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POTASH-BEARING ROCKS OF THE  
LEUCITE HILLS

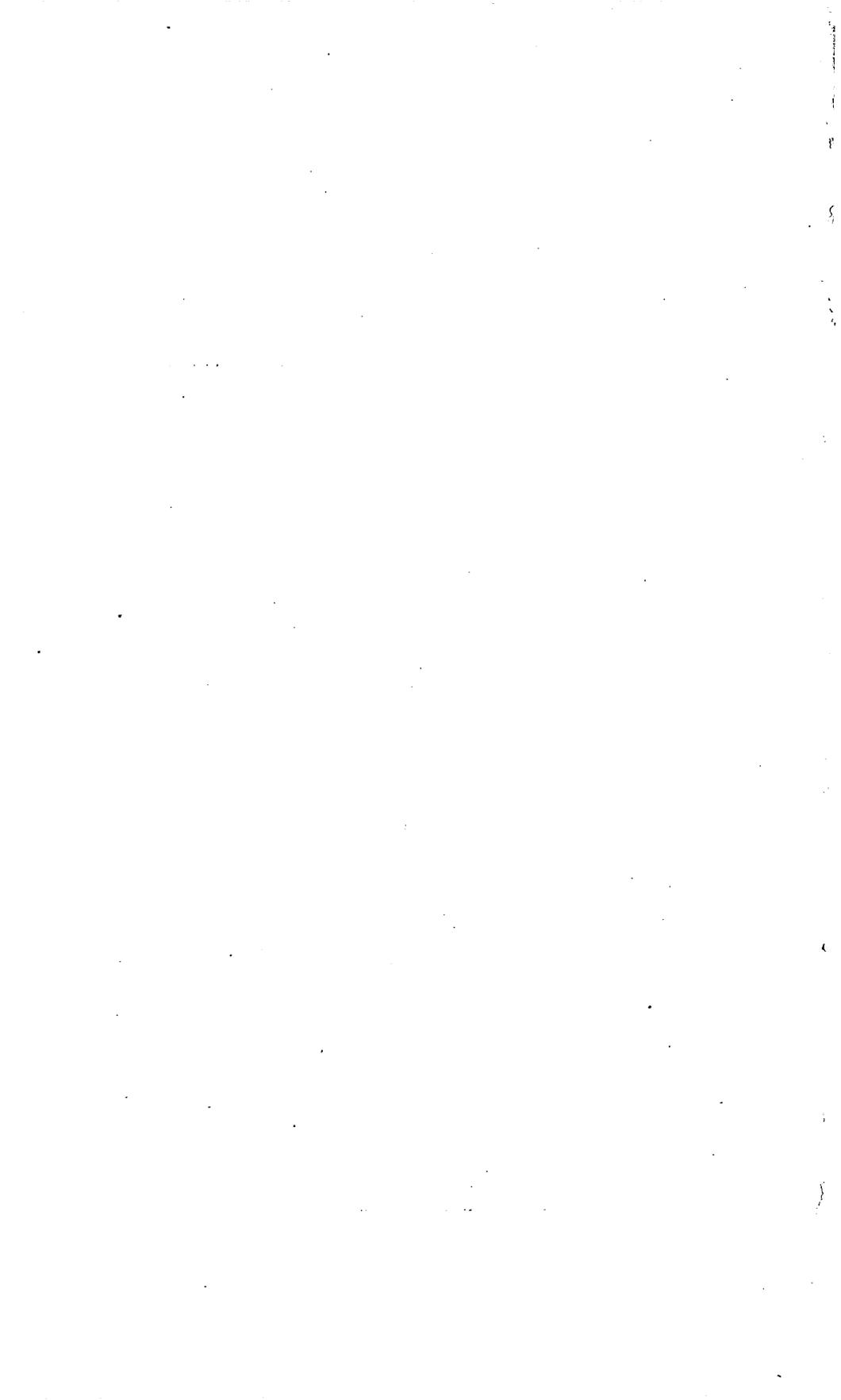
SWEETWATER COUNTY  
WYOMING

BY

ALFRED R. SCHULTZ AND WHITMAN CROSS



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# POTASH-BEARING ROCKS OF THE LEUCITE HILLS, SWEETWATER COUNTY, WYOMING.

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By ALFRED R. SCHULTZ and WHITMAN CROSS.

