

SULPHUR AND PYRITE.

SULPHUR DEPOSITS AT CODY, WYO.

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INTRODUCTION.

The paper here presented is the result of an investigation made during the field season of 1907. The hot sulphur springs and travertine deposits near Cody were described by George H. Eldridge,^a of the United States Geological Survey, in his report on northwest Wyoming. A more recent account of these deposits is given by C. A. Fisher,^b also of the Survey, in his description of the Cody Hot Springs, published in a report on the Bighorn Basin. Since the mines have been opened L. W. Trumbull,^c professor of geology and mining at the State University of Wyoming, has described the occurrence of the sulphur and explained the method used to reduce the ore.

LOCATION AND EXTENT.

The deposits here described are located about 3 miles west of Cody, along the base of Cedar Mountain, on the south side of Shoshone River, in secs. 3 and 10, T. 52 N., R. 102 W. Though geologic conditions are favorable for the formation of sulphur both north and south of the river, the deposits considered workable at the present time are confined to a belt 2 miles long and less than one-fourth mile wide, extending southeastward from the Hot Springs along the foot of the mountains to Sulphur Creek. All the mines now producing sulphur are included in a small area a few acres in extent, located near the north end of the mineralized zone south of Shoshone River. The known area of sulphur-bearing rocks is shown on the accompanying map (Pl. VI).

^a A geological reconnaissance in northwest Wyoming: Bull. U. S. Geol. Survey No. 119, 1894, p. 67.

^b Geology and water resources of the Bighorn Basin, Wyoming: Prof. Paper U. S. Geol. Survey No. 53, 1906, p. 61.

^c Sulphur mining and refining: Mines and Minerals, February, 1907, p. 314.

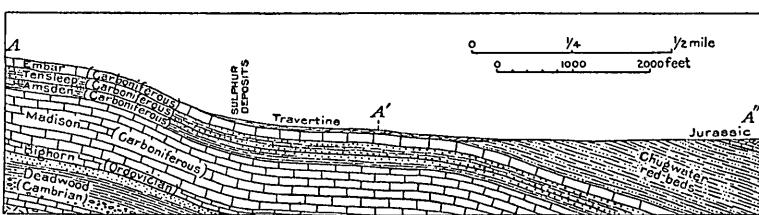
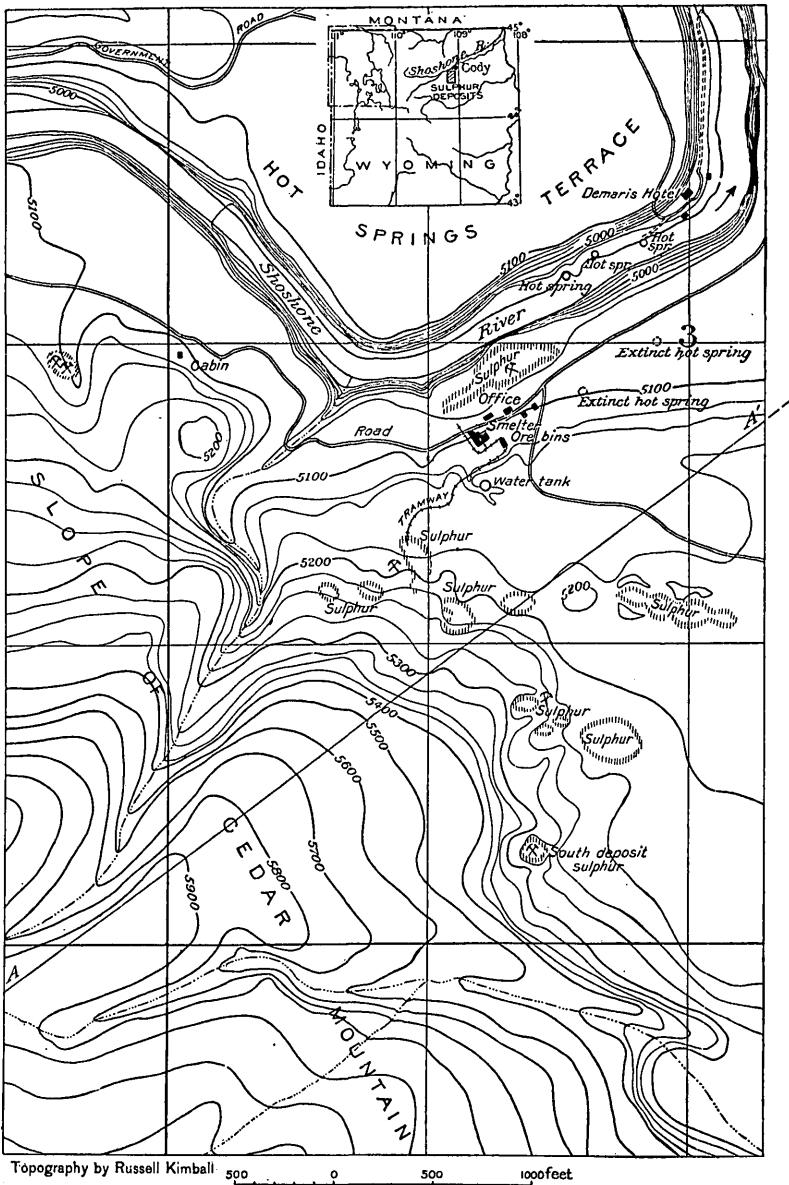
SURFACE FEATURES.

