DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 511

ALUNITE

A NEWLY DISCOVERED DEPOSIT NEAR MARYSVALE, UTAH

BY

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1912

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ALUNITE, A NEWLY DISCOVERED DEPOSIT NEAR MARYSVALE, UTAH.

By B. S. Butler and Hoyt S. Gale.

INTRODUCTION.

DISCOVERY.

An important deposit of alunite, which has but recently been discovered in Utah, is now being developed with so favorable a showing that it promises to afford one source of the much desired class of materials commonly referred to as "potash." Federal geologists visited this locality in March, September, and November, 1911, but even at the later visit the prospect pits were not sufficiently complete to give satisfactory evidence of either the size or the linear extent of the deposit. A reconnaissance study of the geology and ore deposits in the vicinity of Marysvale, incidentally including the alunite, was made in September by B. S. Butler, and a hurried review of the Custer alunite properties was made on November 2 by Hoyt S. Gale. The general review of the geology of the Tushar Range given on pages 12–38 is the work of B. S. Butler.

Although a large vein of "pink spar" in the hills southwest of Marysvale had long been known to prospectors and had been repeatedly located for small metalliferous values said to be found in the siliceous wall rock of the vein, it was not until 1910 that the true nature of the spar was discovered. Specimens sent to the United States assay office at Salt Lake in November, 1910, were later forwarded to an eastern chemist, who is said to have recognized the real value of the material. On January 1, 1911, the claims that had been allowed to lapse were relocated for the sake of the newly recognized deposit.

SIGNIFICANCE OF THE DEPOSIT AS A SOURCE OF POTASH.

Alunite has long been used abroad as a source of potash alum, which it resembles in chemical composition. The alunite contains a relatively larger proportion of alumina than the common potash alum.

It is insoluble but is readily converted to either the soluble potash alum or potassium sulphate by a comparatively simple process of heating, or calcination.[1] A process that has long been established commercially may doubtless be adapted to the American deposits. The Marysvale deposit, so far as now known, is not of such magnitude as to afford a source of all the potash salts now consumed in the United States, but it may prove to be an important factor in providing an American supply that will perhaps be especially available to local and western markets, particularly in meeting the demand for higher-grade salts. Possibly also the greatest importance of the commercial development of this deposit will be in the added stimulus it may afford to exploration for other similar deposits of this mineral, especially in this general region, and it is on the discovery of such other deposits that the provision of a home supply from this source must depend.

LOCATION AND RAILROAD FACILITIES.

The newly discovered deposit of alunite is situated near the head of Little Cottonwood Canyon, about 7 miles due southwest of Marysvale, Piute County, Utah. It is located in and near sec. 16, T. 28 S., R. 4 W., and so far as known is covered by mining-claim locations. Marysvale is the present terminus of the San Pete & Sevier branch of the Denver & Rio Grande Railroad. The deposit lies high in the Tushar Range, outcropping near the top of the ridge separating North Fork of Little Cottonwood Creek from the main branches of Little Cottonwood Canyon. The vein and siliceous wall rocks form the crest of the high ridge leading up to the main divide. The deposit ranges in elevation from approximately 11,000 feet above sea level to about 9,900 feet at its present recognized lower end, which is about 4,000 feet above the railroad at the Marysvale station.

DESCRIPTION OF THE MARYSVALE ALUNITE.

CHARACTER OF THE VEIN.

The alunite of the Marysvale deposit lies principally in a large banded vein, cutting at steep inclination the volcanic rock (dacite or andesite) which forms the greater part of the Tushar Range. The views given in Plates I and II were taken November 2, 1911, and show the character of present development work, and the general appearance of the vein at the outcrop. The smooth rock faces shown in these views are fractures across the vein.

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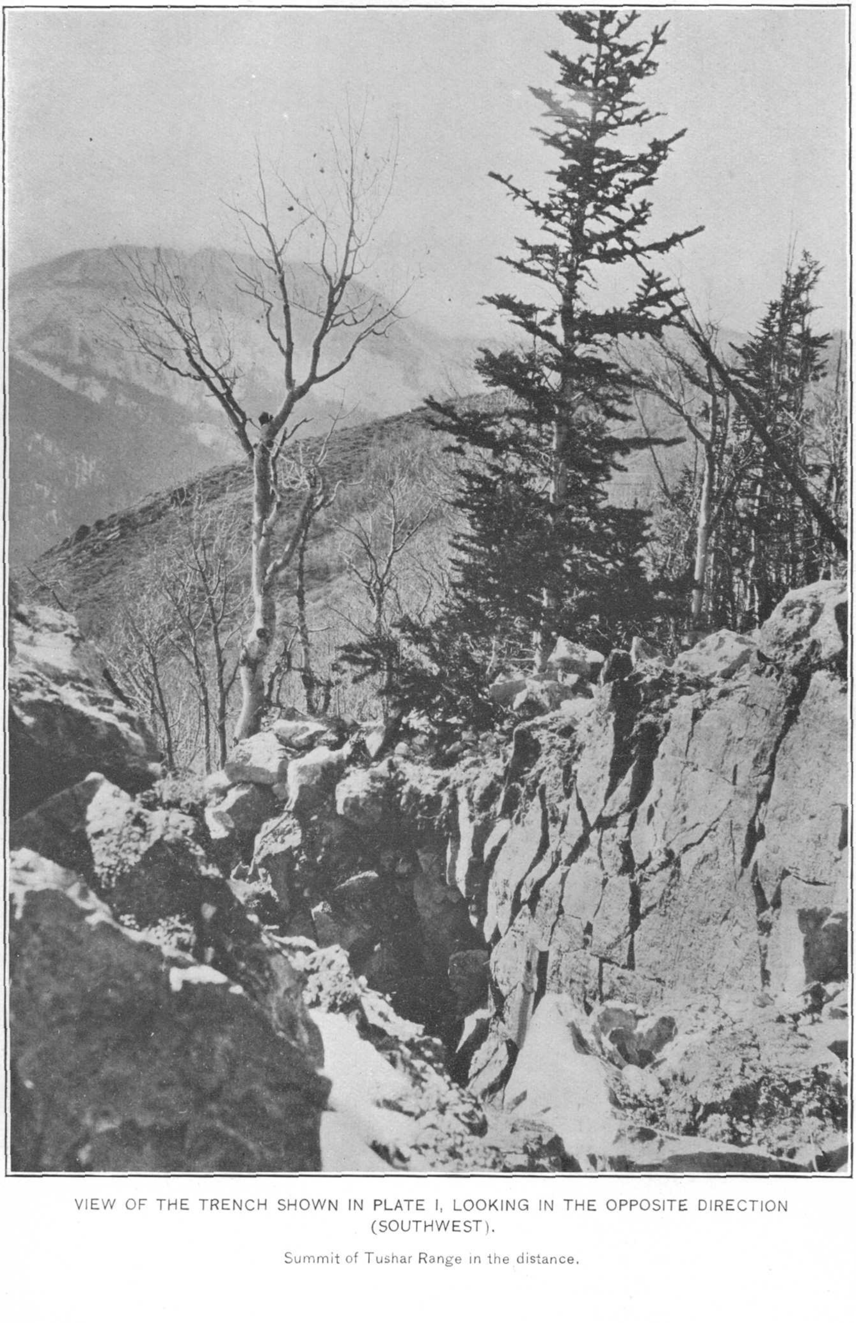
[1] See references to utilization of foreign deposits, pp. 59–61.

PROSPECT CROSSING THE MAIN ALUNITE VEIN NEAR THE NORTHWEST END OF CUSTER NO. 1 CLAIM, NEAR MARYSVALE, UTAH.

The smooth faces are joints crossing the trend of the vein. Most of the loose material strewn about is alunite, as is also the solid face of rock shown in the cut.



VIEW OF THE TRENCH SHOWN IN PLATE I, LOOKING IN THE OPPOSITE DIRECTION (SOUTHWEST).

Summit of Tushar Range in the distance.

The large vein is evidently a fissure filling and not a replacement of the country rock, as the main body of the deposit is remarkably pure and has the banded or crusted structure of a typical fissure vein, That replacement has not produced the larger bodies of alunite is further attested by the fact that the main vein contains but little silica, while in the wall rock where replacement has occurred the quartz phenocrysts remain practically unaltered, and silica that has been set free from the decomposition of other minerals has not been removed.

The real attitude of the vein is not yet very clearly defined. The vein banding is assumed to be approximately parallel to the walls and if this position is continuous below the part at present exposed, the vein is probably nearly vertical in its northern extension and has a distinct dip about 60° SW. toward the south end of the recognized deposit.

On each side of the main deposit smaller veins or bands of alunite alternate with similar thicknesses of much silicified portions of the wall rock, which in place contain iron sulphide in disseminated grains or crystals.

A more detailed and technical description of the alunite veins is given on pages 20–21.

PHYSICAL CHARACTER OF THE ALUNITE.

The larger bodies of the Marysvale alunite are of unusual size and notably free from foreign material. The alunite occurs in massive form, being in part a fine-grained compact rock, breaking with conchoidal fracture, and having a porcelain-like appearance, but containing also considerable masses with a distinctly crystalline structure. A considerable part of the vein material at the outcrop, however, is more or less of an amorphous texture and commonly sheared to a foliated or schistose structure. The crystalline material is generally clear pink to reddish in color and the finer-grained rock varies from a white to a decided pink.

The fine porcelain-like material, of which analysis 19 on page 8 is representative, is seen under the microscope to be a granular mass composed of irregular crystals of alunite. Through this fine-grained material are scattered small veinlets of more coarsely crystalline alunite.

The coarsely crystalline portion of the deposit, of which analysis 18 on page 8 is representative, shows the more distinct crusted structure. The crystals are subtransparent, show a distinct cleavage, and are of a rather coarse granular or tabular form, yielding a splintery fracture in the mass of the rock. The elongation of the crystals, though showing a tendency toward radiation in tufts, is, however, roughly parallel and is normal to the vein banding and the walls.

A considerable portion of the alunite as revealed in the present prospects has an amorphous texture and a more or less schistose structure, which may in part be due to weathering but probably is largely the result of shearing movements in the mass of the rock.

CHEMICAL CHARACTER OF THE ROCK.

The chemical character of the rock is expressed by the following analyses of some of the best and apparently purest material collected at the prospect pits. These analyses, which were made by W. T. Schaller, show a very close approximation to the theoretical composition of the mineral as quoted from Dana's "Textbook of mineralogy" for comparison:

Analyses of alunite from deposit near Marysvale, Utah.

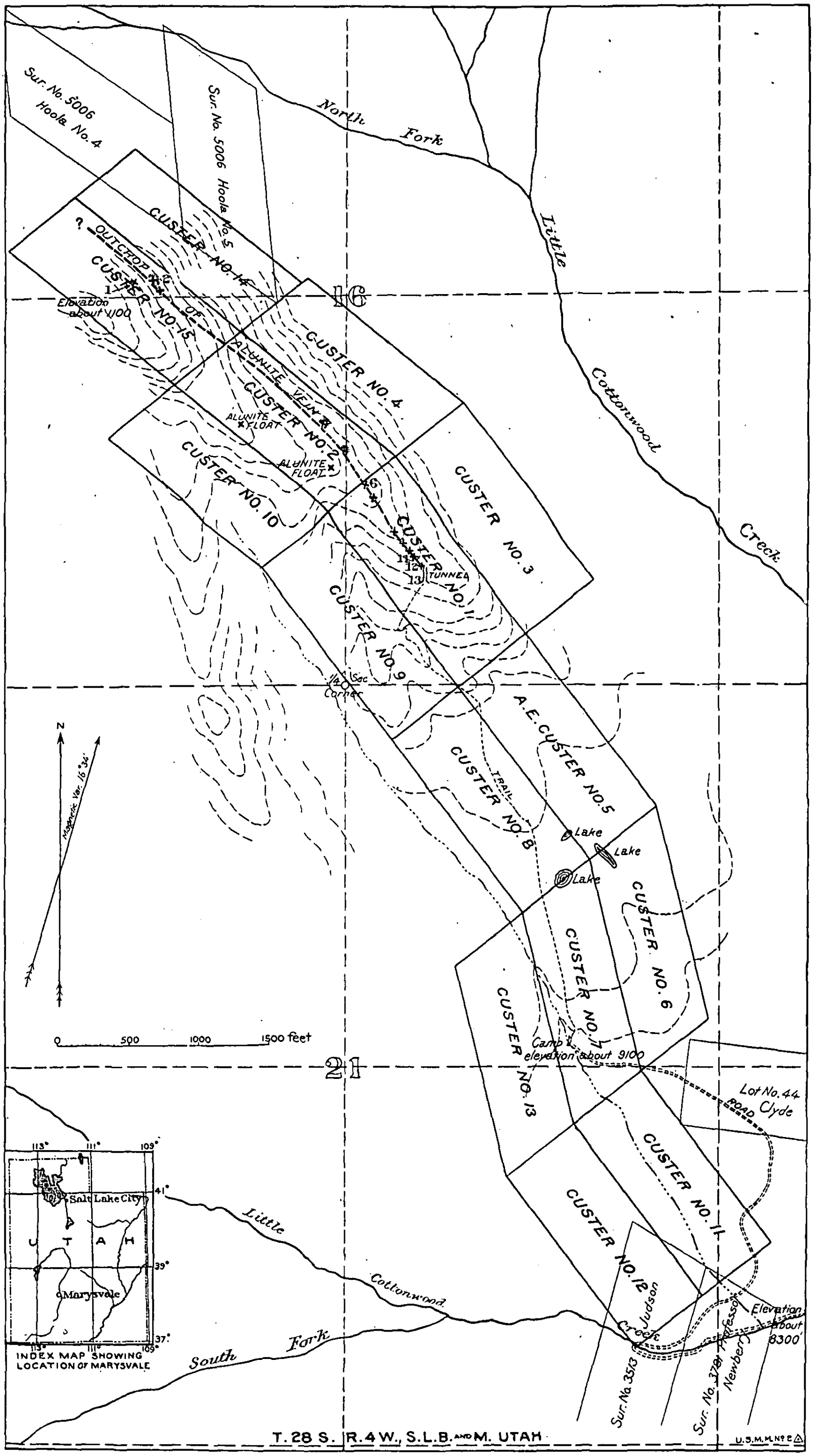
	18	19	Dana.
Al_2O_3	37.18	34.40	37.0
Fe_2O_3	Trace.	Trace.	
SO_3	38.34	36.54	38.6
P_2O_5	.58	.50	
K_2O	10.46	9.71	11.4
Na_2O	.33	.56	
H_2O+	12.90	13.08	13.0
H_2O-	.09	.11	
SiO_2	.22	5.28	
	100.10	100.18	100.0

No. 18 is a selected specimen of the supposedly best material. It consists of clear-pink, subtransparent, coarsely granular crystalline rock. No. 19 is a selected specimen of a light-pink, very finely granular rock, of almost porcelain-like conchoidal fracture and no distinct structure.

EXTENT OF THE MARYSVALE DEPOSIT.

LOCATED CLAIMS.

The principal claims located on the Marysvale alunite deposit are the Custer group, shown on the accompanying plat taken from the official surveys (Pl. III). This group of claims adjoins patented mineral ground and recorded claims both to the northwest and southeast, as is indicated on the map. The Custer group covers the greater part of the alunite deposit as now recognized, the first location made expressly for the alunite having been staked January 1, 1911. Property to the northwest of the Custer claims is said to be covered by mineral locations under the control of the Florence Mining & Milling Co., lessee of the Utah Gold Mountain Mining Co., including the so-called Log Cabin property and also the patented ground known as the Bradburn property. Southeast of the Custer claims is the patented ground of the Clyde property, indicated on the plat.



MAP SHOWING THE PRINCIPAL GROUP OF CLAIMS LOCATED ON THE ALUNITE DEPOSIT NEAR MARYSVALE, UTAH.

Based on plats of mineral survey Nos. 6162, 6163, 6164, 6165, United States Surveyor General's Office, Salt Lake City, Utah. The outcrop of the alunite and the contours shown on the map are based on a hasty field sketch and are only approximate. The numbers indicate points at which specimens described in the text were collected.

CONTINUITY OF THE DEPOSIT.

As yet only what is understood to represent a single large vein deposit of the alunite has been shown by the developments on the Marysvale properties. Proof of the actual continuity of this deposit beyond the area of most numerous prospects (in claims Nos. 1 and 2) is not complete. The vein appears to be limited by fairly well defined walls and to follow a very regular trend, extending nearly due northwest and southeast. As the outcrop and openings are all aproximately in the course of this same general trend, it is likely that they represent one and the same vein, although it is possible that there are more than one possibly related veins. There is some evidence indicating that other deposits may exist, but at present it is believed that none have been opened by prospects far from the main deposit.

The representation of the outcrop of the alunite on Plate III is probably only approximately correct, as it is based on a very hurried compass traverse made at the time of the visit to the property on November 2. The extension of the alunite deposit along the course of the vein to the southeast has not yet been proved beyond the outcrop shown on the plat. Float has been found on the lower claims of the Custer property and this may indicate the existence of some rock in place, but it can not now be said with certainty that the vein extends farther southeast than is shown in the Custer claim No. 1. The deposit has been recognized northwest of the Custer claims, however, where it occurs in massive outcrop, apparently very similar in character to that portion of the vein that has already been prospected. This northwestern outcrop is situated on the crest of the ridge north of the Log Cabin tunnel and about 550 feet above it, near the "Edna Geyser." It is probably half a mile or more northwest of the limit of the outcrop represented on Plate III.

The apparent continuity of the vein on the surface and its vertical range of outcrop from an elevation of somewhat more than 11,000 feet to about 9,900 feet may be assumed as good presumptive evidence of a corresponding continuity of the deposit in depth. However, some considerations which are more completely reviewed in the discussion concerning the probable origin of these deposits (pp. 21–37) tend to indicate that some alunite deposits are of superficial origin and will not be found to be continuous in depth. As will be seen, however, by reference to page 36, the evidence in regard to the Marysvale deposit is thought to favor a deep-seated rather than a superficial origin and the conditions of the deposition of the alunite may not have been dependent on a close proximity to the surface or on any immediate relation to the topography of the present time.

THICKNESS OF THE MAIN DEPOSIT.

The prospects completed at the time of the last visit to the property had traced only about 3,000 to 3,500 feet of the outcrop, which is that portion indicated by the outcrop line of the meander traverse in Plate III. Only that portion of the vein that is covered by the prospects in claims Nos. 1 and 2 can be said to be known with much certainty. Here numerous measurements of the vein as it was exposed in the trenches were made, but most of these were far from satisfactory, owing to the incompleteness of the exposures.

The size of the vein and the apparent purity of the material are probably its most unusual features. According to a number of measurements made from the present developments, there is in one place at least 20 feet of solid alunite in the larger vein and 6 feet more in a parallel vein some 25 feet to one side, with considerable quantities of alunite rock and alternating purer alunite and siliceous wall rock intervening. The lower-grade rock may possibly extend beyond that shown in the present pits. Other measurements made reveal less thicknesses, but in each case it is doubtful whether the trenches that have been dug expose all the alunite that may be present.

With the exception of the outcrop of alunite near the "Edna Geyser" already referred to, the northernmost outcrops examined were in the prospects indicated on the plat as Nos. 1 and 2 in Custer claim No. 15. Alunite was observed in talus, and specimen No. 1 was collected at an elevation at least 75 feet above and southwest of the prospect marked as the discovery on the Custer claim No. 14. It is likely, therefore, that more than one vein of the alunite will be found near this locality, but at present the prospect only incompletely reveals the one vein. A 10-foot hole and shaft exhibit 6 feet of apparently good material without showing distinctly that both walls have been reached. The alunite is massive, of texture which varies from coarsely crystalline to fine porcelain-like, including some sheared material.

Specimens 6 and 7 and the block that was afterward analyzed, No. 19, were collected near the shaft and monument marked "SE. end center Custer No. 2 and NW. end center Custer No. 1." Here the development consists of a 30-foot trench crossing the crest of the ridge, together with a shaft about 20 feet deep. Much alunite has been thrown out on the dump. The trench shows 10 feet of apparently very pure alunite and 5 feet at the north end of the cut composed of mixed vein and wall rock. However, a considerable portion of the trench is cut in loose surface material and probably does not show the whole thickness of alunite at this place. This is the locality illustrated in the views shown in Plates I and II.

