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PRELIMINARY REPORT ON THE ALUNITE DEPOSITS OF THE MARYSVALE REGION, UTAH

BY
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PRELIMINARY REPORT ON THE ALUNITE DEPOSITS OF THE MARYSVALE REGION, UTAH

By Eugene Callaghan

ABSTRACT

The Marysvale alunite region embraces parts of the Tushar Mountains, the Antelope Range, the Sevier River Valley, and the Sevier Plateau in the High Plateaus of southwest-central Utah. Interest in the alunite deposits as a possible source of aluminum as well as of potash has led to a detailed survey, which was initiated in the summer of 1936. This preliminary report outlines some of the major features of the geology and of the alunite deposits and is based on a brief period of field work and previously published data. Much of the surface of the elongate mountain blocks of the Tushar Mountains and the Sevier Plateau is near or above 10,000 feet in altitude. The Tushar Mountains have been deeply dissected, and sharp peaks over 12,000 feet in altitude rise more than 6,000 feet above the lowlands.

The six rock units thus far recognized are as follows: (1) pre-Tertiary sedimentary rocks that include Permian, Lower Triassic, and Jurassic formations; (2) sedimentary rocks of the Wasatch (?) formation, of Eocene age; (3) earlier Tertiary (?) volcanic rocks and associated intrusive bodies of quartz monzonite; (4) later Tertiary (?) volcanic rocks; (5) sedimentary rocks of the late Pliocene or early Pleistocene Sevier River formation herein named; and (6) Quaternary alluvium and glacial debris. With the possible exception of the pre-Tertiary formations, which may be disconformable, all the rock units are unconformable and separated by erosion intervals. The presence of Permian and Lower Triassic fossils has only recently been known. Though plateau structure predominates, there are broad warps, a small amount of close folding, and an abundance of faults. Normal faulting is the common type, but reverse faults have been found. The major elongate mountain and valley blocks are believed to be outlined by fault systems, but each major block is composed of many minor blocks and structural elements. Faulting and folding took place both before and after the deposition of the Sevier River formation.

Alunite was first recognized in the Marysvale region in 1910 and was mined on several properties between 1915 and 1920. The total output was not greatly in excess of the 250,000 tons of alunite produced by the Mineral Products Corporation and treated locally to yield potassium sulphate. Two types of deposits are characterized by their occurrence as veins and as replacement bodies in altered igneous rock. The vein deposits, which are limited to the upper reaches of Cottonwood Creek in the Tushar Mountains, consist chiefly of pink coarse-grained alunite with a minor amount of fine-grained alunite in lenticular shoots from a few feet to 65 feet wide and as much as 1,000 feet long. The vein alunite is the potash variety, and relatively pure material can be obtained. Alunite in the replacement deposits is very fine grained and is associated with highly variable proportions of quartz. The soda variety, natroalunite, makes up some of the replacement deposits. A total of 13 analyses of the vein deposits and their wall rocks and 39 analyses of the replacement deposits gives a clearer impression of the variations in quality of the materials than has heretofore been available. Notes on 19 properties or deposits are included.

INTRODUCTION

The alunite[1] deposits in the vicinity of Marysvale, in the south-west-central part of Utah (fig. 15), have attracted much attention since their discovery in 1910. Alunite, a hydrous sulphate of potassium and aluminum, containing theoretically 11.4 percent of potash and 37 percent of alumina, has been particularly intriguing to industrial chemists and metallurgists. Under the stimulus of excessively high prices for potash during and for a brief period after the World War, the alunite deposits were actively prospected and developed. However, only one mine, that of the Mineral Products Corporation, was developed and made to produce on a large scale. Even with this restricted production, the alunite deposits are credited with 4 to 7 percent of the potash output of the United States during the war period. Though the alumina was separated, it was not sold during this period. With the decline in the price of potash, operations ceased, though small shipments have been made almost every year since that time for fertilizer or for experimental purposes.

The possibility of obtaining metallic aluminum with potash as a byproduct has lately revived interest in the alunite deposits and stimulated fresh experimental research, now in progress. Though this possibility was considered by the early operators, no commercially workable process in the economical treatment of the material was then devised. It was with the hope that sufficient reserves of alunite could be proved to attract industry to the region that Utah citizens requested a detailed survey. In response to this request the topographic and geologic mapping of the region and a detailed study of the deposits were started by the United States Geological Survey in 1936.

This report must be regarded as strictly preliminary, as it is based on field work lasting only 2½ months and on published reconnaissance work of others. By far the greater part of the work, both in the field and in the laboratory, remains to be done. Consequently, both observations and conclusions set forth here may be modified through further work.

The period from July 6 to September 23, 1936, was devoted to field work, which included reconnaissance of much of the region, particu-

[1] Some of the material is the soda variety, natroalunite, but for the purposes of this economic report the term alunite is used throughout.

larly that covered by the published map of the Sevier quadrangle, as well as detailed areal mapping on a field scale of 1:31,680 in the vicinity of Sevier and Belknap. Detailed topographic and geologic

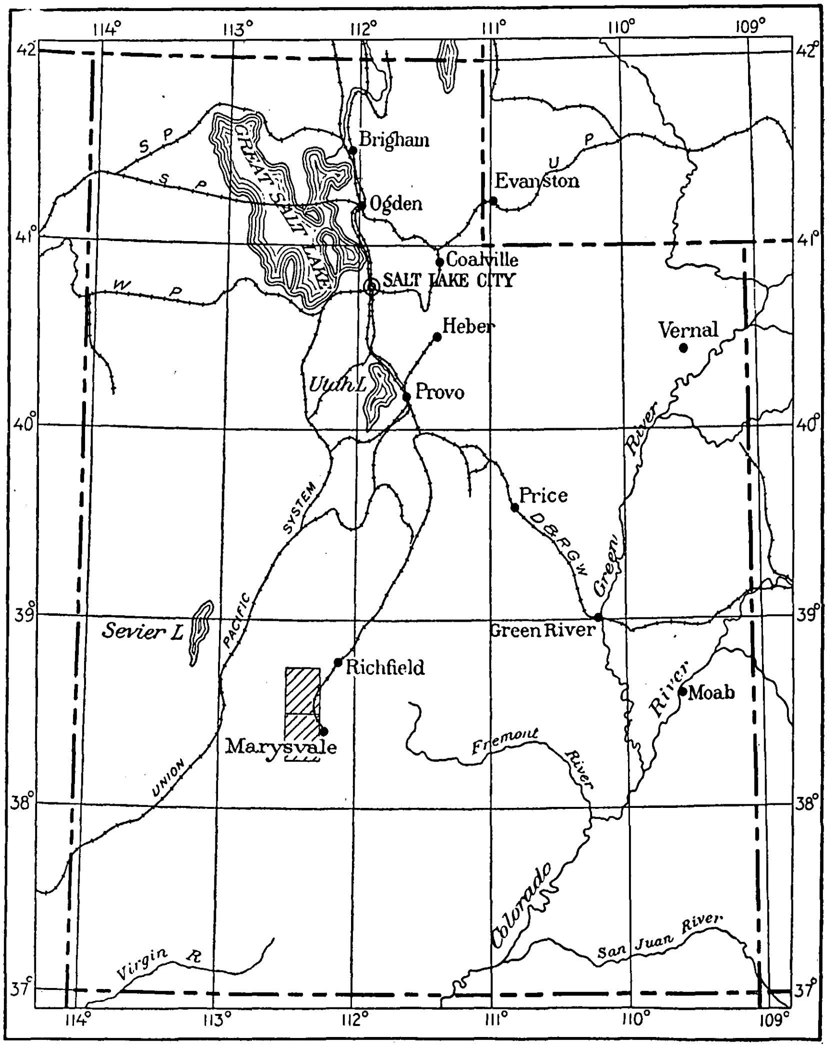

FIGURE 15.—Index map showing location of the Sevier and Delano Peak No. 2 quadrangles in the Marysvale region, Utah.

maps of the Big Star, L. & N., and Sunshine deposits on a scale of 1 inch to 200 feet, were prepared. Mapping of the area around the Mineral Products mine on the 200-foot scale was undertaken, and mapping of the underground workings of this mine was nearly completed. Topographic mapping of the Delano Peak No. 2 quadrangle, which lies immediately south of the Sevier quadrangle, was started by R. T. Evans, W. B. Upton, Jr., and E. S. Rickard.

Throughout the field work the writer was ably assisted by George F. Seager and for a short time by George A. Kennedy. Many people helped in every way possible. The writer is particularly grateful to Nicholas Touroff, who has had charge of the Mineral Products or Armour property since operations ceased; to the late Claude Kenyon, who had charge of the Florence Mining & Milling Co.'s properties; to Joseph Burns, who has a large group of claims in the district; and to H. S. Gibbs, Patrick Henry, Lafe King, Frank Sargent, Jacob Young, and many others at Marysvale. C. N. Gerry, supervising statistician of the Salt Lake section of the United States Bureau of Mines, and Bert Dyer, of the United States Geological Survey, aided with introductory information. Officials of the Fishlake National Forest were very helpful. F. J. Martines, president of the Southern Utah Civic Association, offered material he had collected. To Dr. Arthur Fleischer, manager of the pilot plant of the Kalunite Co. at Salt Lake City, the writer is indebted for a large amount of technical information on the deposits, including compiled maps, engineer's reports, chemical analyses, and other data that were used freely in the preparation of this report. G. H. Girty, K. E. Lohman, and F. S. MacNeil, of the Geological Survey, and J. P. E. Morrison, and H. A. Rehder, of the National Museum, identified the fossils. D. F. Hewett and G. R. Mansfield, of the Geological Survey, have read the manuscript critically.

The geologic features of the alunite deposits have been described by Butler and Gale,[2] Loughlin,[3] and Butler.[4] Butler and Gale visited the region at various times in 1911, shortly after the recognition of alunite there. Their report contains such information as could be obtained at the early stages of exploration of the veins, together with a summary of the geology of the region and a discussion of other alunite occurrences and possible modes of origin. The area was studied briefly by Loughlin in 1914 and by H. S. Gale and V. C. Heikes in 1915. The results of their studies are incorporated in Loughlin's paper, which was written when mining and milling were active and several new prospects had been discovered. Two articles by Tingley[5] add little detailed information. The deposits were visited briefly by J. R. Thoenen,[6] of the Bureau of Mines, whose observations are recorded in a paper published in 1932. R. G. Knickerbocker,[7] of the same bureau, obtained samples for analysis and elec-

[2] Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: U. S. Geol. Survey Bull. 511, 64 pp., 1912.

[3] Loughlin, G. F., Recent alunite developments near Marysvale and Beaver, Utah: U. S. Geol. Survey Bull. 620, pp. 237–270, 1915.

[4] Butler, B. S., Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 181–183, 186–187, 190–195, 546–550, 552–554, 1920.

[5] Tingley, R. H., Alunite deposits in the United States: Rock Products, vol. 25, pp. 38–43, March 25, 1922; Alunite and its products: Eng. and Min. Jour.-Press, vol. 115, no. 11, pp. 494–497, 1923.

[6] Thoenen, J. R., Economics of potash recovery from wyomingite and alunite: U. S. Bur. Mines Rept. Inv. 3190, pp. 22–32, 1932.

[7] Knickerbocker, R. G., and Koster, J., Electrometallurgical studies in the treatment of alunite: U. S. Bur. Mines Rept. Inv. 3322, pp. 39–64, 1936.

trometallurgical study. D. F. Hewett,[8] of the United States Geological Survey, visited the principal mine in connection with the survey of the mineral resources of the region tributary to Boulder Dam. The alunite deposits have been the subject of many private reports by geologists and engineers. Reports on the Pittsburgh property by R. L. Smith, on the Close In property by A. D. Knowlton, and information in a report by Sidney Ball on the White Hills and Close In properties, were all made available to the writer through the courtesy of Dr. Fleischer. Most of the maps and data on file in the offices of the Mineral Products Corporation were destroyed by fire in 1931, but a map of the Mineral Products mine was furnished by Mr. Touroff. Patent surveys of some of the properties have been made.

The general geology of the alunite region has been treated in the first three publications mentioned above and in Dutton's classic treatise on the High Plateaus.[9] The geomorphology of a part of the Marysvale region has been described in a paper by Eardley and Beutner[10] which also includes geologic material. Theses prepared by E. L. Beutner on the geology of the east front of the Tushar Mountains and by J. V. Christianson on the alunite deposits were not seen by the writer.

GEOGRAPHY

With one exception the principal alunite deposits are within a radius of 8 miles of Marysvale, Piute County, Utah (fig. 16). This town of 471 population (1930 census) is the terminus of the Marysvale branch of the Denver & Rio Grande Western railroad. It is 132.2 miles by rail from Thistle, on the main line of the railroad, and 197.7 miles from Salt Lake City. It is about 170 miles by rail from the coal-producing region of Price River Canyon, but about 65 miles by road from the Salina Canyon coal field. A hard-surfaced highway extends 30 miles to Richfield and thence 175 miles by way of Thistle to Salt Lake City. At present Marysvale is served by a daily passenger train and freight trains, as well as by auto stages and truck lines.

The Marysvale region is within that part of the High Plateaus underlain by volcanic rocks and includes parts of the Tushar Mountains, Sevier Plateau, Sevier River Valley, and Antelope Range (fig.

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[8] U. S. Geol. Survey, Mineral resources and possible industrial development in the region surrounding Boulder Dam, pp. 18–19, U. S. Bur. Reclamation, 1934. Hewett, D. F., and others, Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, pp. 146–147, 1936.

