end of a platinum wire, a bit of the solution made by dissolving strontianite in hydrochloric acid and observing the color produced when it is strongly heated in the flame of a Bunsen burner, for the strontium flame persists longer than the calcium flame. Gasoline or alcohol blast lamps made especially for field use may be purchased from chemical supply houses and are excellent substitutes for Bunsen burners. Platinum wire may also be purchased from such dealers. With such equipment, which costs very little, the flame test for strontium can be made with some degree of certainty; but examination of the flame with a hand spectroscope, which may be purchased from dealers in chemical supplies at a moderate price, is far better. After the positions of the characteristic strontium lines on the scale of the spectroscope have been determined by examining the spectrum of a known strontium salt, reliable tests for strontium can be made, and the intensity of the strontium spectrum will roughly indicate whether much or little strontium is present.

A convenient way to distinguish between strontianite and the extraordinarily similar calcite that occurs in the district is to dilute the

solution obtained by dissolving the mineral in hydrochloric acid and to add sulphuric acid; a slowly forming white precipitate coming down under these conditions indicates strontium. Caution should be observed that the solution be kept sufficiently dilute, so as not to precipitate out calcium sulphate. The dilution necessary can be determined by running a control test on a known amount of calcite, and in testing unknown minerals a quantity equal to that of the calcite employed in the control test should be used. Perhaps a simpler method still is to use a solution of calcium sulphate as precipitant instead of sulphuric acid.

The strontianite in the analyzed specimen of strontium-bearing rock from the Upper Brown ledge is found under the microscope to be rather strongly pleochroic in tones of brownish yellow. In some of the crystals the coloring matter is irregularly distributed in a manner analogous to that in certain fluorites.

CALCITE.

In the western part of the strontianite belt calcite occurs as fibrous spherulitic aggregates of resinous color, resembling exactly, therefore, the "rosin strontianite." Chemical examination shows, however, that the mineral contains no strontium, and the determination of its refractive indices proves it to be calcite. Because of its remarkably close resemblance to strontianite many claims have been located on this supposed strontianite rock.

Calcite occurs also in the western part of the belt in flat masses 1 inch thick, which have a cross-fiber structure, resembling flat slabs of wood cut at right angles to the grain. These flat slabs of calcite are scattered in profusion on the outcrop of a thick clay bed, and at the time of my visit they were being sacked in the belief that they were strontianite. They are noticeably lighter than strontianite, however, as a little experience in handling the high-grade strontianite rock will show, and chemical and microscopic tests prove them to be nothing but calcite.

The calcareous nodules and concretions that are common in the clays of the strontium-bearing area generally contain in their interiors crystalline aggregates of calcite, whose color is like that of the strontianite and causes it to resemble the strontianite of the district.

CELESTITE.

Celestite, strontium sulphate, occurs in the western part of the strontium belt. It was particularly noted in the strontium-bearing ledge known as the Upper Brown, a recrystallized limestone consisting largely of granular brown calcite, with minor celestite and some strontianite. Celestite occurs in the main as a microscopic constituent, but in places it forms small glassy crystalline aggregates of somewhat smoky tint.

PROBABLE ORIGIN OF THE DEPOSITS.

At first glance the appearance of the layers of gray aphanitic strontianite suggests that they are beds of strontianite that were deposited as chemical precipitates from the lake in which the gypsiferous clays were laid down and that the coarse spherulitic strontianite is only a recrystallization of the original fine-grained beds. When all the evidence is considered, however, another explanation becomes more probable.

Some thin strata of limestone are intercalated in the clay beds containing the strontianite layers, and these beds show the breccia structure that I have described as probably due to the inclosure of broken algal fragments during the deposition of the limestone. Similar breccia structure appears in the gray strontianite, the angular fragments of the breccia consisting of aggregates of more limpid strontianite than that of the matrix in which they are inclosed. These features suggest that the strontianite deposits were formed by the replacement of such algal limestone breccias. The low-grade strontium-bearing beds of the western part of the field supply convincing evidence as to the validity of this conclusion. Some of the limestone beds are traversed by ramifying systems of veinlets, which, although resembling strontianite, consist largely of calcite, together with minor celestite. The rock adjoining the veinlets and some of the limestone beds have been completely recrystallized into brownish calcite, which in places incloses celestite and strontianite. The microscope shows that the celestite, at least in part, is later than the strontianite, as it traverses radial strontianite in small veinlets. That such an alteration might easily have occurred appears extremely probable because of the prevalence of gypsum in the inclosing strata. Solutions would be likely to dissolve some of this gypsum and would then be able to convert strontianite into the sulphate, celestite.