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## INTRODUCTION.

The purpose of the present paper is to give a brief description of the rocks in the Leucite Hills, Wyo., with an estimate of the amount of leucite-bearing rock available and of the approximate amount of potash that these rocks may yield as soon as a process is discovered by which the potash may be dissociated from the rock cheaply enough for commercial use.

In view of the possibility that some such process may be devised, it is important to know the conditions of occurrence of the rocks, their areal distribution, and the amount of rock available. Several reduction processes for extracting potash from igneous rock have been patented, but thus far none has proved commercially successful. The extraction of all the potash from these refractory silicates involves many difficulties, and not only has no process yet been perfected, but in the opinion of many industrial chemists no promising process has even been suggested that can be successfully applied on a commercial scale. The extraction of all the potash from these rocks involves the extraction of potash from at least three minerals—leucite, phlogopite, and sanidine. Whether or not these potash-bearing rocks will ever be utilized depends entirely on the technologic chemist and the industrial engineer, but the geologic and other data here presented are fundamental and should be at the command of anyone who intends to attack the economic problems of utilizing the potash or other valuable elements contained in the rocks. Any enterprise endeavoring to utilize these lavas for the establishment of a home source of potash should not overlook the fact that foreign potash now commands a price much in excess of the foreign cost of production, including all exporting and transportation charges. This wide margin of profit makes possible extensive reductions in the present prices, which might destroy all chances of success for any competitor entering the field under present conditions. The facts presented in this report are not the result of new but of old work

and are made available to the public in this form so that all the authoritative data on these exceptional rocks may be readily available. The observations here recorded have been made by the geologists of this Survey during the last 30 years in connection with scientific explorations and with detailed examinations of coal land.

Practically all the potash salts of mineral origin consumed in American industries at the present time are imported from Germany, which is the only country in the world where potash mines are profitably worked. These potash salts are extensively used in the United States in the fertilizer industry and are also essential to many other industries that are vitally connected with the welfare of the American people. The imports of potash salts into the United States in 1910 amounted to 1,798,391,012 pounds, valued at \$11,615,134. In view of this enormous quantity of imported potash, costing the American consumers annually nearly twelve million dollars—and the amount may be expected to increase rapidly—it behooves us to ascertain whether or not the United States can itself supply the demand.

Among the sources of mineral potash are the potash-rich rocks and minerals, such as granite, alunite, feldspar, and leucite. The potash feldspar minerals, orthoclase and microcline ( $\text{KAlSi}_3\text{O}_8$  or  $\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$ ), carry from 10 to 12 per cent, with a possible theoretical content of 16.9 per cent of potash ( $\text{K}_2\text{O}$ ); leucite ( $\text{K}_2\text{AlSi}_4\text{O}_{12}$ ) has a theoretical content of potash ( $\text{K}_2\text{O}$ ) equivalent to 21.5 per cent. The richest leucite-bearing rock in the United States thus far studied and analyzed contains approximately 12 per cent of potash ( $\text{K}_2\text{O}$ ).

The largest and best-known area of potash-rich, leucite-bearing rocks in the United States embraces the Leucite Hills, in the north half of the Rock Springs dome, Sweetwater County, Wyo. The exposures in the Leucite Hills area were visited by Mr. Schultz in the summers of 1907 and 1908, while engaged in a study of the Rock Springs coal field. In the present report Mr. Schultz has prepared the geologic and geographic descriptions and the estimates of the quantity of leucite rock present, and Mr. Cross is responsible only for the petrographic descriptions and the discussions of the chemical and mineral composition of the rocks.

#### REVIEW OF EARLIER PUBLICATIONS.

More than half a century ago Alexander von Humboldt published his unchallenged conclusion that leucite was a mineral found only in Europe, and even as late as 1868 the general impression prevailed that leucite was known as a constituent of lavas at only three European localities—the Italian volcanoes about Vesuvius; the Laacher See, in Prussia; and the Kaiserstuhl in the Black Forest, Baden, Germany. In 1850 an occurrence of leucite-bearing rock was discovered by

Loftus near Urmia, in Persia. Since then leucite has been recognized in many of the basalts in Saxony, Bohemia, the Thüringerwald and the Röhn Mountains, in Germany, as well as in Asia, Africa, South America, Australia, and in many other parts of the world. It remained, however, for the geologists and petrographers of the Fortieth Parallel Survey (1867-1873) to prove the existence of leucite-rich rocks in North America, at the locality described in the present paper. The occurrences in this locality, in the Dutch Indies, and in Persia proved the wide distribution of leucite-bearing rocks. The microscopic study of the specimens collected from the Leucite Hills, together with a chemical analysis, proved them to be richer in the mineral leucite and more peculiar in their general composition than any of the rocks occurring in the Old World.