Northwest of this point two other prospects were visited, distant about 250 and 500 feet from the end center monument described.

Specimen No. 18, the anaylsis of which is given on page 8, was collected from the nearer trench. Here a cross section of the alunite vein measured 15 feet, with no apparent partings or inclusions of other material. The farther trench showed 12 feet of solid alunite, but the exposure is probably incomplete, as it runs into slide material at either end. A 15-foot tunnel just below this trench exposed a stringer of alunite, apparently an offshoot from the main vein, as it differs markedly from the vein in direction and pitch.

About 100 feet southeast of the northwest end center stake of the Custer claim No. 1 is an open cut showing a solid face of somewhat more than 12 feet of massive alunite, varying in texture from coarsely crystalline to fine granular. The west wall of this vein is a dense quartz or siliceous rock containing specks of iron sulphide, and beyond this at least 6 feet of alternating alunite and siliceous rock are exposed. The trench ends in slide rock. About 350 feet southeast of the northwest end center stake of the Custer claim No. 1 is a trench 30 to 40 feet long, cut transverse to the course of the vein, which follows the crest of the ridge at this place. Here crustification or banded structure of the vein is quite distinct, and from the attitude of this banding the vein is assumed to be dipping 60° SW. and to have a course N. 50° to 55° W. Some of the ore exposed here has a beautifully clear, banded crystalline structure and is of pink or reddish color. A detailed tape measurement made, allowing for a 60° dip as indicated by the banding, gave a total thickness of 17 feet 6 inches of apparently solid alunite, with at least 10 feet more of alunite and siliceous wall rock in alternating bands exposed in the northeast end of the cut.

About 100 feet southeast of the trench last described is a deep trench or open cut and shaft exposing at least 20 feet of solid alunite vein rock. The banding here strikes N. 50° W. and dips 60° SW. There are some very massive blocks in this exposure, and the whole section exposed would afford an excellent opportunity for taking an average sample. The extension of the cut to the northeast shows admixture with the siliceous wall rock, in part highly stained with red material supposedly iron, and 25 feet from the main deposit is a second vein containing at least 6 feet of the massive alunite. The interval between these veins is made up of alternating bands of alunite and wall rock.

The tunnel (marked 13 on the plat) at the lower end of the prospected ground is reported to run in for 100 feet or more and starts on a course of N. 4° E. Alunite shows in the slide rock over the mouth of the tunnel, but it is said that the main deposit has not been struck. Some smaller veins of alunite have been encountered. It is possible that the dip of the vein would carry the outcrop southwest of the tunnel mouth, so that this may explain why the tunnel apparently misses the main vein entirely, but this can not be stated with much certainty from the hasty measurements made in the present examination. Below the tunnel to the southeast, in the course of the vein, blocks of massive alunite are found from point to point, but it has not yet been shown that the rock in place continues in this direction, and the blocks could readily be accounted for as float derived from the present known outcrop.

TONNAGE.

A conservative estimate of the tonnage in this deposit may be had by assuming an average width of 10 feet in the principal vein for a total length of 3,500 feet and neglecting the rest of the deposit as not sufficiently proved to be taken into consideration at present. This gives a surface area of substantially proved outcrop of 35,000 square feet, or about four-fifths of an acre. The specific gravity of the Marysvale alunite has been determined in several specimens by W. T. Schaller, with results in close accord at about 2.82. Therefore a cubic foot of the ore may be assumed to weigh about 175 pounds. An acre of ground underlain by this rock to a depth of only 1 foot would contain 3,800 short tons of alunite. If the area of available alunite is only 35,000 square feet, as stated above, there would be approximately 300,000 short tons of the rock for each 100 feet of depth so long as the deposit maintains its surface dimensions and quality. If the recoverable potassa or potash (as K_2O) is estimated at 10 per cent of this total, such a deposit would yield 30,000 tons of potassa for each 100 feet in depth. This is approximately one-sixth to one-seventh of the total annual consumption of potash in the United States.

GEOLOGY AND MINERALIZATION IN THE TUSHAR RANGE.

By B. S. Butler.

LOCATION AND GENERAL FEATURES.

The Tushar Mountains form part of a long north-south range between the Sevier River valley to the east and a broad desert valley to the west. This range attains its highest elevation in Baldy and Belknap peaks, northwest of Marysvale. These peaks are nearly 13,000 feet above the sea and their white tops, rising well above the timber line, are prominent landmarks in southwestern Utah. From these points the surface slopes in all directions, long spurs separated by deep valleys leading down to the lower areas.

These mountains rising above the general level receive a relatively high precipitation. In some seasons the deep snows that collect during the winter persist through the entire summer and furnish a continuous water supply to the streams, which are of great value to this region. Vegetation flourishes, many of the higher valleys being clothed with forests. In the matter of water supply and timber the district is unusually favored as compared with the surrounding country.

The drainage of the range is to Sevier River. The streams from the eastern slope flow directly to that river; those from the western slope are tributary to Beaver River, which flows through the Mineral Range and in flood times joins the Sevier north of Milford, near its entrance into Sevier Lake. In the dry season both Sevier and Beaver rivers disappear in the desert sands before their waters reach Sevier Lake.

The Tushar Range lies between two great physiographic provinces. On the east is the plateau province, made up for the most part of nearly flat-lying beds; on the west is the Great Basin province, consisting of north-south ranges separated by broad, flat valleys. These basin ranges have been produced by the breaking of the region into great blocks along north-south faults, and the tilting of these blocks has brought parts of them above the general level. The depressed areas have been filled with débris from the mountains, forming the flat intermountain valleys.

The Tushar Range forms a transition between these two provincial types. It is a great block outlined by north-south faults, but the tilting of the block has been less pronounced than in the range to the west. The outpouring of lavas has built up a great volcanic pile on the sedimentary platform, from the summit of which one can overlook the surrounding country for many miles. To the east the range is bounded by the remarkable troughlike valley of Sevier River, which has been produced by the settling of a great block between two parallel faults.

In recent times the streams have cut deep canyons in the mountains, exposed rocks long buried, and revealed something of the history of the range.

Geologically the Tushar Range is a complex mountain mass composed of sedimentary, extrusive, and intrusive rocks. The sedimentary rocks, so far as shown by exposures, are of slight extent, being confined to a small area west and southwest of Marysvale. The extrusive rocks, lavas, and tuffs are by far the most abundant type and make up the bulk of the range. Two large masses of intrusive rock have been noted, one forming the central part of the Antelope Range, northeast of Marysvale, and the other on the west side of the range near the head of Indian Creek northeast of Beaver.

SEDIMENTARY ROCKS.

Sedimentary rocks are shown for only a few square miles along the front of the range west and southwest of Marysvale, the best exposures being in Bullion, Little Cottonwood, and Tenmile canyons. The series as seen in Little Cottonwod Canyon consists at the base of interbedded quartzites and limestones with an estimated thickness of 500 to 600 feet. Overlying these rocks is 300 to 400 feet of massive quartzite, and this in turn is followed by a series of limestone and shaly beds with a thickness probably exceeding 1,000 feet. This series is overlain by quartzite, which forms the uppermost member and a few hundred feet of which is still preserved. In Tenmile Canyon is exposed a considerable thickness of sandstones and shales that show less metamorphism than those exposed in the canyons to the north and that may be younger, though the relation was not determined.

The age of the sediments has been determined by earlier workers[1] as Jurassic, on the basis of the presence of the fossil *Pentacrinus asteriscus*.

EFFUSIVE ROCKS.

Resting on the eroded surface of the sedimentary rocks is an extensive series of effusive rocks. These were evidently thrown out at intervals covering a long period of time. During the time between eruptions the lavas were eroded and deposits of volcanic sediments accumulated. This process has resulted in the building up of a rather complex series of flows and breccias, with interbedded volcanic sediments derived from the earlier lavas. The lower flows exposed in Bullion, Cottonwood, and Tenmile canyons are in large part massive, with a pronounced porphyritic texture, though there are numerous outcrops of a rather coarse breccia that suggests intrusive breccia of essentially the same composition as the flows. In mineral composition the successive beds show a slight difference, but all are of intermediate type. Quartz phenocrysts are present in most of the rock, though in some places they are relatively scarce. Plagioclase of medium basicity predominates over orthoclase in the phenocrysts. In the groundmass the relative abundance of the feldspars can not be determined. Both hornblende and biotite were abundant, but have usually been partly or entirely altered to secondary minerals. From the microscopic study the rocks are classed as dacite, though a chemical investigation would doubtless show that some of the flows have the composition of quartz latite, and some possibly might be classed as andesite.

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[1] Dutton, C. E., Geology of the high plateaus of Utah: U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880, p. 184.

Overlying the dacite flows and forming the highest part of the range and extending down to the base, especially at the north, is a series of light-colored rhyolite flows and tuffs locally known as "shale." Whether these rhyolitic rocks ever covered the entire range can not be stated positively. Their greater abundance toward the north, however, suggests that they were erupted from vents in the northern part of the range and that if they ever extended over the southern and southeastern portions it was as a relatively thin covering. The latest eruptive rocks in the range are basaltic flows, with their principal development southeast of Beaver, where they cover an extensive area.

INTRUSIVE ROCKS.

Intrusive rocks as observed in the range are of relatively slight areal extent. Two considerable bodies of intrusives were noted and numerous dikes are present in various parts of the district. It is possible and even probable that sills of porphyry are also present, but if so they resemble the flow rocks so closely that a detailed study will be necessary to prove their presence. The larger intrusive bodies are located in the Antelope Range north of Marysvale and on the western flanks of Baldy and Belknap peaks, several miles north of the town of Beaver. Both of these masses are composed of granitic rock, which is distinctly porphyritic near the contact with the flows and in places so closely resembles the porphyritic lava that distinction between the flows and the intrusives is difficult.

Mineralogically the main body of both intrusive masses is composed of rather abundant quartz with orthoclase and plagioclase in about equal amounts. The rock contains also considerable augite, biotite, and magnetite and in composition corresponds to quartz monzonite. Locally the rocks become more acidic and pass into true granite. Some phases of the rocks were noted that showed no free quartz, and they may be classed as monzonite.

Dikes cut both the volcanic and the sedimentary rocks of the range. They are usually rather fine grained, with porphyritic texture, and vary in composition from quartz monzonite porphyry to basic types containing abundant augite and biotite, with the general composition of camptonite. As already stated, the dikes have a porphyritic structure and closely resemble the porphyritic lavas, so that they are not readily distinguished, and without detailed work it is impossible to state how abundant they are. Prominent dikes of the more acidic type are present near the Sevier Consolidated and Annie Laurie mines, and more basic dikes were noted in upper Tenmile Canyon and in the Deertrail mine.

RELATION OF THE INTRUSIVES TO THE FLOW ROCKS.

The relation of the large intrusive masses to the flow rocks is not everywhere obvious, but dike rocks extending from the main mass into the overlying volcanic rocks were noted, and these, together with the change in texture of the intrusive from granitic to distinctly porphyritic near the contact with the flow rocks, show without doubt that the intrusive rocks are later than the flows. Their present relation is due to the intrusion of the granitic rocks into the flows rather than to the burial of an old erosion surface beneath the lavas.

There has been considerable alteration of the flow rocks near the intrusive contact and the outline of the granitic areas in the Antelope Range can be readily traced from a distance by the highly colored rocks produced by the alteration at the contact. A similar alteration is present in the Indian Creek area, as is shown at the Red Buttes, north of the Rob Roy mine.

AGE OF THE IGNEOUS ROCKS.

Within the Tushar Range only Jurassic sediments and those of recent formation are exposed, so that it is impossible to determine closely the age of the igneous rocks. The effusive rocks flowed out on the eroded surface of the Jurassic sediments and are therefore post-Jurassic. From evidence in adjoining areas, however, Dutton has concluded that volcanism began in early Tertiary time and continued through a long period. The latest volcanic activity, the outpouring of basaltic lavas, was of very recent date and may have occurred only a few thousand years ago. It seems probable that the volcanic activity which built up the main range was active at intervals through middle and possibly into late Tertiary time. The granitic rocks are later than the main body of the flows and their intrusion may have taken place as recently as late Tertiary.

FAULTING AND FISSURING.

Faulting has had a prominent part in the production of the present Tushar Range. According to Dutton a fault extends for miles along the eastern front of this range and its extensions. Parallel to this fault, a few miles to the east, is the Sevier fault, and the Sevier Valley is considered to have been formed by the subsidence of the block between these great faults.

The western face of the Tushar Range is in line with the extension of the Hurricane fault, which is prominent farther to the south, and this fault is considered by Lee[1] to form the western boundary of the range. Within the Tushar Range there has been considerable fault-

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[1] Lee, W. T., Water resources of Beaver Valley, Utah: Water-Supply Paper U. S. Geol. Survey No. 217, 1908, p. 13.

ing in a general north-south direction parallel to the great faults that outline the range. These minor faults are, as a rule, not readily recognized, on account of the similarity of the successive flows and the small amount of sedimentary rocks, but in places they are easily determined. Such a fault is well exposed near the Crystal mine, south of Cottonwood Canyon, where the volcanic rocks are thrown down against the quartzites, the fault being marked by a zone of fault breccia. The northward extension of this fault marks the boundary between the quartzite to the east and the volcanic rocks to the west. A similar relation is seen in the workings of the Bully Boy mine, in Bullion Canyon, where in places quartzite forms one wall of the ore vein and volcanic rocks the other, and strong slickensiding testifies to the movement that has taken place. Similar displacements doubtless occur within the volcanic rocks, but, as already stated, the similarity of the rocks renders their recognition difficult without detailed geologic work.

There has been some faulting in a general east-west direction, but this seems to have been less important, both in determining the structure of the range and in connection with the ore deposits, than the north-south movements.

In addition to the faulting there may have been some fissuring of the rocks which was unaccompanied by important movement but which permitted the circulation of mineral-bearing solutions.

The main faulting in the district occurred later than the extrusion of the bulk of the flow rocks. The exact geologic time when it occurred is not readily fixed and, in fact, the movement doubtless continued at intervals over a considerable period. Dutton,[1] from a study of the faults over a wide area, concluded that the main fault movement began in late Tertiary time and continued to a very recent period, perhaps even to the present. That movement along some of these faults is still in progress has been indicated by severe earthquakes occurring in recent years.

It is likely that faulting has been going on throughout the long period of volcanic activity, and, indeed, this has been shown to be the case in neighboring regions; but it is equally likely that a very important period of faulting began in late Tertiary time and probably extended practically to the present, and that the outlines of the Tushar Range as seen to-day are largely resultant from this movement. As already noted, this disturbance took place after the extrusion of practically all the lavas, with the exception of the recent basaltic flows, and it seems not improbable that it was closely associated with the intrusion of the granitic masses which marked one of the very late events in the volcanic history of the range.

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[1] Dutton, C. E., Geology of the high plateaus of Utah: U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

MINERAL VEINS.

The mineral veins of the district are for the most part fissure veins, with a general north-south trend corresponding to the faulting and fissuring already described. Within the sediments "blanket veins" roughly coinciding with the strata are present, as shown in the Deertrail mine, and veins with a general east-west trend also occur. The ore and gangue minerals filled open spaces along faults and fissures. These veins probably occur in all the rocks except the basalt. They are certainly present in the Jurassic sediments, in the earlier porphyritic lavas, in the granitic intrusives, and probably in the rhyolitic lavas and tuffs, though they are of little importance in the last-mentioned rocks, probably because the physical character of these rocks is not favorable to the formation of open fissures.

The individual veins differ considerably in character, but are of a type that is of widespread occurrence in the Tertiary lavas of the Great Basin and adjacent regions. These veins may be broadly characterized as quartz-carbonate veins, and many of them contain notable amounts of adularia, a nearly pure potash feldspar of characteristic crystallization, together with minor amounts of other minerals, including fluorite and metallic sulphides, sulpharsenides, sulphantimonides, selenides, etc. Exceptionally alunite forms an important constituent of these veins. Veins of this type have commonly formed as a filling of open fissures and show a more or less distinct banded structure. Many of the veins in the Marysvale district are rather typical quartz-carbonate veins, the two minerals varying considerably in relative proportion in different veins and in different parts of individual veins and the carbonate ranging from relatively pure calcium carbonate to one rich in iron and manganese. Adularia has been noted in several of them, notably in the Sevier and the Wedge, and in material from the Bradburn tunnel, in the Antelope Range. Fluorite is frequently found, and in the Bradburn tunnel magnetite, garnet, epidote, and tourmaline are associated with the veins. In the Krotki iron mines, in the Antelope Range, iron minerals are abundant, but are apparently secondary, the present developments not having disclosed the original mineralization. In the Deertrail mine is a considerable body of ore of which sericite (muscovite) forms by far the larger part, an analysis of the ore showing 8.40 per cent K_2O. In other parts of the mine quartz is abundant and considerable jarosite was noted.

A most unusual exception to the ordinary vein filling is that of the vein described in this paper, in which the main vein mineral is alunite.

A study of the vein minerals indicates that they were not all formed contemporaneously, and the relative times of deposition of the minerals agree in general with those observed in other districts[1]—that is, the earlier vein minerals consisted of abundant carbonate and the later solutions were rich in silica, potassium, and aluminum, so that the earlier minerals were replaced in varying proportion by quartz and adularia, which formed pseudomorphs after the carbonate and gave rise to the laminar or hackly structure that is characteristic of the ores of this type of vein. In addition to replacing carbonate, fine-grained quartz and adularia form small veinlets transecting the earlier minerals. Many of these veinlets can be detected by their slightly yellowish color. As an example of a vein containing abundant carbonate may be mentioned the strong vein which outcrops a short distance southwest of the Crystal mine, on the south side of Cottonwood Canyon, and which is composed largely of carbonate with quartz and some fluorite. The Sevier and Annie Laurie and many other veins in the region show abundant pseudomorphs of silicates after carbonates, but other veins show little or no evidence of the replacement of carbonates, being composed essentially of fine-grained quartz or of quartz and adularia.

The alteration of the rock adjacent to the veins of the district shows considerable variation in character. More or less silicification, however, is characteristic and in some of the veins this becomes pronounced. The zone of silicification in some places is many feet wide and the outcrops of the vein stand up prominently. These are locally known as "geysers." Among them are the Sheep Rock veins, north of Beaver, the Krotki iron vein, in the Antelope Range, the veins in lower Tenmile Canyon, and the alunite vein in Clyde Basin. To a less extent the other veins of the district show a similar alteration of the wall rock. The characteristic chemical change of the wall rock adjacent to the veins has been a progressive leaching of the more soluble oxides, sodium, calcium, and magnesium, the iron, potassium, and aluminum usually remaining, at least in part, the iron in the form of pyrite and the potassium and aluminum as sericite (muscovite) or alunite. Where there has been extreme alteration practically all the oxides have been removed except silica and some iron, the resulting rock consisting of finely crystalline quartz. Where alteration has been comparatively slight chlorite, carbonate, and kaolinite are important constituents of the altered rock. Sericite, though present in the wall rock of many of the veins, in some places in considerable amount, can not be said to be a characteristic mineral in the alteration.

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[1] Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 115. Schrader, F. C., Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Ariz: Bull. U. S. Geol. Survey No. 397, 1909. Observations by B. S. Butler in the Gold-Springs and adjacent districts, Utah.

The alteration in connection with the alunite vein has been pronounced and extends for many feet on either side of the fissure. Near the vein practically all the sodium, lime, and magnesium of the original rock has been removed. Pyrite is usually abundant and probably most of the iron of the original rock has combined with sulphur to form it. Kaolinite is present in varying amounts. The original feldspar crystals have been altered to a felted mass of quartz, alunite, and kaolinite crystals. In the absence of a quantitative chemical study of the rocks, it is impossible to state positively whether there has been a removal of potassium and aluminum, but from microscopic study the alunite seems sufficiently abundant to account for all the potash present in the fresh rock, it being assumed that the alunite in the wall rock, like that in the vein, is practically pure potash alunite and does not contain important amounts of soda. In some sections of the wall rock examined microscopically small apatite crystals are rather abundant. It is noteworthy that in the alteration of the wall rock the phenocrysts of quartz have undergone almost no change.

