# ALUMINUM AND BAUXITE.

The known bauxite districts of the United States were examined and described in detail some years ago by C. W. Hayes, and so far no large extension of the industry has taken place outside the area covered by his work. That such an extension is possible, however, is evidenced by discoveries which have been made during the last three years. Bauxite deposits of more or less promise have been uncovered in the vicinity of Fort Payne, Ala., as well as in Tennessee, Virginia, and Pennsylvania. In all these places the bauxite is associated with Cambrian or Cambro-Ordovician rocks—the Knox or Shenandoah limestone of the valley regions—so that the newly found ore bodies correspond closely to the type described by Hayes from Alabama and Georgia.

## THE GILA RIVER ALUM DEPOSITS.

By C. W. HAYES.

### INTRODUCTION.

The deposits described in the following pages occupy a small arid region in Grant County, N. Mex., on both sides of Gila River. This area embraces portions of secs. 19, 20, 29, and 30, T. 13 S., R. 13 W. It is about 27 miles due north of Silver City and is at present accessible from that point by a wagon road which reaches Gila River at Lyons Hot Springs, about 6 miles above, and thence follows the river down to the mouth of Alum Creek.

The locality was visited in 1893 by W. P. Blake, who published a brief account of the deposits in the Transactions of the American Institute of Mining Engineers, vol. 24, 1894. A somewhat more extended report by Professor Blake is contained in a pamphlet published privately in 1893 by A. T. Johnston, owner of the property. So far as known these are the only publications containing any first-hand information concerning the deposits, though they have been known to prospectors and ranchers for many years. Some material from the deposits was analyzed by F. W. Clarke in the laboratory of the United States Geological Survey in 1884, and the results of the analysis were published in Bulletin No. 9, though without further information concerning the deposits than their general location.

Professor Blake devoted parts of only two days to the examination of these deposits, and the actual time spent on them by the writer was less than three days, so that the geologic work thus far done must be regarded as purely of a reconnaissance character and the conclusions as preliminary and tentative.

## TOPOGRAPHIC RELATIONS.

The alum deposits occupy a nearly circular depression below the general level of the volcanic plateau. Gila River cuts through the northern edge of this depression, and Alum Creek intersects its eastern portion from south to north. The elevation of the river is about 4,000 feet above sea level; the rim of the basin is between 2,000 and 3,000 feet higher. The inner slopes of the basin rim are very steep and generally surmounted by basaltic cliffs. Except where the river enters and leaves the basin and at one point where Alum Creek heads against the upper branches of Copperas Creek, the rim is practically continuous. The latter point has been selected for a trail which by way of Copperas Creek and the Sapio affords the most direct approach to the basin.

Within this basin is a group of hills, the highest of which, Alunogen Ridge, rises from 1,000 to 1,200 feet above the river. These hills are separated by Alum Creek and its branches into three groups. The largest group, with Alunogen Ridge along its southern border, lies west of Alum Creek, between the west fork and the Gila. On the west it is separated by a deep depression from the western rim of the basin. East of Alum Creek is a smaller group of hills, culminating in a sharp peak something over 800 feet above the river and separated from the east rim of the basin by a shallow depression. Between the two main forks of Alum Creek is a third and smaller group, forming the point of a spur from the southern rim of the basin. This group consists of a series of pinnacles and isolated buttes with nearly vertical sides. North of the rim a fourth group of hills rises abruptly from the slope of the basin.

These hills within the basin are entirely distinct in form from any other topographic features of the region. They are characterized by great numbers of pinnacles and isolated buttes rising abruptly from steep talus slopes. The cliffs are weathered into innumerable intricate and fantastic forms and in many places are covered with heavy masses of incrustations. Even more striking than their peculiar form is their varied and brilliant coloring, which forms a strong contrast with the somber greenish gray and black of the surrounding basaltic basin rim. The prevailing colors are white and red, with all shades of pink, yellow, and green.

## GEOLOGIC RELATIONS.

This portion of New Mexico is occupied wholly by igneous rocks, the nearest sedimentary beds being Carboniferous limestone in the vicinity of Santa Rita, 20 miles to the southeast. The canyon of Gila River exhibits a great series of lava flows alternating with volcanic tuffs and breccias. At Lyons Hot Springs the lower 200 or 300 feet consists of generally vertical cliffs of light-gray rhyolite. Above this is a great thickness of andesitic breccia, containing large fragments of basalt. This resembles a very coarse conglomerate and may be in part water-laid. Between Lyons Hot Springs and Alum Creek the rhyolite and the overlying breccia disappear and are replaced by a series of basalt sheets which extend from the level of the river to the summit of the plateau, 3,000 feet or more above.