The leucite-rich rocks were first found in the Leucite Hills,  $8\frac{1}{2}$  miles northwest of Point of Rocks, Wyo., by S. F. Emmons, who examined the southern mesa and gathered specimens in 1871 while engaged in the work of the Fortieth Parallel Survey. The material thus collected was subsequently studied and described by Zirkel.<sup>1</sup>

In 1877 the most northern areas of the Leucite Hills were visited by F. M. Endlich,<sup>2</sup> of the Hayden Survey. His descriptions of the lava localities, like those of Emmons, are very brief, being based on reconnaissance observations made before the commercial importance of the rocks of the region had been ascertained.

John W. Powell, former Director of the United States Geological Survey, in his geologic explorations of the Uinta Mountains from 1868 to 1875, also visited the westernmost locality of the Leucite Hills and collected specimens from the mesa now known as Pilot Butte. Further than the brief statement made in a single report,<sup>3</sup> no published data resulted from Powell's examinations. The specimens collected by him were held by the United States Geological Survey and subsequently examined and described by Whitman Cross in connection with specimens collected by himself. Cross, with one assistant, W. B. Smith, visited the Leucite Hills late in the fall of 1884 for the purpose of collecting a large number of specimens of rock for the "educational series" then being assembled by the Geological Survey. The results of this examination, together with a careful description of the rocks, from both microscopic study and chemical analysis, were published by the permission of the Director of the Survey in the autumn of 1897.<sup>4</sup>

<sup>1</sup> Zirkel, Ferdinand, *Microscopical petrography*: Rept. U. S. Geol. Expl. 40th Par., vol. 6, 1876, pp. 259-261.

<sup>2</sup> Endlich, F. M., *Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr.*, for 1877, 1879, pp. 6, 9, 10, 119, 133, 134, and 135; *Twelfth Ann. Rept.*, for 1878, 1883, atlas, map 3.

<sup>3</sup> Powell, J. W., *Geology of the Uinta Mountains*, U. S. Geol. and Geog. Survey Terr., 1876, pp. 18-22, 36.

<sup>4</sup> Cross, Whitman, *Igneous rocks of the Leucite Hills and Pilot Butte, Wyo.*: *Am. Jour. Sci.*, 4th ser., vol. 4, August, 1897.

In 1896 J. F. Kemp,<sup>1</sup> with two assistants, visited the Leucite Hills, and the results of their observations were read before the Geological Society of America in December of the same year.

During the summer of 1902 J. F. Kemp and W. C. Knight<sup>2</sup> spent some time together studying, photographing, and collecting from the exposures in these hills. While thus making a detailed study of the different hills they discovered several exposures not previously observed. This was the first attempt to find and map all the distinct masses of these rocks and to determine their structural and stratigraphic relations.

A further study of the geologic conditions and structural features of the vicinity of the Leucite Hills was carried on during the seasons of 1907 and 1908 by the United States Geological Survey in the course of a detailed investigation of the coal deposits of the Rock Springs dome. Although the primary object of the investigation, which was in charge of A. R. Schultz, was the classification and valuation of the public coal land, much additional knowledge regarding the geology, structure, stratigraphy, and physiography of the area and the occurrence and distribution of the leucite-bearing rock was obtained in connection with the coal work. All the 22 known localities were visited by members of the Survey, and extensive collections of specimens were obtained from most of the exposures. Preliminary reports<sup>3</sup> on the coal of the Rock Springs field have been published. The distribution and outlines of the lava exposures are shown on the maps accompanying these reports, but only a brief statement is made concerning the leucite rocks collectively. The specimens collected by members of the Geological Survey are now in the hands of Mr. Cross and a joint report on the occurrence and petrography of these interesting rocks is in course of preparation. A detailed report on the geology and stratigraphy of the Rock Springs coal field will be prepared as soon as time and the work on hand will permit.