[9] Dutton, C. E., Report on the geology of the High Plateaus of Utah, pp. 171–194, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

[10] Eardley, A. J., and Beutner, E. L., Geomorphology of Marysvale Canyon and vicinity, Utah: Utah Acad. Sci. Proc., vol. 11, pp. 149–159, July 1934. Eardley, A. J., Geomorphology of Marysvale Canyon and vicinity, Utah [abstract]: Geol. Soc. America Proc., 1933, p. 77, 1934.

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16). This group of elongate uplands, which in many places attain altitudes of 10,000 feet or more and are trenched by valleys as much as 5,000 feet deep, lies between the Great Basin on the west, the Canyon Lands on the east, the Wasatch Mountains on the north, and the Grand Canyon section of the Colorado Plateaus on the south. In

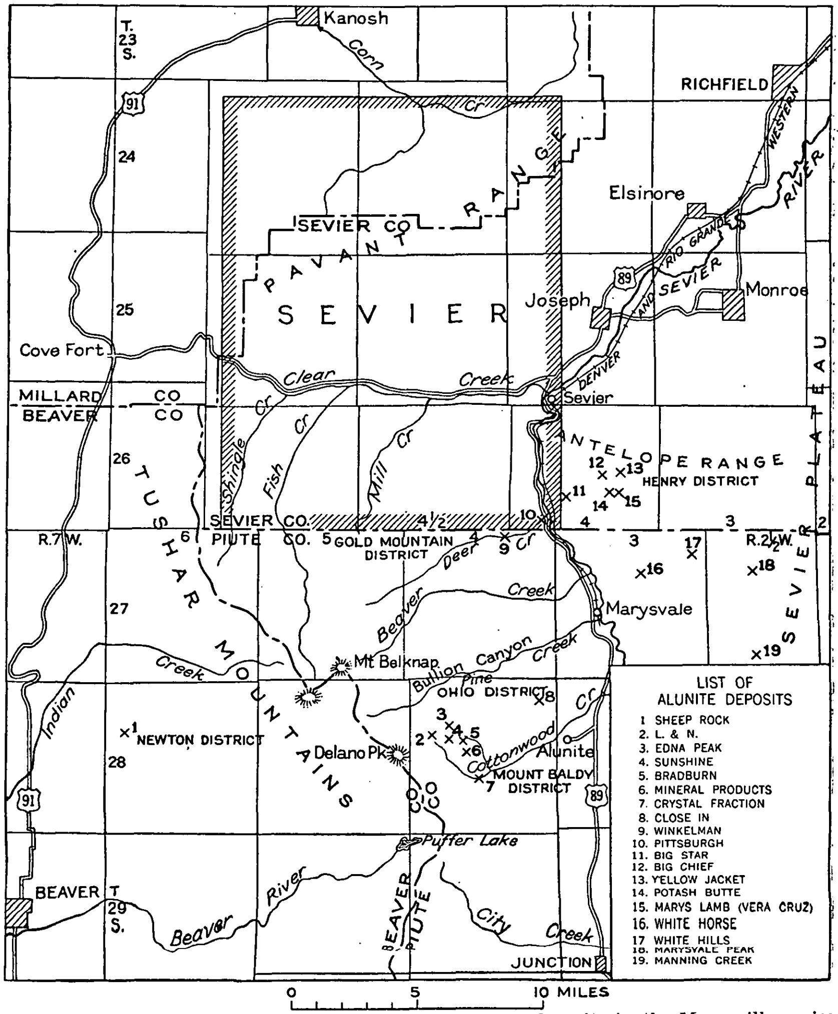

FIGURE 16.—Outline map showing distribution of alunite deposits in the Marysville region, Utah, and outline of the Sevier quadrangle. Base modified from Forest Service map of Fishlake National Forest.

the High Plateaus as a whole the long, narrow uplands and valleys trend in a north-northwesterly direction throughout most of their length, but in the Marysvale region the Tushar Mountains, Sevier River Valley, and Sevier Plateau trend north. The westernmost of the long uplands includes the Markagunt Plateau, the Tushar Mountains, and the Pavant Range in order, from south to north. The central upland includes the Paunsagunt Plateau, the Sevier Plateau, and the Wasatch Plateau in like order. This region is transitional in its structure and appearance between the Great Basin and the Colorado Plateaus.

The Tushar Mountains occupy an area 18 miles wide and 35 miles long and are separated from the Markagunt Plateau on the south by Fremonts Pass and from the Pavant Range on the north by the basin of Clear Creek. Much of the upland surface is above 10,000 feet in altitude, and Delano Peak, the highest point in the State outside the Uinta Mountains, reaches a height of 12,173 feet. Steep slopes 2,000 to 5,000 feet high face the lowlands on the east and west, and the northern slope rises 3,000 to 5,000 feet above the basin of Clear Creek. Though the dip slope is toward the west and southwest, the highest peaks are only slightly closer to the eastern than to the western side. Deep canyons cut both the eastern and western slopes, and the mountains as a whole are more dissected and rugged than any other part of the High Plateaus. However, there are many gently sloping upland surfaces.

The Pavant Range is much lower than the Tushar Mountains and has a much larger area of preserved upland. It slopes more gently into the Sevier River Valley than the Tushar Mountains.

The Sevier Plateau rises abruptly as much as 5,500 feet above the east side of the Sevier River Valley and slopes gently to the east. Despite its height, it is not as deeply dissected as the Tushar Mountains.

The Sevier River Valley is not a simple valley flat but contains individual mountain blocks that rise as much as 1,500 feet above the river. Most of these blocks are parallel to the valley, but at Marysvale Canyon and Circleville Canyon, south of the Marysvale area, the river has been obliged to incise canyons—generally less than 1,000 feet deep—in mountain blocks athwart its path. The block at Marysvale Canyon, known as the Antelope Range, consists of rounded hills on an upland about 1,000 feet above the river. Moderate slopes face both to the north and to the south.

Gravel terraces and rock pediments [11] are prominent features of the valley both north and south of the Antelope Range. Remnants of gravel terraces were found at several levels in Marysvale Canyon and near the mouth of Clear Creek. Alluvial fans occur along the sides of the valleys, but in some places the distinction between fan and gravel-covered pediment is not clear. The heads of some of the streams in the Tushar Mountains have been modified by glaciation, but cirque lakes are rare.

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[11] Eardley, A. J., and Beutner, E. L., op. cit., pp. 149–159. Butler, B. S., op. cit. (Prof. Paper 111), p 537

GEOLOGY

PRINCIPAL FORMATIONS

The preliminary work has not been sufficient to delimit the rock units with certainty. The six units thus far recognized, in order from oldest to youngest, are (1) pre-Tertiary sedimentary rocks, (2) Wasatch(?) formation, (3) earlier Tertiary(?) volcanic rocks and associated intrusive bodies of quartz monzonite, (4) later Tertiary(?) volcanic rocks, (5) Sevier River formation, and (6) Quaternary alluvium and glacial debris. Of all these units the earlier volcanic rocks and associated intrusive bodies are of the greatest economic importance, as they appear to contain all the alunite deposits as well as some gold, silver, and base-metal veins. The pre-Tertiary sedimentary rocks have apparently been unfavorable to the deposition of alunite, but they contain other mineral deposits.

Pre-Tertiary sedimentary rocks.—Sedimentary rocks crop out along the east front of the Tushar Mountains between Tenmile Creek, 3½ miles south of Cottonwood Creek, and Pine Creek. The best exposures are in the face of Deer Trail Mountain, northwest of Alunite, but there are exposures as far west as the upper reaches of Cottonwood Creek and the Bully Boy mine, in Bullion Canyon. Outcrops range in altitude from 6,950 feet at the mouth of Bullion Canyon to more than 10,800 feet on the ridge east of the North Fork of Cottonwood Creek.

A geologic section of the beds exposed on Deer Trail Mountain, mentioned by Butler,[12] includes at the base a bed of quartzite more than 200 feet thick which is succeeded by interbedded quartzite and dolomite with a limestone bed near the top containing Permian fossils. The thickness of the beds above the quartzite is about 650 feet. These beds are succeeded by about 500 feet of thin-bedded limestones and shales containing Lower Triassic fossils. Nonmarine red shales and sandstones having a total thickness of about 1,100 feet lie between the Lower Triassic and a mass of quartzite about 1,000 feet thick. Limestones containing lower Upper Jurassic fossils lie upon the quartzite and are succeeded by yellowish limy shales and thin beds of red sandstone.

These beds have been called Jurassic by Dutton [13] and Butler [14] on the basis of fossil collections assigned to that age, and other writers [15]

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[12] Butler, B. S., Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 538, 1920.

[13] Dutton, C. E., Report on the geology of the High Plateaus of Utah, p. 184, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

[14] Butler, B. S., op. cit., p. 538.

[15] Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: U. S. Geol. Survey Bull. 511, p. 14, 1912. Loughlin, G. F., Recent alunite developments near Marysvale and Beaver, Utah: U. S. Geol. Survey Bull. 620, p. 239, 1915. Eardley, A. J., and Beutner, E. L., Geomorphology of Marysvale Canyon and vicinity, Utah: Utah Acad. Sci. Proc., vol. 11, p. 151, July, 1934.

have followed this designation. However, poorly preserved fossils collected by Jacob Young from Deer Trail Mountain were identified by the Geological Survey in 1931 as of probable Carboniferous age. Subsequent more complete collections by the writer and his assistants have permitted the age assignments given above.

Wasatch (?) formation.—Sandstones, shales, and sparse limestones make up the bulk of the Pavant Range west of Richfield, and they crop out in the northern part of the Sevier quadrangle. These beds are not known to be represented in the immediate vicinity of the alunite deposits.

Near Richfield these rocks are chiefly yellowish and red sandstones, red shales, and sparse whitish fresh-water limestones. Southwest of Richfield soft greenish shales with gypsum lie between the sandstones and the overlying volcanic rocks. Richardson [16] states that red and buff conglomerate and sandstone at least 2,000 feet thick underlie these beds and overlie Paleozoic rocks in the basin of Corn Creek. No age is assigned by Richardson to the lower conglomeratic portion, but he regards the remainder as being part of the Wasatch formation, of Eocene age.

Earlier Tertiary (?) volcanic rocks and associated quartz monzonite bodies.—Volcanic rocks make up the bulk of the Tushar Mountains, the Sevier Plateau, the Antelope Range, and the basin of Clear Creek. Butler and Gale [17] and later writers [18] have recognized two divisions of the volcanic rocks in the Tushar Mountains.

The earlier series is exposed in Marysvale Canyon, along the eastern front of the Tushar Mountains above the pre-Tertiary sedimentary rocks, and in the Antelope Range. In the vicinity of the alunite deposits at the head of Cottonwood Creek this series is at least 2,000 feet thick.

In many places a conglomerate made up of quartzite and dolomite pebbles with limy sandstone beds lies between the volcanic series and the earlier sedimentary rocks. Most of this formation is 50 feet or less in thickness.

The greater part of the earlier group of volcanic rocks is composed of poorly sorted and bedded volcanic breccia and tuff, but some beds of conglomerate partly made up of boulders of limestone and quartzite are exposed in Marysvale Canyon. Over much of the area the volcanic rocks are medium gray with a purplish cast, though those near the mouth of Marysvale Canyon are yellowish. Some of the rock fragments are andesite, but dacite and quartz latite are doubtless represented. The minor proportion of flows appears to be mostly quartz latite, though andesite and dacite are

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[16] Richardson, G. B., Underground water in Sanpete and central Sevier Valleys, Utah: U. S. Geol. Survey Water-Supply Paper 199, p. 10, 1907.

[17] Butler, B. S., and Gale, H. S., op. cit., pp. 14–15.

[18] Loughlin, G. F., op. cit., p. 239. Butler, B. S., op. cit., pp. 538–539. Eardley, A. J., and Beutner, E. L. op. cit., p. 153.

probably present. A thick flow of red porphyritic quartz latite, locally known as the "red porphyry", makes up several high peaks at the head of Cottonwood Creek.

The earlier group of volcanic rocks has been intruded by masses of quartz monzonite. The most conspicuous body is exposed in Marysvale Canyon at the mouth of Deer Creek, and Butler[19] estimates that it occupies an area of 8 to 10 square miles in the Antelope Range. A dike and a plug of related rock are also exposed in Marysvale Canyon. According to Butler,[19] dikes of similar rock are exposed near the Annie Laurie mine, in the northeastern part of T. 27 S., R. 5 W., and a large intrusive body crops out along Indian Creek, on the western slope of the Tushar Mountains. The intruded rocks near the contacts have been modified by the heat and solutions of the intrusive magmas, and in places, such as Marysvale Canyon, have been turned dark gray or black.

From evidence outside this area the earlier group of volcanic rocks is believed to be later than the Eocene Wasatch formation and to have been deposited on an irregular post-Wasatch erosion surface that had exposed pre-Tertiary rocks. It probably belongs to the early or middle Tertiary. The intrusion of the quartz monzonite and the formation of most if not all of the mineral deposits seem to be restricted to the time between the accumulation of this group of volcanic rocks and the accumulation of the later series of volcanic rocks.

Later Tertiary (?) volcanic rocks.—The later Tertiary (?) volcanic rocks crop out most conspicuously in the basin of Clear Creek. They blanket the south end of the Pavant Range and may extend as far south as the head of Bullion Canyon in the Tushar Mountains.

The most conspicuous part of the formation is a white rhyolitic tuff that has been so deeply carved by erosion as to produce high cliffs and impressive scenery along the course of Clear Creek. Toward the north and west this tuff grades into a tuff composed largely of crystal fragments. Interbedded flows or porphyritic quartz latite become prominent in the upper reaches of Clear Creek. The entire formation is well over 1,000 feet thick in the Clear Creek Basin.

