SULPHUR AND PYRITE.

SULPHUR DEPOSITS NEAR THERMOPOLIS, WYO.

By E. G. Woodruff.

INTRODUCTION.

The paper here presented treats of the deposits of sulphur near Thermopolis, Wyo., and describes the processes of mining and refining the ore. The data on which the report is based were collected in the fall of 1908. Previous to that time several writers had described the general geology of the area, but when they visited the region the sulphur deposits had not been explored and their extent was unknown. The first of these writers was George H. Eldridge,[a] who mentions the hot springs and travertine deposits. More recently these springs and the geologic conditions which are thought to give rise to them have been discussed by N. H. Darton[b] and C. A. Fisher,[c] who have also described the geology of the region.

Recent exploration of the sulphur beds by prospect pits and drill holes has offered an opportunity to study the deposits and the conditions which control their deposition. The information gained by this investigation is presented in the following pages in the hope that it may lead to the discovery of deposits now unknown and at the same time prevent needless expenditure of money in prospecting barren ground.

LOCATION AND EXTENT.

The sulphur deposits are located 3½ miles northwest of Thermopolis, Wyo., on the gentle northeast slope of a small eroded anticline adjacent to the valley of Owl Creek, in sec. 21, T. 43 N., R. 95 W. A large number of drill holes put down in this area by the Wyoming

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

[b] The hot springs at Thermopolis, Wyo.: Jour. Geology, vol. 14, 1906, p. 194; Geology of the Owl Creek Mountains, 59th Cong., 1st sess., Senate Doc. No. 219, 1906, p. 39.

[c] Geology and water resources of the Bighorn Basin, Wyoming: Prof. Paper U. S. Geol. Survey, No. 53, 1906, p. 62.

Sulphur Company have found the deposits of sulphur in a zone about one-eighth of a mile in width and one-fourth of a mile in length, along the base of the anticline, to the northeast of a timber-covered limestone ridge. A thorough prospecting of all of the territory in which the geologic conditions are favorable has not been undertaken, but it is believed that the sulphur-bearing zone extends for a considerable distance, possibly one-half mile, to the northwest and a slightly greater distance to the southeast, beyond the limits of the proved ground. One condition that is considered to point to the presence of sulphur within the area outlined above is the occurrence of deposits of travertine upon beds of altered limestone. This association of travertine and limestone seems to be necessary to the deposition of sulphur; travertine alone contains only small particles of the mineral.

SURFACE FEATURES.

Viewed from the crest of the Owl Creek Mountains, the surface of the region consists of a long, gentle northeast slope trenched from top to bottom by many small gulches and terminated to the east by the deep canyon of Bighorn River. This slope merges at its outer margin into a dissected red-beds plain across which the river meanders in a valley bordered by narrow flood plains. Into this valley a few steep-sided ravines enter from the west. The plain in turn is limited on the north by a moderately steep-sided, partly tree-clad limestone ridge, which extends northwestward from Thermopolis, where it is cut transversely by a small canyon of Bighorn River. Remnants of travertine deposits form a mesa at one place on the crest of the ridge and occur in small terraces at various levels along the sides. To the north a plain slopes from the base of this ridge to the valley of Owl Creek.

GEOLOGIC RELATIONS.

Paleozoic rocks arch the summit of the Owl Creek Mountains 3,000 feet above the surrounding plains, and occupy the surface on the north slope. They pass beneath the red beds at the base of the mountains, and again come to view in a small area along the crest of the ridge northwest of Thermopolis, where the rocks are sharply folded into an anticline partly covered by travertine deposits. A section of all the older sediments is exposed in the walls of the Bighorn Canyon. Here the Cambrian conglomerates, shales, and limestones rest upon granites; above the Cambrian rocks are the massive Ordovician Bighorn limestone and Mississippian Madison limestone; these in turn are covered by red shales of the Amsden formation (thought to be of Pennsylvanian age); and the massive Tensleep sandstone and the cherty Embar limestone (both of Pennsylvanian age) occupy the top of the Paleozoic column. Softer Mesozoic rocks have been eroded from the mountains, but remain around the base, where the Chugwater formation (Triassic or Permian?) which occupies the lowest part, is overlain by Jurassic limestones and Cretaceous shales and sandstones. Hot-spring deposits and alluvium rest unconformably upon the upturned and eroded edges of upper Paleozoic and lower Mesozoic rocks. Previous to the present examination no observer has recorded the presence of igneous rocks in the area, though their probable presence was suggested by Darton[a] in 1906. During an examination of the region here discussed two small masses of rock thought to be igneous intrusions were noted in exposures of upturned Upper Cretaceous rocks in an escarpment 2 miles northeast of the sulphur mines and 2½ miles north of the springs at Thermopolis. These supposed igneous rocks occupy an area too small to show their true relation to the structure of the stratified beds. It is believed, however, that they connect below with much larger bodies of igneous rock.