The area treated in this paper includes a part of the eastern slope of Cedar Mountain and a narrow belt of the adjoining plains. Shoshone River crosses the north end and a branch of Sulphur Creek drains the southern part. Cedar Mountain is the southern extension of the Rattlesnake-Cedar Mountain anticline, which is structurally a spur of the Absaroka Range. In this region the anticline pitches sharply to the south, with steep or vertical dips on the west and gentle dips on the east of the axis. That part of the anticline with which this report is concerned presents a uniformly dipping slope somewhat trenched by watercourses. The plains adjoining the bottom of this dip slope constitute part of a great gravel apron which slopes gently eastward from the base of the mountains. Shoshone River crosses both the anticline and the plains, flowing through the former in a deep canyon and through the latter in a gorge 300 to 400 feet wide and 150 to 200 feet deep. There are, in the area here described, portions of two terraces which form part of a series extending along Shoshone River and rising by successive elevations from the stream channel to the level of the plains. The gravel plains are covered near the mountains by travertine terraces, upon the surface of which there occur small cones and circular depressions characteristic of hot-spring deposits. (See Pl. VI.)

Such springs are now active in Shoshone Canyon, where the water issues from a number of vents in crevices in the upper members of the Carboniferous limestone. Several of these springs have their outlets above the water level, while others discharge beneath the river, and are visible only at periods of low water. The waters, which issue at a temperature of 98° F., contain large quantities of hydrogen sulphide and carbon dioxide, and hold in solution compounds of calcium, magnesium, iron, aluminum, lithium, sodium, potassium, chlorine, and some organic matter. The water is clear and emits so strong an odor of sulphur that it may be detected in the canyon 2 miles downstream from the springs.

GEOLOGIC RELATIONS.

The Paleozoic rocks which arch over the summit of the Rattlesnake-Cedar Mountain anticline have been lifted 3,000 feet above the surrounding plains and 8,000 feet above sea level. In the walls of Shoshone Canyon there are exposed massive limestones constituting the Madison and Bighorn formations, which weather into bold, castellated cliffs, overlain by soft red shales of the Amsden formation and resting upon dull-green shales of Cambrian age. Below the Cambrian shales is a mass of granite several hundred feet of which is ex-



MAP SHOWING SULPHUR DEPOSITS NEAR CODY, WYO., WITH SECTION OF STRATA
ACROSS SULPHUR BEARING AREA

posed and which weathers into rugged, precipitous cliffs and is cut by large intrusive dikes of quartz-bearing diabase.

Around the base of the mountains occur the steeply dipping beds of softer Mesozoic rocks, across the upturned ends of which Quaternary gravels have been laid down in the form of terraces. Within and above these gravels heavy layers of travertine have been deposited throughout a narrow zone bordering the base of the uplift.

That portion of the travertine flat which lies north of Shoshone River has a gently sloping surface upon which appear small, low cones of extinct hot springs and shallow depressions such as occur in regions where thermal waters flow over a plain. South of the river the surface is less regular, but it exhibits the same general features that are found on the north.

Geysers may have existed in the region prior to the period of present hot-spring activity and built these cones, which show imperfect tubes extending down into their interior. The travertine is composed in part of crystals of selenite, a variety of gypsum, which seems to be an alteration product of the travertine, due to the action of sulphur waters. Sulphur deposits occur along the upper edge of the travertine flats, where they lie upon the limestone which forms the mountain slope; in fact, the richest sulphur deposits are found in the limestone just under the terrace material, at the upper edge of the flats, where formerly hot springs must have been most active. Some sulphur is also present in the sandstone which underlies the limestone, and other deposits are in the travertine. In one such deposit on the slope from the lowermost broad terrace to a lower, narrow terrace on the edge of the present gorge, the travertine covers a steep scarp and forms the cement of a coarse gravel conglomerate, the pebbles being derived from the terrace gravels. This is intersected by numerous irregular veins of sulphur, which here and there expand into pockets of considerable size. In addition to the sulphur associated with the limestone noted above, that contained in the travertine and sandstone has been tested to a considerable extent, but it is found that the limestone contains the only workable deposits. The cross section at the bottom of Pl. VI shows the relations of the travertine and sulphur to the underlying formations.