A preliminary examination of the wall rock of other veins of the district has not disclosed the presence of alunite, though a more careful study may do so. It may be noted, however, that metallic values are reported from prospects around the "Edna Geyser," where alunitization of the rock is pronounced. Unfortunately the workings of these prospects were not accessible at the time of visit.

In the alteration of the wall rock the alunite develops as platelike crystals in the feldspar, which is finally converted to a felted mass of alunite and quartz crystals. The alunite crystals commonly contain rather abundant minute inclusions of a kaolinite-like mineral whose character could not be positively determined. Fine secondary quartz is also abundant.

The alunite deposit is a banded vein between rather definite walls, though, as already noted, alunite is an important constituent of the wall rock. It is apparent that the main vein is not a replacement of the country rock, for where replacement has occurred in the wall rock the quartz phenocrysts are practically unaltered and the silica set free by the alteration of other minerals is not removed. The vein, on the other hand, is almost free from silica. In some portions of the vein the material is coarsely crystalline, the crystals having a tabular form and in places extending across a layer of the banding. Commonly the crystals show a tendency to diverge from a center as tufts, this character being more noticeable under the microscope than in the hand specimen. The rhombohedral faces of the crystals are not usually well developed, but in many places an open cavity between two bands shows well-developed rhombohedral faces, which, however, have commonly been somewhat etched by later solution.

What in the hand specimen appear to be crystals are seen under the microscope to be composed of numerous smaller crystals diverging from a central axis, forming a very striking plumose structure. The difference in orientation of these component parts of the "crystal" group gives it a wavy extinction between crossed nicols.

The lines marking the separation of the bands forming the vein are seen under the microscope to consist of narrow bands of finely crystalline material of various orientations. The larger "crystals," however, cross these lines without change in orientation and give the general impression that the fine material has been deposited in a fissure breaking across the crystals. It is probable that there was a slight change in conditions of deposition, after which some of the crystals continued their growth while in part crystallization began from new centers.

As seen under a low power of the microscope the material seems to be almost pure, but when studied under the higher power numerous yellow globular masses are seen, most abundantly between the crystals or along minute fractures. These masses are probably limonite. Some small spaces are filled by a cloudy mineral resembling kaolin. Included in the alunite are numerous irregular microscopic masses of a mineral that appears to be isotropic and has an index distinctly below alunite. This mineral has not been determined.

In other parts of the vein the alunite becomes finer grained and locally lighter in color. In some places it has a very dense appearance and breaks with a conchoidal fracture; in others, where there has been some movement, the alunite has a schistose character and shows numerous slickensided faces. Under the microscope the fine-grained material is seen to be a granular mass composed of irregular crystals of alunite. Associated with these in the section examined is a mineral with lower index and having the general characters of kaolinite, though it has not been positively determined. The chemical analysis of this material indicates that both kaolinite and some quartz are present as impurities in the alunite. Through this fine-grained material are scattered small veinlets of more coarsely crystalline alunite. Some such veinlets were noted half an inch or more in thickness.

ORIGIN OF THE ALUNITE DEPOSIT.

The origin of the alunite deposit is of much interest and of considerable importance as an aid in the search for other deposits. At the present time it is not possible to make a positive statement concerning this problem, but certain facts point strongly to the source of the material and manner of formation here discussed.

The close relation of this vein to the other veins of the district, as shown by the high potassium and aluminum content of the vein minerals and further by the reported occurrence of metallic values in some of the alunitized rock and the general relation of the veins, strongly suggests that they are of a common origin and are results of the same general period of mineralization, though the difference in character indicates that the veins were formed under somewhat different conditions and possibly at different parts of the same period. It will also be remembered that the veins other than the alunite veins show considerable difference in mineralogic character, were probably formed under somewhat different physical conditions, and probably also represent progressive changes in the composition of the solutions forming them.

In discussing this difference we may recall that the veins are present in the intrusive and flow rocks as well as in the sediments, and therefore were later than the main volcanic activity of the district (the recent basaltic eruptions excepted).

Within the intrusive rocks, as indicated by the mineralization of the Bradburn tunnel in the intrusive rock of the Antelope Range, occur garnet and magnetite, which point to a relatively high temperature at the time these minerals were formed. In the veins in the flow rocks and sediments the minerals are such as are generally thought to form under conditions of relatively low temperature and pressure.

Moreover, the veins show evidence of a change in the character of solutions during the time of formation, namely, the earlier solutions deposited abundant carbonate, which was later partly replaced by quartz and adularia, and the latest solutions were apparently rich in sulphates.

These facts point to the following order of events: (1) Successive beds of lava were poured out, with intervening periods of quiescence during which the lavas lost most of their heat. (2) A later event in the volcanic history was the intrusion of the monzonitic masses with dikes extending into the lavas and more or less fissuring of the intruded rock. (3) The outer portions of these intrusive masses were crystallized as porphyritic rock, and in the readjustment due to cooling and possibly to other forces both the recently intruded rock and the overlying flows were further fissured. (4) Along these fissures heated solutions rose. Within the intrusive mass they were highly heated, probably under considerable pressure, and deposited minerals characteristic of this condition. As they passed into the cooler overlying rocks both the temperature and the pressure were reduced, and this condition was recorded in the character of the deposits. The solutions seemingly underwent a progressive change in composition, first depositing abundant carbonate, later quartz and adularia, and finally sulphates.

The origin of these solutions can not be positively determined, but the most likely source seems to be the water given off by the crystallization of the magma that formed the intrusive body which underlies the lavas.

In this district, as in others where similar deposits have been studied, it is apparent that potassium and aluminum minerals were more abundantly deposited in the later stages of mineralization—either the solutions became richer in potassium and aluminum or the conditions for deposition of these elements became more favorable. The relative physical conditions under which the quartz-adularia veins and the alunite were deposited are not perfectly clear, but it seems highly probable that the alunite veins were deposited at lower temperature and pressure than the quartz-adularia veins and probably represent a later stage when the composition of the solutions had undergone a change. This is suggested by the fact that the potassium minerals were among the later to be deposited, presumably under conditions of less heat and pressure, and these potash-rich deposits may well represent the latest stage in the deposition of potassium. Moreover, in other districts where the occurrence of alunite has been studied the conditions indicate shallow depth and moderate heat and pressure; furthermore, the relative rarity of alunite deposits as compared with other veins of the type shown in this district may be due to the fact that they form near the surface and consequently have only in a few places been preserved. It is evident that when the alunite was formed the solutions were rich in sulphate, and if this deposit is later than the carbonate and quartz-adularia veins, as seems probable, it is to be expected that instances will be found where the sulphate deposits are superimposed on the earlier deposits, as the quartz-adularia veins are on the earlier carbonate veins.

The source of the potassium and aluminum entering into the deposits has not been positively determined, but certain facts bearing on this point may be stated. In general, the potash contained in alunite has been thought to have been derived from the alteration of the feldspar of the rock in which the deposits occur, and for many deposits this is doubtless true. In part, such an origin can be confidently stated for the alunite of the Marysvale deposit, but that it holds true for the main vein is not evident.

As already stated, the characteristic alteration of the wall rock of veins of this type consists in a progressive leaching of the elements, potassium being one of the latest to be removed, but in some places potassium also has been leached out. In the wall rock of the alunite vein near Marysvale, however, alunite appears to be sufficiently abundant to account for all the potassium of the original rock, and it is certain that the potassium has not been removed in important amount, and therefore the rock immediately adjacent to the vein can not be considered as furnishing the potassium for the vein by lateral secretion. In some of the other veins, however, notably that of the Krotki iron deposit, in the intrusive rocks of the Antelope Range, practically all constituents except silica and iron have been removed and have not been deposited near by. This permits the interpretation that a part at least of the potassium and aluminum content of the vein may have been derived from the wall rock at greater depth where conditions were favorable for solution, the enriched solutions, rising into cooler zones, having redeposited these elements. If this is true one might expect that if the vein could be traced to the original surface the alunite deposit would gradually merge into one carrying other salts that were precipitated at still lower temperatures—if, indeed, alunite did not extend to the surface while more soluble salts were carried out on the surface in solution—and that on the other hand with increasing depth a zone would be reached that was not favorable to the deposition of alunite.

That the potassium and aluminum in the veins of this district were introduced by the solutions and were not derived directly from the wall rock is further indicated by the high potassium and aluminum content (as muscovite) of the Deertrail ores; these occur in quartzite and limestone, which do not contain notable amounts of potassium or aluminum, and consequently both of these elements must have been introduced. There seems no reasonable doubt that the mineral content of the veins, for the most part at least, was introduced by solutions of deep-seated origin.

In this respect the evidence in the Marysvale region agrees with that in other districts of the West where Tertiary veins of a similar character occur. Lindgren[1] has already called attention to the similarity of the deposits in the northern part of the district to those of the De Lamar deposits of Idaho, and further similarities are shown by the sericitic ores of the Deertrail mine, which seem to resemble closely some of the "talcose" ores of the Idaho deposits that carry as high as 12.91 per cent[2] of potassa (K_2O). Lindgren concludes[3] that the main content of the Idaho veins was brought up from depth by thermal waters; moreover, he notes that the removal of alumina

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[1] Lindgren, Waldemar, The Annie Laurie mine, Piute County, Utah: Bull. U. S. Geol. Survey No. 285, 1906, p. 90.

[2] Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 171.

[3] Idem, p. 166.

from the wall rock indicates the presence of sulphuric acid in the waters, though sulphates do not seem to have been deposited, or if they were they have not been preserved. Spurr[1] has concluded that the veins in the Tonopah district, Nevada, which contain notable amounts of potassa in the form of adularia and in many respects resemble the adularia veins in the Marysvale district, derived their mineral content from heated waters given off by crystallizing magmas.

Schrader[2] has described similar deposits in the Black Mountains, Mohave County, Ariz., containing notable amounts of potassa in the form of adularia, and attributes their origin to hot waters ascending through the lavas at the close of igneous activity.

Schrader[3] has also described very similar deposits in the Jarbidge district, Elko County, Nev., which contain as high as 11.84 per cent of potassa (K_2O) in the form of adularia. He concludes that the veins were formed by ascending thermal solutions rich in silica, aluminum, and potassium.

Similar veins in New Mexico have been attributed by Lindgren, Graton, and Gordon[4] to the action of ascending thermal waters, and a similar origin has been stated by Umpleby[5] for veins carrying some adularia in the Republic district, Washington. The present writer, who has seen the mineral deposits in the Gold Springs and State Line districts, Utah, and the adjacent Fay district, Nevada, believes that the veins which carry notable amounts of adularia are to be attributed to an origin similar to that indicated in the examples cited above.

There appears to be a uniformity of opinion, therefore, that the veins carrying adularia were deposited by ascending thermal waters rich in silica, alumina, and potassa. Nowhere, however, outside of the Marysvale district have important alunite deposits associated with the adularia veins been recognized.

Of the alunite deposits of which detailed descriptions are available the one that shows the closest relation to the type under discussion is that at Goldfield, Nev., where alunite occurs as an important primary gangue mineral of gold deposits. As shown in the following

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[1] Spurr, J. E., Geology of the Tonopah mining district, Nevada: Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 262.

[2] Schrader, F. C., Mineral deposits in the Cerbat Range, Black Mountains, and Grand Wash Cliffs. Mohave County, Ariz.: Bull. U. S. Geol. Survey No. 397, 1909, p. 48.

[3] Schrader, F. C., A reconnoissance of the Jarbidge, Contact, and Elk Mountain mining districts, Elko County, Nev.: Bull. U. S. Geol. Survey No. 497, 1912.

[4] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910, p. 71.

[5] Umpleby, J. B., Geology and ore deposits of the Republic mining district: Bull. Washington Geol. Survey No. 1, 1910, p. 42.

quotation Ransome[1] has thoroughly discussed the different methods by which the deposit at Goldfield might be formed:

> Since the preceding chapters contain an ample presentation of the problem now awaiting solution, only a brief recapitulation is needed of some of the most significant facts with which an adequate explanation of ore genesis must harmonize.
>
> Beyond all question the intimate association of unusually rich gold ores with the mineral alunite is the most remarkable feature of the deposits and is the one that promises to shed most light on their origin. Alunite is not a common mineral, and although it was recognized in small quantity in the oxidized zone at Cripple Creek, it is at Goldfield alone, so far as is at present known, that it is found with sulphides and tellurides as a characteristic mineral of unoxidized gold ores. The presence of this mineral and the kind of alteration undergone by the rocks containing it prove * * * that the ores were deposited from solutions containing sulphuric acid. Whether this acidity was an original property of the gold-bearing solutions or whether the solutions, primarily of different character, became acidic at the place of precipitation or during their journey thither, are questions presently to be considered.
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> Other chemical and mineralogical features of the ores to be kept in mind are the occurrence of telluride and selenide of gold, sulphide of bismuth, and compounds of copper, sulphur, antimony, and arsenic (enargite, famatinite, and goldfieldite), of which the mineral species is not in every case determinable, the cryptocrystalline character of the quartz, and the extraordinary concentration of the gold. Due consideration must be given also to the volcanic history of the region, the recent age of the deposits, the slight depth at which they were formed, and, as a corrollary of these facts, the brief time and the short vertical distance available for any secondary concentration that may be postulated in connection with erosion.
>
> Attention will first be directed to the question of the source of the sulphuric acid, since if it can be satisfactorily answered the other phase of the main problem should crystallize clearly about this nucleus.

THE DIRECT VOLCANIC HYPOTHESIS.

That some fumaroles emit sulphur dioxide has long been known. As early as 1858 Sainte-Claire Deville and Leblanc[2] found it in gases from Vesuvius and other Mediterranean volcanoes. From one fumarole in the crater of Vesuvius they collected a gas which proved to contain hydrochloric acid and sulphur in the ratio of 86.2 parts of the former to 13.8 parts of the latter, together with water vapor and the constituents of ordinary air. They concluded from their investigations that carbon dioxide and sulphur dioxide never came simultaneously from the same fumarole. This, however, does not accord with the results of some other workers, as is shown by the following table, prepared by F. C. Lincoln,[3] which is of theoretic interest from the fact that calcite and alunite occur together at one place in the Goldfield district:

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[1] Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: Prof. Paper U. S. Geol. Survey No. 66, 1909, pp. 189–195.

[2] Mémoire sur la composition des gaz rejetés par les évents volcaniques de l'Italie méridionale: Annales chim. phys., 3d ser., vol. 52, 1858, p. 45.

[3] Econ. Geology, vol. 2, 1907, p. 802.

Fumarole gases containing both CO_2 and SO_2.

No.	Volcano (or locality).	Spot.	Temperature.	CO_2.	SO_2.	HCl.	N_2.	O_2.
			°*C.*					
1	Tuquerres	3,908 meters elevation	86	93.5	Trace.	0	6.5	0
2	Hekla	Great crater	....	2.44	1.54	0	81.81	14.21
3	Vesuvius	Cone of 1863-64	218	5.38	Trace.	....	79.16	18.46
4	.....do	Halfway up eruptive crater	....	4.90	3.40	....	73.48	18.13
5	.....do	At eruptive center	....	1.42	2.61	2.14	76.22	17.61
6	.....do	.....do	....	3.00	2.25	3.00	73.71	18.04
7	.....do	.....do	....	3.97	1.32	1.98	70.88	21.85
8	Vulcano	Interior of great crater	360	23.40	Trace.	73.80	2.28	.52
9	.....do	.....do	250	22.00	Trace.	66.00	9.60	2.40
10	.....do	.....do	150	59.62	Trace.	27.19	10.99	2.20
11	Santorin	200 meters from cone of Giorgios.	115	68.5	12.0	19.4	....	....
12	.....do	On slope between Giorgios and lava stream.	110	98.5	.4	1.0	....	....

Authorities: (1) Boussingault, J. B., Annales chim. phys., 2d ser., vol. 52, 1833, p. 21. (2) Bunsen, R. W., Annales chim. phys., 3d ser., vol. 38, 1853, p. 259. (3) Franco, Compt. Rend., vol. 66, 1868, p. 159. (4) Franco, Compt. Rend., vol. 66, 1868, p. 1352. (5–7) Franco, Annales chim. phys., 4th ser., vol. 30, 1873, pp. 98–99. (8–10) Fouqué, F., Compt. Rend., vol. 61, 1865, p. 565. (11–12) Gorceix, H., Compt. Rend., vol. 75, 1872, p. 270.

Van Hise[1] states that in the gases emitted from fumaroles and solfataras sulphur dioxide is probably next in abundance to steam. This, however, does not appear to accord with the testimony of published analyses of volcanic gases. F. C. Lincoln,[2] on the basis of 50 selected analyses, concludes that, after steam and nitrogen (the latter being difficult to rank owing to the possibility of admixture of air), carbon dioxide is the most important gas, followed by hydrogen sulphide and sulphur dioxide.

Sulphuric acid or sulphuric anhydride is apparently still less common in volcanic emanations than sulphur dioxide. Geikie[3] states that "occasionally, also, the production of sulphuric acid is observed at active vents," which probably means merely that the acid is formed superficially by oxidation of sulphur dioxide. In the interesting crater lakes of Taal volcano described by R. F. Bacon[4] free sulphuric acid is present in large quantities. It is apparently formed, however, by the oxidation of fumarolic sulphur dioxide which bubbles up through the boiling water.

On the whole, it appears to be very doubtful whether sulphuric acid or sulphuric anhydride is actually emitted from the deeper part of any volcanic vent. There is a strong suggestion, moreover, that the sulphur dioxide which streams from some fumaroles is not all of deep-seated origin but may in part be due to an admixture of air with the true telluric gases, particularly with hydrogen sulphide. Here we are confronted, however, with the difficulty of distinguishing sharply between primary and secondary volcanic products. At what depth, for example, must water or oxygen be introduced in order to be classed as a primary volcanic product? By magmatic water do we mean only such as has been locked in the earth's interior since the planet took its present form, or may we mean also water that the magmas have subsequently absorbed in some such manner as that advocated by S. Arrhenius?[5]

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[1] A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, p. 491.

[2] Magmatic emanations: Econ. Geology, vol. 2, 1907, pp. 261–264.

[3] Textbook of geology, vol. 1, 1903, p. 268.

[4] Philippine Jour. Sci., vol. 2, 1907, p. 115.

[5] Zur Physik des Vulkanismus: Geol. Föreningens Stockholm, Förhandl., vol. 22, 1900, pp. 395–419.

May not the water emitted from volcanoes be both magmatic and meteoric as these terms are used by most writers? This is still a vexed question, although the available evidence favors the view that meteoric water does not reach the source of magmas.[1] Granted that the water of volcanic eruptions, however introduced or formed, comes mainly from the molten magma, there is no a priori difficulty in postulating the emission of oxygen compounds of sulphur, since Fouqué[2] has shown that in some cases the constituent gases of water are dissociated and the liberated oxygen might under some circumstances unite with sulphur. As a matter of fact, however, the oxides of sulphur are not nearly so common or abundant, and when they do occur are not so clearly of deep derivation as is hydrogen sulphide.

There is evidence also of the deep-seated formation of sulphuric acid in the presence of sulphates, such as barite and celestite,[3] as primary minerals in some veins. Recently, too, Lindgren[4] has called attention to the occurrence of anhydrite as a primary mineral with tourmaline and chalcopyrite at the Cactus mine in the Frisco district, Utah. The presence of the minerals haüynite $[(Na_2Ca)_2(NaSO_4Al)Al_2(SiO_4)_3]$ and noselite $[Na_4(NaSO_4Al)Al_2(SiO_4)_3]$ in phonolitic rocks proves that under some circumstances sulphur trioxide may be present in molten magmas and consequently may exist in magmatic solutions. There are, however, no phonolitic rocks known at Goldfield.