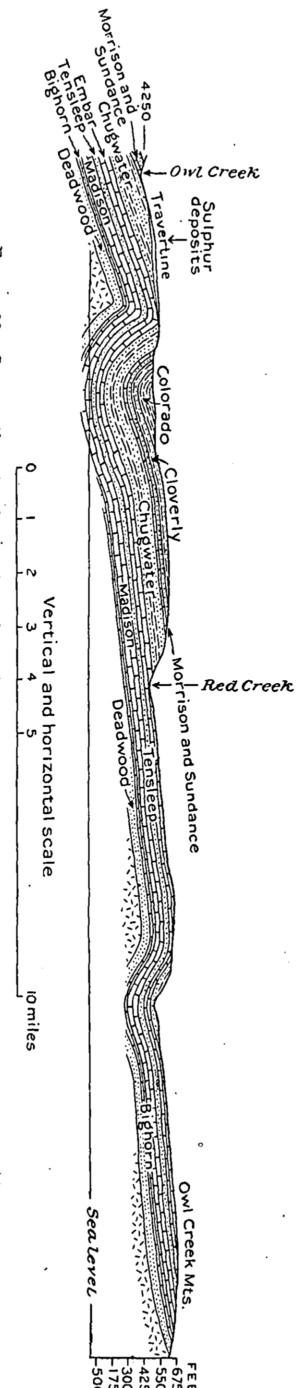

FIGURE 28.—Cross section showing stratigraphy and structure from crest of Owl Creek Mountains to Owl Creek.

STRUCTURE.

The surface rocks of the region show that the beds have a moderate dip from the crest of the Owl Creek Mountains northeastward into the interior of the Bighorn Basin. The uniformity of the major structure, however, is interrupted by two minor undulations that parallel the mountain uplift. One of these is a slight fold on the mountain slope and the other forms a sharp unsymmetrical anticline, which gives rise to the high ridge trending northwestward from Thermopolis. The structure is shown by figure 28, which represents a cross section of the beds from the crest of the moun-

[a] Darton, N. H., The hot springs at Thermopolis, Wyo.: Jour. Geology, vol. 14, 1906, p. 200.

tains northeastward to the valley of Owl Creek. The rocks in this small anticline have been sharply folded and probably sufficiently fractured along the crest to form passages, through which the heated water escapes to the surface.

HOT SPRINGS.

At the present time one mammoth hot spring and several small ones are discharging their water into Bighorn River near Thermopolis, at a rate estimated to be 3,000 to 4,000 gallons a minute. The water issues from the large spring at a temperature of 135° F. The odor of hydrogen sulphide is strong about the spring and the quantity of carbon dioxide escaping indicates that the water is saturated with that gas also. An analysis has shown potassium, sodium, magnesium, calcium, and iron salts in large quantities. These salts are deposited when the water spreads out and cools, and in this way the terraces are built up.

Though the springs are now building their terraces rapidly, there is evidence that they have had a long period of activity and that they have been distributed over several square miles, as extinct cones and terraces along the river show a wider distribution at about the present level. The earlier positions of the springs are indicated by the terraces at various levels along the side and crest of the anticline. One bed of travertine caps a mesa 3 miles northwest of Thermopolis and 700 feet higher than the mammoth spring. This does not indicate, however, that the travertine is 700 feet thick at any one point, but that there has been continuous deposition while the streams of the region have lowered their channels that amount. Although the travertine is not thick its distribution is rather widespread, as is shown by remnants of terraces over an area of several square miles. It is most extensive adjacent to Bighorn River, but occurs at short intervals on the crest and slopes of the anticline between the river and Owl Creek. The remnants of the travertine are too few and scattered to determine with precision the previous extent of these beds or their greatest thickness. The first springs seem to have been situated at the crest of the anticline, about 3 miles northwest of Thermopolis; since they began to issue there has been a gradual progression toward the present site on Bighorn River, the springs probably following the stream in its meandering and downward cutting. To the west, however, there seem to have been two periods of activity, one along the crest of the anticline and another, of later date, during which the travertine and sulphur were deposited along the base of the uplift.