#### GENERAL CHARACTER OF LEUCITE-BEARING ROCKS.

The silicate of alumina and potash to which mineralogists have given the name leucite is a primary constituent of several kinds of igneous rocks known in many parts of the world. While by no means uncommon, the leucite-bearing rocks are very much less abundant than those containing the potash feldspar called orthoclase or sanidine, a similar silicate of alumina and potash. This comparative rarity of leucite has led many petrographers to emphasize its pres-

<sup>1</sup> Kemp, J. F., The Leucite Hills of Wyoming: Bull. Geol. Soc. America, vol. 8, February, 1897, pp. 169-182.

<sup>2</sup> Kemp, J. F., and Knight, W. C., Leucite Hills of Wyoming: Bull. Geol. Soc. America, vol. 14, 1903, pp. 305-336.

<sup>3</sup> Schultz, A. R., The northern part of the Rock Springs coal field, Sweetwater County, Wyo.: Bull. U. S. Geol. Survey No. 341, 1909, pp. 256-282; The southern part of the Rock Springs coal field, Sweetwater County, Wyo.: Bull. U. S. Geol. Survey No. 381, 1910, pp. 214-281; Weathering of coal in the arid region of the Green River basin, Sweetwater County, Wyo.: Idem, pp. 282-296.

ence as a distinguishing characteristic of certain rocks by giving them such names, as "leucite basalt," "leucite tephrite," and "leucitite," even though the rock contains but small a percentage of leucite.

Leucite rocks are specially abundant in Italy, in a long chain of volcanoes stretching northwestward from Vesuvius. Some of the lavas of this vent are particularly noted for their prominent leucite crystals and in most mineral collections the best specimens of leucite are from this source.

There are but three localities in the United States where leucite-rich rocks are known. Two of these are in Montana, in the Bearpaw and Highwood Mountains, the rocks of which have been described by Weed and Pirsson.<sup>1</sup> None of the Montana rocks is so rich in potash as to possess probable value as a source of this substance, except under a method of extraction not applicable to potash feldspar.

The lavas of the Leucite Hills, Wyo., contain on the average a somewhat larger percentage of potash than any other known igneous rocks. A brief untechnical description of the various rock types found in this district follows:

### THE ROCKS OF THE LEUCITE HILLS.

#### EXTERNAL CHARACTER.

The lavas of the Leucite Hills are all very fine grained, rather earthy-looking rocks, and in most of them a dark mica in small hexagonal plates is the only mineral that can be recognized by the unaided eye. In many of the rocks these mica plates are arranged in rude parallel position, causing an easy fracture, the face of every parting glistening with the reddish-brown mica flakes, while at right angles to the partings the mass is dense and only here and there can cross sections of the flakes be seen. Most of the mica crystals are but 2 or 3 millimeters in diameter.

The rocks vary in color from a dull reddish or yellowish gray to straw-yellow. The denser rocks are the darkest in tone and have the most pronounced schistose appearance. The lighter-colored varieties are usually porous in some degree, the cavities being minute and irregular in shape except in the pumiceous material, which is abundant in some places. No coarsely vesicular lava has been found. Some of the pumice is very light, with nearly round pores, and in places the pores are drawn out as delicate tubes.

In some of the reddish porous lava glistening cleavage surfaces of feldspar grains can be seen, but leucite has not been detected in it except with the help of the microscope.

The abundant material collected by Mr. Schultz indicates that the flow rocks of all the mesas and hills in this region exhibit practically

<sup>1</sup> Weed, W. H., and Pirsson, L. V., *The Bearpaw Mountains of Montana*: Am. Jour. Sci., 4th ser., vol. 2, 1896, p. 147. Pirsson, L. V., *Petrography and geology of the igneous rocks of the Highwood Mountains, Montana*: Bull. U. S. Geol. Survey No. 237, 1905.

the same textural varieties. As a rule the plugs or volcanic necks consist of dense and notably schistose rock.

The point northwest of Rock Springs known as Pilot Butte, which may be considered as an outlier of the Leucite Hills, is made up of a lava that is closely allied to those already described, but contains only 8 per cent of potash.