While these occurrences are to be regarded as favoring the view that sulphuric acid can form at volcanic centers, their testimony, as regards importance in ore deposition, is opposed by the absence of sulphates from contact metamorphic deposits and of sulphuric acid from most hot springs. Springs carrying sulphuric acid are, it is true, not unknown. The water of a hot-acid spring in the so-called geysers of Sonoma County, Cal., according to an analysis by Thomas Price, contains 145 grains of free sulphuric acid per gallon.[5] Other springs at the same locality contain smaller quantities of the same acid. All these waters, however, are saturated with hydrogen sulphide, and it is possible that the sulphuric acid may have been formed by the oxidation of the sulphydric acid within the zone penetrated by surface waters. Hot sulphuric-acid springs occur also in the Coso Range, Inyo County, Cal., accompanied by deposits of sulphur containing hydrogen sulphide.[6] Similar acid springs carrying hydrogen sulphide issue from sulphur deposits near Maverick Springs, El Paso County, Tex. The water from one of these, according to E. M. Skeats,[7] contains 136 parts per 100,000, or 79.08 grains per gallon, of free sulphuric acid. W. T. Lee has described a similar occurrence at Sulphurdale, Utah.[8] Analyses of 11 other springs' waters containing less sulphuric acid than those above mentioned are given by F. W. Clarke.[9]

The chemical activity of free sulphuric acid in spring water would, of course, lead to the rapid formation of sulphates during the upward course of the water and to consequent neutralization of the free acid. But there is a limit to such

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[1] For a recent discussion of this problem see Chamberlin, R. T., The gases in rocks: Pub. Carnegie Inst. Washington No. 106, 1908, p. 69.

[2] Santorin et ses éruptions, Paris, 1879, p. 230.

[3] Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colorado: Prof. Paper U. S. Geol. Survey No. 54, 1906, pp. 220–221.

[4] Oral communication before the Geological Society of Washington: Abstract in Science, new ser., vol. 28, 1908, p. 933.

[5] Anderson, Winslow, Mineral springs of California, San Francisco, 1892, p. 150.

[6] Idem, p. 254.

[7] Bull. Univ. Texas Min. Survey No. 2, 1902, p. 34.

[8] Water resources of Beaver Valley, Utah: Water-Supply Paper U. S. Geol. Survey No. 217, 1908, pp. 19–20.

[9] Data of geochemistry: Bull. U. S. Geol. Survey No. 330, 1908, pp. 155–157.

rapid neutralization, and in persistent and copious springs it might be expected that some free acid could in most cases be brought to the surface were it commonly generated below. Furthermore, if sulphuric acid were formed in any considerable quantity at great depth during volcanic activity we should expect to find alunite a more common constituent of rocks which have been uncovered by erosion than experience indicates. Moreover, it is questionable whether waters rich in sulphuric acid would be efficient carriers of gold, sulphides, and tellurides. It is probable that they would precipitate these constituents from the alkali sulphide solutions, of which the solvent efficiency has been repeatedly shown by experiment[1] and by geologic evidence.

In view of these considerations, and of others presently to be brought forward, the hypothesis, suggested with some favor in a preliminary paper,[2] that the ore-depositing solutions may have come from below already charged with sulphuric acid, has been abandoned.

HYPOTHESIS OF DERIVATION OF THE SULPHURIC ACID FROM THE OXIDATION OF PYRITE.

The hypothesis that the alunitization of the rocks at Goldfield was effected by cold sulphate solutions percolating generally downward from masses of oxidizing sulphides, principally pyrite, has some facts in its favor. The small quantity of impure alunite found at Cripple Creek was undoubtedly formed in this manner, and observations indicate that a part of the alunite at Goldfield, namely, some of the soft varieties which fill interstices in the partly oxidized ore, may have been, if not originated, at least dissolved and redeposited during oxidation. According to De Launay[3] the alunite at the classic locality of Tolfa is the product of such solutions acting upon a particular feldspathic trachyte. The formation of alunite by cold percolating solutions probably requires these to be more strongly acid than is necessary for the production of kaolinite.

The intimate association of the alunite with kaolinite at Goldfield has a bearing on the problem. The origin of this mineral has been the subject of much recent discussion,[4] the general trend of which is to emphasize the connection between kaolinization and weathering. Lindgren[5] has recently intimated that although he himself formerly referred to the mineral as characteristic of certain classes of veins, kaolinite should not be considered as a gangue mineral of any class of ore deposits except those formed under the influence of oxidation. In a subsequent paragraph he somewhat modified this statement by the expression of belief that "kaolin is rarely formed by alkaline hot water at any considerable depth below the surface." The preponderant weight of careful observations made during the last few years is unquestionably on the side of the thesis thus moderately stated; and the occurrence of kaolinite at Goldfield, where the intimate association of this mineral with the alunite, gold, sulphides, tellurides, and sulphantimonites, as determined by microscopical work, shows that all were formed at the same time by one general process, is an additional point against what has been called the direct volcanic hypothesis.

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[1] As regards tellurides, see Lindgren, Waldemar, and Ransome, F. L., Geology and ore deposits of the Cripple Creek district, Colorado: Prof. Paper U. S. Geol. Survey No. 54, 1906, pp. 223–224.

[2] The association of alunite with gold in the Goldfield district, Nevada: Econ. Geology, vol. 2, 1907, p. 688.

[3] La métallogénie de l'Italie: Cong. géol. intern., Mexico, 1906, vol. 1, 1907, p. 681.

[4] See especially Zeitschr. prakt. Geologie, 1907 and 1908.

[5] The relation of ore deposition to physical conditions: Econ. Geology, vol. 2, 1907, p. 120.

Much kaolin originally described by various authors as formed by the solutions which first brought up the ores associated with it has later been proved to have resulted from oxidizing processes, it being one of the most characteristic products of the action of percolating weakly acid solutions upon aluminous rocks. The kaolin at Cripple Creek is a good example. Much so-called primary or pneumatolytic kaolin, moreover, has been shown to be sericite, and some is perhaps alunite.

On the other hand, these facts seem scarcely to warrant the total elimination of kaolinite from the list of gangue minerals found in ore deposits, the connection of which with oxidation is at least not obvious, and which are certainly not affected by ordinary weathering. The mineral occurs as an original constituent of some of the ores of the San Juan Mountains, Colorado,[1] and W. H. Weed[2] has described it as a product of the metasomatic action of the waters of Boulder Hot Springs, Montana, upon granite. Kaolinization has also been noted by Béla von Inkey[3] in the dacitic country rock of the Nagyag veins, the material being afterward investigated by F. Kollbeck,[4] whose analysis indicates a mixture of kaolinite and sericite.

The principal objections to the view that the alunitization at Goldfield is connected with the oxidation of older pyritic ores are based largely on what appears to be the quantitative insufficiency of the proposed explanation. No such available primary masses of sulphides are known, and study in the district has failed to bring to light any bodies of sulphides that are distinctly older than the ores and that are not accompanied by alunite. There is no evidence yet found which indicates the superposition of a distinctly younger phase of deposition characterized by the formation of alunite upon an older phase not associated with that mineral.

The mines of Goldfield are still comparatively shallow, but they have penetrated about 500 feet below the bottom of the weathered ores, and if the alunitization were the result of ordinary weathering it is likely that secondary products would somewhere have been found distinctly imposed upon earlier nonalunitic material. It is probable that at a depth greater than that now attained alunite will become less abundant, but the change will, it is believed, be gradual, and there is nothing to indicate that it will exhibit such a definite relation to the general ground-water level as might fairly be expected under the hypothesis now under consideration.

The alunitization of the rocks * * * is very extensive, and is by no means confined to the immediate vicinity of known ore bodies. Except in the zone of superficial oxidation the alunite is crystallized with pyrite and consequently has not formed under conditions involving the destruction of this sulphide in the zone now accessible. To account for the alunitization by the oxidation of pyrite would require the assumption that the material stripped from the district by erosion was much more heavily pyritized than the rocks at present visible. The thickness of this vanished overburden, as has been shown, can scarcely have exceeded 1,000 feet (305 meters), and probably was very much less. Moreover, the period available for alunitization was geologically very brief, since the process had already taken place when the Pozo formation was laid down. We are thus confronted by the contrast of a process remarkable for the extent and intensity of its action with condi-

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[1] Ransome, F. L., Economic geology of the Silverton quadrangle, Colorado: Bull. U. S. Geol. Survey No. 182, 1901, p. 73.

[2] Mineral-vein formation at Boulder Hot Springs, Montana: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 253.

[3] Nagyág und seine Erzlagerstätten, Budapest, 1885, p. 143.

[4] Untersuchungen über die Zersetzung des Quarztrachyts neben Goldersgängen von Nagyág: Oesterr. Zeitschr. f. Berg- und Huttenwesen, vol. 36, 1888, pp. 25–27.

tions which, if not markedly unfavorable, were at least not such as would be expected to produce the observed effects under the present hypothesis. The remarkable concentration of the gold and associated minerals in these deposits appears to be out of all proportion to any leaching action possible within the the time and distance available. This discrepancy will, it is believed, become more marked when the character and genesis of the metallic minerals of the ores are considered, as they will be in connection with the next hypothesis.

HYPOTHESIS OF SIMULTANEOUS SOLFATARISM AND OXIDATION.

The third hypothesis to be tested postulates that the ore constituents were brought up in hot solutions charged with hydrogen sulphide, a little carbon dioxide, and probably also with some alkali sulphides; that the hydrogen sulphide was oxidized at and near the surface to sulphuric acid, which percolated down through the warm rocks to mingle with the uprising currents carrying sulphydric acid; and that the precipitation of the richest ores took place in the zone where the two kinds of solutions mingled and as a consequence of such mingling. As Van Hise [1] has pointed out, the chemical reactions of weathering and of solfataric action are not so different as might be supposed, and this process differs from that of the second hypothesis chiefly in greater intensity of action and in the smaller demands that it makes on time and erosion. The hypothesis differs from the first one considered mainly in that the sulphuric acid acted as the precipitant rather than as the carrier of the ore constituents which came up in sulphide solutions. This latter view has the initial advantage of being in much better accord with all that has been learned of the chemistry of natural sulphide deposition than is the first supposition. Any explanation of the origin of the Goldfield deposits which calls for natural solvents radically different from those which carried the carefully studied ores of Tonopah, the Comstock, Grass Valley, Cripple Creek, and many other districts in this country and abroad is burdened at the outset with presumptive improbability.

In accordance with the third hypothesis the hot ascending waters carried abundant hydrogen sulphide, as shown by the extensive change to pyrite of the iron originally present in the dacite and other rocks as a constituent of magnetite and silicates. This change was not confined to the rocks now alunitized but extended outward to what has been called the propylitic aureole of alteration. The experiments of Becker [2] and Doelter,[3] supported by studies of metasomatically altered wall rock in various districts, suggest that the sulphur of the original solutions was in part combined with or accompanied by sodium and potassium. The changes in the dacite investigated in Chapter XIV, notwithstanding the development of the potassium and sodium bearing mineral alunite, do not show any addition of alkalies to the original rock, but such negative evidence does not prove that no alkali sulphides were present in the primary solutions.

They may have been largely oxidized to sulphates and carried away to accumulate in the playa deposits of the region, just as is happening at the present day at Alkali Spring. If so, it is to be expected that at greater depth than is now reached at Goldfield the feldspars of the rocks are extensively sericitized with some addition of alkalies. That the ore-bearing solutions contained carbon dioxide is indicated by the alteration of calcium-bearing

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[1] A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, p. 494.

[2] Geology of the quicksilver deposits of the Pacific slope: Mon. U. S. Geol. Survey, vol. 13, 1888, chap. 15.

[3] Einige Versuche uber die Loslichkeit der Mineralien: Tschermak's Min. u. petr. Mitth., vol. 11, 1859, p. 319.

silicates to calcite in the propylitic zone. It is not to be supposed that calcite would form abundantly in rocks soaked with sulphuric acid. It does occur, however, with alunite in rhyolite on the east slope of Vindicator Mountain, and this association of minerals is probably the result of local conditions which retained under pressure and fixed in combination the carbon dioxide that otherwise would have escaped in the presence of the acid solutions necessary for the production of alunite. Such local conditions of pressure are more readily conceivable in connection with hot uprising waters than under the circumstances of ordinary weathering.

In addition to sulphydric and carbonic acids the solutions carried the following, either as compounds or in ionized condition: Gold, silver, copper, zinc, lead, bismuth, antimony, arsenic, tellurium, and selenium. They probably contained also some iron and silicia, although the study of rock alteration recorded in Chapter XIV shows subtraction, not addition, of these constituents to the wall rock. On the other hand, the actual ledge matter contains more silica and pyrite than was in the original rock. How much of this excess was contributed by the uprising solutions directly and how much was merely concentrated from the surrounding country rock is not determinable. There was probably some direct addition, however, from deep-seated sources in the immediate vicinity of the fissures.

It has been shown that the fissuring of the district was very complex and irregular, affording innumerable devious channels for the passage of solutions. Thus the hot solutions presumably reached the surface at many places, and this distribution of the outflow must have been far more favorable to oxidation of the hydrogen sulphide to sulphuric acid and to the subsequent activity of the latter than if the uprising waters had flowed from a single vent. There is reason to believe that the climate at the time the ores were deposited was comparatively arid. It is likely, therefore, that the mineral-bearing solutions upon reaching the surface were not only oxidized but were concentrated by evaporation as they flowed over the surface or percolated down through the rocks. The sulphuric waters as they penetrated downward must have exerted a strong leaching action on the superficial rocks similar to that observable at Sulphur Bank, Cal., at the present day, where basalt has been altered to spongy masses of snowy silica by the removal of its basic constituents. At moderate depth the acidic descending solutions met uprising solutions charged with hydrogen sulphide and ore constituents and mingled with them in a zone characterized by the presence of sulphydric, sulphurous, and sulphuric acids and by the simultaneous development of alunite and sulphides. The vertical range of this zone must have been considerable—probably 1,000 feet (305 meters) or more. The mixing of the solutions may have been effected partly by differences in density between the hot ascending currents charged with gases and the cooler descending waters, partly by convection, partly by diffusion, and perhaps partly by osmotic action. The sulphuric acid solutions would in general have greater power of penetrating the substance of the country rock than would the silicia and the in part colloidal bases of the uprising solutions.[1] It is to be remembered also that the rocks at the time of ore deposition were as a whole hard and brittle, had been recently fractured, and were much more generally permeable than at present, when much of the country rock, softened by alteration, is incompetent to maintain open fissures. Evidently, with the process once initiated, the waters reaching the surface would no longer represent the original ore-bearing solutions, but would be

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[1] See Sullivan, E. C., Experiments on the separation of the constituents of a solution by filtration through a mineral fiber: Econ. Geology, vol. 3, 1908, pp. 750–756.

mixtures of these with sulphate waters and would contain various constituents abstracted from the rocks during alunitization. * * *

At no time in their history were the depositing solutions, if we may judge from their work, strong solvents for silica, and the quantity of this constituent transported by them was small. The ledges, it is true, are siliceous, but most of the quartz was derived from the rock now altered to ledge matter and from the alunitized rock in the vicinity. Some silica doubtless came up with the solutions, but had these been very siliceous it is to be expected that they would have filled all interstices with solid crystalline vein quartz of the usual kind. On the contrary, the quartz at Goldfield is flinty or cryptocrystalline and occurs either as a metasomatic mineral replacing the country rock or as porous vuggy fillings formed by the accumulation of successive thin crusts, the process having rarely gone far enough to produce a solid mass of quartz. In this respect the deposits at Goldfield resemble those at Cripple Creek. It is possible that the crystallinity of vein quartz does not depend wholly or chiefly on the supply of silica available but is largely a function of pressure and temperature. At one end of the series may be the coarsely crystalline quartz of the pegmatite dikes or veins; at the other end the cryptocrystalline quartz of deposits formed close to the surface. If so, the character of the quartz at Goldfield is to be added to the other evidence in favor of superficial origin of the deposits.

It is believed that the process outlined as the third hypothesis best explains the abundant formation of alunite with subordinate diaspore and the intimate association of these minerals with the sulphide ores and especially with the pyrite in the altered rock which surrounds the ores. This explanation of the genesis of the alunite is in accord with the experiments of Sainte-Claire Deville,[1] who produced the mineral artificially by subjecting, for several months, fragments of volcanic rock, suspended in water, to a stream of hydrogen sulphide mixed with air. By providing an efficient precipitant (sulphuric acid), supplied continuously to a definite zone traversed by the uprising metalliferous solutions, the hypothesis appears to account well for the remarkable concentration of the gold and associated constituents in this zone. As already mentioned, it is difficult to harmonize the extent and intensity of the alunitization with the hypothesis of oxidation of lean deposits during erosion. It is still more difficult to explain by such secondary enrichment the unusual concentration of the gold with so much tellurium and bismuth as are present in the Goldfield ores.

Many of the important minerals of epigenetic deposits, as is well shown in the useful tables compiled by W. Lindgren[2] and W. H. Emmons,[3] can be formed under different conditions and by solutions of diverse origin. The individual minerals that can be accepted with confidence as characteristic of a single bathymetric zone and of a single mode of genesis are certainly very few. Taken altogether, the minerals of the Goldfield ores suggest deposition at moderate or slight depth. They are not, however, as a group characteristic of what is ordinarily understood as secondary enrichment. The tellurides particularly, in view of the recent investigation at Cripple Creek,[4] are more indicative of deposition from uprising hot solutions than of enrichment by cold descending waters.

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[1] De l'altération, par voie naturelle et artificielle, des roches silicatées, au moyen de l'acide sulfhydrique et de la vapeur d'eau: Compt. Rend., vol. 35, 1852, pp. 261–264.

[2] The relations of ore deposition to physical conditions: Econ. Geology, vol. 2, 1907, p. 125.

[3] A genetic classification of minerals: Econ. Geology, vol. 3, 1908, pp. 618–622.

[4] Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colorado: Prof. Paper U. S. Geol. Survey No. 54, 1906, p. 204, and Chapter XI.

In applying these theories of formation to the Marysvale occurrence the theory of formation as the result of oxidation of pyrite may be eliminated, it would seem, owing to the fact that oxidation has extended but a short distance below the surface, even the shallow pits disclosing rock containing unoxidized pyrite, and this rock practically free from oxidation contains abundant alunite. Moreover, it is doubtful if the pyrite present in the rock is sufficient to account for the sulphur present in the alunite. Furthermore, if the alunite has been produced by the action of surface solutions it is logical to expect similar deposits in all the veins in the volcanic rocks that contain pyrite; but while pyrite is a characteristic mineral in the alteration of the wall rock of the veins in volcanic rocks, alunite has not been recognized in them, and although it may be present it certainly is not abundant.

The hypothesis that solutions containing hydrogen sulphide rose to the surface and were oxidized to sulphuric acid that descended and reacted with the potassium-aluminum silicates of the rocks, which Ransome finds to best explain the deposits at Goldfield, does not appear to be in accordance with the observed facts of occurrence of the Marysvale deposit. In such a mode of origin it would be expected that the solutions in their downward migration would be likely to disseminate and there would be little tendency to form large and distinct veins of the mineral. Moreover, the potassium and aluminum of the deposit would be derived from the altered rock, but, as already noted, the contents of the Marysvale vein are believed to have been introduced.

The reasons for rejecting the volcanic theory as accounting for the Goldfield deposit do not seem entirely applicable to the occurrence at Marysvale. In the first place, both the alumina and the potassa content of the Goldfield alunite appear to have been derived from the alteration of feldspar of the country rock and to have migrated but little. At Marysvale this is doubtless true of the alunite occurring in the wall rock adjacent to the vein, but apparently not true of the vein material, for, as stated elsewhere, there appears to have been little leaching of alumina and potassa from the wall rock, and an outside source must be sought. Moreover, the alunite veins at Marysvale are not known to carry sulphides or allied minerals, though pyrite is present in the wall rock, and sulphides, sulpharsenides, and selenides occur in the other veins of the district that are thought to be allied to the alunite veins and are possibly closely associated with the alunite in the "Edna Geyser" prospects.