No definite age can be assigned to this formation. It appears to be later than the intrusive rocks and mineral deposits but is earlier than the overlying late Pliocene or early Pleistocene Sevier River formation. This series of volcanic rocks probably accumulated in middle or late Tertiary time.

Sevier River formation.—A series of partly consolidated sediments has been conspicuously exposed by the dissection of pediments over an area of about 4 square miles north of the junction of

[19] Butler, B. S., op. cit., p. 539.

Clear Creek and the Sevier River. Several smaller detached areas have been preserved by down-faulting in the synclinal basin of Clear Creek. Similar sediments make up low hills west of Marysvale and crop out in partly dissected pediments southwest of Marysvale.

In the Clear Creek area these sediments consist of fanglomerate, conglomerate, sand, and silt derived chiefly from the rhyolitic tuffs and to a lesser extent from the quartz latite flows of the later Tertiary (?) volcanic rocks. The fanglomerate and conglomerate grade eastward into pinkish sand and silt, which in turn grade into white diatomite beds, evidently deposited in a lake. Some opalized beds were found in the pinkish silts. The pinkish beds near Marysvale contain quartzite fragments.

On the atlas sheets prepared by Dutton [20] parts of the areas occupied by this formation are shown as Tertiary. On Richardson's reconnaissance map [21] a part of this formation is shown as the Wasatch formation. However, the diatomite beds 2 miles north of Sevier yielded, in addition to fresh-water gastropods, diatoms that K. E. Lohman, of the United States Geological Survey, regards as of upper Pliocene or lower Pleistocene age. The name Sevier River is here applied to this formation.[22] The Sevier River formation is of particular significance in providing a reference for dating structural and stratigraphic events in the region.

Quaternary alluvium and glacial debris.—The floors of the valleys both north and south of Marysvale Canyon are mantled with gravel and silt. Pediments [23] are veneered with alluvium. Terrace gravel was found 600 feet above the present channel of Clear Creek and 300 feet above the present course of Sevier River near the south end of Marysvale Canyon. Broad terraces are particularly prominent south of Marysvale.

Lateral glacial moraines are preserved along Cottonwood Creek northwest of the Crystal Fraction alunite prospect. Other glacial deposits doubtless veneer areas in the high portions of the Tushar Mountains.

STRUCTURE

At the present time little can be added to the discussions of structure given in other reports.[24] It is believed that the steep eastern

[20] Dutton, C. E., Report on the geology of the High Plateaus of Utah, atlas sheet 2, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

[21] Richardson, G. B., op. cit., pl. 2.

[22] Callaghan, Eugene, Alunite deposits of the Marysvale region, Utah [abstract]: Econ. Geology, vol. 32, p. 191, 1937.

[23] Eardley, A. J., and Beutner, E. L., op. cit., p. 150.

[24] Dutton, C. E., Report on the Geology of the High Plateaus of Utah, pp. 28–29, 172–173, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880. Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: U. S. Geol. Survey Bull. 511, pp. 16–17, 1912. Loughlin, G. F., Recent alunite developments near Marysvale and

and western fronts of the Tushar Mountains are determined by systems of faults, so that the mountain block is essentially a horst. The western front of the Sevier Plateau, in which the bedding is inclined eastward, is also believed to be outlined by a fault system called the Sevier fault by Dutton.[25] The rocks underlying the Sevier River Valley are broken into several blocks, the bedding in most of which strikes nearly parallel to the valley and dips toward the east.

Throughout the greater part of the Tushar Mountains the bedding, though locally warped, dips toward the west and southwest. This applies to the pre-Tertiary as well as to the Tertiary rocks. However, in the northeastern part the structure is more complex. Incomplete mapping indicates that the beds of volcanic rock dip northward toward Clear Creek and eastward toward Marysvale Canyon. The bedding dips to the south and southeast near the south end of Marysvale Canyon. Eardley and Beutner [26] pointed out that the Tushar fault on the east side of the Tushar Mountains does not extend farther north than the vicinity of Beaver and Deer Creeks. It appears from these observations that at least the western part of the Antelope Range is an eastward-sloping projection of the Tushar Mountains. Dips to the north at the north side of the Antelope Range and to the south at the south side indicate that it is to some extent anticlinal.

The valley of Clear Creek occupies an eastward-plunging syncline whose axis is close to the course of the creek. This syncline is cut off on the east by several faults which are in line with the northeastward-trending eastern front of the Pavant Range and strike southwestward into the face of the Tushar Mountains. The Pavant Range appears to be anticlinal in part, with sandstone beds curving downward against faults along the east front of the range.

Though plateau structure predominates, there has been broad folding and warping, possibly some close folding, and much faulting in both the mountain and valley blocks. One of the northeastward-trending faults 1½ miles west of Sevier is a rotational or scissors fault. For a short distance north of the point of change in throw, the reverse portion of the fault dips as low as 22° W., with the later Tertiary (?) volcanic tuffs overriding the Sevier River formation. Faults in the vicinity of the vein deposits of alunite near the head of Cottonwood Creek trend both northwest and west, but the veins do not appear to have been appreciably disturbed by postmineral faulting.

Beaver, Utah: U. S. Geol. Survey Bull. 620, p. 239, 1915; Butler, B. S., Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 540, 1920. Eardley, A. J., and Beutner, E. L., Geomorphology of Marysvale Canyon and vicinity, Utah: Utah Acad. Sci. Proc., vol. 11, pp. 149–159, 1934.

[25] Dutton, C. E., op. cit., pp. 30–32.

[26] Eardley, A. J., and Beutner, E. L., op. cit., p. 151.

SUMMARY OF GEOLOGIC HISTORY

An interpretation of the geologic history of the Marysvale region derived from the meager information at hand must be recognized as highly provisional and subject to material revision in the light of further data. However, it may serve to coordinate the information given in the preceding pages, part of which is derived from published sources.

The Wasatch (?) formation was probably distributed over an irregular surface of older beds that included Permian, Triassic, and Jurassic sedimentary rocks in the western part of the Marysvale region and possibly Cretaceous rocks in the now buried eastern part. It is possible that the pre-Tertiary rocks in the Tushar Mountains were never covered by the Wasatch formation.

The Wasatch (?) formation was moderately warped, probably faulted, and considerably eroded before the accumulation of the earlier Tertiary (?) volcanic rocks, which appear to make up the greater part of the volcanic sequence. These rocks were warped and faulted and intruded by quartz monzonite magma. Vein deposits characterized by quartz, carbonate, and adularia with gold, silver, and sulphides of the base metals followed the intrusion. This mineralization was followed by the alunitic alteration and vein filling, which was essentially barren of the metals associated with the earlier veins. All these rocks were probably extensively eroded before the accumulation of the later Tertiary (?) volcanic rocks.

The accumulation of the later Tertiary (?) volcanic rocks is believed to have been subsequent to all the events listed above, though proof is not yet complete. These rocks were probably deposited on an uneven erosion surface in Miocene or possibly in Pliocene time. Probably the major structural elements of the region were blocked out after the accumulation of the Tertiary (?) volcanic rocks.

The region was evidently moderately mountainous at the time of deposition of the later Pliocene or early Pleistocene Sevier River formation. The Tushar Mountain block had been uplifted and eroded sufficiently to expose the pre-Tertiary sedimentary rocks, for fragments of quartzite were found in the Sevier River formation near Marysvale. Though this formation must have extended far up into the mountains, the finer-grained sediments are near the Sevier River Valley. Lakes in which diatomite was deposited occupied part of what is now the Sevier River Valley. The upland erosion surfaces now partly preserved may have been formed after the deposition of the Sevier River formation and in part upon it.

Extensive warping and faulting took place after the deposition of the Sevier River formation, which was involved in such movements.

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Successive relative uplifts of the mountain blocks interspersed with periods of quiescence and widespread erosion may account for some of the benches formed on the sides of the Sevier River Valley. The Antelope Range, because of its attachment to the Tushar Mountain block, has not been depressed to the same extent as some of the other blocks within the Sevier River Valley. Possibly its position at the point of change in the regional structure may be a factor in its position above the valley floor. The Sevier River formation may have extended across the Antelope Range, and the river may have been superposed in its present course across older rocks from a surface on this soft formation. Detailed mapping and broad studies of the river valley should lead to more definite conclusions concerning the history of Marysvale Canyon.

Pediments on the soft Sevier River formation and gravel terraces attest to various stages in the lowering of the grade of the Sevier River. The proportion of the valley due to down-faulting and that due to erosion may never be clearly established, but the river has undoubtedly removed a vast amount of material.

The distribution of glacial debris suggests strongly that the land surface is practically the same now as it was during the Wisconsin glacial epoch. Probably many of the diastrophic and erosional events took place during the later part of Pliocene or early part of Pleistocene time.

ALUNITE DEPOSITS

HISTORY, DEVELOPMENT, AND PRODUCTION[27]

The alunite area in the Tushar Mountains has long been prospected for gold and silver. Many claims were located and some were patented on ground that was found later to contain alunite. In November 1910 Tom Gillen, one of the prospectors in the area, was sufficiently interested in the "pink spar" to send a sample to A. E. Custer, who was then connected with the United States assay office in Salt Lake City. This material was forwarded to the Geological Survey, where it was recognized as alunite. Samples were also sent to Howard F. Chappell, an industrial chemist, who recognized the possible value of the material. Custer authorized Gillen to locate as many claims as possible that might contain alunite, with the result that previous locations which had been allowed to lapse were relocated for alunite on January 1, 1911. Chappell soon examined and purchased these claims, which have since been known as the Custer group. He also located contiguous claims within

[27] Based largely on the reports by Butler and Gale, Loughlin, and Butler; the annual chapters on potash in Mineral Resources of the United States; notes in the Engineering and Mining Journal and Mineral Industry; and conversations with local people, particularly Messrs. Nicholas Touroff and Claude Kenyon.

the next 2 years. The Mineral Products Corporation was organized for exploitation of the deposit, with interest divided among Chappell, the Armour Fertilizer Works, and the United States Smelting, Refining & Mining Co.

Little was done until 1915, when the great increase in the price of potash made it apparent that the deposit could be worked commercially. The lower tunnel on the Custer No. 1 claim had reached the vein by 1913, but later explorations were largely confined to an upper tunnel 208 feet higher. Though a lens of alunite about 60 feet wide was exposed on the surface, it soon disappeared in the upper tunnel. This tunnel was continued, however, another lens of alunite reached, and sufficient reserves were blocked out to justify construction of a recovery plant. An aerial tramway having a capacity of 12½ tons an hour was built to take the crude alunite from the mine to a point on Cottonwood Creek about 1,800 feet lower, whence it was hauled in wagons 3½ miles to the mill. The recovery plant, constructed in 1915, was built a short distance east of the mouth of Cottonwood Canyon and 5 miles south of Marysvale. All parts of the plant were in operation by October 19, 1915, and the first shipment of 28 tons averaging 95.39 percent of potassium sulphate was made on October 22, 1915. The initial capacity of the plant was 100 tons of alunite daily, and as much as 25 to 30 tons of potassium sulphate was recovered daily.

Alum has long been obtained from foreign deposits of alunite by heating the alunite to a red heat, leaching the calcines in water, and crystallizing alum (hydrous potassium-aluminum sulphate) from the solution on evaporation. As a result of simple experiments in the laboratory of the United States Geological Survey, Schaller [28] found that 92 percent of the available potash present in the alunite was obtained as potassium sulphate by ignition at a higher temperature than red heat and subsequent leaching. Part of the sulphur trioxide and water was driven off by the ignition, and a residue of alumina was left after leaching. A commercial process utilizing this principle was developed and patented by Howard F. Chappell and was the only process used at the plant of the Mineral Products Corporation. The process as finally adopted is described by Thoenen [29] as follows:

> At the mill the ore was dumped on the ground for storage or directly to a no. 6 gyratory crusher, where it was reduced to 1½-inch size. The crusher discharged to a 50-ton bin which fed a set of 16- by 36-inch rolls crushing to ¼-inch, with no provision for return of oversize. The fine ore was elevated to a ¼-inch whip-tap screen with no oversize return, discharging into a 1-ton weighing hopper. The ore was then fed through a 6-inch water-jacketed pipe

[28] Schaller, W. T., in Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: U. S. Geol. Survey Bull. 511, p. 58, 1912.

[29] Thoenen, J. R., Economics of potash recovery from wyomingite and alunite: U. S. Bur. Mines Rept. Inv. 3190, pp. 24–25, 1932.

to a 6- by 130-foot rotary kiln with 9-inch fire-brick lining. The kiln was fired with pulverized coal.

Kiln gases were sent through a brick chamber with one baffle and thence escaped to the air. By means of a damper in the stack the gases could be drawn through two cyclone separators and a bag dust collector of local design. The gases from the cyclones were drawn through a series of air-cooled inverted U tubes to a second pair of cyclones and baggers. The cooled gases from the bagger were drawn back through the outside of the U tubes and heated before escaping to the stack.

The hot calcined ore was elevated to a steel clinker bin, which fed two 20-foot log washers. The discharge from the log washers was elevated to a 3-disk Aikens classifier from which the coarse material was sent to waste and the fines and liquor to four Dorr thickeners—28, 32, 34, and 36 feet in diameter by 9 feet in depth. The thickener constituted a countercurrent leaching system, with the liquor from no. 4 tank going to no. 3, from no. 3 to no. 2, from no. 2 to no. 1, and from no. 1 to the evaporator. The thickened pulp was discharged to waste. The solution which contained the potash values was sent to a 12- by 5-foot Kelly filter press or a 48- by 48-inch 60-leaf Schreiber filter press and thence to eight wooden storage tanks 9 by 20 feet. From these tanks the liquors went to three triple-effect Swenson vacuum evaporators heated by exhaust steam from the power plant. The condensed steam was returned as boiler-feed water. The salts from the evaporators were sent to open square wooden tanks, where the liquor was drained off and returned to the log washers for further leaching. The salts were centrifuged and bagged.