TRAVERTINE AND SULPHUR.

NATURE AND OCCURRENCE.

The travertine is composed in part of carbonate of lime and in part of sulphate of lime in small crystals of the mineral selenite, which seems to be an alteration product due to the action of the sulphur waters. It occurs in small irregular plates formed by the evaporation of the water on plane surfaces or in fibers when deposited about the threads of algæ, which are abundant in the thermal waters. The travertine generally contains some native sulphur in isolated crystals or small nodules, but the quantity of the mineral is too small to be extracted with profit. The minable sulphur deposits occur in the altered Embar limestone which lies immediately below the travertine and through which the sulphur-bearing waters passed in their course to the surface. The sulphur seems to be present in very irregular deposits or pockets about the sites of extinct springs, where the sulphur-bearing water came into contact with the limestone. Few if any of these deposits exceed 100 feet in horizontal diameter; their depth is uncertain, but probably the beds do not connect with large deep-seated masses. One drill hole is reported to have passed through 30 feet of barren rock before entering the ore, and then to have continued for 15 feet in the mineral without reaching its base. There is no uniformity in the shape, size, or arrangement of these ore-bearing pockets. In general they occur in groups where the sulphur-bearing waters found passage to the surface through a number of vents. The number and arrangement of these pockets in the groups depend, therefore, on varying subterranean conditions which can not be determined from a surface investigation.

The cross section (fig. 28) shows the relation of the travertine and sulphur to the structure of the region.

Native sulphur in this district occurs in two forms—in small yellow crystals filling veins or cavities in the rocks, and in a massive form where the original structure of the limestone is retained, but where the calcium carbonate is replaced by the sulphur. The sulphur is found in crevices, channels, or cavities such as water courses make where they traverse limestone beds. The cavities 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 chambers were completely filled or, in some places, only partly filled before the passage was stopped at some point and the water diverted to other channels. As previously stated, no regular arrangement of the cavities can be discovered, though they seem to occur in groups at places where the water found free passage. In the areas between the groups of cavities only a small amount of sulphur is present, but in the enriched pockets the amount reaches 30 to 50 per cent of the rock or even more, and becomes commercially important. Some of these abandoned water courses are arranged in a close network with the interspaces so completely mineralized that the whole area is now a mass of sulphur, but in general the channels lie close together near the site of the extinct spring and farther apart away from the old vent. Laterally a deposit may be rich at one point and barren 10 feet away. The sulphur ore thus varies from a low percentage associated with barren rock to small masses of almost pure mineral, but as the deposits follow no general laws, all of the area where geologic conditions are favorable must be tested to locate the sulphur beds.

ORIGIN OF THE SULPHUR ORE.

The presence of sulphur in the water now issuing from the hot springs at Thermopolis, 3½ miles from the mines, and the fact that the mineral occurs chiefly in channels such as water forms when it flows through limestone are considered to indicate deposition by hot springs. Further evidence is afforded by the discovery of the best deposits of sulphur at the sites of extinct springs, where they issued from the limestone. A consideration of the geologic conditions surrounding these deposits seems to show that the water enters the strata on the slopes of the Owl Creek Mountains to the south and passes downward along some permeable stratum, probably the Tensleep sandstone, to the bottom of the syncline, rises in the anticline, and finds escape at the top through fractures in the sharply folded beds. In such a simple passage of the water there is nothing to account for the temperature of 135° in the present springs, or for the sulphur the water contains. Inasmuch as dikes of igneous rock intrude strata much higher than those from which the water discharges, and only 2½ miles away, it is supposed that larger bodies of uncooled igneous rock lie sufficiently close to the surface to furnish both heat and sulphur to the water which percolates through them. Chemical reactions concerned in the liberation of the sulphur and other minerals probably add slightly to the heat otherwise obtained, but this action alone could not maintain the water at the high temperature it possesses.

The chemical conditions which are supposed to be concerned in the deposition of sulphur in hot springs have been previously discussed.[a]

A comparison of the sulphur deposits at Cody and Thermopolis shows that both occur in altered Embar limestone about the seat of former hot springs, in crevices, cavities, and channels associated with gypsum, the deposits being also near active hot springs and adjacent

[a] Woodruff, E. G., Sulphur deposits at Cody, Wyo.: Bull. U. S. Geol. Survey No. 340, 1908, p. 454.

to an anticline. They are so similar even in minor details that the conditions which caused the deposition of sulphur at one place must have acted to produce a similar result at the other. The association of considerable sulphur only with altered limestone is more clearly shown in the sulphur deposits near Thermopolis than in those at Cody.