That sulphates were present in some of the solutions forming the veins of the district is indicated by the fact that barite is rather abundant in the Lucky Boy deposit and is present to some extent in other mines. Moreover, the Horn Silver deposit at Frisco, Beaver County, which has been studied by the writer and shows some resemblances to the Marysvale deposits, contains barite in relative abundance as a primary gangue mineral. It may be noted also that at Sulphurdale, 20 miles north of Beaver, Lee[1] has observed a mineral spring whose waters contain abundant sulphate and free sulphuric acid, but he considers the acid to be the result of the oxidation of hydrogen sulphide (H_2S).

Hayes[2] has described deposits of alum in Grant County, N. Mex. He considers the sulphuric acid that formed the deposits to be of volcanic origin.

Spurr[3] has described deposits of potassium alum (kaolinite) near Silver Peak, Esmeralda County, Nev., which he considers as being formed "by a combination of the steam and the sulphuric acid emitted from the solfataras with the potash and aluminum contained in the rhyolite."

The sulphur deposits with which alunite is associated near Humboldt House, Nev., described by Adams,[4] are thought to have a similar origin.

It may further be noted that deposits of somewhat different character in Shasta County, Cal., contain abundant barite and anhydrite (the anhydrite largely altered to gypsum). Graton[5] considers that these minerals have been deposited directly from ascending thermal solutions of volcanic origin.

Lindgren[6] has described the occurrence of abundant sulphate minerals in the primary ores of the Cactus mine, Beaver County, Utah. He suggests that "during the later part of the mineralization the anhydrite was precipitated by a reaction between ascending solutions of sodium sulphate and descending solutions containing calcium carbonate."

From the occurrences cited above, together with those discussed by Ransome, it would seem that there are no inherent reasons for considering that the sulphate content of the alunite deposit may not

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[1] Lee, W. T., Water resources of Beaver Valley, Utah: Water-Supply Paper U. S. Geol. Survey No. 217, 1908, p. 19.

[2] Hayes, C. W., The Gila River alum deposits, New Mexico: Bull. U. S. Geol. Survey No. 315, 1907, p. 215.

[3] Spurr, J. E., Alum deposits near Silver Peak, Esmeralda County, Nev.: Bull. U. S. Geol. Survey No. 225, 1904, p. 501.

[4] Adams, G. I., The Rabbit Hole sulphur mines near Humboldt House, Nev.: Bull. U. S. Geol. Survey No. 225, 1904, p. 500.

[5] Graton, L. C., The occurrence of copper in Shasta County, Cal.: Bull. U. S. Geol. Survey No. 430, 1910, pp. 102, 103.

[6] Lindgren, Waldemar, Anhydrite as a gangue mineral: Econ. Geology, vol. 5, 1910, p. 522.

have been contained in the ascending solutions. On the other hand, the alunite deposits are believed to have been formed near the surface and therefore the possibility of the sulphuric acid having been produced by the oxidation of hydrogen sulphide or other sulphur compounds can not be eliminated.

The evidence in the Marysvale district, however, indicates that the materials constituting the veins were deposited by ascending solutions and that these solutions brought in the constituents of the alunite. At just what stage the sulphuric acid may have been formed can not now be positively stated, but it seems most natural to suppose that it was a part of the original solutions and that the potassium and aluminum were in part original in the solution and in part dissolved from the walls of the fissure at greater depth.

The apparent absence of metallic minerals in the alunite veins and their presence in the associated veins are worthy of note and might be thought to indicate that the alunite veins of the district constitute a separate class of deposits. Such a supposition, however, does not appear to be well founded, for the carbonate veins of this and similar districts ordinarily carry low, if any, metal values, though there can be little doubt that they are most closely allied to the quartz and quartz-adularia veins that followed and in many cases partly or wholly replaced them. The lack of sulphide and allied metallic minerals in these earlier veins is nearly as marked as in the supposedly later sulphate veins, a fact which permits the interpretation that the earliest carbonate solutions did not carry important metal values. Ransome states that "it is questionable whether waters rich in sulphuric acid would be efficient carriers of gold, sulphides, and tellurides. It is probable that they would precipitate these constituents from the alkali sulphide solutions, of which the solvent efficiency has been repeatedly shown by experiment and by geologic evidence." The Marysvale deposit seems to support this view and to indicate that solutions as rich in sulphates as those depositing the alunite did not carry sulphides in solution. In fact, a review of the alunite occurrences described gives the impression that the solutions which formed or deposited this mineral were not suited to the carrying of metallic values, that the Goldfield deposit is the exception rather than the rule, and that ordinarily alunite may be looked upon as an unfavorable rather than a favorable indication of metallic values. This statement, of course, would not apply to alunite that has formed as a secondary mineral, resulting from the oxidation of sulphide ores, or to a deposit formed by ascending solutions and superimposed on an earlier metallic deposit, in which case it would have had no bearing on the original deposition. It may be noted, however, that, so far as the writer has observed, where alunite has been formed by descending solutions in considerable bodies showing some migration it is remarkably free from metallic contents.

The deposition of metallic minerals in the Marysvale district seems to have occupied a rather sharply defined period between the formation of the earlier carbonate veins on the one hand and the later sulphate veins on the other.

PROBABLE EXTENSION OF THE ALUNITE IN DEPTH.

While definite data making possible a statement as to the probable extension in depth of a deposit of this character are highly desirable, they are unfortunately not at hand. So far as known to the writer no deposit of this type has been worked to a sufficient depth to determine this point in even an individual case, and certainly enough data to warrant a general conclusion are not available. However, some facts bearing on this important point may be stated. It is assumed as a general rule that a fissure which persists over a long distance horizontally will also show persistence in depth. As the vein at Marysvale shows a very considerable horizontal extension it may reasonably be expected to extend to a depth correspondingly great. It may be noted, however, that some veins of the general type shown in this district outcrop strongly and yet nearly or quite pinch out at no great depth, the downward extension being represented by a zone of altered rock with stringers of vein material, while others continue downward to very considerable depths with no notable change in size.

It is worthy of consideration also that although the vein may persist in depth there may be a change in its mineralogic character. The occurrences of alunite indicate that this mineral does not form at great depth under conditions of high heat and pressure. It doubtless does form, however, through a vertical range of at least several hundred feet, and if the present outcrop of a vein is near the original surface it may be expected to have a considerable downward extension without notable change. If, however, many hundred feet have been eroded from the original outcrop the downward extension of the vein from the present surface will be correspondingly less, and in a region where there has been considerable erosion since mineralization occurred veins of this character may have been entirely removed.

The amount of erosion that has taken place in the Marysvale district can not be positively stated, though it is believed to have been not great. The outcrop of the alunite vein described is among the highest of the well-defined outcrops in the district, though nearly 2,000 feet below the summit of the highest peak. Moreover, it is probable that the rhyolitic beds which form the higher areas never extended over this part of the district with the same thickness that they show to the northwest. It is therefore reasonable to suppose that the erosion of the veins in the district has not been very extensive, and that in consequence the alunite vein is likely to persist downward to some considerable depth.

The observed outcrops of alunite in the district vary in elevation from about 9,900 feet to over 11,000 feet, and while it is not safe to assume that the veins outcropping at the higher elevation will persist to the depth indicated by the lower, nevertheless the outcrops show that the mineral has formed over a very considerable vertical range.

KNOWN OCCURRENCES OF ALUNITE IN THE UNITED STATES.

In papers by members of the United States Geological Survey numerous occurrences of alunite have been described, and from these the following notes concerning alunite deposits in the United States are principally taken.

The first extensive deposit of alunite to be noted in this country was that of the Rosita Hills, Colorado, the following description of which has been furnished by Dr. Whitman Cross:

ALUNITE DEPOSITS OF ROSITA HILLS, COLORADO.

By Whitman Cross.

About 25 miles southwest of Canon City, Colo., on the eastern slope of the Wet Mountain Valley, is a group of low volcanic hills named after the mining town of Rosita, which is situated in a little valley on their eastern border. In the Rosita Hills are two localities the rocks of which contain notable amounts of the hydrous sulphate of alumina and potash called alunite, which is of interest as a possible source of potash salts. The geology of the Rosita Hills was worked out more than 20 years ago, and a report with geologic map dealing with this area was published in 1896.[1] Although no estimate was made of the amount of alunite rock present in these occurrences, it is known to be considerable, but the material is somewhat impure.

A branch line of the Denver & Rio Grande Railroad reaches Silver Cliff. The wagon road from Silver Cliff to Rosita passes near one of the localities to be described, and the other is also easily reached. The deposits occur in the hills known as Democrat Hill and Mount Robinson.

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[1] Cross, Whitman, Geology of Silver Cliff and the Rosita Hills, Colorado: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, pp. 263–403. Emmons, S. F., the Mines of Custer County, Colo.: Idem, pp. 405–472.

DEMOCRAT HILL.

Democrat Hill is in fact merely the prominent end of Democrat Ridge, which lies between Leavenworth and Good Hope gulches. The locality is about 5 miles east of Silver Cliff and little more than a mile west of Rosita. The wagon road between these places crosses Leavenworth Gulch less than half a mile to the south.

The hill rises about 350 feet above the junction of Leavenworth and Good Hope gulches at its southern base. The upper part of the hill is characterized by rough cliffs and projecting knobs of a massive rock resembling granite, as seen at a little distance. This is the quartz-alunite rock to be described. Below the cliffs great talus heaps obscure the rock in place.

At the south base of the hill are two tunnels, formerly and perhaps still known as the Ben Eaton and the Democrat. These run in a northerly direction under the summit of the hill, following two parallel trachyte dikes, now greatly altered to kaolin and quartz. A raise from one of these tunnels reaches the surface, following the soft decomposition product of the dike rock. Several crosscuts from these tunnels also assist in revealing the inner constitution of the hill.

The alteration of the rhyolite, producing alunite, was probably accomplished by solfataric vapors or by waters containing such vapors in solution. The alteration apparently took place before the intrusion of the trachyte dikes, for these do not exhibit the alteration to alunite, although trachyte is rich in potash feldspar suitable for the production of alunite by the agents that attacked the rhyolite.

The material of the upper part of Democrat Hill is a hard, somewhat porous rock, of light-pinkish or whitish color, weathering in roughly rounded masses very much resembling those often seen in granite exposures. The rock itself has a strong resemblance to some granites, for its most prominent constituent is a mineral looking much like orthoclase, with a perfect cleavage and a pearly luster, occurring in irregular grains or rude tablets, many of which are one-eighth to one-fourth inch in diameter. The angular spaces between these tablets are filled by quartz grains, usually smaller than the alunite tablets. The quartz grains are also scattered through the mass of the alunite and there is a much larger amount of quartz in the rock than one would estimate from casual examination.

The cavities common in the rock are lined by rude crystals of alunite and quartz and many of them contain some kaolin. Kaolin is also found between quartz and alunite in the mass of the rock. A part of the rock is fine grained, though apparently as rich in alunite as the coarser-grained portion. The microscopic study of this rock shows the mineral occurring in tablets to possess the optical and other physical properties of alunite.

An analysis of the coarse granite-like rock, by L. G. Eakins, gave this result:

Analysis of quartz-alunite rock from Democrat Hill.

	Per cent.	Molecular ratio.
SiO_2	65.94	
Al_2O_3	12.95	127 =3.26
K_2O	2.32	$\left.\begin{matrix}25\\19\end{matrix}\right\}=1.13$
Na_2O	1.19	
H_2O	4.47	248 =6.36
SO_3	12.47	156 =4.00
Other substances	.55	
	99.89	

The sulphuric acid, alumina, alkalies, and water are present in very nearly the ratio 4:3:1:6 required by the formula of alunite, $(KNa)_2O.3Al_2O_3.4SO_3.6H_2O$. The analyzed rock therefore consists practically of quartz two-thirds and alunite one-third. But of the sulphate nearly one-half is the soda compound corresponding to the pure potash of the mineral to which the name alunite is given. As a matter of fact the pure potash mineral is rare.

No examination has been made to determine whether the alunite of Democrat Hill is throughout so rich in soda as the sample analyzed.

As to the amount of the alunite rock in Democrat Hill, nothing very definite can be said, without further examination. The upper 250 feet of the hill, with a diameter of about 800 to 1,000 feet on the 9,000-foot contour level, is undoubtedly chiefly made up of the alunite-rich rock. In the tunnels and crosscuts below no such material was seen, but as the workings were driven mainly in the kaolinized trachyte they do not give conclusive evidence as to the presence or absence of alunite rock in the lower part of the hill. The fact is, however, that the partly altered rhyolite noted in a few surface outcrops and in the prospect workings indicates that possibly the alunitization was extensive only in the upper levels of the hill, which may have been near the surface at the time of eruption.

MOUNT ROBINSON.

The highest point in the Rosita Hills, known as Mount Robinson, is about a mile northwest of Rosita, and reaches an altitude of 9,723 feet. It is a hill of irregular shape, with a gentle slope to the north and a jagged crest line with a cliff or abrupt face to the south. This irregular crest is due to a broad dike of rhyolite, which has been greatly altered, the principal product being a quartz-alunite rock. In some places the mass consists chiefly of quartz and diaspore (alumina hydrate); in others kaolin is abundant.

The alunite and diaspore bearing rocks with quartz as the dominant mineral are so resistant to weathering that the portion of the dike exhibiting the most thorough alteration stands out above the softer neighboring rocks. The dike has a length of about a mile and a width in places of 300 feet. It is greatly altered throughout its extent, but the more extreme forms, such as the quartz-alunite and quartz-diaspore rocks, are best developed near the summit of the mountain. As in the case of Democrat Hill, no definite statements can now be given as to the amount of the quartz-alunite rock present.

The quartz-alunite rock of the crest of the mountain near its east end has the composition given in column 1 of the table below. The quartz-diaspore rock from a prospect pit just west of the summit of Mount Robinson has the composition shown in column 2. Both analyses were made by L. G. Eakins.

Analyses of rocks from Mount Robinson.

	1	2
SiO_2	69.67	76.22
TiO_2	....	.11
Al_2O_3	13.72	19.45
CaO	.07	Trace.
K_2O	2.44	Trace.
Na_2O	.34	Trace.
H_2O	4.73	3.84
SO_3	9.27	.29
P_2O_5	....	.13
	100.24	100.02

The analysis of column 1 corresponds to 24 per cent of alunite, a very little kaolinite, and the balance quartz. The mass having the composition given in column 2 consists almost entirely of quartz and diaspore.

As the analysis shows, the alunite of Mount Robinson seems relatively much richer in potash than that of Democrat Hill, but without further tests it is unwarrantable to assume that the analyses of samples from either locality are representative of the masses.

RICO MOUNTAINS, COLORADO.

Cross[1] later gave a description of an extensive occurrence of alunite rock in the Rico Mountains, Colorado, from which the following is quoted:

> *Solfataric action.*—The alteration of the porphyry of Calico Peak into a rock consisting largely of alunite, a hydrous sulphate of alumina and the alkalies, * * * can be explained only as the result of the attack of sulphurous agents, and from the circumstances of occurrence there can be no doubt that the action is to be attributed to solfataric emanations of the Rico eruptive center in the period of waning igneous activity.

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[1] Cross, Whitman, and Spencer, A. C., Geology of the Rico Mountains, Colorado: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 92–94.

The cone of Calico Peak is made up of a light-colored rock which is either nearly white or stained various shades of red and yellow, often in brilliant hues. The rock has either a marked porphyritic structure or is highly brecciated. No contacts were seen, owing to the extensive talus slopes which conceal it on all sides. * * * The alteration is so extreme that it is not certain that all of the rock belongs to a single mass, though it is apparently of that character.

The rock of the greater part of the peak was plainly porphyritic and contained many large feldspar crystals, and from this fact it is supposed that the rock was originally of the type of monzonite porphyry with large phenocrysts of glassy orthoclase, which has been described above and which occurs in fresh form only in the vicinity of Calico Peak in long dikes. * * * In its present condition the rock of the peak contains no dark silicates; the former feldspar phenocrysts are represented either by a mass of white kaolin or by a granular mass of an early colorless mineral, ordinarily too fine grained for recognition. The groundmass is grayish in tone and may be fine or coarse grained. In some places the rock has become largely a porous quartzitic mass. The room of the larger feldspar crystals is seldom completely filled by the alteration product, which usually appears as an aggregate of rude plates, a definite crystal outline being, however, rare. These plates are rough crystals of alunite, the basal plane predominating and being bordered by the low hemihedral pyramid commonly developed in this mineral. No good crystals of polished faces were found.

At several places the freshly fractured rock was found to exhibit a very distinct yellow color in the porous areas representing feldspar phenocrysts, the color being due to native sulphur in minute round crystalline particles.

The more massive rock found in many places consists of a coarse-grained aggregate of irregular rude tablets with kaolin filling the interstices. Small veins of uniform fine grain also traverse the rock locally, the character of the material being unrecognizable megascopically.

The general character of the Calico Peak rock was recognized by the writer from its resemblance to the quartz-alunite rock found by him in the Rosita Hills, Custer County, Colo. In the latter case the material was formed by solfataric action upon rhyolite in a small volcanic center,[1] and the alunite made up a much smaller part of the rock than at Calico Peak. But fairly good crystals were found in the Rosita Hills, associated with diaspore.

Microscopial study of the Calico Peak rocks confirms fully the identification of the principal substance of the Calico Peak mass as alunite and shows that kaolin and quartz are the only other minerals of importance present in the specimens examined. Diaspore has not been certainly identified in these rocks, and the chemical analyses given below show that there can be but very little present.

In the table on the following page are presented quantitative analyses of two of the Calico Peak specimens and one of a rock from the Rosita Hills. I is the analysis of a coarse-grained rock almost resembling a pearly-gray marble from the west slope of Calico Peak. II is a fine-grained white vein on the south ridge of the peak. III is an alunite-quartz rock from Mount Robinson, in the Rosita Hills, republished from the descriptions cited above. Analyses I and II are by George Steiger and III was made by L. G. Eakins, all in the laboratory of the Geological Survey. In the column following each analysis is given the molecular ratio.

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[1] Cross, Whitman, Geology of Silver Cliff and the Rosita Hills, Colorado: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, pp. 314–319; On alunite and diaspore from the Rosita Hills, Colorado: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 466–475.

Analyses of alunite rocks.

Constituent.	I		II		III	
SiO_2	2.54	42	1.79	30	69.67	....
SO_3	35.24	440	37.92	474	9.27	114
Al_2O_3	[a] 42.35	415	[a] 37.66	370	13.72	134
CaO	.08	....	.38	....	.07	....
Na_2O	4.02	65	2.12	34	.34	32
K_2O	3.27	35	6.77	72	2.44	
H_2O below 110°	.13	....	.06	....	4.73	263
H_2O above 110°	11.99	666	13.03	724		
	99.62	....	99.73	....	100.24	....

[a] Contains TiO_2 and P_2O_5, if present.

From the molecular ratios of I and II it appears that the substances analyzed consisted mainly of alunite with a little kaolin. The alkalies are a little below the required amounts for the sulphuric acid found, but if the losses of the analyses be assumed to be soda, and the lime be supposed to replace alkali in alunite, the analyses are very satisfactory. It is notable that the vein alunite (II) is much richer in K_2O than the replaced rock (I).

The alunite-bearing rock of the Rosita Hills contains a great deal of quartz, but the Calico Peak mass is, in some parts at least, nearly pure alunite.

SILVERTON, COLO.

Alunite has been described from the National Belle mine, near Silverton, Colo., by Hurlbut[1] and by Ransome,[2] the following quotation being from Ransome's report:

> As shown by E. B. Hurlbut, however, not all of the white crystalline powder found in the National Belle is kaolin, but alunite also occurs in nearly identical form, clearly associated with enargite. Hurlbut's analysis is here quoted:

Analysis of alunite from National Belle mine.

SO_3	38.93
Al_2O_3	39.03
K_2O	4.26
Na_2O	4.41
H_2O	13.35
Insoluble	.50
	100.48

CRIPPLE CREEK, COLO.