Originally the hot kiln discharge was digested with steam for 40 minutes at 40 pounds pressure in two 10- by 20-foot autoclaves before filter pressing. This overloaded the press, and the practice was abandoned in favor of the log washers.

The filter cake and the discharge from the thickener constituted the raw alumina, which was stored on the surface. A refined product was never made, although this was contemplated. The crude Al_2O_3 was marketed only for experimental purposes.

Slack coal was delivered at the mill for $6.56 per ton. It was stacked in piles on the ground, whence it was taken to a 5- by 50-foot cylindrical dryer, thence by an 18-inch belt conveyor to an 18- by 18-inch roll discharging to an elevator feeding a hopper over two 48-inch pulverizers. From these the coal was blown to the kiln.

Water was obtained from Cottonwood Canyon and delivered through 2,000 feet of redwood pipe at the rate of one-twentieth cubic foot per second.

Numerous difficulties were encountered in the treatment process. Losses during calcination were high, due to (1) incomplete calcination, leaving alum in the discharge, (2) overcalcination, resulting in volatilization losses, and (3) decrepitation and dusting of the ore when suddenly heated.

Excessive water was necessary for complete extraction, thus increasing evaporation costs. The tailings contained a high percentage of moisture, thus carrying considerable K_2SO_4 to waste. Under certain conditions, salts would precipitate in the evaporator tubes and make trouble. Alum and aluminum sulphate corroded the tubes, necessitating frequent replacements.

With several important interruptions, the mine and plant of the Mineral Products Corporation continued in operation from October 1915 to late in 1920. On November 2, 1916, the headhouse and other buildings at the mine burned, with the result that the cables on the tramway had to be replaced. According to a State report, during

1916 the production was 2,772.38 tons, presumably of potassium sulphate (K_2SO_4), the gross income was $610,266, the expenditures were $539,782, and the net return was $70,488. The capacity of the mill was increased to 175 tons of alunite daily, and 250 men were employed. On October 25, 1917, the main building of the plant was burned after an explosion. The rebuilt mill, with capacity increased to 200 tons a day, was in operation in April 1918. The maximum daily production of K_2SO_4 was 40 tons. Early in 1919 the Armour Fertilizer Corporation purchased the interests of the other owners and closed the plant. However, operations were resumed during the summer and continued until late in 1920, though the official closing date was January 1, 1921. Mr. Touroff, who had been mine superintendent since 1917, has remained in charge of the property. The equipment was kept in repair until 1928. A large part, if not all, of the K_2SO_4 produced was shipped to the Armour Fertilizer Works at Jacksonville, Fla.

Though the Mineral Products Corporation was the only well-organized, well-equipped, and successful operator in the region, many other alunite properties were developed to some extent. The large group of claims of the Florence Mining & Milling Co., adjoining the Custer claims of the Mineral Products Corporation on the northwest, had already been located for gold prospecting. Alunite was found along the ridge in a continuation of the zone exposed on the Custer claims, and most of the alunite veins now known had been prospected by 1914. After much delay a calcining plant was built a short distance south of the railroad station at Marysvale and placed in operation in August 1917. Alunite was hauled in wagons from the Sunshine mine to the mill, which had a capacity of 80 tons of alunite a day. The plant produced alunite calcines, which without further refinement were shipped to the Carraleigh Fertilizer & Phosphate Works at Raleigh, N. C. Later a potash plant of 100 tons capacity was built at the mine and completed in October 1918. Though reverberatory furnaces rather than rotary kilns were installed, no potash is known to have been produced. There was little subsequent development.

In 1918 Swift & Co. became interested in the alunite on the Bradburn claims, adjoining the Mineral Products property on the north, put up cabins and compressor, developed a large lens of alunite, and shipped alunite to their plant at Harvey, La.

In the area north of Marysvale the Yellow Jacket group of claims was developed by the American Smelting & Refining Co., and some alunite was shipped to its alum plant, erected in 1918 at Murray, Utah. The Utah Potash Co. took alunitized rock from large quarries on what are now the Marys Lamb and Santa Francis claims. This material was shipped from Vaca station to a plant at Trenton, N. J., where recovery by the Detwiler process was attempted. No production was reported. The Pittsburgh-Utah Potash Co., organized in 1916, constructed 3,600 feet of spur track from Belknap to its property at the mouth of Deer Creek and assembled some second-hand equipment on the ground but never reached the producing stage. The Aluminum-Potash Co. of America in 1919 took over the Copper Butte group of claims on Deer Creek, 2 miles from the railroad, built a camp called Winkelman at the mouth of Deer Creek, assembled some equipment, and started the erection of an aerial tramway 9,100 feet long from the quarries to the railroad. The old Florence Mining & Milling Co.'s mill at Marysvale was taken over for experimental purposes, but no appreciable quantity of potash salts is known to have been produced.

The Close In property, which had been prospected by Tom Gillen in 1915, was included with the White Hills property in an operation planned by the Industrial Potash Co. in 1920. Many other properties were explored to a small extent during this period, and small shipments were made for experimental purposes to plants in various parts of the country or to the old Florence Mining & Milling Co.'s mill. Small shipments have been made almost every year up to the present time.

No complete information on output of alunite or of its refined products is available. Mr. Touroff [30] estimates that 250,000 tons of alunite was taken from the mine of the Mineral Products Corporation. Thoenen [31] obtained an estimate of 12,000 tons of alunite as the product of the Sunshine mine of the Florence Mining & Milling Co. Other properties perhaps yielded a total output of a few thousand tons of alunitic material. The figures in the production table below represent the refined product from all alunite properties in the United States, though the bulk of this yield undoubtedly came from the plant of the Mineral Products Corporation. The output for the last 3 months of 1915 is not given. It was limited to potash salts, as only experimental shipments of the alumina were made. Small lots of this material have recently been shipped for use in copper refineries as a mold wash. The tailings dump at the Mineral Products mill is estimated [32] to contain 45,000 tons of alumina.

[30] Oral communication.

[31] Thoenen, J. R., op. cit., p. 26.

[32] Hewett, D. F., and others, Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, p. 147, 1936.

Potash produced from alunite in the United States

[From annual chapters on potash in Mineral Resources of the United States, U. S. Geological Survey]

Year	Number of producers	Crude potash (short tons)	Available potash		Value of sales f. o. b. plant
			Short tons	Percent of total production	
1916 [1]	3		1,850		$715,000
1917	4	7,153	2,402	7	892,763
1918	4	6,180	2,621	5	1,276,774
1919	7	6,599	2,294	7.1	718,506
1920 [2]	3	4,311	2,127	4.4	457,576
Total		24,243	11,294		4,060,619

[1] Includes production from silicate rocks and furnace dust.
[2] Includes production from silicate rocks.

It is generally conceded that the cost of producing potash as the sole product of the alunite deposits is too great to permit them to compete with the present low-cost American producers in California, Texas, and New Mexico. Production was maintained only under the stimulus of high prices. The price of K_2SO_4 rose from $48.07 a ton on December 28, 1914, to $140 a ton on March 29, 1915, to $205 a ton on June 28, 1915, and to $440 a ton on January 3, 1916. A break in price in 1919 caused the initial closing of the plants, but it was found that imports did not enter in large quantity until late in 1920, when high-cost producers were compelled to close. The production table shows that the alunite deposits yielded a maximum of only 7.1 percent of the total potash output in the United States, even before the development of the present large resources. Attempts to make fertilizer in competition with other materials have apparently not been successful. Though the production of metallic aluminum was considered from the beginning of the development of the Marysvale deposits, it is only recently that serious efforts are reported to have been made to produce the metal experimentally. This outlet is regarded by most people as the sole hope of further exploitation of the alunite.

MINERALOGY

A moderately simple mineral assemblage in the alunite deposits of both the replacement and vein types is indicated by the work done thus far. Alunite, quartz, clay minerals, pyrite, limonite, titanite, and leucoxene are the principal substances. As the minerals have been described in detail by Loughlin [33] only brief statements will be made here.

Typical coarsely crystalline alunite from veins on Alunite Ridge on the upper reaches of Cottonwood Creek consists of banded aggregates of pink to red parallel or slightly diverging crystal groups

[33] Loughlin, G. F., op. cit., pp. 242–246 and 260–261.

that are normal to the banding. Though these bands may be only a small fraction of an inch wide, they are commonly half an inch or even an inch wide. What appear to be prismatic crystals prove, under the microscope, to be plumose aggregates. Crystal terminations in the many cavities and vugs in this variety of alunite suggest the rhombohedral form of alunite but are very jagged and irregular. The coarse-grained alunite near the surface is stained and contains films of limonite. Alunite relatively unaffected by surface waters appears under the microscope to be essentially free of other minerals, though Loughlin observed some minute pyrite cubes.

A very fine-grained pink to white massive variety of alunite occurs in the veins with the coarsely crystalline variety. The minute laths and plates are mostly less than 0.1 millimeter in length. This material seems to have formed earlier than the larger crystals, which fill veinlets in the finer material and in part replace it. The relations of the two varieties are similar to those of microcrystalline and coarse-grained comb quartz in many metalliferous deposits. Some of the alunite has been sheared by late fault movements that have produced a very fine-grained, highly oriented variety.

Alunite in the replacement deposits in the Antelope Range is typically white, massive, and extremely fine-grained. Though the prevailing color is grayish white, some varieties are slightly pink, and others are dark gray or yellowish. Some of this material is soft and powdery, some is very hard and stony, and some has a horny, subtranslucent appearance. All degrees of orientation of the crystal plates were observed. The grain size rarely exceeds 0.1 millimeter and is commonly much smaller. Some of this material is natroalunite rather than alunite.

Quartz is inconspicuous as an integral part of the coarsely crystalline alunite veins, but it forms a large part of the altered wall rocks of the veins and is a major constituent of essentially all the fine-grained replacement deposits. In both the altered wall rock of the veins and the fine-grained alunite of the replacement deposits the quartz constitutes an extremely fine-grained aggregate. Residual quartz phenocrysts are preserved in some of the altered rock. In the Mineral Products mine fine-grained quartz veinlets cut the altered rocks but are in turn cut by the alunite veins. At the Sheep Rock deposit, according to Loughlin, [34] closely spaced bands in alunitized rock consist of alternate layers of a mixture of very fine-grained alunite and quartz and coarser-grained quartz.

Clay minerals probably occur in nearly all the deposits, though their relative proportion is difficult to determine. An extremely fine-grained, bluish-white clay that fills cavities and veinlets in coarsely crystalline alunite in the L. & N. and Sunshine areas was

[34] Loughlin, G. F., op. cit., p. 260.

identified by C. S. Ross, of the United States Geological Survey, as dickite. Dickite probably also occurs in the fine-grained alunite and altered rocks associated with the coarsely crystalline alunite. Other clay minerals are probably associated with quartz and alunite in the fine-grained white replacement deposits. A clay mineral of the beidellite type was observed in weathered material.

Pyrite is abundant in unweathered altered rock associated with the coarsely crystalline alunite deposits. It was found in one small mass of fine-grained white alunite of the replacement type but seems to be extremely rare in the coarse-grained alunite. Alunite of the vein deposits as well as country rock near the surface is stained or crusted with iron oxides, doubtless derived from weathering of pyrite in the altered rocks. Small aggregates of minute grains of titanite as well as residual sparse grains of apatite and zircon are observed under the microscope in the altered rocks associated with the veins. Leucoxene is a common constituent of the very fine-grained white replacement deposits.

The wall rock of the alunite veins has been altered by solutions that favored the formation of quartz, alunite, pyrite, possibly a small amount of a clay mineral, and titanite. Analysis as well as petrographic examination indicates that these minerals account for essentially all the chemical components of the rock except very small amounts of residual quartz and apatite and a trace of zircon. The altered rock is light gray to brown. Though most of the altered rock on Alunite Ridge is more resistant to weathering than the surrounding unaltered tuff and volcanic breccia, that near the L. & N. vein has been more deeply eroded than the neighboring volcanic breccias and flows. Traces of original rock and mineral structure remain in much of the altered rock. However, with the exception of quartz phenocrysts and a little apatite and zircon the original minerals have been destroyed. Aggregates of alunite laths fill areas that were formerly feldspar phenocrysts, but quartz in microcrystalline mosaic aggregates associated with plates of alunite makes up most of the groundmass. Some of the residual quartz is partly replaced by alunite, and alunite also fills veinlets. Pyrite cubes mostly less than 1 millimeter in diameter and in places partly enclosed in films of alunite make up more than 3 percent of the rock. The titanite aggregates are rather evenly distributed.