The rocks which are of chief importance in the present connection, and which occupy the greater part of the topographic depression described above, are andesitic breccias. Although this rock presents considerable variation in appearance, its different phases grade into each other and there is nowhere any difficulty in distinguishing it from the surrounding basalt. Its breccia character is generally evident to the unaided eye, the rocks being made up of angular fragments embedded in a fine-grained groundmass. The angular inclusions are in the main similar to the matrix in composition and structure, though somewhat finer grained. Here and there they are composed of an entirely distinct type of rock. This is most common near the contact with the basalt, where fragments of that rock are in places abundant. Considerable portions of the rock, however, show no breccia character.

This andesitic volcanic breccia will be referred to as the alum rock.

## DISTRIBUTION AND RELATIONS TO BASALT.

The distribution of the alum rock is shown on the accompanying sketch map (fig. 6). Owing to lack of time, contacts were traced in detail at only a few points, and they will doubtless be materially modified by further study. In a general way, however, the map shows the more important facts of distribution.

It will be seen that the main mass of the alum rock occupies a nearly circular area, lying for the most part south of Gila River and west of Alum Creek. About the margins of this main mass are smaller areas occupied by the alum rock, the largest being north of the river and several small ones lying in the upper basin of Alum Creek. It is possible that the mass north of Gila River is continuous with the main mass to the south, though more probably it is entirely distinct. Doubtless there are other small masses in addition to those shown on the map.

The relations of the alum rock to the adjacent basalt are well shown on the steep eastern slope of Alum Canyon. The contact here extends about N. 60° E., and is marked by a deep, narrow ravine. To the north the alum rock forms a series of pinnacles and in places the original outer surface of the mass is shown, the basalt having been the more easily eroded of the two rocks. At this point the contact is vertical and the alum rock contains numerous fragments of the basalt up to several feet in diameter. The relations here indicate clearly that the alum rock has broken through the basalt in the form of an igneous intrusion, probably with intense explosive violence. The basalt shows a foliation or platy structure parallel to the contact and extending several feet from it. Within this zone it is deeply weathered to a greenish clay, though the structure of the rock remains.

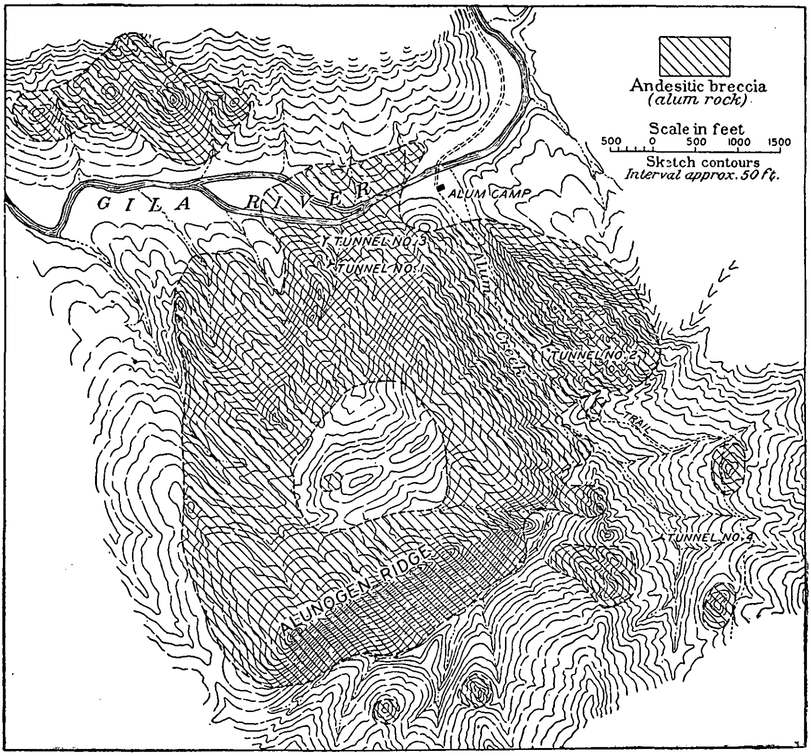

FIG. 6.—Sketch map of Gila River alum deposits, based on claim map prepared by R. L. Powell, United States deputy surveyor.