As stated in the earlier publication, it is believed that the cause which produces the heat also frees the sulphur and permits it to come to the surface, but the real cause can only be conjectured. As the waters ascend through the rocks the sulphur compounds are cooled and oxidized and part of the mineral is deposited. Both oxidation and loss of heat can best take place near the surface; hence the deposits formed in this way are probably shallow. It is of interest also to note that the ore is associated chiefly with calcareous 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 limestone is essential to the precipitation of the sulphur from solution, though it renders more difficult the explanation of the absence of sulphur in the travertine. It is thought, therefore, that deposits of sulphur large enough to be mined will be found only near the surface and in beds of altered limestone. All the essential conditions mentioned above are operative in the area here described. Hot springs are active, limestone is abundant, and the hot water holds H_2S and CO_2 in solution.

MINING, SMELTING, AND MARKETING.

The Wyoming Sulphur Company, of Thermopolis, Wyo., the only company operating in the area at the present time, began development in the fall of 1908. Mining is carried on in open-pit quarries, in which promising places are located, small drill holes are put down to prove the ground, the surface rock is removed from favorable sites, and the rock and ore are extracted by drilling and blasting. The rock is then broken to convenient size and sorted by hand, and all ore estimated to contain sufficient sulphur for treatment is hauled by wagon to the reduction works, one-fourth of a mile distant. At the smelter the ore is placed in bins, from which it is discharged into small steel cars with perforated sides, each holding about two tons. A string of three cars is then run into a large cylindrical retort, the door closed, and steam admitted at 60 pounds pressure for two hours. The sulphur is melted and flows to the bottom of the retorts, from which it escapes through a trap into bins, where it is allowed to cool. When the sulphur has been melted the cars containing the gangue are removed from the retort, other cars are admitted, and the process is 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 is lost in the refuse. After the sulphur is cooled it is crushed in an 8-inch Blake crusher and pulverized to an impalpable powder in a rotary grinder. It is then sacked and taken to Crosby, 8 miles distant, for shipment to various points in Wyoming and adjoining States.

PRODUCTION.

The plant now installed has a capacity of 20 tons a day, but has not yet been operated to the full capacity. According to a statement of the superintendent of the company on December 15, 1908, the plant had produced up to that time 200 tons of sulphur and was then yielding 10 tons a day. The demand for ground sulphur is reported to be fairly good at $35 a ton at destination.

SURVEY PUBLICATIONS ON SULPHUR AND PYRITE.

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

These publications, except those to which a price is affixed, may be obtained free by applying to the Director, U. S. Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

ADAMS, G. I. The Rabbit Hole sulphur mines, near Humboldt House, Nev. In Bulletin No. 225, pp. 497–500. 1904. 35c.

DAVIS, H. J. Pyrites. In Mineral Resources U. S. for 1885, pp. 501–517. 1886. 40c.

ECKEL, E. C. Gold and pyrite deposits of the Dahlonega district, Georgia. In Bulletin No. 213, pp. 57–63. 1903. 25c.

——— Pyrite deposits of the eastern Adirondacks, N. Y. In Bulletin No. 260, pp. 587–588. 1905. 40c.

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

MARTIN, W. Pyrite. In Mineral Resources U. S. for 1883–84, pp. 877–905. 1886. 60c.

PHALEN, W. C. Sulphur and pyrite. In Mineral Resources U. S. for 1907, pt. 2, pp. 673–683. 1908.

RANSOME, F. L. Geology and ore deposits of Goldfield, Nev. Professional Paper No. 66. (In press.)

RICHARDSON, G. B. Native sulphur in El Paso County, Tex. In Bulletin No. 260, pp. 589–592. 1905. 40c.

ROTHWELL, R. P. Pyrites. In Mineral Resources U. S. for 1886, pp. 650–675. 1887. 50c.

SPURR, J. E. Alum deposit near Silver Peak, Esmeralda County, Nev. In Bulletin No. 225, pp. 501–502. 1904. 35c.

WOODRUFF, E. G. Sulphur deposits at Cody, Wyo. In Bulletin No. 340, pp. 451–456. 1908.