TYPES OF DEPOSITS

Two types of alunite deposits are readily distinguished on the basis of structure and composition. The vein or high-grade type, so far as is known, is restricted to the upper reaches of Cottonwood Creek and the immediate vicinity. Most of the veins so far discovered are on Alunite Ridge between the two forks of Cottonwood

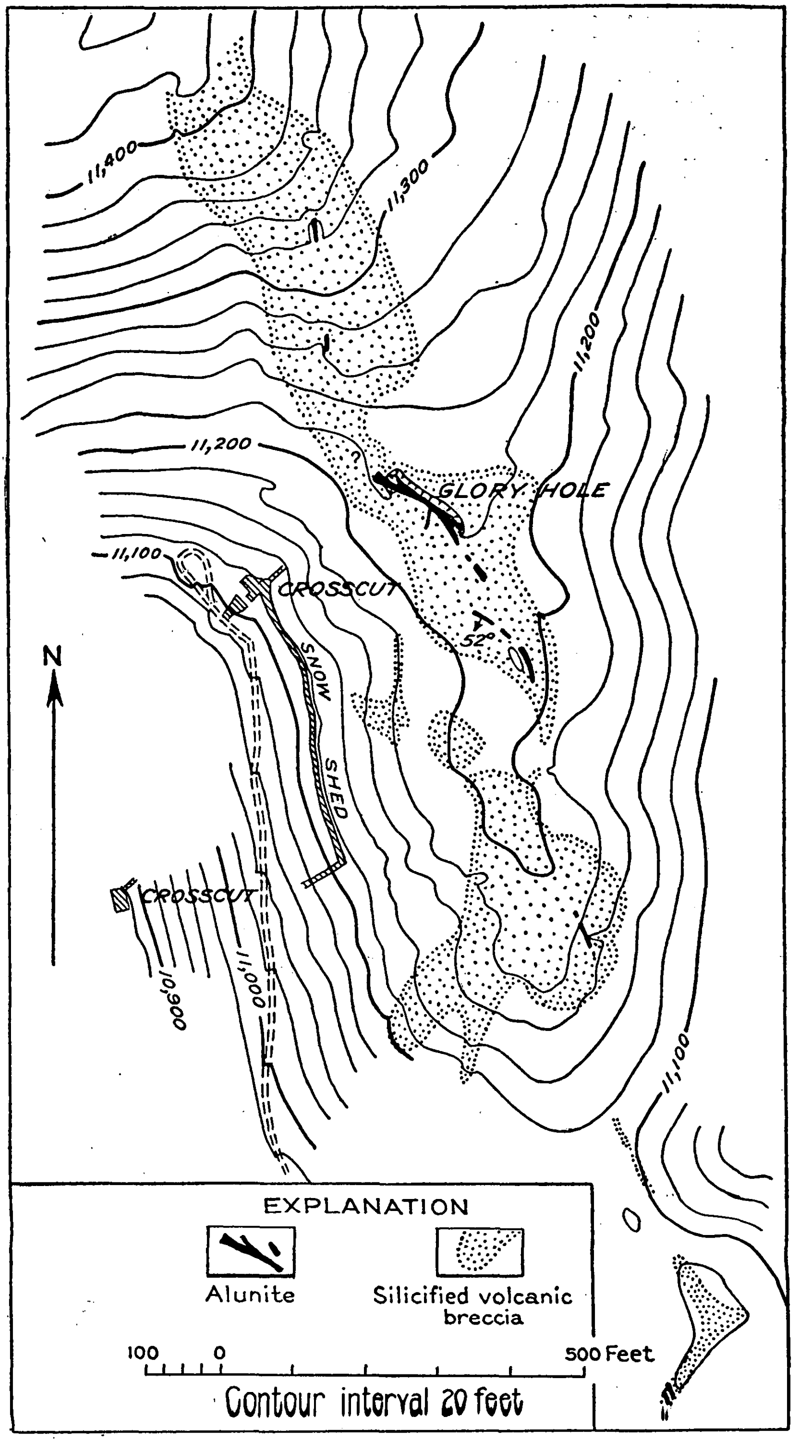

FIGURE 17.—Map of Sunshine area showing variable distribution of silicified and alunitized country rock and alunite veins.

Creek, where they have a dominant northwesterly trend along the course of the ridge, though a few of the veins are normal to this trend. The replacement type is much more widespread than the vein type, but most of the deposits are near the quartz monzonite body in the Antelope Range. These alunitic masses have replaced igneous rocks, and, as they commonly contain considerable quartz and other materials, they are known locally as the low-grade deposits.

Vein deposits.—The vein deposits occupy fractures within irregular envelopes of altered rock and are not known to extend beyond such rock. The masses of altered rock are highly variable in size and shape, though most of them have a northwesterly trend, as shown in figure 17, which also shows the discontinuity of the veins and their variation in trend within the envelopes of altered rock. The fact that the veins are not simple lenses but fork and curve in a complex pattern is brought out by the map of the upper tunnel of the Mineral Products mine shown in plate 18. The veins expand, contract, curve, branch, and diverge from place to place in a complex way. The West vein, shown in plate 18, branches from the Main vein, but becomes normal to it. The Main vein dips very steeply to the west, but the West vein dips much more gently to the north. The East vein is nearly barren on this level, though it was productive above. The lens of alunite at the portal was 65 feet wide but pinched out within 180 feet to the northwest. The main productive lens is about 1,000 feet long, reaches over 200 feet to the surface, and continues down 208 feet to the lower level. Multitudes of alunite veins and veinlets cut the altered rock near the larger veins. Lenses or horses of altered rock, most of them angular, occur in many places in the veins, as shown in plate 18, and in parts of the veins are sufficiently abundant to lower the grade of the run of mine product. Not all the alunite veins are of identical age, as some are cut by other veins and are offset along them. All are later than the quartz veins, but dickite veinlets are later than the coarse-grained alunite. Steep fractures shown on the map (pl. 18) cut the alunite veins, without, however, appreciably displacing them. A few of these fractures contain very thin seams of alunite, indicating that they were formed at the end of the period of alunite vein formation.

Replacement deposits.—The replacement deposits are characterized by extreme irregularity in size, shape, and composition. They are parts of masses of altered rock in which there is a wide variation in alunite content. Consequently, the limits of what may be considered workable source rock must be determined by assay specifications at the time. Some of the better portions of the replacement deposits are in the form of lenses where a fault or fracture has facilitated replacement. In places a breccia of country rock cemented by very fine-grained alunite is recognizable. In certain deposits small masses are sporadically distributed through altered rock. In other deposits the more alunitic material appears to be parallel to original bedding, suggesting selective replacement of a particular bed in a sequence of volcanic rocks. The size of the bodies of better-grade material has not been determined except at the Big Star deposit, where there is a lens about 120 feet long and 40 feet wide. The most highly alunitic part of this lens is about 8 feet wide and 20 feet long. Most of the shallow workings explore only the weathered parts of these deposits. Prospecting and development work has been so slight that little is known of the changes to be expected with increase in depth.

CHEMICAL COMPOSITION

A considerable number of analyses of samples from both types of deposits have been made and are included with the descriptions of the various properties. Sixteen analyses were made in the laboratories of the United States Geological Survey from channel samples taken by the writer. Analyses taken from other sources are properly acknowledged.

Selected samples of the high-grade vein deposits are nearly pure potash alunite. Such material was found by Schaller to be within a fraction of 1 percent of the theoretical composition for each of the constituents—that is, 37.0 percent of Al_2O_3, 11.4 percent of K_2O, 38.6 percent of SO_3, and 13 percent of H_2O. A sample of the fine-grained alunite from the veins was found to have over 5 percent of SiO_2, slightly more Na_2O, and proportionately less of the other constituents, except H_2O, than the coarse-grained material. However, channel samples taken across full widths of veins and samples of run-of-mine material show a considerable decrease in the ratio of potash alunite to other materials. In analyses of three channel samples and one carload sample, Al_2O_3 ranges between 34.7 and 39.45 percent, K_2O between 7.67 and 9.78 percent, Na_2O between 0.26 and 1.12 percent, SO_3 between 29.3 and 36.1 percent, and SiO_2 between 2.2 and 10.85 percent. The excessive amount of Al_2O_3 in some analyses may be due to clay minerals. In only one analysis of the vein alunite does Na_2O constitute more than 2 percent; in most analyses it is much less. The grade of material obtained in mining the veins will be determined largely by the degree to which blocks of included wall rock are sorted out. Analyses so far available indicate that run-of-mine material may average about 35 percent of Al_2O_3, 8 percent of K_2O, and 6 percent of SiO_2. In some processes of treatment iron compounds are highly undesirable. Most analyses show less than 1 percent of Fe_2O_3, but one sample that included iron-stained, altered rock contained 5.3 percent of Fe_2O_3.

The low-grade replacement deposits show a much greater range in all constituents. In 28 analyses of samples from seven different deposits, Al_2O_3 was found to range between 17.58 and 37.8 percent, K_2O between 0.71 and 8.86 percent, Na_2O between 0.50 and 4.72 percent, Fe_2O_3 between 0.14 and 10.87 percent, SO_3 between 8.5 and 36.5 percent, and SiO_2 between 3.72 and 62.82 percent. One analysis shows 3.8 percent of TiO_2, though most analyses show less than 0.75 percent. Inspection of the analyses suggests that the average content of Al_2O_3 may be 25 percent, K_2O 4 percent, Na_2O 1.5 percent, Fe_2O_3 1.0 percent, and SiO_2 35 percent. However, such average figures have critical value only when applied to bodies of known size and chemical content.

The samples analyzed in the chemical laboratory of the United States Geological Survey were tested spectographically by George Steiger for silver, beryllium, arsenic, bismuth, cadmium, germanium, and zinc, with negative results. Tests for fluorine by K. J. Murata, of the Geological Survey, were likewise negative.

ORIGIN AND PROBABLE EXTENSION IN DEPTH

It was the conclusion of Butler and Gale[35] corroborated by Loughlin[36] and further amplified by Butler[37] that the vein deposits and the alteration of the wall rock accompanying them owe their origin to ascending solutions and that the K_2O and Al_2O_3 were derived from a deep-seated source rather than leached from the immediately surrounding rocks. No evidence of any other origin was obtained during the past season. Analysis of wall rock adjacent to the vein at the Mineral Products mine shows that K_2O was added to rather than abstracted from the wall rock, though the proportion of Al_2O_3 has remained nearly constant. A suggestion is offered that the solutions brought the K_2O, Al_2O_3, FeS_2, and SO_3 from the magmatic source rather than abstracting them from wall rocks a short distance below the present position of the alunite deposits. Quartzite and other pre-Tertiary rocks that are particularly barren of most of these constituents crop out only a short distance below the Mineral Products mine. If the solutions came through these rocks, it seems reasonable to conclude that they must have brought the constituents of the alunite with them from the magmatic source.

It appears that the first solutions making their way along the fracture system on Alunite Ridge and spreading out into the volcanic breccias were primarily siliceous. The formation of alunite

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[35] Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: U. S. Geol. Survey Bull. 511, p. 36, 1912.

[36] Loughlin, G. F., Recent alunite developments near Marysvale and Beaver, Utah: U. S. Geol. Survey Bull. 620, pp. 253–255, 1915.

[37] Butler, B. S., Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 195, 1920.

in the wall rock was essentially contemporaneous with the silicification but probably lasted a little longer, as veinlets of alunite cut the siliceous material. This alunite was also probably slightly later than the well-formed crystals of pyrite. The brittle silicified rock so formed later fractured readily in response to renewed movements and opened spaces for solutions that had freed themselves of SiO_2 and iron and deposited essentially pure alunite. The first portion of this vein-filling alunite to be deposited seems to have been the fine-grained variety, but this was followed and partly replaced by the coarse-grained material. Undoubtedly there was repeated reopening and filling of veins. Not all the veins are of the same age, for some were found to cut and displace others. The last stage was marked by the deposition of dickite in fractures and cavities in the coarse-grained alunite.

Not only does the sulphate content suggest the acid character of the solutions at the time of deposition of alunite, but it is interesting to note that carbonate, abundant in rock not affected by alunitic alteration, is entirely removed in the altered rock. In general, the formation of the alunite veins and the accompanying alteration were due to solutions different from and later than those that formed the carbonate-bearing veins.

The evidence for the origin of the replacement deposits is not so conclusive as that for the vein deposits. Possibly they could have been formed (1) by ascending solutions such as those that produced the wall-rock alteration in the vicinity of the veins. Loughlin[38] regards this as the most likely origin for the replacement deposit at Sheep Rock. They could have been formed (2) by the action of sulphuric acid, in descending solutions and derived from the oxidation of pyrite, on potassic igneous rocks. Whether sufficient pyrite was present to effect such alteration is not known. They could also have been formed (3) according to the hypothesis[39] of simultaneous solfatarism and oxidation, that is, by ascending solutions meeting descending solutions bearing sulphuric acid and depositing alunite. It seems at the present stage of the investigation that ascending sulphate-bearing solutions have been the primary source of the replacement deposits but that migration and concentration of alunite may have taken place under the influence of descending sulphate-bearing solutions derived from the oxidation of pyrite. The solubility of alunite in H_2SO_4 suggests the possibility of modifications of the original distribution of alunite.

It is believed that the extension in depth of the vein deposits has been determined by structural conditions as opposed to other factors. The veins fill fractures, and the degree of opening available

[38] Loughlin, G. F., op. cit., p. 262.

[39] Ransome, F. L., Geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, pp. 193–195, 1909.

for vein filling has been determined both by the nature of the rocks and by the forces applied to them. If fractures in the pre-Tertiary rocks have not opened as widely as those in the overlying volcanic rocks, the pre-Tertiary rocks may limit the depth of the workable alunite deposits. The alunite veins at the present time have a known range in altitude of 2,000 feet in a distance of 7,500 feet; therefore, though alunite is generally assumed to be a deposit characteristic of those formed near the surface, its actual depth range may be 2,000 feet or considerably more, as the relation of the present surface to that existing at the time of deposition of the alunite is unknown. Though alunite is now being formed at the surface at Mount Lassen [40] and in Yellowstone Park,[41] Graton and Bowditch [42] have found it to extend to the greatest depth reached in the Cerro de Pasco mine, a distance of 2,100 feet below the present surface. On the other hand, the replacement deposits are believed to be largely restricted to the volcanic rocks, because these rocks were favorable to alunitic replacement. No tests of their extent in depth have been made, though the different deposits have a considerable range in altitude.