Similar relations between the alum rock and the basalt were observed at several other points, notably on the point of the ridge between the forks of Alum Creek and along the western margin of the main mass. In every place where the contact was well exposed it was either vertical or at a high angle, and the alum rock contained fragments of the basalt. One peculiar feature shown by the map is the large body of basalt entirely surrounded by the alum rock, near the center of the main mass. Although its relations are obscure, this appears to be merely a large inclusion, broken off from some underlying basalt sheet and floated up to its present position by the intruded mass.

### ALUM ROCK.

The most striking peculiarity of the alum rock is its extreme alteration. This is evident to the unaided eye and even more so when the rock is examined under the microscope. Careful search failed to reveal at any point within the Alum Creek basin a trace of the unaltered breccia for determination of its original character. Where exposed to leaching, as in the upper parts of pinnacles and cliffs, the rock is invariably porous, giving a hollow sound under the hammer. It is evident that a considerable part of its substance has been removed in solution.

The least altered phase of the alum rock is seen in tunnel No. 2, which is driven about 180 feet into the face of the cliff on the east side of Alum Canyon. The rock is fine grained and was originally composed of minute crystals of plagioclase feldspar embedded in a glassy groundmass. Both feldspar crystals and matrix are much altered, only the outlines of the former remaining. There are also abundant very fine, dustlike particles of pyrite. Near the face of the cliff the rock is white and chalky, but a few feet in from the face it has a white chalky base more or less mottled with bluish-gray patches in which the alteration is evidently less complete. A rock originally very similar to that in tunnel No. 2 forms the point of the spur between the forks of Alum Creek.

The composition of the various phases of the alum rock is shown in the accompanying analyses.

*Analyses of alum rock from Gila River, New Mexico.*

[W. T. Schaller, analyst.]

| | A. | B. | C. | D. |
|---|---|---|---|---|
| Soluble in water: | | | | |
| $Al_2O_3+Fe_2O_3$ | 0.51 | 0.22 | | |
| $SO_3$ | 1.83 | 1.64 | | |
| Insoluble in water: | | | | |
| $SiO_2$ | 55.76 | 50.45 | 57.25 | 83.51 |
| $Al_2O_3$ $(+TiO_2)$ | 20.64 | 18.61 | 32.27 | 5.55 |
| $Fe_2O_3$ (total iron) | 4.16 | 3.79 | Trace. | Trace. |
| Loss on ignition | 18.07 | 23.85 | 12.07 | 7.38 |
| Ignited residue insoluble in water | 81.19 | 76.16 | 88.00 | 91.69 |

A. Alum rock, white, mottled bluish gray, from tunnel No. 2, 50 feet from mouth of tunnel.
B. Alum rock, disintegrated, from dump of tunnel No. 2.
C. Alum rock, white, chalky, from point of ridge between forks of Alum Creek.
D. Alum rock, pinkish white, porous, from summit of Alunogen Ridge.

Of the four samples analyzed A and B represent practically the same material, the only difference being that the material on the dump has been thoroughly disintegrated by exposure to the weather for thirteen years. It contains nearly 6 per cent more water and less silica and alumina than the tunnel rock, though the ratio of silica to alumina is practically the same in both. In C the ratio of silica to alumina is lowest and the material contains practically no iron. D is highly siliceous, as was to be expected from its appearance and its exposed position.

## INCRUSTATIONS.

Two forms of incrustations having entirely different chemical composition are common in association with the alum rock wherever the conditions are favorable for their accumulation.

Upon the sides of the cliffs, particularly where they overhang or are undercut and pitted by erosion and afford some protection from rain, are extensive deposits of material, evidently leached out of the adjacent rock and deposited from solution. These incrustations vary in thickness from a few inches to 3 or 4 feet. The outer surface has a fluted appearance, resembling some stalactitic cave deposits. It is generally yellowish white in color and is fairly hard, with a porous, cellular structure. Within this outer crust the material is much softer and in many places occurs as a perfectly white powder. This incrustation consists of the hydrated sulphate of aluminum, alunogen. The white powdery material is very pure and has practically the theoretical composition of alunogen; the outer crust contains a slight amount of impurities and less than the theoretical amount of water.