Alunite has also been noted at Cripple Creek by Lindgren and Ransome,[3] who say:

> Alunite was identified from level 5 of the Last Dollar mine. It follows the vein fissure as a rather hard and compact, fine-grained white substance, looking very much like kaolin. It was also noted from the adjoining Modoc mine and probably occurs at many other places. It seems to be confined to the oxidized zone.

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[1] Hurlbut, E. B., On alunite from Red Mountain, Ouray County, Colo.: Am. Jour. Sci., 3d ser., vol. 48, 1894, pp. 130–131.

[2] Ransome, F. L., A report on the economic geology of the Silverton quadrangle, Colo.: Bull. U. S. Geol. Survey No. 182, 1901, p. 235.

[3] Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colorado: Prof. Paper U. S. Geol. Survey No. 54, 1906, p. 125.

GOLDFIELD, NEV.

The most extensive deposit of alunite yet discovered in Nevada is that at Goldfield, which has been described by Ransome[1] as follows:

> The hexagonal (rhombohedral) hydrous sulphate of potassium ($K_2O.3Al_2O_3.4SO_3.6H_2O$),[2] known as alunite or, in massive form, as alumstone, is so abundant in the Goldfield district and so generally associated with the intense alteration of the rocks in the vicinity of the ore bodies that it must be regarded as one of the most characteristic minerals of the gold deposits. It is not limited, however, to the immediate vicinity of the ore deposits, but * * * occurs in practically all of the Morena rhyolite, in the rhyolite about Vindicator Mountain, in the dacite and andesite of Preble Mountain, and elsewhere.
>
> Alunite occurs at Goldfield chiefly in two forms—(1) as a soft white or slightly pink material, closely resembling kaolinite and like that mineral filling cavities in ledge matter or ore, and (2) as an integral constituent of altered rocks.
>
> In the earthy, massive form alunite is very abundant in the January and Combination mines, where it plays much the same part in the sulphide zone that kaolin does in the oxidized zone. It has been found in considerable quantity also in the Lone Star mine and in leases on the Commonwealth claims, about 2 miles east of Goldfield, and is probably not entirely absent from any of the ore bodies in dacite.
>
> In the Combination mine much of the interstitial material between the nodules of rich native gold and sulphide ore near the 230-foot level is alunite. As a rule, the pure massive alunite can be distinguished from the pure kaolinite by a faint pink tint. The crystallinity of alunite, too, is usually greater than that of kaolinite, and examination with a hand lens shows tiny crystal faces with pearly luster. The texture of kaolinite, on the other hand, is normally too fine to show crystal planes, even under the microscope, and with a hand lens it appears uniformly dull and earthy. Inasmuch as alunite is a sulphate, its distinction from kaolinite or sericite may readily be made by simple chemical tests.
>
> While alunite is not entirely absent from the completely oxidized ores, most of the soft white material found filling crevices in the weathered zone has proved to be kaolinite. Kaolinite and limonite often occur together, but the association of alunite with an oxide of iron is comparatively rare. Kaolinite and alunite occur together, however, in some of the oxidized ore of the Combination mine. The material is pulverulent and slightly yellow, the color being perhaps due to the presence of some jarosite, a mineral isomorphous with alunite but differing from the latter in containing iron instead of aluminum.[3] The massive alunite in many places, particularly in the Combination mine, contains abundant small, embedded crystals of pyrite.
>
> A somewhat unusual occurrence of massive alunite was observed in 1905 in a 95-foot shaft on the Commonwealth No. 3 lease, about 2 miles (3.2 kilometers) east of Goldfield. The country rock is silicified latite. This has been irregularly fissured and the fissures and irregular interstices are filled with

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[1] Ransome, F. L., Geology and ore deposits of Goldfield, Nev.: Prof. Paper U. S. Geol. Survey No. 66, 1909, pp. 129–133.

[2] Or, as written by Hillebrand and Penfield in Bull. U. S. Geol. Survey No. 262, 1905, p. 38, $K_2[Al(OH)_2]_6[SO_4]_4$.

[3] See Hillebrand, W. F., and Penfield, S. L., Some additions to the alunite-jarosite group of minerals: Bull. U. S. Geol. Survey No. 262, 1905, pp. 32–41.

faintly pink alunite, within which are embedded spherical nodules of snowy kaolinite ranging in size from that of a pea to that of a small marble.

In the Dixie mine, on the west slope of Preble Mountain, massive alunite, which in some places is very compact, with almost the texture and hardness of some varieties of opal, is abundant on the 110-foot level, filling fissures and irregular crevices in porous silicified dacite.

The most coarsely crystalline form of the mineral found is in an irregular veinlet, from a half to 3 inches (1.2 to 7.6 centimeters) in width, in altered dacite on the northeast slope of Preble Mountain. This material, as exposed at the surface, is a buff-colored aggregate of platy, irregular crystals and resembles some forms of coarse dolomite.

The greatest interest attaches to the alunite as a rock constituent. Attention was first directed to its occurrence in this form by the finding of small nests or crystalline aggregates, up to 5 millimeters in diameter, of a pale-pink mineral in a greatly altered, nearly white rock exposed on the east shoulder of Vindicator Mountain, about 2 miles northeast of the town of Goldfield. The rock contains quartz phenocrysts and was probably originally a rhyolite. The microscope shows that the feldspar phenocrysts, as well as the groundmass, have been altered to an aggregate of quartz and alunite, the optical determination of the latter mineral being checked by chemical tests in the United States Geological Survey laboratory by Mr. George Steiger. With the alunite is associated a subordinate quantity of diaspore.

Microscopical study of the bleached altered rocks of the district soon showed that alunite is present in nearly all of them. The rhyolite forming the summit of Columbia Mountain, just north of the towns of Goldfield and Columbia, has been altered to a quartz-alunite rock, the alunite with some quartz forming pseudomorphs after the feldspar phenocrysts, which probably were originally orthoclase. Alunite is very abundant in the altered andesite and dacite of Preble Mountain and vicinity and is present, down to the deepest workings, in practically all of the altered dacite which forms the country rock of the Mohawk Combination, Florence, January, Red Top, Jumbo, and other mines near Goldfield. * * * It is also abundant directly associated with the sulphide ores in these mines, and is in many cases intercrystallized with pyrite. * * *

As a constituent of altered rocks in the Goldfield district, the alunite does not have complete crystal form. It is usually tabular in habit, the basal pinacoid being well developed and the rhombohedral faces being absent or indistinct. In thin section * * * it shows distinct cleavage parallel to the basal pinacoid and parallel extinction with reference to the cleavage. The birefringence is apparently rather stronger than the difference $\gamma-\alpha=0.018$ given in the table of Michel Lévy and Lacroix,[1] the interference colors in good thin sections being mostly yellow but rising in places to red or blue of the first order. The mineral gives a positive uniaxial interference figure in sections showing no cleavage. The index of refraction is distinctly higher than the balsam of the slide (1.54), that given for the alunite of Tolfa being $\omega=1.572$ and $\epsilon=1.592$.[2]

In some thin sections alunite might, on superficial examination, be mistaken for sericite. The latter mineral, however, has higher double refraction with the color mottling characteristic of the micas, has finer cleavage, and is op-

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[1] Les minéraux des roches, Paris, 1888. Also Iddings, J. P., Rock minerals, New York and London, 1906.

[2] Iddings, J. P., op. cit., p. 476.

tically negative. The difference in optical orientation is most quickly detected by the use of gypsum plate or quartz wedge. In alunite the higher colors appear when the basal cleavage is parallel to the direction of greatest elasticity in the plate or wedge. In sericite the higher colors occur in the transverse position.

The minerals most commonly associated with the alunite as constituents of the altered rocks are quartz and pyrite. Some of the andesite on the south slope of Preble Mountain has been altered to a nearly white, fine-granular aggregate consisting almost wholly of quartz and alunite. The altered dacite forming the country rock of the Goldfield group of mines consists of quartz, alunite, pyrite, and kaolinite in various proportions. In many varieties of the rock these minerals are accompanied by small quantities of diaspore.

The gold, famatinite, bismuthinite, and other constituents of the richest ore are generally inclosed in quartz, not alunite. The latter mineral, however, frequently occurs in the same microscopical section less than a millimeter distant from the metallic minerals. In ore from the Jumbo-Extension mine, near Diamondfield, alunite and a telluride of gold are crystallized together, as was found by the microscopical study of thin sections.

Calcite and alunite do not ordinarily occur together, but microcrystalline calcite, a little sericite, and probably some kaolinite have been found associated with much larger crystals of alunite in an altered rhyolite from the east slope of Vindicator Mountain. The molecular ratio of soda to potash in this alunite, as determined by Dr. Hillebrand, is as 40 to 45. It is possible, however, that the result obtained for potash may be high in consequence of some decomposition of the sericite by the sulphuric acid used to dissolve the alunite.

The occurrence together of alunite and calcite, apparently developed simultaneously, shows that the alteration took place under conditions which did not permit the free escape of carbon dioxide. It is scarcely conceivable, for example, that calcite could form in the presence of sulphuric acid percolating down from an overlying deposit of oxidizing pyrite.

As shown above, part of the alunite contains considerable sodium, and the calculations of the mineralogical compositions of some of the altered rocks from their chemical analyses * * * indicate that most of the mineral occurring in the Goldfield district is not the pure potash salt but is intermediate between alunite proper and natroalunite.[1]

Alunite differing in habit from most of the mineral thus far found near Goldfield occurs in the Hat lease on the Blue Bull Mining Co.'s ground, 1½ miles (1.4 kilometers) east of Goldfield. The country rock here is andesite. This has been locally brecciated and the fragments are silicified. Between the fragments, and cementing them together, is much bright-red hematite, which in the croppings is partly changed to limonite. The workings when visited were only about 50 feet (15 meters) deep and the hematite extends at least to that depth.

Occurring as irregular bunches and streaks in this hematitic breccia is much soft fine-grained material of light-gray color with irregular reddish-gray bands. In texture this material resembles a fine sandstone. It is firm but can be crumbled between the fingers and gives a reddish streak when struck with a pick.

Under the microscope the powdered material proves to be made up of small, sharply bounded colorless crystals, the largest being less than 0.03 millimeter in diameter. The crystals are apparently octahedral but in reality are probably combinations of a rhombohedron and basal pinacoid. They are doubly refracting and can not, therefore, belong to the isometric system.

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[1] Hillebrand, W. F., and Penfield, S. L., op. cit., p. 38.

Chemical tests by Mr. W. T. Schaller show the presence of alkalies and sulphuric acid, and the mineral is without much doubt alunite, natroalunite, or an intermediate variety of this isomorphous group. The crystals are associated with microscopic rosettes of hematite, the latter giving the red streak when the material is scratched. Such ore as had been sacked for shipment at the time of visit consisted mainly of this alunitic material.

The mineral is also abundant, with sulphur in altered rhyolitic pumice, near Cuprite, 12 miles south of Goldfield.

As alunite is still a comparatively rare mineral, as it has not been recognized hitherto as an important mineral in ore deposits, and as its presence with the rich ores at Goldfield suggests problems of great interest connected with the genesis of epigenetic ores, some reference to other occurrences and to opinions held as to the origin of the mineral may not be amiss.

Alunite was first noted at Tolfa, near Rome, where it was used as early as the fifteenth century for the manufacture of potassium alum ($K_2O.Al_2O_3.4SO_3.24H_2O$).[1] This salt, containing 2 parts less of Al_2O_3, with 18 parts more of water, is obtained from the alunite by roasting and lixiviation. The mineral is found also on some of the islands of the Grecian Archipelago, near Muszay in Hungary, on Mount Dore in France, and in a few other localities in Europe, as well as with the opal of Qúeretaro, in Mexico. In the United States it has been described in the Rosita Hills,[2] on Calico Peak, near Rico,[3] in the National Belle mine near Silverton,[4] and at Cripple Creek,[5] all in Colorado. It occurs also at Tres Cerritos, Mariposa County, Cal.[6] W. Lindgren[7] found alunite in the Ryerson mine, near Morenci, Ariz., associated with pyrite and kaolin. He regarded it as formed by the attack of descending sulphuric acid solutions upon sericite away from free oxygen. In Nevada alunite has been described by G. I. Adams[8] as associated with sulphur and cinnabar at the Rabbit Hole mines, and by S. H. Ball as in a silicified rhyolite of the Cactus Range, east of Goldfield.[9]

Until recently geologists and mineralogists have regarded alunite as formed exclusively by the attack of sulphurous fumarolic vapors upon feldspathic rocks.[10] At Cripple Creek, however, the mineral was found only in the oxidized ore and, like the kaolinite of that district, is probably secondary with reference to the original telluride ores. De Launay,[11] moreover, has recently maintained

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[1] For the latest account of this celebrated locality, with a bibliography, see De Launay, L., La metallogénie de l'Italie: Tenth Geol. Cong., Mexico, 1906, pp. 125–132. [See also pp. 51–55 of the present bulletin.]

[2] Cross, Whitman, Geology of Silver Cliff and the Rosita Hills, Colorado: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, pp. 52–56; also Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 466–475.

[3] Cross, Whitman, and Spencer, A. C., The geology of the Rico Mountains, Colorado: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 92–94.

[4] Hurlbut, E. B., On alunite from Red Mountain, Ouray County, Colorado: Am. Jour. Sci., 3d ser., vol. 48, 1894, pp. 130–131. Also Ransome, F. L., A report on the economic geology of the Silverton quadrangle, Colorado: Bull. U. S. Geol. Survey No. 182, 1901.

[5] Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colorado: Prof. Paper U. S. Geol. Survey No. 54, 1906, p. 125.

[6] Turner, H. W., Rocks and minerals from California: Am. Jour. Sci., 4th ser., vol. 5, 1898, pp. 424–426.

[7] The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, pp. 119–120, 169, 193–194.

[8] Adams, G. I., The Rabbit Hole sulphur mines near Humboldt House, Nev.: Bull. U. S. Geol. Survey No. 225, 1894, p. 500.

[9] Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California: Bull. U. S. Geol. Survey No. 308, 1907, p. 48.

[10] Cross, Whitman, Geology of Silver Cliff and the Rosita Hills, Colorado: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 314. Cross, Whitman, and Spencer, A. C., Geology of the Rico Mountains, Colorado: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 33. Iddings, J. P., Rock minerals, New York, 1906, p. 476. Hillebrand, W. F., and Penfield, S. L., op. cit., p. 40.

[11] Op. cit.

with cogency that the alunite of Tolfa is probably not, as commonly supposed, a solfataric product, but is due to the action of percolating surface water, charged with sulphuric acid by the oxidation of pyrite, upon a particularly feldspathic facies of the trachyte. It is accordingly no longer justifiable to regard the occurrence of alunite as proof of former fumarolic activity. The mineral may form under very different sets of conditions, and it is necessary in seeking the explanation of any occurrence of it to keep alternative hypotheses in mind.

In all four of the Colorado localities the alunite occurs in regions which contain ore deposits. In the Rosita Hills and in the Rico and Silverton districts it is apparently not a product of superficial oxidation. No close kinship between this mineral and the ores, however, has been shown, although it was doubtless recognized by all the workers in those districts that there might be some genetic relation between the metallic sulphides and the volcanism of which the sporadic solfataric metamorphism of feldspathic rocks to quartz-alunite aggregates was one manifestation. It is worth noting in this connection that the indexes of two of the best and most recent works[1] on ore deposits contain no reference to alunite, showing that the mineral has not been commonly recognized as one intimately associated with ores. Neither is it mentioned, so far as I am aware, in C. R. Van Hise's work on metamorphism.[2] J. H. L. Vogt,[3] however, in discussing metasomatic vein processes, has remarked: "I would mention also the formation of alumstone, quartz-alunite rocks, quartz-diaspore rocks, etc., and also the formation of bauxites, etc. But I do not know that these changes have been anywhere observed in genetic relation with ore veins."

MISCELLANEOUS OCCURRENCES IN NEVADA.

Ball[4] has noted the occurrence of alunite in silicified rhyolite in the Cactus Range east of Goldfield. Adams[5] has described the mineral associated with sulphur deposits near Humboldt House as follows:

> In the cavities of the rock formations carrying sulphur deposits there is found a considerable amount of white pulverulent material, which on chemical examination proves to be alunite. This is hydrous sulphate of aluminum and potash, a mineral which is thought to be formed in many cases by the reaction of sulphurous vapors on rocks, especially on feldspars that carry aluminum and potash. It usually occurs at places where solfataric action is known to have taken place, and the fact that alunite is found at the Rabbit Hole sulphur mines may be regarded as supplementary proof of the mode of origin of the sulphur. Alunite, when it occurs in sufficient quantities, may be used as the source of alum, its chemical composition being similar to kaolinite, or native alum.

Hill[6] has described alunite as occurring in highly altered rocks about 22 miles southeast of Las Vegas, Nev. He considers the min-

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[1] Beck, Richard, Lehre von den Erzlagerstätten, Berlin, 1901. Stelzner, A. W., and Bergeat, A., Die Erzlagerstätten, Leipzig, 1904–1906.

[2] A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904.

[3] Problems in the geology of ore deposits: Trans. Am. Inst. Min. Eng., vol. 31, 1902, p. 150.

[4] Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California: Bull. U. S. Geol. Survey No. 308, 1907, p. 48.

[5] Adams, G. I., The Rabbit Hole sulphur mines, near Humboldt House, Nev.: Bull. U. S. Geol. Survey No. 225, 1904, p. 500.

[6] Hill, R. T., Camp Alunite; a new Nevada gold district: Eng. and Min. Jour., vol. 86, 1908, pp. 1203–1206.

eral as the result of the alteration of the rocks by "hot ascending acid volcanic mineralized vapors."

TRES CERRITOS, CALIFORNIA.

Turner[1] has described an occurrence of alunite at Tres Cerritos, Mariposa County, Cal., as follows:

> Southwest of Indian Gulch, in Mariposa, County, Cal., are three sharp buttes known as the Tres Cerritos. The original material of these buttes appears to have been chiefly meta-augite andesite tuffs (augite-porphyrite tuffs) and clay slate. The Tres Cerritos lie immediately east of a considerable area of clay slates which are pretty certainly of Jurassic age. They are supposed to belong to the Mariposa formation. Not far west of the buttes by the road to Merced these slates have been metamorphosed into typical chiastolite schists by a granitic rock.
>
> The rocks of the Tres Cerritos have been subjected to solfataric action and their angular outline is due to the hardness of the altered rocks. The larger portion of these metamorphosed rocks are light brown in color, highly siliceous, resembling quartzite megascopically.
>
> The southeast butte, which was examined with the most care, is composed chiefly of a greenstone schist which is a dynamometamorphic form of the meta-augite andesite tuff. This contains layers of vein quartz, associated with which is pyrophyllite in considerable masses crystallized in beautiful stellate forms. The much decomposed and rusty schists in the creek at the west base of the butte strike about 60° west of north and dip at an angle of 80°. At one point about due west of the butte the schists are covered with an efflorescence. Some of this was collected and examined by Dr. H. N. Stokes in the laboratory of the United States Geological Survey, who reported that the efflorescence is composed of hydrated sodium and magnesium sulphates with a little chloride. In the interior of this efflorescence are grains of calcium sulphate.
>
> The quartzite-like rock under the microscope is seen to be made up chiefly of grains of quartz and a positive uniaxial mineral of greater relief than the quartz, extinguishing parallel to the cleavage and having bright interference colors. Dr. Hillebrand made a chemical examination of this rock and came to the conclusion that the unknown mineral might be alunite.

Chemical analysis of alunite No. 870 S. N.