SUGGESTIONS FOR FURTHER PROSPECTING

It is evident even in the present state of this investigation, that the possibilities of the vein deposits have not been completely revealed by exploration work done so far. Several veins on the Mineral Products ground have been prospected, and a main vein and two branches have been partly mined. More extensive crosscutting may reveal other veins. However, as available evidence indicates that the veins do not extend appreciably beyond the masses of altered rock, initial prospecting should be limited to such masses. The coarsely crystalline alunite does not weather away much faster than the associated siliceous rocks, so that it persists as float for distances of several hundred feet from the outcrop of the vein. In such places as the forested eastern slope of Alunite Ridge, where there has been extensive soil creep, it is very difficult to find the veins, even though there is abundant float.

The areas of altered rock in which deposits of the replacement type are found are readily distinguished from surrounding unaltered rocks, but the proportion of alunite within them is less readily determined. If it is found that such deposits can be utilized,

[40] Anderson, C. A., Alteration of the lavas surrounding the hot springs in Lassen Volcanic National Park: Am. Mineralogist, vol. 20, no. 4, pp. 240–252, 1935.

[41] Allen, E. T., and Day, A. L., Hot springs of the Yellowstone National Park: Carnegie Inst. Washington Pub. 466, pp. 138, 484, 486, 498, 1935.

[42] Graton, L. C., and Bowditch, S. I., Alkaline and acid solutions in hypogene zoning at Cerro de Pasco: Econ. Geology, vol. 31, no. 7, p. 665, 1936.

the limit of minable material will probably be largely determined by exploratory work and chemical analysis.

RESERVES

Not sufficient information has been gathered to justify revision of the estimate of 3,000,000 tons of alunite given by Hewett.[43] Estimates of reserves are seriously affected by the lack of development work, the depth of soil and forest litter on much of the ground that may contain workable veins, the variation of the veins in size and continuity, and their lenticular shape. The extent of the altered rock containing the replacement deposits is more readily outlined, but the extreme variation in grade over short distances makes the determination of reserves difficult without extensive exploratory work and chemical analysis. The lower limit of grade specified for established processes and the economics of operation will determine the available reserves in the replacement deposits.

MINES AND PROSPECTS

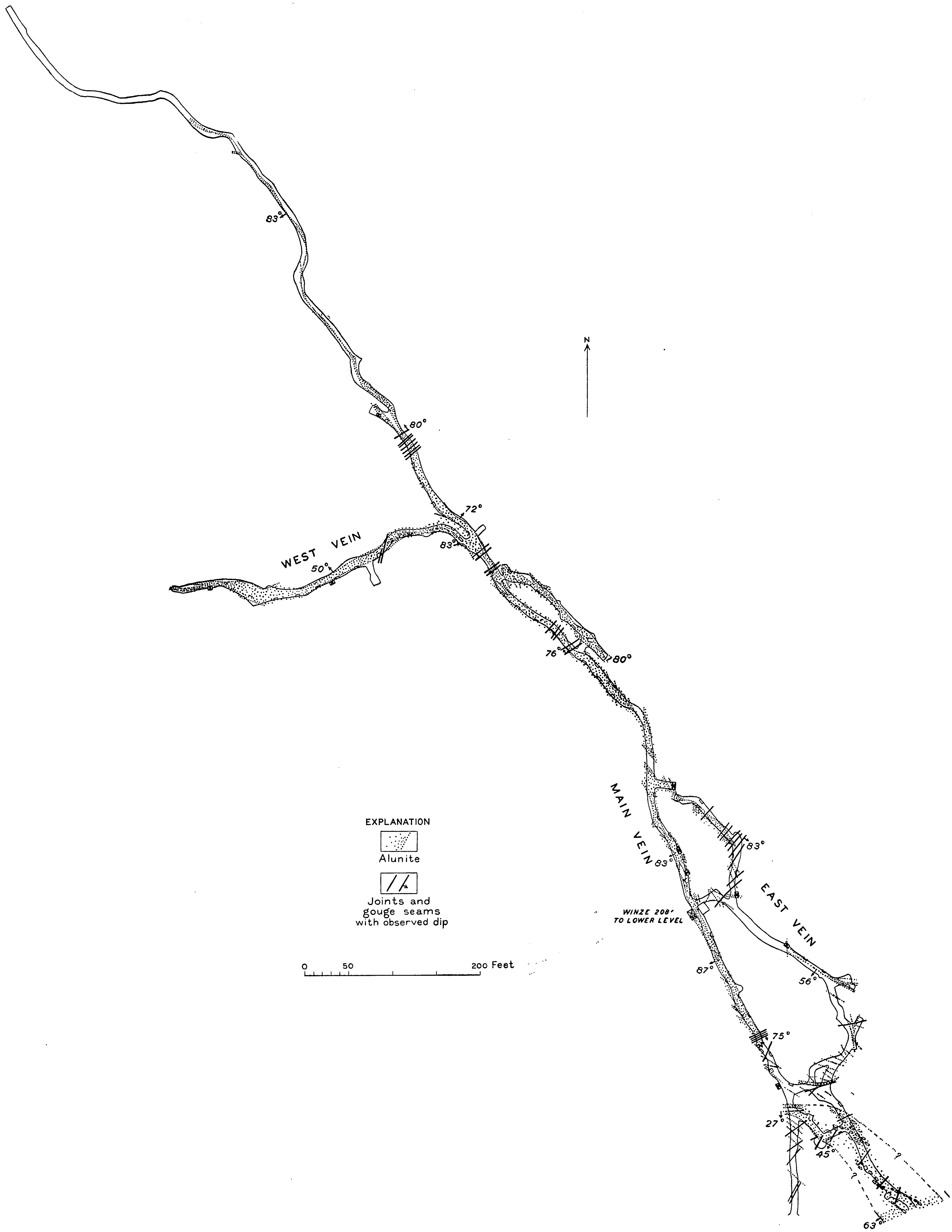
MOUNT BALDY DISTRICT

Mineral Products.—The alunite mine of the Mineral Products Corporation was the only one operated on a large scale. A total yield of 250,000 tons of alunite is estimated by Mr. Touroff. The portals of the main tunnels are in the SE¼ sec. 16, T. 28 S., R. 4 W. The 12 patented claims lie along the crest of Alunite Ridge in sections 16 and 17, but there are also several unpatented claims in Clyde Basin, an open, meadowlike area sloping 11° from the foot of Alunite Ridge. The upper tunnel enters the steep southeasterly front of Alunite Ridge at an altitude of 10,118 feet.

An aerial tramway extends 6,000 feet in a southeasterly direction from bins at the upper tunnel to Cottonwood Creek, about 1,700 feet lower. The power line of the Telluride Power Co. is 4,600 feet south of the tunnels, and the source of water for use at the mine is 3,700 feet south and 1,000 feet lower. The former wagon road to the mine is in disrepair.

Two tunnels have been driven northwestward on the alunite vein. The upper tunnel (pl. 18), 208 feet above the lower tunnel, has a total length of workings of about 3,600 feet and follows the vein for 1,680 feet. The lower tunnel, connected with the upper tunnel by a winze 210 feet long, has a total length of workings of 1,700 feet, of which 840 feet explores the alunite vein. According to Mr. Touroff, the Main vein is stoped out above the upper tunnel for a

[43] Hewett, D. F., and others, Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, p. 147, 1936.



MAP OF UPPER TUNNEL OF MINERAL PRODUCTS MINE SHOWING STRUCTURAL DETAILS OF ALUNITE VEINS.

length of about 1,070 feet. No stoping has been done below the upper tunnel.

The veins are included in an envelope of brownish silicified and alunitized country rock. The unaltered country rock is largely if not wholly a purplish-gray volcanic breccia. A part of the breccia was found on chemical analysis to be andesite rather than quartz latite, but preservation of quartz phenocrysts in some of the altered rocks suggests that dacites or quartz latites are present. Beyond the end of the principal alunite lens, where the vein becomes narrow, the envelope of silicified rock also becomes narrow, and purplish volcanic breccia appears in places in the tunnel walls. Quartzite crops out in fault blocks southeast of the mine.

The strike of the Main vein in the upper tunnel ranges from north to west, but the average strike is N. 32° W. The vein is nearly vertical, but in places dips are as low as 83° W., and in parts of the large lens near the portal, the dip is only 45° SW. On this level (pl. 18), there is an interval of 70 feet between the two main lenses; that near the portal is wide but pinches sharply. Both this lens and the long principal lens, which averages more than 10 feet in width, contain many horses and blocks of altered rock. The narrow lens continues below the lower tunnel, but its persistence below this level has not been proved.

The East vein diverges to the east from the Main vein, and though it was productive above the upper tunnel, it fades out into a number of small stringers on this level. The West vein curves away from the Main vein, has an average strike of S. 82° W., and dips 50°–60° N. A raise said to be 360 feet long follows this vein to the surface.

The analyses given in the table below afford some impression of the quality of the material. Considerable silicified rock was commonly broken down with the alunite, and some method of sorting can probably be used to maintain a fair grade. Samples 4 and 5 are composite, representing material from the Bradburn and Sunshine area as well as from the Mineral Products mine.

Analyses of alunite from the Mineral Products and other mines

	1	2	3	4	5
Al_2O_3	37.18	34.40	34.70	38.28	37.97
K_2O	10.46	9.71	9.26	8.20	9.78
Na_2O	.33	.56	.48	2.02	.35
SO_3	38.34	36.54	34.10	35.68	35.66
H_2O+	12.90	13.08	13.50	15.01	14.35
H_2O-	.09	.11		.05	.06
SiO_2	.22	5.28	7.77	.52	2.16
Fe_2O_3	Trace	Trace	.93	.02	.14
TiO_2	----------	----------	.23	----------	----------
P_2O_5	.58	.50	.57	----------	----------
CaO	----------	----------	.26	----------	----------
MgO	----------	----------	.14	----------	----------
	100.10	100.18	101.94	99.78	100.47

1. Selected sample of coarsely granular crystalline alunite. W. T. Schaller, analyst. U. S. Geol. Survey Bull. 511, p. 8, 1912.
2. Selected sample of light-pink finely granular rock with conchoidal fracture. W. T. Schaller, analyst. U. S. Geol. Survey Bull. 511, p. 8, 1912.
3. Average sample to represent four carloads from Mineral Products mine. Sampled for and analyzed by the Kalunite Co.
4. Composite sample of pink coarse-grained alunite from Mineral Products, Bradburn, Florence Mining & Milling Co., and Christmas Extension properties. U. S. Bur. Mines. Rept. Inv. 3322, p. 46, 1936.
5. Composite sample of massive silky white fine-grained alunite from the same properties and same reference as no. 4.

Other occurrences of alunite on the property have been prospected to a slight extent. A group of workings 1,200 feet northeast of the mine has an average trend of N. 75° W., but not enough work was done to determine the extent and trend of the veins. The Crowfoot tunnel, 800 feet northeast of the mine, reveals alunite in place. Alunite is said to have been found in cuts along the top of the ridge northwest of the mine. Recent work in a tunnel on an unpatented claim in Clyde Basin reveals soft, white, pyritic, very fine grained nodules and veinlets in pyritic volcanic rock. Partial analyses furnished by Dr. Fleischer show that this material contains a small amount of alunite. Alunite float is widespread on the claims, and perhaps some veins remain undiscovered.

The alunite in the mine has by no means been exhausted, though workings are not sufficiently extensive to prove as much alunite remaining as has been mined. Other veins have been prospected, but are not sufficiently developed to prove any particular quantity of alunite.

Bradburn.—The Bradburn group of nine claims is in secs. 8, 9, 16, and 17, T. 28 S., R. 4 W. Most of the claims are on the east side of Alunite Ridge and in the basin at the head of the North Fork of Cottonwood Creek, but one detached claim lies west of Edna Peak. One of the claims adjoining the northeast corner of the Mineral Products property has been explored by several cuts and a tunnel, locally known as the Swift tunnel. Some alunite was shipped to the plant of Swift & Co. at Harvey, La. A former wagon road up North Fork is in disrepair.

The vein has a southwesterly trend, nearly normal to the course of Alunite Ridge. Most of the open cuts reveal large masses of alunite, and the tunnel follows a wide vein for 250 feet. In the face of this drift vertically layered alunite is exposed for a width of over 25 feet. The large lens of alunite on this property has been mined only slightly.

Sunshine.—The Sunshine, Edna Peak, and L. & N. alunite areas are on a large group of claims belonging to the Florence Mining & Milling Co. A claim said to be held by H. S. Gibbs corners near the Sunshine glory hole. The Sunshine deposit is on the crest of Alunite Ridge (fig. 17), in sec. 17, T. 28 S., R. 4 W. It has been more extensively prospected and mined than the other deposits on this property, and a total yield of 12,000 tons of alunite is attributed to it by Thoenen.[44] The property is reached by a wagon road.

General features of the Sunshine area are shown in figure 17. The principal lens of alunite thus far prospected has been explored by a glory hole and underground workings on two levels reached from crosscuts shown in the figure. These workings reached a depth of 350 feet below the outcrop. The Log Cabin tunnel (not shown in fig. 17), about 1,600 feet southwest of the glory hole and about 600 feet lower, was driven a short distance toward the vein. The long Franklin tunnel (not shown in fig. 17), a short distance north of the Log Cabin tunnel, was driven northward under Edna Peak. All the underground workings are inaccessible.

The country rock of the veins is silicified and alunitized volcanic breccia, which, though broken into rubble by frost action, stands well above the surrounding unaltered purplish-gray volcanic breccia. The very irregular distribution and discontinuity of the altered rock is brought out in figure 17.