#### MICROSCOPIC FEATURES.

The study of thin sections under the microscope shows the denser form of the rock to consist principally of three minerals. The mica is rich reddish brown, its color varying, of course, with the thickness of the plates. Besides the mica there are two colorless minerals. One of these appears in sharply defined prisms of octagonal form, the properties of which show it to be a nearly iron-free pyroxene called diopside. The other colorless mineral is leucite, in innumerable round grains of minute size crowded between the mica and diopside crystals. The leucite is in some rocks developed in the characteristic crystal form, but more commonly it appears in droplike particles. The little grains of leucite vary ordinarily between 0.01 and 0.05 millimeter in diameter. Aside from these three minerals there is a considerable amount of a very pale pinkish or colorless glass serving as a matrix to bind the crystals together. No other minerals of quantitative importance occur in the rock of this type. The dense, generally reddish rock consisting essentially of leucite, diopside, and mica is called wyomingite. No very similar rock is known from any other part of the world.

The more abundant vesicular rock has mica, diopside, and leucite of the same characteristics as those in the denser type, with a variable amount of orthoclase, the potash feldspar, which, as developed in lavas, is more frequently called sanidine. In some specimens examined sanidine equals leucite in amount, but no varieties have been seen in which leucite is less abundant than sanidine. There is no doubt a continuous series of rocks between that free from sanidine and the form richest in that mineral. The rock containing both leucite and sanidine in notable amount is called orendite, to distinguish it from the purely leucite type. According to Mr. Schultz's observations, this sanidine-bearing variety is much more abundant than the wyomingite. The rock of Pilot Butte, known as madupite, consists of phlogopite, diopside, and a glassy base which is rich in potash and would probably have produced much leucite had this lava become completely crystalline.

#### CHEMICAL COMPOSITION.

One partial and six complete analyses of the leucite-rich rocks have been made in the laboratory of the Geological Survey, and two less complete ones were made for the Fortieth Parallel Survey reports. These nine analyses, together with one of a rock from Bearpaw Peak, Mont., are given in the table on page 11.

No. 1 is an analysis made by Pawel, published in the German résumé of Zirkel's report.<sup>1</sup>

No. 2 is by R. W. Woodward and was quoted by Emmons<sup>2</sup> and Endlich.<sup>3</sup> Nos. 1 and 2 were probably made on the same material, the exact locality being unknown. The only specimens collected by the Fortieth Parallel Survey belong to wyomingite.

No. 3 is of wyomingite from the Boars Tusk, a dark-gray variety of the rock richer in mica and diopside than the other kinds.

No. 4 represents rock near Fifteenmile Spring, on the northeast side of Zirkel Mesa. It is the typical dense reddish-brown wyomingite such as occurs in many of the mesas and hills. It is identical in appearance with the specimens of the Fortieth Parallel Survey collection.

No. 5 is of orendite found associated with the wyomingite of analysis 4 at Fifteenmile Spring.

No. 6 is of orendite from the north cliff of Table Mountain, a light straw-yellow variety of the rock with very prominent micas. This is also a common type of the rock. Analyses 3 to 6 were made by W. F. Hillebrand.

No. 7 is an analysis by Chase Palmer, not previously published, of orendite from Hallock Butte, collected by Mr. Schultz.

No. 8 is a partial analysis by Chase Palmer of orendite from Emmons Mesa.

No. 9 is an analysis of madupite from Pilot Butte, by W. F. Hillebrand.

No. 10 is an analysis of "leucitite" from Bearpaw Peak, Mont., made by H. N. Stokes and given here for comparison.