The following analyses give the composition of this incrustation:

*Analyses of alunogen from Gila River, New Mexico.*

| | A. | B. | C. |
|---|---|---|---|
| $Al_2O_3$ | 16.29 | 15.52 | 15.3 |
| $SO_3$ | 36.93 | 34.43 | 36.0 |
| $H_2O$ | 46.45 | 42.56 | 48.7 |
| Insoluble residue | ........ | 7.62 | ........ |
| | 99.67 | 100.13 | 100.0 |

A. Analyst, George H. Corey. Carefully selected crystals.
B. Analyst, F. W. Clarke. Pinkish crusts. Bull. U. S. Geol. Survey No. 9, 1884, p. 13.
C. Theoretical composition of alunogen—$Al_2(SO_4)_3+18\ H_2O$.

The second form of incrustation is most abundant on the walls of the tunnels which have been driven into the alum rock, particularly in No. 2. This tunnel was driven in 1893, and since that time its walls have become coated with a heavy incrustation from 3 to 6 inches thick, consisting of halotrichite, a silky fibrous mineral closely resembling asbestos in appearance. It has a very pale greenish color and a strongly astringent taste. The outer exposed surface of the incrustation has generally lost its fibrous structure, becoming compact and assuming a yellowish color. Although the incrustation may be several inches thick, the individual fibers are rarely more than a third or a half of an inch in length, the crust being made up of successive layers of short crystals. Each layer probably represents the growth of a single season during which the supply of percolating water was relatively abundant. The layers of crystals are in places separated by a very thin film of the rock which has been split off by the growth of a subsequent layer of crystals.

The chemical composition of this fibrous halotrichite is shown below.

*Analyses of halotrichite from Gila River, New Mexico.*

| | A. | B. | C. |
|---|---|---|---|
| $FeO$ | 7.94 | 13.59 | 7.8 |
| $Al_2O_3$ | 11.77 | 7.27 | 11.0 |
| $SO_3$ | 35.25 | 37.19 | 34.5 |
| $H_2O$ | 45.09 | 40.62 | 46.7 |
| Insoluble | ........ | .50 | ........ |
| | 100.05 | 99.17 | 100 |

A. Analyst, W. T. Schaller. Carefully selected fibrous crystals from tunnel No. 2.
B. Analyst, F. W. Clarke. "Fibrous mineral of silky luster." Bull. U. S. Geol. Survey No. 9, 1884. Contains a trace of $Fe_2O_3$.
C. Theoretical composition of halotrichite—$FeSO_4+Al_2(SO_4)_3+24H_2O$.

As shown in the foregoing analyses, the halotrichite is the double sulphate of aluminum and iron, and the alunogen is the sulphate of aluminum and is free from iron except as a minor impurity. The relations of the two minerals may be explained as follows:

As a result of chemical reactions within the alum rock the double sulphate, halotrichite, is formed. This is carried to the surface in solution by the slow capillary circulation and on the evaporation of the solvent water is deposited as a crystalline incrustation. Wherever water subsequently gains access to this deposit it is redissolved and carried downward. This solution, however, particularly when it forms a thin film trickling down the face of a cliff, affords abundant opportunity for oxidation and the iron is converted from the ferrous to the ferric state and thereby becomes insoluble. It is deposited as ferric oxide, which accounts for the prevalence of red color in the rocks and soil, whereas the aluminum sulphate, unaffected by the oxidizing conditions, remains in solution and either passes off with the surface waters or by the evaporation of the water is deposited in stalactitic forms and incrustations upon the cliffs.

In the report already cited, Blake suggests two methods by which the chemical reactions necessary for the formation of sulphates within the alum rock may be produced, namely, (1) the oxidation of the contained pyrite with the production of free sulphuric acid, and (2) the ascent of acid solutions and gases from a deep source with the resulting solfataric action which often characterizes the final phases of volcanic activity.

The andesitic breccia generally contains fine disseminated grains of pyrite, probably enough to produce by their oxidation the necessary sulphuric acid for all the sulphates present. So far as observed, however, the pyrite in the alum rock is perfectly fresh and unoxidized. Further, the mineral halotrichite, which seems to have been the form of sulphate first formed, is extremely unstable under oxidizing conditions, the iron passing readily to the ferric condition and becoming at once insoluble. Hence halotrichite could not be formed under conditions favorable for the oxidation of pyrite. If the pyrite had been the source of the sulphuric acid the mineral produced would have been one of the more stable sulphates.