In short, then, the strontianite deposits are believed to have been formed by the replacement of limestone beds, doubtless by cold meteoric waters. The high-grade deposits represent the most complete replacement, the aphanitic layers being fine-grained replacements and the "rosin strontianite" coarse-grained replacements.

SOURCES AND USES OF STRONTIUM.

The two commercial sources of strontium are celestite and strontianite. Celestite is by far the more common and supplies the bulk of the demand. In fact, strontianite has been mined in profitable amounts only in the Münster district in the Province of Westphalia, Prussia, but these deposits are now nearly exhausted.

Strontianite, which is the carbonate of strontium (SrCO_3), is the more valuable strontium mineral for two reasons: (1) It is readily soluble in acids and is therefore easily convertible into the required strontium compounds, or it can be converted into the oxide by simple

calcination; and (2) it contains for a given weight more strontium than the same weight of celestite, which is the sulphate (SrSO_4). Pure strontianite, represented by the formula SrCO_3 , contains 59.36 per cent of strontium, or 70.2 per cent of strontia (SrO), whereas pure celestite, represented by the formula SrSO_4 , contains 47.7 per cent of strontium, or 56.42 per cent of strontia. All strontianites, however, contain a certain proportion of isomorphous calcium carbonate, as shown on page 261, and therefore none have the theoretical content of strontium; many celestites, on the other hand, closely approximate the theoretical composition. In recent years strontianite commanded in the German market about six times the price of celestite. A somewhat lower ratio appears to hold in the American market, as shown in late quotations for strontium "ore"¹—"Crude carbonate, 83 per cent, 7 cents per pound for 200-mesh material. Crude sulphate, 90 per cent, 1 cent for lumps and 2 cents for 200-mesh."

The principal use of strontium is as strontium hydrate in the Scheibler process for the recovery of sugar from beet-sugar molasses. This process is employed in Germany, Russia, and France, but not in the United States, apparently on account of the high price of strontium hydrate. Other uses of strontium are in signal lights, such as railroad fuses, and in fireworks, the purpose of the strontium compound in these uses being to give a brilliant red color to the flame during combustion.

Large amounts of molasses are unavoidably produced during the manufacture of beet sugar. The production of this molasses is undesirable, as it contains more than half its weight in sugar, which is prevented from crystallizing out because of the presence of certain constituents. Approximately 150,000 tons of molasses of this origin was produced in the United States during the season of 1916, and about one-half of this quantity was "desugarized"—that is, the sugar was extracted in marketable form. Three processes are available for the desugarization of molasses, but in the United States only the Steffens process is employed. According to Meyer,² of the three processes available,

The most effective, efficient, and economical is the strontia or Scheibler process. This depends on the reaction that occurs when an excess of strontium hydroxide is added to a dilute sugar solution at a temperature exceeding 100°C . The work is carried out in suitable boilers provided with steam coils and agitators, a 20 per cent to 25 per cent solution of the hydroxide being first heated and the molasses added in amount equal to about one-third that of the strontium solution. The liquid is then rapidly agitated, the temperature being kept above 100°C ., when there occurs a granular, sandy precipitate of strontium disucrate. This is rapidly filtered and washed with a boiling 10 per cent solution of strontium hydroxide, the disucrate being insoluble in hot solutions.

¹ Eng. and Min. Jour., vol. 104, p. 109, July 14, 1917. Quotations supplied by Foote Mineral Co., Philadelphia.

² Meyer, H. C., Strontium in the beet-sugar industry: Jour. Ind. Eng. Chemistry, vol. 6, pp. 1036-1037, 1914.