*Analyses of leucite-bearing rocks.*

	Wyomingite.				Orendite.				Madu- pite.	"Leu- ci- tite."
	1	2	3	4	5	6	7	8	9	10
Silica (SiO <sub>2</sub> )	56.30	54.42	50.23	53.70	54.08	54.17	51.07	51.38	42.65	46.51
Titanic acid (TiO <sub>2</sub> )			2.27	1.92	2.08	2.67	2.13		1.64	.83
Alumina (Al <sub>2</sub> O <sub>3</sub> )	12.63	13.37	11.22	11.16	9.49	10.16	9.93	10.31	9.14	11.86
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )	6.92	.61	3.34	3.10	3.19	3.34	2.72		5.13	7.59
Ferrous oxide (FeO)		3.52	1.84	1.21	1.03	.65	1.19		1.07	4.39
Magnesia (MgO)	5.08	6.37	7.09	6.44	6.74	6.62	10.31		10.89	4.73
Lime (CaO)	5.63	4.38	5.99	3.46	3.55	4.19	4.87		12.36	7.41
Soda (Na <sub>2</sub> O)	2.21	1.60	1.37	1.67	1.39	1.21	.82	1.69	.90	2.39
Potash (K <sub>2</sub> O)	11.50	10.73	9.81	11.16	11.76	11.91	9.92	11.40	7.99	8.71
Water (H <sub>2</sub> O)		2.76	2.65	3.41	3.50	1.53	4.23		4.22	3.55
Phosphoric acid (P <sub>2</sub> O <sub>5</sub> )			1.89	1.75	1.35	1.59	1.53		1.52	.80
Sulphur trioxide (SO <sub>3</sub> )			.74	.06	.29	.16	.33		.58	Tr.
Fluorine (Fl)			.50	.44	.49	.36			.47	Tr.
Other constituents		1.82	1.68	.92	1.03	1.65	.61		1.55	.96
Specific gravity	100.27	99.58	100.62	100.40	99.97	100.21	99.66		100.11	99.73
			2.779	2.627	2.686	2.699			2.857	

<sup>1</sup> Zirkel, F., Über die krystallinischen Gesteine längs des 40ten Breitengrades in Nordwest Amerika: Ber. K. Sächs. Gesell. Wiss., Jan., 1877, p. 239.

<sup>2</sup> Emmons, S. F., Rept. U. S. Geol. Expl. 40th Par., vol. 2, 1877, p. 237.

<sup>3</sup> Endlich, F. M., Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., for 1877, 1879, p. 135.

Among the less important constituents shown by analysis of the rocks of the Leucite Hills are manganese, baryta, strontia, zirconia, and several other substances. The distribution of the main elements will be plain from the discussion of the chemical composition of the minerals.

#### COMPOSITION OF THE MINERALS OF THE LEUCITE-BEARING ROCKS.

While analyzing the wyomingite and orendite Dr. Hillebrand was successful in separating nearly pure mica and diopside in sufficient amount for analysis. The leucite and sanidine particles are too small and too intimately intergrown with other minerals for such separation, but their composition must be nearly the theoretical one, for the crystals are fresh and pure. In the following table is given the theoretical composition of the leucite and sanidine and that found by Hillebrand, by analysis, of the mica and diopside. The small amount of soda shown by the analyses is doubtless for the most part contained in the leucite.

*Composition of minerals of the leucite-bearing rocks.*

	Leucite.	Sanidine.	Diopside.	Phlogopite.
Silica (SiO <sub>2</sub> ).....	55.0	64.7	50.86	42.56
Titanic oxide (TiO <sub>2</sub> ).....			3.03	2.09
Alumina (Al <sub>2</sub> O <sub>3</sub> ).....	23.5	18.4		12.18
Chromic oxide (Cr <sub>2</sub> O <sub>3</sub> ).....				.73
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ).....			1.19	2.73
Ferrous oxide (FeO).....			1.82	.90
Magnesia (MgO).....			17.42	22.40
Baryta (BaO).....				1.00
Lime (CaO).....			23.23	.20
Soda (Na <sub>2</sub> O).....			.76	.44
Potash (K <sub>2</sub> O).....	21.5	16.9	.42	10.70
Water (H <sub>2</sub> O).....			.31	2.35
Fluorine (F).....				2.46
Other substances.....			.03	.06
Less O for F.....	100.0	100.0	99.16	100.80
				1.03
				99.77

In the original description of these leucite-bearing rocks by Mr. Cross there may be found much more extensive discussion of the chemical composition of both rocks and minerals than is appropriate in this place. But certain things need to be pointed out as bearing on the availability of these rocks as sources of potash.

The analyses show the diopside to be unusually poor in iron and to carry but very little potash. The mica is found to be the magnesia and potash rich species known as phlogopite, which is rare in igneous rocks. Its presence here is due to the high percentage of magnesia and potash as compared with iron and alumina.

The molecular proportions of silica, alumina, and potash in leucite and sanidine (orthoclase) are as follows:

	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O
Leucite.....	4	1	1
Sanidine.....	6	1	1

That is to say, sanidine contains 50 per cent more silica than leucite, expressed in number of molecules. The rarity of leucite in igneous rocks is explained by the laws of chemical affinity affecting igneous magmas, which under usual conditions favor the formation of feldspar rather than leucite, if there is enough silica present. Quartz and leucite are therefore very rarely found together.