Surface work indicates a great variation in the size, shape, trend, and distribution of the alunite bodies, though according to Mr. Kenyon the vein was more continuous and regular in the underground workings. Though curved, the vein in the glory hole strikes N. 52° W., dips 40°–70° SW., and has a maximum width of 15 feet. Several branches of the vein are revealed; one is nearly normal to the trend of the vein. Open cuts show alunite 400 feet northwest of the glory hole and 600 feet to the southeast, but these outcrops do not represent a continuous vein on the surface. Too little of the veins is exposed to make any accurate estimate of reserves.

The channel samples for the analyses shown in the table below were taken in cuts at the surface and probably represent the variations to be expected. Samples 2 and 3 contain about 1 percent of Fe_2O_3, not shown in the analysis.

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[44] Thoenen, J. R., Economics of potash recovery from wyomingite and alunite: U. S. Bur. Mines Rept. Inv. 3190, p. 26, 1932.

Analyses of alunite from the Sunshine area

[R. K. Bailey, analyst]

	1	2	3	4		1	2	3	4
Al_2O_3	39.45	35.35	37.70	30.70	H_2O-	0.15	0.15	0.10	0.30
K_2O	7.67	7.00	8.25	6.51	SiO_2	2.20	10.95	4.65	21.00
Na_2O	.68	.67	1.12	.42	Fe_2O_3				5.30
SO_3	36.10	31.50	34.00	25.20					
H_2O+	13.33	12.50	13.00	11.50		99.58	98.12	98.82	100.93

1. Channel sample to represent 4.2 feet of pink coarse-grained alunite containing some fragments of altered rock, from pit 140 feet southeast of glory hole.
2. Channel sample to represent 6 feet of soft platy, very fine-grained alunite on the south side of the coarse-grained portion of the vein at the southeast end of the glory hole.
3. Channel sample to represent 4.2 feet of extremely hard white or slightly pinkish fine-grained alunite at the northwest end of the glory hole on south side of raise.
4. Channel sample to represent 5 feet of reddish alunitized rock containing some coarse-grained alunite veinlets. Adjoins no. 3 on the north.

Edna Peak.—Silicified and alunitized rock in the prominent summit on Alunite Ridge known as Edna Peak is known to contain outcrops of alunite,[45] but there has been very little development work.

L. & N.—The L. & N. area is at the corner of secs. 7, 8, 17, and 18, T. 28 S., R. 4 W., but the greater part of the alunite is in section 17, on a slope extending southeastward from a saddle in the divide between Pine and Cottonwood Creeks. Though the zone of altered rock crosses the divide, the alunite, with the exception of two cuts, is limited to the southeasterly slope.

The zone of altered rock has been prospected by many open cuts and trenches for a distance of over 2,000 feet. The westerly drift of a short tunnel that forks 20 feet from the portal has been driven N. 60° W. 80 feet from the portal, which is at an altitude of 11,023 feet, 200 feet below the saddle.

The country rock is all gray volcanic breccia, but the hills both to the northeast and to the southwest are capped by red porphyritic quartz latite. The difference in altitude of the base of this flow on the two summits indicates a displacement of over 150 feet along the zone of altered rock, which evidently follows a fault. In the saddle the zone of altered rock is 300 feet wide, and though it is somewhat larger on each side, it narrows both to the northwest and to the southeast.

The vein or group of veins and the zone of altered rock have an average strike of N. 55° W. A vertical vein 9.4 feet wide is exposed in cuts above the tunnel on the south side of the divide. In the tunnel 150 feet southeast of the cuts three principal seams and some lenses of alunite are exposed over a width of 28 feet, but only a small part of this width is alunite. According to Loughlin[46] a trench extending southwest from the tunnel exposed 35 feet of alunite, though it did not reach the southwest wall. Loughlin obtained a

[45] Loughlin, G. F., Recent alunite developments near Marysvale and Beaver, Utah: U. S. Geol. Survey Bull. 620, p. 250, 1915.
[46] Loughlin, G. F., op. cit., pp. 248–249.

true thickness of 20½ feet of alunite and 5½ feet of quartz in this exposure. At that time the workings were fresh, and Loughlin found that alunite persisted for 2,400 feet down the southeast slope. The workings are sufficient to indicate that there is considerable alunite in the L. & N. area, but no accurate estimate of reserves can be made now. The analyses given below represent an exposure of the coarse-granular alunite, one of the fine-grained variety, and one of the adjacent altered rock. Dickite is conspicuous in the vein from which sample 1 was taken; the relatively high content of SiO_2 and Al_2O_3 may be due to this mineral.

Analyses of alunite and wall rock from the L. & N. area

[R. K. Bailey, analyst]

	1	2	3		1	2	3
Al_2O_3	38.50	28.70	21.40	H_2O-	0.10	0.10	0.20
K_2O	7.90	6.75	1.11	SiO_2	10.85	27.10	65.80
Na_2O	.26	.38	.16				
SO_3	29.30	26.20	4.02		100.24	98.73	100.02
H_2O+	13.33	9.50	7.33				

1. Channel sample to represent 9.4 feet of pink coarse-grained alunite with small masses of fine-grained alunite and small veinlets and fillings of dickite. T-shaped cut on south side of saddle.
2. Channel sample to represent 4.3 feet of fine-grained alunite with some fragments of silicified rock at face of west drift in main tunnel.
3. Channel sample to represent 8 feet of soft white altered rock on southwest side of vein in same cut as no. 1.

Crystal Fraction.—Blocks of fine-grained pink alunite with some coarse-grained veinlets were observed on the dump of a caved tunnel on the north bank of Cottonwood Creek just north of the Crystal mine, in the southwest corner of sec. 22, T. 28 S., R. 4 W. The direction of the caved tunnel at the portal is N. 55° W. According to Joseph Burns, under whose direction the tunnel was driven, the alunite was in a continuous vein that reached and penetrated red shale. The surface is now covered with debris, and no vein can be seen.

Close In.—The Close In property of Max Krotki is in sec. 1, T. 28 S., R. 4 W., in the hills at the foot of Deer Trail Mountain, about 4 miles southwest of Marysvale. Maps in engineer's reports furnished to the writer by Dr. Fleischer show that several short tunnels and a shaft have an aggregate length of over 3,600 feet and are distributed over an area approximating one full claim in size. These reports indicate the presence of several bodies of alunitic material of greatly varying alunite content in volcanic rocks. The best-grade material is said to be in nodules separated by altered rock of lower grade. Most of the partial analyses indicate a content of 50 percent or less of alunite, on the basis of the amount of SO_3. The first three analyses given below are taken from a report by Knickerbocker and Koster [47] and no. 4 was supplied by Dr. Arthur Fleischer.

[47] Knickerbocker, R. G., and Koster, J., Electrometallurgical studies in the treatment of alunite: U. S. Bur. Mines Rept. Inv. 3322, p. 46, 1936.

Analyses of alunite from the Close In deposit

	1	2	3	4		1	2	3	4
Al_2O_3	21.30	23.05	35.38	20.00	SiO_2	39.90	54.82	1.48	44.30
K_2O	5.39	1.91	9.80	4.83	Fe_2O_3	3.77	1.23	.54	3.00
Na_2O	.23	.55	.55	.52	TiO_2				.27
SO_3	20.70	9.15	36.82	19.10	P_2O_5				.42
H_2O+	9.55	9.55	15.37	8.84					
H_2O-	.09	.36	.06			100.93	100.62	100.00	101.28

1. "Massive white alunite."
2. "Small sample of soft pink deposit 300 feet in south tunnel."
3. "Pink alunite in pockets adjoining massive white alunite."
4. Sample to represent 1 carload of alunite from quarry. Sampled for and analyzed by Kalunite Co.

Other prospects.—Unpatented claims that belonged to the late Claude Kenyon and adjoined the Mineral Products property on the north are said to show alunite float and possibly some alunite in place. Workings on a claim of Joseph Burns adjoining the Mineral Products claims on the east reveal alunite. Alunite float has been found on claims of Joseph Burns adjoining the Mineral Products claims on the west. Alunite is also said to have been found in the Bearshole, a ravine followed by the power line west of the Crystal Fraction deposit.

NEWTON DISTRICT

Sheep Rock.—The Sheep Rock deposit, on the west side of the Tushar Mountains, was not examined during the present investigation, and nothing can yet be added to the following description, quoted from Professional Paper 111.[48]

The Sheep Rock deposit is a quartz-alunite rock of too low grade to be of immediate commercial importance as a source of alunite but of considerable scientific interest.

Sheep Rock is in the Newton mining district, at the west base of the Tushar Mountains, about 10 miles northeast of Beaver. It is a bare-topped, nearly circular ledge about 900 feet in diameter, with a gently rounded summit of nearly white quartz-alunite rock, in part weathered into clusters of rounded residual boulders, which when seen from a distance bear a striking resemblance to a flock of sheep.

The relations of the deposit to the andesitic country rock are very obscure. Its west, south, and north sides are covered with talus and brush and pass beneath the alluvium of the valley; and the saddle connecting it with the andesite foothills is covered with float.

The float, however, shows that the two rocks merge within a short space, and that the Sheep Rock deposit was formed by the replacement of andesite. No definite connection with neighboring metalliferous quartz veins is apparent on the surface, and none has been made in the underground workings of the mine.

The three following partial analyses of the quartz-alunite rock, two of average samples and one of the high-grade variety, were made by R. K. Bailey, of the United States Geological Survey:

[48] Butler, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 549–550, 1920.

Analyses of quartz-alunite rock from the Sheep Rock deposit

	1	2	3
Silica (SiO_2)	60.83	70.78	30.12
Sulphate radicle (SO_3)	13.83	10.56	26.53
Potash (K_2O)	3.89	2.90	6.87

1. Average sample at summit of Sheep Rock.
2. Average sample around stake no. 2.
3. High-grade sample, north slope of Sheep Rock.

In analysis 1 the ratio of the sulphate radicle to potash is almost exactly that of pure potash alunite. Calculation from these data gives over 13 percent of alumina and 35.6 percent of alunite. In analysis 2 the excess * * * of the sulphate radicle over the ratio between the sulphate radicle and potash for alunite is 0.6 percent, a small excess which may have been present in the soda alunite molecule. The calculated percentage of alumina is only 9.5 percent, and of alunite 25.7 percent. In analysis 3 the excess of the sulphate radicle is 3.2 percent, which also may have been present in soda alunite. The calculated percentage of alumina in no. 3 is 22.3 percent, and that of alunite 60.3 percent.

GOLD MOUNTAIN DISTRICT

Winkelman.—The Winkelman group of eight patented and three unpatented claims, sometimes known as the Copper Butte group and originally developed by the Aluminum Potash Co. of America, is on Deer Creek in secs. 2 and 3, T. 27 S., R. 4 W., about 2 miles from the railroad. According to engineers' reports, the deposit has been explored by a shallow quarry and several cuts. A total of 30 carloads of material is said to have been taken from the property.

The deposit is of the replacement type in altered igneous rock. Very fine-grained samples loaned by Dr. Fleischer range from white to yellowish and dark gray and have a horny appearance. The analyses in the table below show the wide range of composition to be expected in a deposit of this type.

Analyses of alunite from the Winkelman deposit

	1	2	3	4	5	6	7
Al_2O_3		32.36	29.94	36.50	24.50	30.14	31.31
K_2O	7.76	5.12	8.58	8.86	5.90	4.60	5.20
Na_2O	.66	1.80	1.36	1.31	1.12	3.60	1.73
SO_3	28.55	30.04	27.00	36.50	23.40	30.24	30.07
H_2O+			7.71	12.91	8.64	11.32	11.26
H_2O-						.11	.09
SiO_2		20.96	24.40	3.72	35.20	19.74	18.32
Fe_2O_3		.14	.74	.20	.71	1.17	2.74
TiO_2		Trace			.22		
P_2O_5					.56		
Ignition loss [1]		39.60					
CaO		Trace					
MgO		Trace					
			99.73	100.00	100.25	100.92	100.72

[1] Includes both SO_3 and H_2O.

1. Partial analysis of yellowish flinty, very fine-grained sample submitted by Dr. Fleischer. R. K. Bailey, analyst.
2. Sample of hard semitranslucent material from quarry. Pittsburgh Testing Laboratory, analyst. From copy of report of 1920 by R. L. Smith to Pittsburgh-Utah Potash Co.; loaned by Dr. Fleischer.
3. Sample to represent 25 feet of light-gray dense material in face of quarry. From copy of report by Smith Emery Co. to Aluminum Potash Co. of America; loaned by Dr. Fleischer.
4. Sample to represent best grade of material; same locality and same reference as no. 3.
5. Average sample to represent one carload from quarry. Kalunite Co., analyst.
6, 7. "Massive white alunite." Knickerbocker, R. G., and Koster, J., U. S. Bur. Mines Rept. Inv. 3322, p. 46, 1936.

Pittsburgh.—The Pittsburgh property of 16 patented claims, mostly in secs. 29 and 30, T. 26 S., R. 4 W., lies on the rugged west slope of Marysvale Canyon just north of the mouth of Deer Creek. Though a railroad spur 3,600 feet long was built to the property, it was developed only by shallow pits and some short tunnels. No alunite is known to have been mined.

The deposits are of the replacement type in beds of altered volcanic rock that are inclined southward against a fault trending west. The rocks south of the fault are not altered near the mouth of Deer Creek. The large intrusive body of quartz monzonite crops out on the east side of the Sevier River. The lower part of the volcanic sequence is a mass of black to gray pyritic altered rock, weathered at the surface and veined with gypsum. The analysis (no. 10) given below indicates that this material is not appreciably alunitic. The yellowish altered rocks above the massive material retain bedding structure and contain the masses of alunitic material. No estimate of reserves has been made. All the analyses given below except no. 11 are taken from a copy of a report by R. L. Smith to the Pittsburgh-Utah Potash Co., loaned by Dr. Fleischer. The samples, collected in 1920, were analyzed by the Pittsburgh Testing Laboratory.