After the precipitate has been thoroughly washed, it is dissolved in a cold solution of hydroxide and allowed to stand for several days in crystallizing tanks. At the end of this time about 50 per cent of the hydrate separates in crystalline form and the saccharine solution is decanted and the crystalline residue centrifuged to free it from the solution. Carbon dioxide is then passed through the sugar solution, thus causing a precipitation of the balance of the strontium as the carbonate. This compound is reconverted into the hydroxide by calcining and dissolving the resultant oxide in water. The ratio of the total strontium hydroxide required for the precipitation of sugar in the beet molasses is approximately $2\frac{1}{2}$:1. A remarkably pure sugar solution is obtained by the strontia process, so that the sugar after crystallization can be placed directly on the market without further refining.

At the present time the methods in vogue in this country are the osmosis and the lime or Steffens process. The former is rather slow and necessitates the handling of the same solution a number of times. The lime process requires special cooling apparatus, as the temperature of the sugar solution must be kept below 15° C. during the precipitation of the tricalcium sucrate, which is readily soluble at a higher temperature. There are numerous other minor objections to both of these processes, so that although the initial cost of the strontia process may be more than either of these, it can be readily seen that it is much more effective and rapid.

In connection with the regeneration of strontium hydrate, an American patent has just been issued describing a process for the rapid conversion of strontium carbonate into the oxide through the use of certain fluxes, such as fluorspar, soda ash, etc. In the past some difficulty has been experienced in treating the impure strontium carbonate precipitated from sugar solutions, owing to its being contaminated with lime, silica, and certain organic substances.

Statistics show that Germany desaccharizes annually about 100,000 tons of beet-sugar molasses. As nearly all the continental beet molasses is desugared by the strontia process, this would indicate that over 100,000 tons of strontium hydroxide are employed in Germany alone. It must be remembered, however, that this does not indicate the annual consumption, which is probably very much less than this figure, owing to the fact that the strontium compounds are nearly all recovered by various regenerative processes, so that the percentage of loss is rather small.

DOMESTIC PRODUCTION.¹

In 1916 about 250 tons of strontium-bearing material was produced in the United States, mainly from Arizona, California, and Washington. In previous years there had been no domestic production, the demand being supplied by the importation of English celestite. The embargo placed by the British Government in 1916 on the exportation of all strontium compounds, combined with other abnormal conditions produced by the war, has stimulated domestic production and has awakened considerable interest in domestic sources of strontium.

THE CHIEF COMMERCIALY PRODUCTIVE STRONTIUM DEPOSITS OF EUROPE.

Those engaged in prospecting and developing new deposits of strontium are greatly interested in all information on the geology

¹ Hill, J. M., Strontium: U. S. Geol. Survey Mineral Resources, 1916, pt. 2, p. 186, 1917.

and economic features of the world's commercially productive strontium deposits. The deposits of England, Germany, and Sicily have heretofore dominated the world's strontium market. As the information concerning these deposits has been so far nowhere brought together, it is accordingly assembled in the following pages in summarized form. The American deposits are fully described by Phalen¹ and by Hill.²

CELESTITE DEPOSITS OF THE BRISTOL DISTRICT, ENGLAND.³

The productive celestite deposits of England are near Yate, in Gloucestershire, 10 miles northeast of Bristol. Formerly celestite was produced at several other localities in Gloucestershire and also in Somerset, south of Bristol.

English celestite is unsalable if it contains less than 90 per cent strontium sulphate. The output has fluctuated greatly; the maximum annual output, 32,281 long tons, was made in 1902, and in recent years it has ranged from 4,761 to 19,370 long tons. The output and value of English celestite is shown in the following table:

Celestite produced in England, 1910-1914.

	Quantity (long tons).	Value. ^a
1910.....	4,761	£3,570
1911.....	5,869	4,400
1912.....	19,370	15,020
1913.....	18,425	14,287
1914.....	13,157	(b)

^a Some of these values are reported to be only estimates.

^b Not available.

In explanation of the irregular output of English celestite, Sherlock says:

It is not unlikely that the more marked of these changes are due to variations in the demand for strontia in the beet-sugar industry. Scheibler seems to have published his strontia process in 1882, and in that year it was announced* that a large refinery for sugar was to be erected in Bohemia for working molasses by means of strontia. The undertaking was organized by the refinery at Dessau (the destination of the English strontium), which also had at its disposal the strontianite deposits of Westphalia. It would appear that this process was not wholly successful, and this may be the explanation of the great drop in the value of strontium in 1885. Scheibler invented an improved method in 1886, which has been a success and may explain the irregular rise in output which lasted until 1903. The problem is complicated by the fact that only a limited amount of molasses has its sugar extracted, the greater part being used for cattle food.