Knowing the composition of wyomingite and of its chief minerals, one may calculate the approximate mineral composition. The result for the rock from the Boars Tusk (No. 3, p. 11) is as follows:

*Approximate mineral composition of rock from Boars Tusk.*

Uncombined silica.....	18.7
Leucite.....	26.1
Noselite.....	8.7
Diopside.....	18.8
Phlogopite.....	19.9
Accessory minerals.....	7.8
	100.0

This result is peculiar, for the free silica is more than enough to have formed sanidine instead of leucite, and no explanation of this unusual development of leucite has been found. The uncombined silica is mostly in the glassy base to which reference has been made. No quartz or tridymite—the latter another form of pure silica—has been observed in any section of wyomingite.

A similar result is obtained from the calculation of analysis 4 (p. 11). This gives a still larger amount of uncombined silica, with leucite 35.7 per cent, phlogopite 22.3 per cent, and diopside only 10.7 per cent.

The calculation of the mineral composition of orendite is more difficult because it contains a peculiar hornblendic mineral, the composition of which is unknown.

The potash content of wyomingite is distributed between leucite, phlogopite, and a glassy base, most of which must be uncombined silica. In orendite another portion must be contained in sanidine, and very possibly a small amount is in the hornblende referred to. Soda appears to replace a part of the potash in leucite, or, where considerable sulphur trioxide is present, the whole may be found in the mineral noselite, as in the Boars Tusk wyomingite.

The extraction of the entire potash content of these rocks must therefore be effected by a process applicable to leucite, sanidine, and phlogopite at least, and probably to other minerals.

#### POTASH AND SODA NITRATES.

On the north side of Table Mountain, in a cleft by which the cliff surrounding this flat-topped hill can be easily scaled, there were found in 1884 some masses of a white, sugar-like substance, which chemical analysis proved to be nearly pure potash nitrate or niter. This mineral partly filled protected cavities and crevices in the cliff on the east side of the cleft. Its character was not recognized when it was found and no observations were made satisfactorily determining its origin. It may be of organic source but possibly is connected with the leucitic lavas.

An incrustation on the east face of the Boars Tusk, in protected cavities found in 1884, proved on analysis to be soda niter with small contents in potash.

These nitrates are of no economic importance, but the explanation of their occurrence is a matter of some scientific interest, and it is to be hoped that future examination of the Leucite Hills may settle this point.

#### STRATIGRAPHY AND GEOLOGY.

Structurally the Rock Springs field consists of a huge dome of Cretaceous and Tertiary rocks, which rises in the midst of the nearly horizontal rocks of the Green River Basin and partly divides the southern portion into two smaller basins—the Bridger Basin on the west and the Red Desert or Washakie Basin on the east. The major north-south axis of the dome is approximately 90 miles long and is located close to the west limb of the anticline. The beds along this limb dip from  $5^{\circ}$  to  $30^{\circ}$  W.; those along the east limb dip from  $5^{\circ}$  to  $10^{\circ}$  E. The minor axis is approximately 50 miles long, extending across the dome in a direction north of east and south of west, passing north of Aspen Mountain and through a point 4 miles north of Black Buttes, a station on the Union Pacific Railroad. Several small anticlines and synclines are developed upon the main dome, but for the most part they are unimportant.

This dome has been greatly reduced by erosion. From its crest have been removed all of the Tertiary and late Cretaceous ("Laramie") and most of the Montana formations. No important creeks or rivers flow through or rise within the Leucite Hills area. Bitter Creek, the largest waterway, passes south of the Leucite Hills but receives the drainage from Killpecker Creek, which rises near the Boars Tusk, and also from a few gulches along the south side of the Leucite Hills and from the valley heading at Fifteenmile Spring. All the remainder of the drainage from the hills east and south of Steam-

boat Mountain goes eastward and is tributary to the Great Divide Basin. Northwest of Steamboat Mountain the area is drained by Jack Morrow Creek, which flows in a northwesterly direction into the Sandy and thence into Green River.