THE SULPHUR.

NATURE AND OCCURRENCE.

The sulphur, which occurs native in small yellow crystals and in gray streaks in the rocks, is now being mined and smelted at the plant of the Bighorn Sulphur Company, near the mouth of Shoshone Canyon, on the south side of the river. Where the sulphur is mined it is

found in irregular beds in limestone and travertine associated with fine white crystalline aggregates, filling cavities 2 to 8 inches in diameter, and disseminated through the limestone, where it has been deposited by sulphur-bearing gases permeating small crevices in the rock. The cavities just mentioned seem to be portions of subterranean channels through which the hot sulphur-bearing waters flowed, and on the walls of which the sulphur was gradually deposited until the chamber was partly or entirely filled. No regular arrangement of the cavities can be discovered, though they seem to be in groups at places where the waters found free passage. In the areas between the groups of cavities only a small amount of sulphur is found, but in the enriched pockets the amount of sulphur reaches 30 to 50 per cent of the rock and becomes commercially important. Laterally a deposit may be rich at one point and barren 10 feet away. The depth of the mineralization is not known, as mining and prospecting have not been carried below 20 feet, but it seems improbable that rich pockets of sulphur will be found far below the surface. As previously stated, a small amount of sulphur is found in the sandstones and travertine, but the quantity in these rocks is too small to pay for mining.

GENESIS OF THE ORE.

That the sulphur was deposited by hot springs is indicated by the presence of sulphur in the waters now issuing from the Hot Springs in Shoshone Canyon, and also by the evidence that ore is found in channels such as water forms when it flows through openings in limestone. The water probably comes from the Rattlesnake-Cedar Mountain anticline, but may have a more distant source. As the source of the water is not known, the cause of the heat remains undiscovered. There is no evidence of solfataric origin and the indications are that only a small amount of the heat is derived from chemical reactions, because but little of the material produced by chemical changes below is brought to the surface. It is known that intensive activity must necessarily take place to maintain the water at a temperature above 98° F., the temperature found in these springs. It is supposed, therefore, that the heat is derived from slowly cooling magmatic bodies, probably intrusions, and increased slightly by heat from chemical reactions.

CHEMICAL CONDITIONS.

The same chemical changes which produce the increased heat are thought to free the sulphur and permit it to come to the surface. As the waters approach the surface the sulphur compounds are cooled and oxidized and the mineral is deposited. Both of these processes, oxidation and loss of heat, can best take place near the surface; hence

it is expected that the best deposits will be shallow. It is of interest also to note that the ore is associated chiefly with calcareous deposits and not with siliceous rocks, though the solutions must have traversed sandstone beds in their passage from below. This fact is believed to indicate that the limestone is essential to the precipitation of the sulphur from the solutions. Prof. Chase Palmer, of the United States Geological Survey, has made a special study of the chemical changes supposed to be involved in the deposition of sulphur, and suggests the following reactions:

It has long been known that a deposit of sulphur may be caused by direct oxidation of hydrogen sulphide in water through the agency of atmospheric oxygen alone: $2\text{H}_2\text{S} + \text{O}_2 = 2\text{H}_2\text{O} + 2\text{S}$, to which reaction the formation of sulphur deposits has sometimes been attributed.

Winogradsky^a has recently shown, however, that certain bacteria, which are found only in sulphur waters, utilize hydrogen sulphide, and by oxidizing it store the sulphur product in their cells. The sulphur does not long remain thus in storage, but is soon oxidized further by the cells to sulphuric acid, which is neutralized by the bicarbonates usually present in such waters, forming sulphates: $\text{H}_2\text{SO}_4 + \text{H}_2\text{Ca}(\text{CO}_3)_2 = \text{CaSO}_4 + 2\text{CO}_2 + 2\text{H}_2\text{O}$. The presence of these bacteria probably accounts for the deposition of only a part of the sulphur formed by hot-spring activity.

Most of the sulphur deposited from natural sulphur waters is probably the result of several changes in which various compounds are involved. One of these various reactions was noted by Béchamp,^b who found that insoluble calcium carbonate is readily attacked when suspended in water charged with hydrogen sulphide, in which case two soluble calcium compounds are formed, viz., calcium hydrosulphide and calcium bicarbonate: $2\text{CaCO}_3 + 2\text{H}_2\text{S} = \text{Ca}(\text{SH})_2 + \text{H}_2\text{Ca}(\text{CO}_3)_2$.