¹ Phalen, W. C., Celestite deposits in California and Arizona: U. S. Geol. Survey Bull. 540, pp. 526-531, 1913.

² Hill, J. M., op. cit.

³ Sherlock, R. L., Celestine and strontianite: Special Reports on Mineral Resources of Great Britain, vol. 3, pp. 41-54; England and Wales Geol. Survey Mem., 1915.

⁴ Jour. fabr. sucre, 1882; Jour. Chem. Industry.

The celestite-bearing belt at Yate is about 600 yards wide and 5 miles long. The celestite occurs as irregular masses and lenses localized along a definite horizon in Triassic marl; it occurs also in fissures in the underlying steeply dipping rocks on which the marl was unconformably deposited. The layers of celestite are locally as much as 3 feet thick but pinch out abruptly. Although not continuous, they appear again farther on at the same level.¹ Gypsum occurs near the celestite masses but not in them.

The celestite is prospected by probing with a boring tool. If none is found to a depth of 9 feet, a new site is chosen. If celestite is found, a pit is dug and enlarged as the mineral is extracted. If the floor on which the marl rests is reached, a crowbar is used to find any mass of celestite that may occur in the bedding planes of the underlying rocks or in cavities in them. One pit may yield several thousand tons, whereas the next may yield very little. About one half the celestite obtained comes from the marl and the other half from the underlying rocks.² The workings are all shallow, and, as they are on flat ground, they become flooded during the winter, so that operations must be suspended.

SICILIAN CELESTITE DEPOSITS.

Celestite occurs in the Sicilian sulphur deposits in association with crystallized sulphur, aragonite, calcite, and gypsum.³ These minerals are localized in fissures, where they have been deposited from solutions that have partly dissolved and redeposited the minerals of the primary sulphur and gypsum beds, which are of upper Miocene age. At certain localities the celestite occurs in considerable quantities and is worked for export. At the Grotta Calda mine layers of celestite 7 to 8 centimeters thick alternate with beds of limestone and sulphur.

The production is not accurately known but at times is fairly large, as considerable quantities have been shipped to Germany. According to Sherlock⁴ the price of English celestite "is kept down by the extensive deposits in Sicily, which ordinarily do not pay for transport on mule back to the coast. But when the price rises a little above the present figure the Sicilian deposits come on the market and prevent further advance."

WESTPHALIAN STRONTIANITE DEPOSITS.⁵

The German strontianite deposits are in the Münster district, Westphalia, in western Prussia. As long ago as 1834 strontianite

¹ Baker, B. A., Celestine deposits of the Bristol district: Bristol Naturalists Soc. Proc., vol. 9, p. 162, 1901.

² Sherlock, R. L., op. cit., p. 47.

³ Stutzer, O., Die wichtigsten Lagerstätten der Nicht-Erze, pp. 206-207, 1911.

⁴ Sherlock, R. L., op. cit., p. 54.

⁵ Venator, Emil, Ueber das Vorkommen und die Gewinnung von Strontianit in Westfalen: Berg. u. Hüttenm. Zeitung, Jahrg. 41, pp. 1-4, 11-13, 18-19, 1882. Dammer, B. and Tietze, O., Die nutzbaren Mineralien, Band 1, pp. 463-467, 1913.

was known to occur here, but not until 1874 were the deposits largely or systematically worked. In the early seventies the managers of the sugar refinery at Dessau decided to use the strontia process for extracting the sugar from molasses, and in 1874 the strontianite deposits of the Münster district were examined with a view to determining whether a large and steady production of strontium could be attained. As a result of favorable recommendation, the deposits were developed by the refinery, and a veritable boom set in. At the height of the mining activity, in 1883, 45 mines were in operation and 2,350 men were employed. The mine owned by the Dessau refinery employed alone 600 men. The strontianite at the end of the seventies commanded a price of \$100 a ton. In 1910 there were only two mines in operation, which produced 800 tons of strontianite, reckoned on the basis of 100 per cent strontium carbonate, the average value of which was \$40 a ton.¹