SiO_2	2.64	K_2O	4.48
TiO_2	.40	Na_2O	2.78
Al_2O_3	38.05	P_2O_5	Trace.
Fe_2O_3	.23	CO_2	None.
FeO	Not looked for.	H_2O 100°−	None.
MnO	None.	H_2O 100°+	11.92
CaO	.55	SO_3	38.50
BaO	Not looked for.		
MgO	Trace.		99.55

To make this more certain, a quantity of the rock was powdered and the alunite-like mineral separated by means of the Thoulet solution. The specific gravity of the mineral is 2.78, as determined with the Westphal balance by

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[1] Turner, H. W., Rocks and minerals from California: Am. Jour. Sci., 4th ser., vol. 5, 1898, pp. 424–425.

grains suspended in Thoulet solution. Some of the material was heavier than this, but this greater specific gravity was undoubtedly due to inclusions of a brownish-red mineral in minute grains without crystal outlines. These grains are too minute for satisfactory determination with the microscope, but a quantitative test of some that were separated from the rock, made by Mr. William Valentine, shows that the mineral is rich in titanium. The mineral does not resemble titanite in color, at least such titanite as ordinarily is found in granitic rocks. It may be brookite, but, as before noted, occurs in somewhat rounded forms and not in the small tabular crystals said to be characteristic of brookite. Possibly the mineral is rutile.

An analysis of the alunite has been made by Mr. William Valentine. It is probable that the titanic oxide in this analysis was obtained from some of the minute grains of the titanium mineral above noted. As the material was sensibly pure, the analysis may be regarded as representing its composition after deducting the titanic oxide.

Alunite has not been previously found in California so far as known.

CLIFTON-MORENCI DISTRICT, ARIZONA.

The occurrence of alunite in the Clifton-Morenci district, Arizona, is described by Lindgren[1] as follows:

> *Alunite* ($K_2O.3Al_2O_3.4SO_3.6H_2O$).—This white and inconspicuous sulphate of potassium and aluminum was found filling a narrow seam on a contact between shale and porphyry in the main adit of the Ryerson mine at Morenci, where it forms a white earthy mass not unlike kaolin.
>
> It is also found in some altered porphyries of the same mine associated with pyrite and kaolin. It occurs here as microscopic rhombohedral crystals, showing quadratic or hexagonal sections, as grains or irregular masses and as fibrous aggregates. The birefringence is of medium strength, the colors at most reaching pale yellow. The index of refraction is low.

Developments since the study of these deposits by Lindgren have shown alunite to be a more abundant mineral than appeared at that time. Alunite has been observed by the writer in the Bisbee district, Arizona, where its occurrence seems to be similar to that at Morenci. Some analyses of the material made for the geologic department of the Copper Queen mine show it to be relatively pure alkali aluminum sulphate, though in some of the specimens analyzed sodium (Na_2O) was relatively abundant.

BEAVER COUNTY, UTAH.

In Utah, in addition to the occurrence at Marysvale described in this paper, alunite has been noted in the Horn Silver mine, Beaver County, where it has apparently resulted from the action of sulphuric acid, derived from the oxidation of sulphides, on the feldspar of the volcanic rocks in which the ores occur. In the upper part of the deposit it forms a rather persistent layer on the footwall of the vein, varying from a few inches to 18 inches in thickness. It is a white kaolin-like material that can be readily powered in the fingers and is so fine grained that even between the teeth no grit can be felt in it.

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[1] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, pp. 119–120.

FOREIGN OCCURRENCES OF ALUNITE.

Alunite is reported from a number of foreign localities, among which may be mentioned the well-known occurrence at Tolfa, near Civita Vecchia, about 35 miles northwest of Rome, and the deposits near the village of Bullah Delah, in the county of Gloucester, New South Wales; near Smyrna, in Turkey; at La Solfatara, near Naples, and at Montioni, Tuscany, in Italy; at Puy de Garcey, Breuil, and on Mount Dore, in the Auvergne, France; in Sicily; on the islands of Milo, Volcano, and Santorin (Thira), in the Grecian Archipelago; at Muszyna and at another locality in Hungary; and near Hadji-Khan, Bokhara. Alunite occurs also with the opal and hyalite of Queretaro, in Mexico; and alunite or closely allied minerals are found at several localities in Spain, especially near Benahabux, in the province of Almeria.

TOLFA, ITALY.

The Tolfa deposits have been worked for four centuries and are probably the best known. A discussion concerning the origin of these deposits is given by De Launay,[1] a translation of a part of whose paper is appended:

> The only deposits worked in the region of Tolfa are veins of alunite—deposits, therefore, of a very special type. But I shall endeavor to show that these alunites are in reality a particular case of superficial alteration of pyritic veins included in alkaline feldspathic rock. It is therefore desirable to assign these deposits of alunite to their proper place in the metallogeny of the region of Civita Vecchia, by describing briefly the other complex sulphur-bearing veins which are present.
>
> The region of Tolfa is formed chiefly of Eocene strata, above which have been poured out the trachytes of Allumiere, forming a triangular massif of about 8 or 9 kilometers on the side and overlain, in turn, on the east side, by the gypsiferous clays of the upper Miocene. Along the whole south side of the trachytic massif, which does not itself appear to have taken part in the phenomena, but at a certain distance from it, the Eocene has undergone an intense metamorphism, which shows itself in the limestones by crystalline banks, with garnet, wollastonite, epidote, etc., analogous to those which surround the isle of Elba, the granitic rocks of Mount Capanne, and in the schists by siliceous layers. At the same time, by a connected reaction, veins of pyrite, more or less altered, sometimes accompanied by other sulphides (galena at Cava del Piombo, etc.), are abundant and their alteration accompanied by substitution has often given place in the midst of the limestones to stocks of sesquioxide of iron, which extend to the southwest in the direction of Civita Vecchia almost to the classic thermal springs, the baths of Trajan.
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> The most important of these stocks, those of Roccaccia, Pian Ceraso, Edificio del Ferro, etc., are, by a phenomenon already seen many times in this study,

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[1] De Launay, L., La métallogénie de l'Italie: Compt. Rend. Tenth Internat. Geol. Cong., Mexico, pt. 1, 1907, pp. 679–686. De Launay cites the following papers: Gîtes métallifères, t. 2, pp. 607–612. Klitsche de la Grange, Le trachiti della Tolfa e le formazioni aluminifere; Sulle miniere di ferro de la Tolfa, Roma, 262 pp., 4°, 1881 et 1882. Lotti Brevi considerazioni sulla trachite de la Tolfa: Proc. verb. Soc. Tosc., V, 1886. Lotti, I giacimenti metalliferi della Tolfa: Rassegna mineraria, t. 13, Dec. 11, 1900.

concentrated at the contact of limestones and the schists altered by superficial action. They consist at their outcrop of limonite and hematite visibly substituted for the limestone; going down, pyrite is found. Sometimes a little phosphate of iron seems to show the original presence of phosphorus in the limestones.[1] The lead veins of Cava del Piombo appear to extend N. 110° E.

When the trachytic mass is penetrated pyritic veins are no longer met, but the famous veins of alunite worked for four centuries and a half.[2] It appears to me unquestionable that these represent another superficial form of deposits to add to all the other examples of alteration which I have tried to group in this study.

Alunite is, in my opinion, a product of the decomposition of feldspar similar to kaolin, which is worked in the same region, and often from the same veins, and, like this kaolin, is bound to disappear in depth. The theory which was formerly held is somewhat different. It was thought that the sulphur vapors of solfataric kinds circulated in the fissures of trachyte and attacked directly in depth the feldspars of the latter, and a relation was supposed to exist between these different phenomena and the trachyte itself. I believe, on the contrary, that there are two entirely distinct phases in the phenomenon—first, a vein deposit clearly delimited, of pyritic trachyte corresponding, perhaps, to the veins of a trachyte particularly feldspathic and at the same time pyritic like the granulites of Berezowsk (Oural); second, penetration by superficial waters of the feldspathic rocks, producing, where pyrite fails, the ordinary forms of altered feldspars—that is to say, kaolin, but where, on the other hand, pyrite furnishes sulphuric acid, crystalline alunite.[3]

The observations which I have tried to group are well explained by this hypothesis.

In the first place the conditions necessary for the production of an intense alteration—that is, the existence of an abundant water circulation and of a deep hydrostatic level—are clearly realized. This trachytic massif, which is hardly 12 kilometers from the port of Civita Vecchia, is 400 to 500 meters above it and the absorption of water by the trachytes is so evident that the inhabitants of the village of Cave Vecchia, near Tolfa, are obliged to go down 300 meters to find drinking water.

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[1] I have noted a fact of the same kind at Boccheggiano. The phosphorus appears often also in lead outcrops (pyromorphite) and has likewise formed combinations with the cinnabar of Idria (coral earth).

[2] The alunites of Tolfa have belonged since 1878 to the French Compagnie d'Alun Roman, which has, besides the concession of 2,340 hectares granted September 22, 1873, a mill at Civita Vecchia and one at Rouen. During four centuries, from 1460 to 1860, only large open excavations were made, with a very crude treatment of ores in large blocks by simple calcination, leaving the débris, which is worked to-day. About 1873 a mill was established at Civita Vecchia and in the following year, by chance, the Providenza vein was discovered, which has since furnished the entire production. In 1901 the production was scarcely 4,000 tons.

The present production is about 8,000 tons of raw product, estimated (in 1902 at the rate of 7.5 francs per ton, according to actual statistics; in 1904 at the rate of 6 francs), or 5,000 tons of commercial product; at Rouen, 4,000 tons composed entirely of sulphate fo alumina; at Civita Vecchia 1,000 to 1,200 tons (entirely of alum). The greater part of the product is sold in Germany, 700 to 800 tons of "white mineral," with a minimum of sulphate of alumina guaranteed. Besides the ancient uses of alum, the manufacture of paper consumes large quantities of sulphate of alumina as a substitute for alum, except for certain superior papers. In the manufacture of alum an essential point is the elimination of iron which renders the product unsalable.

[3] It is known that alunite differs from alum by an excess of alumina which renders it insoluble. While it is formed at the same time as the crystals of alum in all regions of volcanic rocks, where, for any reason, waters charged with sulphuric acid circulate, alunite is a very rare mineral as its crystallization requires special conditions of temperature and pressure, the reactions being otherwise the same.

On the other hand, note the arrangement of the veins of alunite. The mineral of crystallized alunite and of quartz forms a series of veins in the midst of the trachyte, the arrangement of which appears to be lenticular in direction as well as in inclination, so that they have been considered contraction fissures in the rock filled by a later exudation from sulphurous fumaroles. These veins, which individually form well-marked veins, with well-defined walls, may be considered in the aggregate to form a network so complicated[1] by interlacing in stockwork that at their outcrops they occupy so much surface that they have been able to furnish, for four centuries, immense open excavations, the remains of which are seen on all sides. Then, one after another, these networks of fissures decrease with depth and the alunite disappears, just as the kaolin is always seen to disappear under the same conditions.

Since 1874 the works have been restricted to one vein, extending northwest and southeast, the Providenza vein, besides which some work was done during five or six years on the north side on the Rotella vein, now abandoned. This Providenza vein, which in places attains a width of 10 meters and ceases to be workable when it decreases to less than 0.8 meter, has been worked over 100 meters in depth; but its limit is clearly seen about the level 390 meters, which corresponds very closely to the hydrostatic level, for the termination of the pockets of alunite is generally marked by very abundant flows of water.

The impoverishment begins to show itself with the appearance of pyrite at a level of 412 meters above the sea; 20 meters farther down the deposit ends.

* * * * * * *

This pyritic trachyte is, then, certainly the deep form of alunite which disappears where its superficial alteration ceases. This alteration, moreover, follows the usual laws which are seen in reactions of the same kind. For example, there are found with the alunite, as with the kaolins, two forms of silica—first, grains of quartz, constituting the residue of the attack of feldspathic rocks, and, second, quartz retained from the dissolution of the silicates dissolved at the same time as the double sulphate of alumina and potassium and recrystallized with it. The alunite then appears as a mixture with crystallized quartz, and the entrapping of this silica dissolved in the deep parts makes the proportion of quartz in the veins increase with depth. The veins of alunite appear thus to become more and more quartzose. The same phenomenon is observed in the kaolins and in the veins of phosphorite of Spain and in certain veins of manganese and of baryte which represent other examples of similar reactions.

At the same time, the baryte, which is associated with the lime and the alkalies in the feldspars of the rock, is, as always, concentrated in these superficial reactions, and secondary crystallizations of barytes are found in certain workings (level 390). In a general way there are found in the alunite all the basic elements of the feldspars, of which the relative proportion is modified only according to the laws which I have elsewhere pointed out, by the elimination of the soluble elements and accessorily of elements which enter less easily into solution; also by increase of potassium with respect to the soda (12 parts in 100 of sulphate of potash on the average as against 2 parts per 100 of the sulphate of soda),[2] of baryte with respect to the lime (1 part in 100 altogether), and of the manganese with respect to iron, etc.

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[1] I have given elsewhere (Gîtes métallifères, t. I, p. 608), according to M. Fuchs, a plan of these fissures which appears to be too diagrammatic.

[2] There may be as much as 16 parts in the 100 of sulphate of potassium. Pure alunite contains 21 parts in the 100, and there are ores containing 90 parts in the 100 of alunite.

The formation of kaolin and that of alunite are two different types of the same phenomenon. The passage of the one mode of alteration to the other shows itself constantly, and the boundary of the veins of alunite horizontally is often formed by the substitution of kaolin for alunite, the primitive vein which has furnished the two minerals by alteration having at this point ceased to be pyritized. There exist on the outcrops quarries of kaolin in the midst of quarries of alunite, and in the depths pockets of kaolin are frequently encountered.

Finally, in these alteration reactions, there occur by the oxidation of the pyrite the two ordinary forms of peroxidation and of dissolution that are found, for example, in calamine deposits of a similar origin. Just as there are red calamines, white calamines, and calamine earths, so are there red alunites, white alunites (which are sorted out with great care for exportation, to avoid the iron in the manufacture of alum), or even yellow earths of alunite, sometimes accompanied by kaolin.

The red alunite is found likewise associated with red trachyte under the white alunite associated with the white trachyte, not because there are two different types of trachyte superposed from which are derived the two types of alunite, but because the zone in one case is that of peroxidation, in the other that of cementation. So also, when a new opening is made in the pyritic trachyte it is seen that with the excess of air alteration begins to show itself by spots of oxide of iron among the crystals of sulphate. The encountering of the hydrostatic level appears to be accompanied by a deposit of oxide of iron corresponding to a very active circulation of superficial waters.

It is also found in approaching a fault, which abruptly limits the workings at all levels, that the alunite becomes very white and contains more and more quartz. The circulation of waters by this fault has served to carry away iron and to bring in silica, etc.

To summarize, the secondary origin of alunite from its relatively superficial character (perhaps localized at the point which was the zone of cementation at the moment of its crystallization) does not appear at all questionable. But there remains one obscure point, namely, the exact nature and precise origin of these vein zones of pyritic trachyte, which, localized in the midst of a trachyte free from pyrite, have been able to produce at certain depths the crystallization of alunite.

Sometimes, as I have said, the veins of alunite are clearly inclosed in a very hard trachyte, which can then be worked even to a thickness of 0.8 meters. It is almost impossible to imagine a partial alteration of such a thin, simple vein of pyrite inclosed in the trachyte which can be produced by substitution in the inclosing trachyte; we are almost forced to admit that the reactions have taken place in a vein already well defined, to which the pyritic impregnation for some cause was limited, and that, for example, a section of dislocated rock comprised between two faults served as channels for ascending waters, or that, perhaps, a later vein of some pyritic trachyte, more feldspathic, analogous to those pyritic granulites which form the veins in the auriferous field of Berezowsk, played an analogous rôle to that of veins of pegmatite in the kaolinization of large granulitic massifs. Besides, it is true in the larger number of cases that the alunite, in place of being inclosed in hard trachyte, is in contact with decomposed trachyte, but nevertheless the contrast still exists; the alteration of the inclosing trachyte is a kaolinization, not the formation of alunite—that is to say, it did not contain pyrite capable of furnishing sulphuric acid to its alkaline and aluminous elements. There also the pyrite was limited to the veins which to-day we find in the state of alunite. Finally, there should be noted some movements of the ground posterior to the crystallization of the alunite, which is cut by faults and shows slickensides within. I have already noted a large fault which bounds the workings. Furthermore, there are frequently found in the alunite bands of ferruginous clay which produce slips sometimes.

The minerals resulting from these phenomena are extremely polymorphous. Sometimes the alunite is crystallized in lines, sometimes in radial, spherical masses; it also has the form of a white petrosiliceous mass which effloresces in the air to a yellow earth.

NEW SOUTH WALES.

One of the most important alunite deposits commercially is probably that at the Bullah Delah, in New South Wales, of which a good description has been given by Pittman.[1] The greater part of this description is quoted below:

> What is probably one of the most remarkable deposits of alunite in the world occurs east of the township of Bullah Delah, in the parish of Bullah Delah, County of Gloucester.
>
> It consists of a narrow mountain range about 3 miles long and having a maximum altitude of 900 feet, which for a mile or more of its length is composed almost entirely of the mineral alunite of greater or less purity.
>
> In the center of the township of Bullah Delah are seen beds of yellowish-gray calcareous sandstones, containing numerous fossils belonging to the (Upper?) Marine series of the Permo-Carboniferous system. These beds dip W. 40° S. at 45° and are succeeded conformably on the east by thick-bedded strata, consisting of fine-grained bluish-gray (tuffaceous?) sandstones, containing a few carbonized plant remains and occasional waterworn pebbles of quartz felsite.
>
> Between these beds and the mountain range, a distance of less than a mile, the rocks are, for the most part, obscured by soil, etc., but here and there beds of this sandstone are seen to outcrop, showing that it forms an important feature in the series. The sides of the mountain, for a height of 500 feet, are formed of a steeply sloping talus, consisting of fallen alunite rock, which effectually obscures the underlying formation. Above this, for a height of 400 feet, the central escarpment of the mountain range is apparently formed of a steep anticline, the beds of alunite on both sides of the summit being inclined in opposite directions at angles of 80°–83° with the horizontal. Although the planes of bedding have been almost entirely obliterated, rough traces of them can be distinguished in places. A slight cutting has been made, on a gap in the range, for a tram line to the alunite quarry, and in this excavation the rocks underlying the alunite have been exposed in the form of a distinct arch or anticline, and these rocks consist of rhyolites, which show spherulitic structure in places. Farther away, to the south of the range, there is a great development of these rhyolites, which exhibit remarkable flow structure and in places are spherulitic, the spherules being occasionally an inch or more in diameter.
>
> Masses or dikes of volcanic glass (obsidian) are also seen at intervals in the rhyolites. On the eastern side of the range there is an area of the Permo-Carboniferous coal measures, and at least two seams of coal outcrop near the northwestern corner of portion 67, parish of Bullah Delah.
>
> It seems evident that the rhyolites are interbedded with the Permo-Carboniferous rocks and that they were deposited as contemporaneous lava sheets.

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[1] Pittman, E. P., Alunite or alumstone in New South Wales: Rept. Geol. Survey New South Wales, 1901, pp. 419–429.

The alunite range, which is about 3 miles long and very narrow, has a singularly symmetrical outline when viewed from the town. A large, almost perpendicular, crown of alunite, 400 feet high, occupies the center, while at intervals along the backbone of the ridge, to the north and south of this, are other projecting crags of the same material, but of lesser height. The range slopes gradually downward to its northern and southern extremities. Between the projecting crags are gaps, or saddles, which are occupied by dikes of dolerite, trending across the range. The saddles have, in fact, been formed owing to the tendency of the dolerite to decompose more rapidly than the alunite rock.

In view of the fact that both sides of the summit of the mountain are formed of the same bed, owing to the sharp fold of the anticline, it seems probable that the alunite will be found to extend below the talus of fallen rock and soil which slopes from the base of the cliff toward the undulating plain.

Although the range may be said to be almost entirely composed of the mineral alunite, it must not be supposed that it is all of a quality suitable for commercial purposes. On the contrary, it differs materially in its composition, the most impure variety being the most abundant. At the same time, considering the comparatively small amount of prospecting work that has been performed, there is evidence of the occurrence of large deposits of high-grade mineral.

The impure alunite contains occasional water-worn pebbles of quartz felsite similar to those previously mentioned as occurring in the bluish-gray sandstones of the Permo-Carboniferous beds. In some places stalactitic or concretionary forms of alunite are seen, and at intervals the mineral is marbled by wavy and more or less concentric markings, such as would be produced by the gradual percolation of solutions.