The importance of the limestone in the deposition of the sulphur from hot waters is shown by some comparative experiments recently made by myself on the solvent action of sulphur waters on calcium carbonate, which indicate that the presence of sodium chloride increases materially the solvent power of a hydrogen sulphide water on calcium carbonate.

It is also known that the soluble polysulphides are decomposed by acids, reproducing hydrogen sulphide, and causing copious deposits of sulphur. Even carbon dioxide is capable of decomposing the polysulphides in this manner: $\text{CaS}_2 + 2\text{CO}_2 + 2\text{H}_2\text{O} = \text{H}_2\text{Ca}(\text{CO}_3)_2 + \text{H}_2\text{S} + \text{S}$. The thiosulphates which often accompany the sulphides in natural waters are also similarly attacked by carbon dioxide, yielding a deposit of sulphur: $\text{Na}_2\text{S}_2\text{O}_3 + \text{CO}_2 + \text{H}_2\text{O} = \text{NaHCO}_3 + \text{NaHSO}_3 + \text{S}$.

All the essential conditions mentioned above are operative in the area here described. Hot springs are active, limestone is abundant, and the hot waters hold H_2S , CO_2 , and sodium and potassium salts in solution. It seems very probable, therefore, that the methods of deposition indicated by Professor Palmer are at least the active if not the essential reactions by which the sulphur was deposited.

^a Lafar, Franz, Technische Mykologie, 1897 edition.

^b Annales de chimie et de physique, 4th ser., vol. 16, 1869, p. 202.

MINING, SMELTING, AND MARKETING.

Mining is carried on by open-pit quarry methods, in which promising places are located, small drill holes are put down, and the rock is blasted with powder. The rock is then sorted by hand and all ore estimated to contain over 30 per cent of sulphur (the yearly average of the ore smelted is 35 per cent) is taken to the smelter by wagon or tram. At the smelter the ore is placed in bins, from which it is discharged into small steel cars with perforated sides, each holding about $1\frac{1}{4}$ tons of ore. A string of three cars is then run into a large cylindrical retort, the door closed, and steam admitted at 65 pounds pressure for an hour and three-quarters. The sulphur is melted and flows to the bottom of the retort, from which it escapes through a trap into bins, where it is allowed to cool. When the sulphur has been melted from the rocks the cars containing the gangue are removed from the retort, other cars admitted, and the process repeated. This process is not considered highly efficient, as only about two-thirds of the sulphur which the rock contains is melted out; the remainder, being contained in the gangue, is thrown on the refuse dump. After the sulphur is cooled it is ground in an 8-inch Blake crusher and pulverized in a rotary grinder to a powder apparently equal in fineness to flowers of sulphur. The sulphur powder is sacked and taken to Cody, 3 miles distant, for shipment.

PRODUCTION.

The sulphur refining and milling plant was built in 1906, and during the first year of operation 850 tons of sulphur were produced from 2,833 tons of ore. Of this amount 350 tons were sent to Omaha, Nebr., the chief distributing point, and the remainder was used in compounding sheep-dipping preparations in Wyoming and adjacent States. The market price is \$35 per ton at Cody.

SURVEY PUBLICATIONS ON SULPHUR AND PYRITE.

The list below includes the important publications of the United States Geological Survey on sulphur and pyrite:

ADAMS, G. I. The Rabbit Hole sulphur mines, near Humboldt House, Nev. In Bulletin No. 225, pp. 497-500. 1904.

DAVIS, H. J. Pyrites. In Mineral Resources U. S. for 1885, pp. 501-517. 1886.

ECKEL, E. C. Gold and pyrite deposits of the Dahlonega district, Georgia. In Bulletin No. 213, pp. 57-63. 1903.

— Pyrite deposits of the eastern Adirondacks, N. Y. In Bulletin No. 260, pp. 587-588. 1905.

LEE, W. T. The Cove Creek sulphur beds, Utah. In Bulletin No. 315, pp. 485-489. 1907.

MARTIN, W. Pyrites. In Mineral Resources U. S. for 1883-84, pp. 877-905. 1886.

RICHARDSON, G. B. Native sulphur in El Paso County, Tex. In Bulletin No. 260, pp. 589-592. 1905.

ROTHWELL, R. P. Pyrites. In Mineral Resources U. S. for 1886, pp. 650-675. 1887.

SPURR, J. E. Alum deposit near Silver Peak, Esmeralda County, Nev. In Bulletin No. 225, pp. 501-502. 1904.