The strontianite-bearing area is 24 square miles in extent. The prevailing country rock is a rather firm bluish-gray calcareous shale ("marl") of Cretaceous age. This formation is traversed by a large number of veins, which generally dip from 70° to 90°, or nearly at right angles to the bedding. The larger veins are remarkably persistent, some of them being traceable for more than a mile. They vary abruptly in thickness, ranging from a mere film of clay to bodies 6 feet and exceptionally 10 feet thick. The vein filling consists of strontianite, calcite, shale fragments, and a small amount of pyrite. Many of the veins are symmetrically banded, the calcite forming the layers adjoining the walls and the strontianite occupying the central part of the veins. The strontianite occurs in the veins as lenses also, some of which attain as much as 60 feet in length. The barren stretches between such strontianite lenses are commonly rather long. In depth the veins contain more and more calcite, and this impoverishment, together with the heavy inflow of water, made them become unprofitable, so that they were unable to survive competition with English celestite. The deepest working attained a depth of 175 feet. Only two veins, which range from 8 to 12 inches in thickness, were being worked in 1911.

SUMMARY AND CONCLUSIONS.

The strontianite deposits near Barstow, Cal., have been formed by the replacement of lacustral limestone beds that are interstratified in the clays of the middle member of the "Barstow formation," of upper Miocene age. They thus differ considerably from the only other commercially productive strontianite deposits—those of the Münster district, Westphalia—which consist of a series of steeply dipping veins cutting horizontal marine calcareous shales of Upper Cretaceous age. They resemble the Westphalian deposits in one

¹ Schulze-Höling, *Der Strontianitbergbau im Regierungsbezirk Münster: Glückauf*, vol. 48, pp. 518-519, 1912.

fundamental respect, however—they were formed later than the strata that inclose them.

The California strontianite occurs in two forms. The high-grade strontianite is crystallized in slender needles which make up radial and spherulitic aggregates; the lower-grade material resembles exceedingly fine grained, dense gray limestone. No great quantity of strontianite is in sight at any one point, but the number of places at which strontianite has been found is surprisingly large.

A considerable amount of strontianite can readily be obtained by gathering the high-grade float from the numerous strontium-bearing beds. Deep mining will be impracticable, if not impossible, on account of the loose, unconsolidated condition of the clays in which the strontiferous beds are inclosed, and all operations will necessarily be restricted to open-cut work. An initial shipment of 7 tons of high-grade strontianite was made early in 1917 to a manufacturing chemist at Los Angeles to be worked up into strontium salts.

The requirements of the beet-sugar industry have hitherto dominated the world's strontium market. These requirements centered in Germany, which supplied the strontium hydrate required not only by its own refineries but also by those of France and doubtless those of Russia. The German demand and the English supply of celestite have in the past determined the market price of strontium ore. These conditions have been gravely affected by the war and the British embargo on the exportation of all strontium compounds, crude or manufactured. As a result the production and search for new deposits in the United States has been strongly stimulated, but the permanence of the domestic strontium industry would seem to depend on the adoption of the strontia process by American beet-sugar refineries; and this, in turn, probably depends on the assurance of a regular supply of strontium hydrate at a reasonable price.

In recent years strontianite has commanded more than three times the price of celestite. Therefore, although English celestite containing less than 90 per cent of strontium sulphate is unsalable, it seems reasonable to expect that strontianite ore carrying considerably less than 90 per cent of strontium carbonate would find a market; and, in fact, recent quotations show that material containing as low as 83 per cent of strontium carbonate is acceptable.

In conclusion it may be pointed out that the discovery of strontianite in the lake beds of the Barstow syncline suggests the possibility that similar deposits may be found wherever the same series of lake beds occurs in the region adjacent to Barstow. The areas in which these beds are likely to occur have been outlined by Pack¹ and are shown on Plate XI, which is reproduced from his report.

¹ Pack, R. W., Reconnaissance of the Barstow-Kramer region, Cal.: U. S. Geol. Survey Bull. 541, pp. 141-154, 1914.