Analyses of alunite from the Pittsburgh property

	1	2	3	4	5	6	7	8	9	10	11
Al_2O_3	24.26	33.02	21.68	36.46	19.41	25.00	17.59	37.80	32.78	18.50	36.68
K_2O	3.90	4.85	3.79	4.91	.71	3.12	2.37	4.85	1.78	2.09	8.47
Na_2O	.92	1.12	.56	2.90	1.10	.78	.23	3.13	1.74	.85	.47
SO_3	19.84	29.40	19.58	34.00	10.98	21.96	13.98	34.60	23.12	8.50	27.23
H_2O+	------	------	------	------	------	------	------	------	------	------	11.84
H_2O-	------	------	------	------	------	------	------	------	------	------	.19
SiO_2	43.60	18.90	47.20	8.24	56.70	36.60	59.30	5.86	29.50	57.86	12.74
Fe_2O_3	.14	.28	.14	1.14	2.43	1.00	.71	1.00	.42	1.00	1.91
TiO_2	.60	.60	.60	1.20	1.20	1.20	1.20	Trace	.80	1.00	------
Ignition loss [1]	26.85	40.30	25.75	44.30	17.95	31.30	18.05	47.24	33.10	12.90	------
CaO	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	5.52	------
MgO	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	------
	120.11	128.47	119.30	133.15	110.48	120.96	113.43	134.48	123.24	108.22	99.53

[1] Includes both SO_3 and H_2O, accounting for the high totals.

1. Sample to represent altered rock from bed overlying pyritic rock in Alum Peak or Big Rock Candy Mountain, American Flag No. 1 claim.
2. Sample to represent same outcrop as no. 1, but 750 feet distant. American Flag No. 1 claim.
3. Sample to represent white flinty rock from shallow open tunnel about 200 feet east of west end of Potash King No. 2 claim.
4. Sample to represent 6 feet of soft yellow fine-grained material in open cut on Potash King No. 8 claim.
5. Sample to represent powdered rock from tunnel 40 feet long near east end of Potash King No. 8 claim.
6. Sample to represent white powder with angular fragments of harder material from tunnel 63 feet long about 200 feet from east end of Potash King No. 2 claim.
7. Sample to represent soft white material from open cut 60 feet long on crest of ridge about 175 feet from east end of Potash King No. 8 claim.
8. Sample to represent white material from a vein 12 feet wide trending S. 20° E. on Ironside No. 1 claim.
9. Sample to represent soft white material from sample taken across 40 feet of material on Pay Ledge No. 1 claim.
10. Sample to represent soft brown material that bleaches white on drying, about halfway up face of Alum Peak.
11. "Pink to yellow fine powder." Knickerbocker, R. G., and Koster, J., U. S. Bur. Mines Rept. Inv. 3322, p. 46, 1396.

HENRY DISTRICT

Big Star.—The Big Star property, formerly known as the Wilson, has been relocated by E. G. Nelson on the north side of Belknap or Antelope Canyon in sec. 21, T. 26 S., R. 4 W., 1 mile east of Belknap siding. Until the road was washed out in the summer of 1936, the property could be reached by automobiles. The deposits, which are on a steep spur ridge, are prospected by two quarries and three tunnels, one of which is about 300 feet long. A steam shovel was operated at the quarries, but the amount of material shipped is unknown. The lower quarry at the end of the spur ridge is 80 feet long, 40 feet wide, and over 40 feet high at the face. The upper quarry, 700 feet to the north and 120 feet higher than the lower quarry, has been opened in a series of steps. The width of the upper quarry is 40 feet, and the length in a westerly direction is 140 feet, of which about 60 feet is in the alunitic zone. A short tunnel has been driven S. 85° W. under the deposit.

These replacement deposits are in a large area of yellowish altered volcanic rock at the north side of the quartz monzonite body. The more altered rock is overlain by less altered andesite and tuff beds, all of which are inclined to the northeast at an average angle of about 40°. The beveled edges of these beds are overlain by much later unaltered spherulitic rhyolite and flow breccia. The altered rocks undoubtedly belong to the earlier Tertiary(?) sequence of volcanic rocks, but the unconformable rhyolite may belong to the later Tertiary(?) sequence or may even be younger.

The principal lens of alunite (natroalunite) is exposed in the upper quarry and extends southwestward for 120 feet. The maximum width is about 40 feet, but the limits of the better-grade material are gradational. The eastern part of the lens is cut off at the bottom by a flat fault and appears to have moved out over talus material. The best-grade material is slightly pinkish white, powdery, and flaky; harder material on each side contains more silica. The unusually high content of Na_2O shows that the sulphate is natroalunite. The best sample in the upper quarry represents a lens only 8 feet wide and about 20 feet long. The lower quarry evidently contains only siliceous material. The analyses show a wide range from relatively pure natroalunite to siliceous altered rock. The long tunnel southwest of the upper quarry exposes pyritic altered rock in the face, but nearer the portal a stockwork of fibrous halotrichite, an iron-bearing alum, is exposed.

Analyses of alunite (natroalunite) from the Big Star deposit

[R. E. Stevens, analyst]

	1	2	3	4	5	6	7	8	9
Al_2O_3	24.80	22.88	24.59	27.20	27.57	35.50	31.98	24.96	17.58
K_2O	1.04	.92	.91	4.74	3.01	4.60	4.11	3.65	.72
Na_2O	3.11	2.77	2.85	3.06	3.69	4.61	4.23	3.28	1.64
SO_3	16.86	15.13	14.19	27.42	27.50	37.77	33.85	26.89	9.01
H_2O+	8.61	8.04	8.80	10.09	9.96	12.43	11.39	9.09	6.35
H_2O-	.34	.25	.24	.46	.56	.12	.30	.49	.41
SiO_2	43.78	49.01	45.87	26.21	26.99	4.39	13.08	30.39	62.82
Fe_2O_3	.81	.88	1.74	.77	.49	.61	.70	.63	.83
TiO_2	.62	.62	.74	.28	.42	.29	.39	.37	.56
CaO	--------	--------	--------	--------	--------	.05	--------	--------	--------
MgO	--------	--------	--------	--------	--------	.03	--------	--------	--------
	99.97	100.50	99.93	100.23	100.19	100.40	100.03	99.75	99.92

1. Channel sample to represent southernmost 9.2 feet in lower part of upper quarry.
2. Channel sample to represent next 7.0 feet north of no. 1.
3. Channel sample to represent next 7.0 feet north of no. 2.
4. Channel sample to represent southernmost 11.5 feet in upper part of upper quarry. This line of samples is 31 feet on 38° slope west-southwest of the line from which preceding samples were taken.
5. Channel sample to represent next 6.9 feet north of no. 4.
6. Channel sample to represent next 8.0 feet north of no. 5. This is best grade of natroalunite; it exhibits faint veining and is pinkish and soft.
7. Channel sample to represent 6 feet of material north of no. 6 but separated from it by 2 feet of rubble.
8. Channel sample to represent 6 feet of best-appearing material in north center of open cut 60 feet southwest of top of upper quarry.
9. Channel sample to represent 6 feet of whitest, best-appearing part in lower quarry over short tunnel.

Big Chief.—Some workings on the steep southwesterly slope of Twin Buttes, a sharp peak in the Antelope Range in the SE¼ sec. 15, T. 26 S., R. 4 W., have been relocated as the Big Chief claims by E. G. Nelson. The workings could be reached by a light truck in 1936. This property was examined briefly by G. F. Loughlin, of the United States Geological Survey, whose unpublished report is the basis of the following notes.

The mountain has two summits capped by very resistant silicified volcanic rock. Beneath the silicified capping is a bed of tuff, in part replaced by oxides of iron and manganese, both of which have been mined; below the tuff is volcanic breccia. The main tunnel, from which several crosscuts and a raise have been driven, extends 250 feet N. 65° E. in the southwesterly slope of the mountain. The tunnel is driven in the breccia, which samples show to be partly alunitized. The samples for which analyses appear below were taken by Loughlin and Dyer from the south wall of the tunnel by a short crosscut 220 feet from the portal. Sample 1 consists of a small white streak of soft material picked as free as possible from brown coloring material and thought to represent the purest alunite obtainable in the tunnel. Sample 2 consists for the most part of white streaks 1 to 4 inches thick alternating with dark-colored streaks in which the structure of the original rock is partly preserved. The analyses show that the sulphate is natroalunite.

Analyses of alunite (natroalunite) from the Big Chief deposit

[J. G. Fairchild, analyst]

	1	2		1	2
Al_2O_3	38.17	33.01	SiO_2	5.13	7.86
K_2O	2.04	3.29	Fe_2O_3	1.68	10.37
Na_2O	4.72	3.40	TiO_2	.35	3.80
SO_3	32.37	24.71			
H_2O	14.80	12.21		99.26	98.65

Yellow Jacket.—The Yellow Jacket quarry is in sec. 14, T. 26 S., R. 4 W., in a saddle in the ridge extending eastward from Twin Buttes. The quarry could be reached by a light truck in 1936. Shipments amounting to about 500 tons are said to have been made to the alum plant of the American Smelting & Refining Co. at Murray, Utah. The deposit is in a large area of altered volcanic rock, much of it highly silicified. The analysis given below was furnished by Dr. Fleischer and is said by him to represent an average sample of two carloads from the quarry.

Analysis of alunite from the Yellow Jacket deposit

Al_2O_3	26.90	TiO_2	0.20
K_2O	5.37	P_2O_5	.71
Na_2O	1.20	CaO	.11
SO_3	22.80	MgO	.15
H_2O	9.51		
SiO_2	31.00		99.69
Fe_2O_3	1.74		

Potash Butte.—The Potash Butte claims, owned by William Johnson, are a short distance southeast of Twin Buttes in secs. 22 and 23, T. 26 S., R. 4 W. Several pits have been dug, and a large quarry exposes light-yellow altered volcanic rock throughout its width.

Marys Lamb (Vera Cruz).—A property variously known as the Vera Cruz, Santa Cruz or Santa Kruze, and Utah Potash Co., has been relocated by E. G. Nelson as the Marys Lamb and Santa Francis groups of claims in sec. 23, T. 26 S., R. 4 W. A quarry and tunnel on the south bank of a wash are the principal workings on the Marys Lamb group, and a large quarry on another wash to the southwest of the first is the principal working on the Santa Francis group. An unknown quantity of alunitic material was hauled to Vaca station and shipped to New Jersey.

The yellowish to purplish-gray altered rock, which apparently was a rhyolite or latite, in both quarries is strongly banded and breaks readily into large thin slabs. A partial analysis by R. K. Bailey, of the United States Geological Survey, of a sample submitted by Dr. Fleischer shows K_2O 8.35 percent, Na_2O 1.04 percent, and SO_3 32.10 percent.

AREA EAST OF MARYSVALE

White Horse.—The unpatented White Horse property of E. G. Nelson is in the gently sloping foothills 2½ miles northeast of Marysvale, in sec. 10, T. 27 S., R. 3 W. The ridge in which the deposits are located is dominated by a prominent outcrop of light-colored altered rock. The prospects are readily reached by road from Marysvale.

Several masses of altered volcanic rock have been prospected by a number of pits and short tunnels. Partial analyses given in a report made for the Kalunite Co. indicate a variable but generally low content of alunite in the altered material. An analysis made by the Kalunite Co. of an average sample of a carload from the glory hole is given below.

Analysis of alunite from White Horse property

Al_2O_3	23. 66	Fe_2O_3	0. 81
K_2O	5. 88	TiO_2	. 05
Na_2O	. 50	P_2O_5	. 38
SO_3	21. 95	CaO	Trace
H_2O	9. 42	MgO	. 01
SiO_2	38. 50		
			101. 16

White Hills.—The White Hills group of unpatented claims, owned by Max Krotki, is on the hills northeast of Marysvale, in secs. 1 and 12, T. 27 S., R. 3 W. The property is reached by road from Marysvale. According to a map prepared for the Kalunite Co., several bodies of altered rock are prospected by pits and by four principal tunnels, which have an aggregate length with crosscuts of 1,650 feet. Partial analyses accompanying the map show a wide range of alunite content in the altered material. On the basis of the SO_3 content, the ratio of alunite to other constituents ranges mostly between 10 and 50 percent. The analyses given below are taken from the report by Knickerbocker and Koster [49] and represent massive white material from the glory hole.

Analyses of alunite from the White Hills deposit

	1	2		1	2
Al_2O_3	22.11	25.39	H_2O-	0.10	0.12
K_2O	3.82	4.88	SiO_2	42.44	37.46
Na_2O	.92	.80	Fe_2O_3	1.16	.73
SO_3	22.13	22.14			
H_2O+	7.90	9.03		100.58	100.55

Marysvale Peak.—Areas of altered volcanic rock on the west and southwest slopes of Marysvale Peak, a summit on the western scarp of the Sevier Plateau in sec. 10, T. 27 S., R. 2½ W., have been prospected to a slight extent. A group of unpatented claims here have been held by Edward Delaney. A road extends from Marysvale as far as Smith Canyon, but from this point a steep mountain trail leads to the deposit. The altered rocks are said to contain a moderate amount of alunite.

Manning Creek.—Areas of altered rock within the Sevier Plateau between forks of Manning Creek near the southeast corner of sec. 27, T. 27 S., R. 2½ W., have been prospected to some extent. A road from Marysvale reaches the mouth of the canyon of Manning Creek. No information on the alunite content was obtained.

[49] Knickerbocker, R. G., and Koster, J., Electrometallurgical studies in the treatment of alunite: U. S. Bur. Mines Rept. Inv. 3322, p. 46, 1936.

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