Another source for the sulphuric acid must therefore be sought, and its volcanic origin is at once suggested. As has been shown, the alum rock was originally an andesitic breccia which filled the neck of a volcano. This volcanic neck cuts through and is therefore later than the great basaltic lava sheets which occupy so much of this region. It may very easily have been active in late Tertiary or Quaternary time and have been, in part, at least, the source of the great beds of tuff and breccia which fill an old valley to the north, now in part reexcavated by Gila River. The brecciated character of the material filling the volcanic conduit permitted the easy ascent and circulation of gases and solutions from great depths, and if these contained free sulphuric acid they would be entirely competent to produce the alteration observed in the breccia and the sulphates which it contains. The alteration is confined almost entirely to the breccia within the volcanic conduit, generally extending only a short distance into the surrounding basalt. The alteration of the basalt is most extensive where it was most fractured by the intrusion, as in the vicinity of the numerous small intrusions of breccia southeast of the main mass. As the basalt consisted largely of ferromagnesian minerals, it yielded under the action of the acid solutions chiefly hydrated magnesian silicates and gypsum, the latter being rather abundant as selenite crystals in the residual greenish clay.

The determination of the agent producing the chemical changes in the breccia has more than a theoretical scientific interest. If these changes were due to the acid produced by the oxidation of pyrite, they would not be expected to extend beyond the relatively shallow zone of oxidation. If, on the other hand, they are due to ascending acid solutions, they may be expected to extend to much greater depths.

It is probable that the fumarolic activity to which the chemical changes appear to be due has entirely ceased in this particular volcanic neck. No thermal springs and no emanations of acid gases have been observed within the area of the alum basin. A few miles distant up Gila Canyon hot springs occur at three separate points. No analyses of the waters from these springs are available, but they show no evidence of being highly mineralized. The only deposit at these vents is a very slight incrustation of the rocks over which the waters flow, and this is apparently silica. Their presence, therefore, near the breccia-filled volcanic vent is probably without significance.

## UTILIZATION.

In his paper on these deposits Blake states that the residual rock from which the soluble sulphates have been leached consists essentially of hydrated aluminum oxide or bauxite. The analyses given on page 219 do not indicate the presence of free aluminum oxide, but, on the contrary, show that the residual rock is essentially the silicate of aluminum, having approximately the composition of kaolin. The value of the deposits will therefore depend on the utilization of the soluble sulphates which they contain. The present surface accumulations of alunogen, though probably amounting to many hundreds or, more probably, thousands of tons, represent but an insignificant quantity compared with the sulphates still in the rock. Wherever observed the rock is highly porous, and the extent of its porosity represents the amount of material removed. In the higher and more exposed ledges the rock is thoroughly leached and will yield nothing more. At lower levels the rock still contains a part of its soluble constituents, which are coming to the surface by the capillary circulation of surface waters. The extent of this loss is shown in tunnel No. 2, where the average annual accumulation of halotrichite is about half an inch. No test has been made of the rock below drainage level, but it is probable that here, where there has been no opportunity for leaching, will be found the largest amount of soluble constituents.

Since this deposit presents so many unique characteristics, it is hazardous to venture a prediction as to its future utilization. New methods of mining and treatment must be devised to meet the peculiar conditions, and success will depend largely on the skill with which the problem is handled. That there exists here an almost unlimited supply of aluminum sulphate appears, however, certain, and in view of the rapidly growing demand for this substance in the arts, in sanitary engineering, and as a source of the metal, there is little question that the supply will in time be fully utilized. The essentials for such utilization appear to be transportation facilities and chemical engineering skill.

# SURVEY PUBLICATIONS ON ALUMINUM ORES—BAUXITE, CRYOLITE, ETC.

The following reports published by the Survey contain data on the occurrence of aluminum ores and on the metallurgy and uses of aluminum:

CANBY, H. S. The cryolite of Greenland. In Nineteenth Ann. Rept., pt. 6, pp. 615–617. 1898.

HAYES, C. W. Bauxite. In Mineral Resources U. S. for 1893, pp. 159–167. 1894.

—— The geological relations of the southern Appalachian bauxite deposits. In Trans. Am. Inst. Min. Eng., vol. 24, pp. 243–254. 1895.

—— Bauxite. In Sixteenth Ann. Rept., pt. 3, pp. 547–597. 1895.

—— The Arkansas bauxite deposits. In Twenty-first Ann. Rept., pt. 3, pp. 435–472. 1901.

SCHNATTERBECK, C. C. Aluminum and bauxite [in 1904]. In Mineral Resources U. S. for 1904, pp. 285–294. 1905.

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

STRUTHERS, J. Aluminum and bauxite [in 1903]. In Mineral Resources U. S. for 1903, pp. 265–280. 1904.