A yellowish waxy-looking mineral, which appears as segregated masses in the alunite in places, has the following composition, according to the analyst to the department of mines:

Moisture at 100° C	1.24
Combined water	13.42
Silica (SiO_2)	45.84
Alumina (Al_2O_3)	39.58
Magnesia (MgO)	.15
Potash (K_2O) Soda (Na_2O)	.19
Phosphoric oxide (P_2O_8)	.04
	100.46

It is evident, therefore, that the mineral is halloysite.

Four varietes of alunite are recognized by the manager of the mines, viz, (1) "light pink," containing 1.7 per cent of silica; (2) "chalk white," containing 16.4 per cent of silica; (3) "purple," containing 19.5 per cent of silica; (4) "granular," containing 39.5 per cent of silica. The light-pink variety is much the best as regards percentage of alumina, but some of it carries badly, being very brittle, and consequently making much "smalls" in transit. It is an exceedingly pretty waxy-looking mineral of a bright pink color. It occurs in patches, sometimes showing as thin veins and splashes, at others being massive and many feet in width. Only the pink ore is at present worked, and shipments are kept below 10 per cent of silica contents.

In the main quarry a face of 60 feet in width is being taken out, and the stone is subjected to rough hand picking before being loaded into trucks, the "purple" and "chalk-white" ore being discarded. It is carried by a horse tram to the base of the central escarpment, and is then sent down an incline, worked on the main and trail-rope system, on the slope of the talus. From the bottom of the incline it is conveyed in carts to the wharf on Myall River, half a mile distant, whence it is shipped to England for the manufacture of alum. The works are situated at Runcorn, on the Manchester Canal, and the mines are owned by the Australian Alum Co. (Limited).

Typical samples of the four varieties of mineral were selected at the mine and were analyzed in the laboratory of the department of mines with the following results:

	Light pink.	Chalk white.	Purple.	Granular.
Moisture at 100° C.	0.06	0.46	0.16	0.22
Combined water	13.19	13.86	9.65	10.26
Silica (SiO^2)	1.92	19.34	32.40	23.45
Ferric oxide (Fe_2O_3)	.26	.27	.07	.04
Alumina (Al_2O_3)	37.52	37.37	25.91	30.17
Lime (CaO)	Nil.	Nil.	.07	.01
Magnesia (MgO)	Nil.	Nil.	Trace.	Trace.
Potash (K_2O)	9.51	5.68	6.53	8.00
Soda (Na_2O)	1.12	1.08	.82	.63
Sulphuric anhydride (SO_3)	36.76	22.09	24.47	26.88
Phosphoric anhydride (P_2O_5)	Trace.	Trace.	.02	.07
Chlorine (Cl)	Trace.	Trace.	Trace.	Trace.
	100.34	100.15	100.10	99.73

Origin of the deposit.—It has already been mentioned that deposits of alunite in other parts of the world, where their mode of occurrence has been studied, are believed to have been formed by the action of sulphurous vapors upon trachytic and other allied igneous rocks.

At Bullah Delah everything points to the rhyolites as the origin of the alunite. They occur interbedded with the Permo-Carboniferous rocks in the form of contemporaneous lava sheets, and it is possible that the whole series of sandstones and lava sheets was folded into the form of an anticline by earth movements. Subsequently, during the Tertiary period, these rocks were intersected in an east and west direction by a number of dolerite dikes. These later volcanic intrusions were probably attended or followed by evolutions of steam and sulphurous acid vapors, and it is reasonable to suppose that it was by the action of these that the rhyolites were decomposed, with the production of beds of alunite. Finally, in post-Tertiary times, the softer sandstones were removed by denudation, leaving the anticlinal arch of the harder alunite rock to form the summit of the Bullah Delah Mountain.

OTHER DEPOSITS.

Other data concerning the occurrence or utilization of the foreign alunite deposits are not at present at hand. Alum is reported to have been manufactured from the rock at Smyrna, but whether the raw material was obtained near by or from a more distant source, is not clear. Recent interest in the development of similar minerals in Spain seems to warrant a brief quotation of recent date concerning these deposits. The Spanish occurrences are noted as containing a new mineral galafatite, an aluminum-potassium sulphate, similar in composition to alunite. From the following description[1] it ap-

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[1] Preus, Nordal, A new mineral and a new source of potassium sulphate: Eng. and Min. Jour., Feb. 4, 1911, p. 261.

pears that the occurrence and treatment of the ore is similar to that of alunite.

The most important deposit was that found near Benahabux railway station, only 10 kilometers from the port of Almeria.

The ore is especially interesting on account of its composition, which is as follows: SO_3, 77 per cent; Al_2O_3, 37.98 per cent; K_2O, 9.64 per cent; H_2O, 17.61 per cent. The compact ore has a specific gravity of 2.75 and a hardness of 3.5. It is an aluminum-potassium sulphate and, as it is a new mineral, has been given the name galafatite, after its discoverer, Galafat. The ore when pure is perfectly white, has a conchoidal fracture, and when recently taken from the lode is very compact. In its natural state it does not dissolve in water and resists the action of acids. Heated, it will partially dissolve in hydrochloric acid and somewhat better in dilute sulphuric acid. It is easily dissolved after being fused with a sufficient quantity of sodium bicarbonate and attacked with hydrochloric acid.

Alumina, potassium sulphate, and alum may be produced from this ore. The ore is transformed into marketable condition through calcination and washing in water. By the calcination process water and the part of the sulphuric anhydride which is combined with the alumina are eliminated, leaving a residue of a mixture of alumina and potassium sulphate. By washing, the potassium sulphate is dissolved in water, leaving the alumina almost pure, only retaining small quantities of hygroscopic water.

The average contents of the calcined mineral are as follows: Alumina, 65 to 70 per cent; potassium sulphate, 25 to 30 per cent.

The situation of the mine is favorable, being, as stated above, only 10 kilometers from the port of Almeria, the climate of which is especially effective for the necessary evaporation. The mining concessions cover 1,000 hectares, or 10,000,000 square meters. Several parallel veins have been found, with a width of 5 to 6 meters. The working of these lodes is easy, and the extraction of the crude ore should be done cheaply. Considerable quantities will be put on the market in 1911.

COMMERCIAL AVAILABILITY OF ALUNITE.

Alunite has not until recently been widely recognized in the United States, and hitherto no attempt has been made in this country to save or utilize this mineral. From the results of simple experiments with the Marysvale alunite in the laboratory of the Geological Survey W. T. Schaller has made the following observations:

Laboratory experiments showed that on igniting the powdered alunite all of the water and three-quarters of the sulphuric acid are volatilized. On leaching the residue with water the potassium sulphate is dissolved, leaving the insoluble aluminum oxide behind.

The average amount of potassium sulphate leached from the ignited mineral powder is 17.9 per cent of the original material used. As the coarsely crystallized alunite was found to contain 19.4 per cent of potassium sulphate, 92 per cent of the total potash present was obtained by simple ignition and subsequent leaching.

It is worth noting that, according to the laboratory experiments, 32.7 per cent of the ignited alunite consists of available potassium sulphate, which can be extracted by simple water leaching and evaporation. The remaining 67.3 per cent consists of nearly pure aluminum oxide.

Several of the foreign deposits have, however, been successfully worked, and the commercial availability of the mineral in this country may be inferred by a consideration of the processes that have been developed. The foreign alunite has been utilized chiefly in the manufacture of alum, as indicated in the following description:[1]

> A considerable amount of alum is prepared from alunite. Alunite contains the elements of potassium alum, basic aluminum sulphate, and free alumina. In Sicily it is made into heaps and calcined in the open air. At Tolfa, where the manufacture is carried out on a larger scale, the roasting is conducted in furnaces like limekilns, lined with refractory materials. The mineral is heated in large pieces by the flame without direct contact with the fuel until sulphur dioxide begins to escape. The calcination requires about six hours, the mass losing about 35 per cent of water. During the ignition the excess of alumina beyond that necessary to produce alum is rendered insoluble and no longer has the property of precipitating basic sulphates from the solution. The calcined mass is exposed to the air upon a clay floor for some weeks, during which time it is occasionally moistened. The mud-like product is agitated in boilers with water at 70° C., and the clear decanted liquid, of density 10°-12° B., is evaporated to 32° B. and crystallized in small wooden tubs. The crystals are cubic, opaque, and reddish from the presence of ferric oxide. This iron is, however, quite insoluble, and may be separated by recrystallization; the soluble iron is said to be less than 0.005 per cent. In this way "Roman alum" was formerly largely produced. On account of their great purity the red crystals were much sought after.
>
> Alunite is now largely converted into alum by treatment with sulphuric acid and addition of potassium sulphate. Guyot[2] has examined this process and recommends the following method:
>
> On ignition of alunite the free alumina is first rendered anhydrous and soluble in sulphuric acid; at a higher temperature the basic sulphates become soluble, but if the temperature be allowed to rise too high the alumina becomes vitrified and is insoluble. Guyot recommends ignition at 800° C. for three hours as the best means of rendering the maximum of both these substances soluble. The composition of the calcined mass is determined, and acid is used in proportion to the amount of soluble sulphate contained. For a product of the following composition, K_2SO_4, 14 per cent; $Al_2O_3.3SO_3$ (present as alum), 26.55; $Al_2O_3.3SO_3$ (free), 6.56; Al_2O_3 (free), 18.58; OH_1, 11.90; Fe_2O_3, 0.80; siliceous residue, 21.61 per cent, the proportions given below would be most satisfactory. Into a clay oven is poured 12.5 tons of sulphuric acid of 52° B. diluted to 30° B. and heated to 80° or 90° C. Eight tons of the calcined mineral is then added in portions and well stirred. After the whole has been added, the liquid is left for two hours, then evaporated to 38° B. and treated with 2.7 tons potassium sulphate. The process up to this point occupies 10 hours; after a further period of 13 hours, the clear liquid is decanted off; its density should not exceed 42° B. The muddy liquid remaining is reduced to 24° B. by the addition of mother liquor from a previous crystallization, stirred, allowed to settle, drawn off clear, mixed with the first decantate, and crystallized in a vat. After one day the crystals are removed, redissolved, and recrystallized. The muddy residue is crystallized out for a further crop of alum. The total yield of alum is about 2.3 times the original weight of ore. The insoluble matter contains 3 per cent alumina and 2.01 per cent potassium sulphate, in addition to silica, etc.

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[1] Thorpe, T. E., Dictionary of applied chemistry, London, 1890, p. 78.

[2] Guyot, M. P., Sur la richesse industrielle de l'alunite crue, en poudre: Compt. Rend. Acad. Sci. Paris, vol. 95, pp. 693, 694; Expériences sur la calcination de l'alunite en poudre, destinée à la fabrication de l'alum et du sulfate l'alumine: Idem, pp. 1001-1003.

According to C. Schwartz,[1] the best temperature for the roasting is 500° C., and the acid used should have a density between 1.297 and 1.530.

The summary concerning the utilization of the Australian deposit at Bullah Delah is contained in the following paragraph from the description of this deposit already quoted:[2]

> The following is a process by which alum is manufactured from alunite: The mineral is ground and then calcined in reverberatory furnaces, to dehydrate it and drive off part of the SO_3. It is next treated with a weak solution of sulphuric acid in lead-lined tanks, heated to boiling point by steam jets. The liquor is allowed to settle in the same vats, and the clear solution is run off into crystallizing tanks, which are kept in constant agitation while cooling, the alum crystallizing out and sulphate of alumina remaining in solution. The residue in the vat is boiled again with water, and the solution run off again in the same way. The liquor containing sulphate of alumina is then returned to the vats and sufficient of the calcined mineral added to completely neutralize any free acid. It is then heated to boiling point and ebullition continued until partial reversion takes place, the reversion being accompanied by a precipitation of the hydrated ferric oxide.
>
> The alum, after collection, is washed and then refined in vats, similar to but deeper than those originally employed, and the concentrated solution is run into roaching tuns, in which it is crystallized; it is then broken up and packed ready for the market.
>
> The sulphate of alumina solution, after all the alum has been crystallized from it, is concentrated in small vats heated with steam coils, and the lower qualities of sulphate of alumina are formed by running the liquor onto lead tables and breaking the solidified material into blocks, the higher qualities (containing over 17 per cent of soluble alumina) being cast on copper trays. These higher qualities, which vary in color from yellow to green in the slabs, are then ground in a disintegrator, and the material assumes a snow-white appearance.
>
> It is, of course, feasible, by the addition of K_2SO_4, to convert the whole of the alumina contained in the stone into alum if desired, but the more profitable method of treatment, when the better classes of sulphate of alumina can be sold at standard prices, is to make only so much alum as there is sulphate of potash present in the stone to produce, and convert the rest of the alumina into soluble sulphates of alumina (of commerce).
>
> Sulphur may be obtained by distilling the mineral in the presence of any reducing gas like coal gas. Sulphuric acid may also be distilled from the mineral. Heating with carbonate of baryta produces aluminate of potash.

Pittman also gives the following statistics of production:

Production of alunite at Bullah Delah, Australia.

Year.	Quantity.	Value.	Year.	Quantity.	Value.
	Tons.			*Tons.*	
1890	220	£3,000	1896	1,372.0	£4,116
1891	704	1,888	1897	724.5	2,172
1892	821	3,284	1898	2,941.0	8,823
1893	1,284	5,136	1899	921.0	2,763
1894	862	3,448			
1895	832	3,328		10,681.5	37,958

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[1] Ueber die Auschliessung des römischen Alunits: Ber. Deutsch. chem. Gesell., vol. 17, p. 2887.

[2] Pittman, E. P., Alunite or alumstone in New South Wales: Rept. Geol. Survey New South Wales, 1901, pp. 419–429.

One subject that does not appear to have received direct consideration in the processes applied to the foreign alunites is suggested in Schaller's experiments and relates to the feasibility of utilizing the potassium in the form of the simple sulphate instead of as an alum. For agricultural purposes the sulphate is probably the most desired form in which to use the potash; at least it is so quoted in regard to the German salts.

It is also evident that the oxide of aluminum in a rather pure state would result as a by-product in the reduction suggested by Schaller's experiments. At present it is not known that this alumina is directly available for the manufacture of metallic aluminum, but its use as a possible substitute for the mineral bauxite is a natural suggestion. Bauxite, a natural hydrous oxide of aluminum and now the principal source of the metal, is rapidly becoming scarcer, as the deposits are of a type that may become exhausted unless some satisfactory substitute can be found. This suggestion is further borne out in the following note:[1]

> The expiration of the aluminum-process patents and the great increase in output of metallic aluminum, have given rise to many scientific researches and commercial inquiries regarding new methods of producing metallic aluminum. These inquiries are appropriate in view of the fact that bauxite is found in comparatively few places, must be transported long distances, and contains so much silica as to require costly chemical operations to purify it in the manufacture of metallic aluminum. Aluminum silicates, on the other hand, are found almost everywhere, and the separation of the silica from them may, at some future time, not cost more than to counterbalance the scarcity, inaccessibility, and impurities of the bauxite deposits.

SUGGESTIONS AS TO PROSPECTING FOR ALUNITE.

Until recently there has been no incentive to search for alunite and most of the known occurrences in this country have been noted by geologists who were making studies of the areas where it occurs. There is little doubt that if prospectors had searched for alunite with the same diligence that they have shown in their search for the metallic ores a far greater number of occurrences would be known. Since it was shown by Ransome that alunite is associated with the rich gold ores of Goldfield, Nev., it has attracted more attention, and if the mineral itself proves to be of commercial value the search for it will be still further stimulated.

In the case of a mineral whose occurrence has been studied in so few places it is impossible to give a definite and positive statement of the conditions under which it may be expected to be found; or if such a statement were made it would probably be modified by future discoveries. The study of the occurrences thus far described, how-

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[1] Mineral Resources U. S. for 1910, chapter on production of bauxite and aluminum, U. S. Geol. Survey, 1911.

ever, does point rather definitely to certain conditions under which the mineral may form and the conclusions derived from this study may therefore aid in a further search for it.

As has been shown in the foregoing pages, there are at least two distinct conditions under which the mineral is deposited:

1. It may form by the action of descending acid solutions, derived from the oxidation of sulphides, on potassium-aluminum silicates (feldspars or micas). Several occurrences have been noted where the mineral is thus associated with oxidized ores, usually in or close to feldspathic rocks, and a more careful examination of material that has been called kaolin and talc will doubtless show some of it to be alunite. As yet no body of this type that promises to be of commercial importance has been discovered, but it is by no means impossible that such bodies exist and large bodies now described as kaolin and talc, but not definitely known to be such, may well be tested to determine whether they are not alunite. It may be stated in this connection also that the closely allied mineral jarosite has been noted in the oxidized zone of several ore bodies, and this mineral, too, may in some places occur in considerable abundance.

2. The deposits that at present give the greatest promise of commercial importance have resulted either from the action of hot waters carrying sulphuric acid on rocks containing potassium-aluminum silicates or from the deposition in veins from ascending thermal solutions. In the former type the resulting alunite is largely disseminated through the altered rock, though small veins of nearly pure material are not uncommon; in the latter type, as shown in the Marysvale deposit, it has been carried in the solutions and deposited as a large vein. The deposits of these types thus far discovered have been in or closely associated with the extensive bodies of Tertiary igneous rocks that are abundant in the Great Basin and Rocky Mountain region.

In connection with the alteration that has produced the alunite there has been a silicification of the rock which has rendered it resistant to weathering and the outcrops are usually rugged, standing above the surrounding rocks. Pyrite is also commonly formed in the wall rock during the alteration, and in places the oxidation of this mineral at the surface imparts an iron stain to the outcrop. As has already been pointed out, it is believed that the Marysvale deposit is closely associated with metallic veins of a type widely distributed through the Western States. It is certain that in some of the districts where such veins occur alunite is not present, at least not in important amounts, but it is by no means improbable that it may be found in other districts, and an examination of supposed "spar," "talc," or "kaolin" veins may show the presence of the mineral. Although it may be expected to occur in districts with metal veins and is believed to be closely related to them in origin, the alunite deposits themselves may not contain important metal values, as is indicated by the Marysvale deposit and the two Colorado deposits mentioned above. On the other hand, as at Goldfield, it may be closely associated with the metallic deposits.

In the Tushar and neighboring ranges there are reported to be numerous silicified vein outcrops described as "geysers," which on examination may prove to carry alunite or other salts of commercial importance.

FIELD TEST FOR ALUNITE.

The following simple field test for the mineral alunite has been suggested by W. T. Schaller: Boil the powdered sample with water or with hydrochloric acid for several minutes; after allowing the powder to settle pour off the liquid and repeat the operation to insure the removal of all soluble sulphates. Dry the powder and heat to a dull red. Again boil in water and, after settling, pour off some of the clear liquid. To this add a small fragment or a solution of barium chloride. If the mineral is alunite a heavy white precipitate will form. To be sure that the water used in this test does not contain sulphates in solution it should be tested with barium chloride, and if it gives a marked precipitate it can not be used. For this test all that is required that is not included in a miner's or prospector's outfit is a little barium chloride, which can be carried in a small bottle or cartridge.

WARNING TO INVESTORS.

Deposits may exist on ground adjoining the claims already located and partly developed, but it should be borne in mind that the present developments have not yet proved the continuity either in depth or even with certainty for a very great distance on the surface. Prospective investors should understand that until the true character and commercial availability of a deposit of this type have been demonstrated, they are taking chances in investing in the stock of any company professing to be about to develop such a deposit. The Geological Survey has been assured on reliable authority that the property covering the best-known part of the alunite deposit, which is described in the foregoing pages, is not for sale, and its owners are not in need of assistance, financial, technical, or otherwise, for the development of the property to its best advantage. It should be unnecessary to say to anyone who is familiar with the usual procedure in such an enterprise that if responsible persons have secured control of a deposit which offers large and unusual promise but whose actual commercial value is not wholly proved, it will not be necessary for them to advertise widely for contributions or express a willingness to distribute large quantities of stock, if they actually intend to develop the property on a commercial basis. Such a procedure should of itself be a warning to any who may be contemplating an investment of this character.

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