Resting on or cutting through the sedimentary rocks in the north half of this dome are the Leucite Hills, which rise like monadnocks out of the dissected table-land, or like sentinels from the bottoms of the eroded valleys. The leucite-bearing rock masses of Pilot Butte and Steamboat Mountain are supported on Tertiary (Green River) beds. The Boars Tusk, Matthew Hill, Table Mountain, North Table, South Table, and Black Rock rest on or cut through the basal Tertiary (Wasatch) beds; others, such as Orenda Mesa and some of the dikes about Table Mountain, are in contact with the Wasatch and "Laramie" formations; all the remainder come into contact with various formations of Montana age. The separate or detached exposures of the Leucite Hills range from talus-covered hills, volcanic necks, and associated dikes, as in the Boars Tusk, Badger Teeth, Iddings Butte, and others, to intruded lava sheets, stocks, dikes, and flows with one or more cones, as in Emmons Mesa, Steamboat Mountain, Orenda Mesa, and Zirkel Mesa. Some of the mesas have been built up of successive flows, on top of which rise cones formed of fragmental pumice or of very cellular scoria. Some of the cones, as on Steamboat Mountain and one on Zirkel Mesa, are made up of solid lava which has welled up in the form of a huge blister. Most of the cones are composed of fragmental reddish rock and are remnants of old cinder cones whose missing segments were either destroyed during an eruption or have since been removed by erosion.

The volcanic activity which forced the leucite-bearing rock out toward the surface is certainly younger than the Green River formation, as the leucite-bearing rock at Pilot Butte and Steamboat Mountain rests as surface flows upon that formation. It appears that after the fresh-water beds of the Eocene had been laid down there was a long epoch of erosion in which the entire region was reduced to a peneplain or nearly level surface. This was succeeded by mild volcanic activity, during which the leucite-lava flows north and west of Rock Springs were poured out on a planed off, nearly level surface, formed by the truncation of the underlying rocks. This volcanic activity culminated in or accompanied the orographic movements that resulted in rapid erosion and the deposition of an extensive gravel sheet known as the Bishop conglomerate over the entire region from the Uinta Mountains northward to Bitter Creek. This gravel sheet is independent of the folds and faults in the underlying rocks, which are beveled across, entirely irrespective of either hardness or structure. From this gravel-covered lava-capped plain the present topographic features have been carved in late Quaternary time, almost solely by erosion.

## QUANTITY OF LEUCITE-BEARING ROCK.

No detailed account of the geologic, dynamic, and stratigraphic features of the leucite-bearing rocks will be given here, but a brief description of each occurrence will be presented and a computation made of the approximate acreage and tonnage of leucite-bearing rock in each locality and the approximate amount of potash it contains. A map showing the location of the potash-bearing rocks forms Plate I. The method of extracting the potash from the rock and its use will not be considered in this paper.

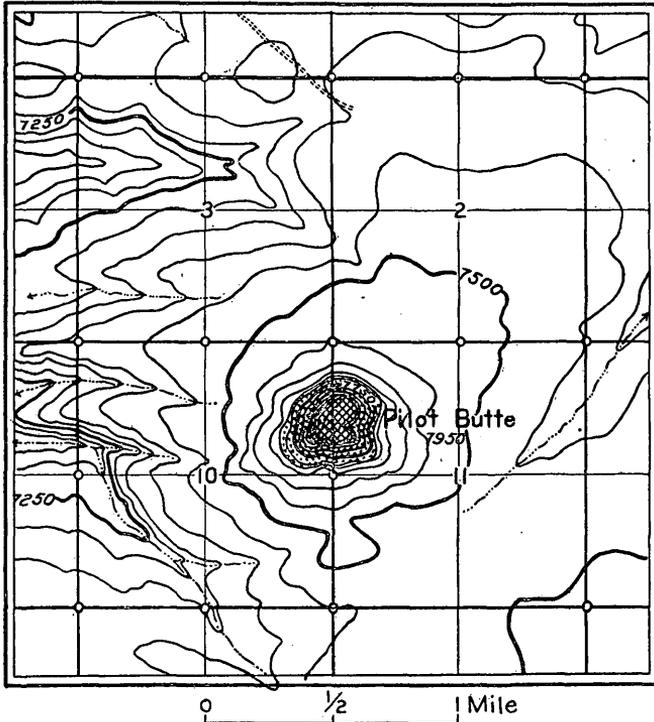
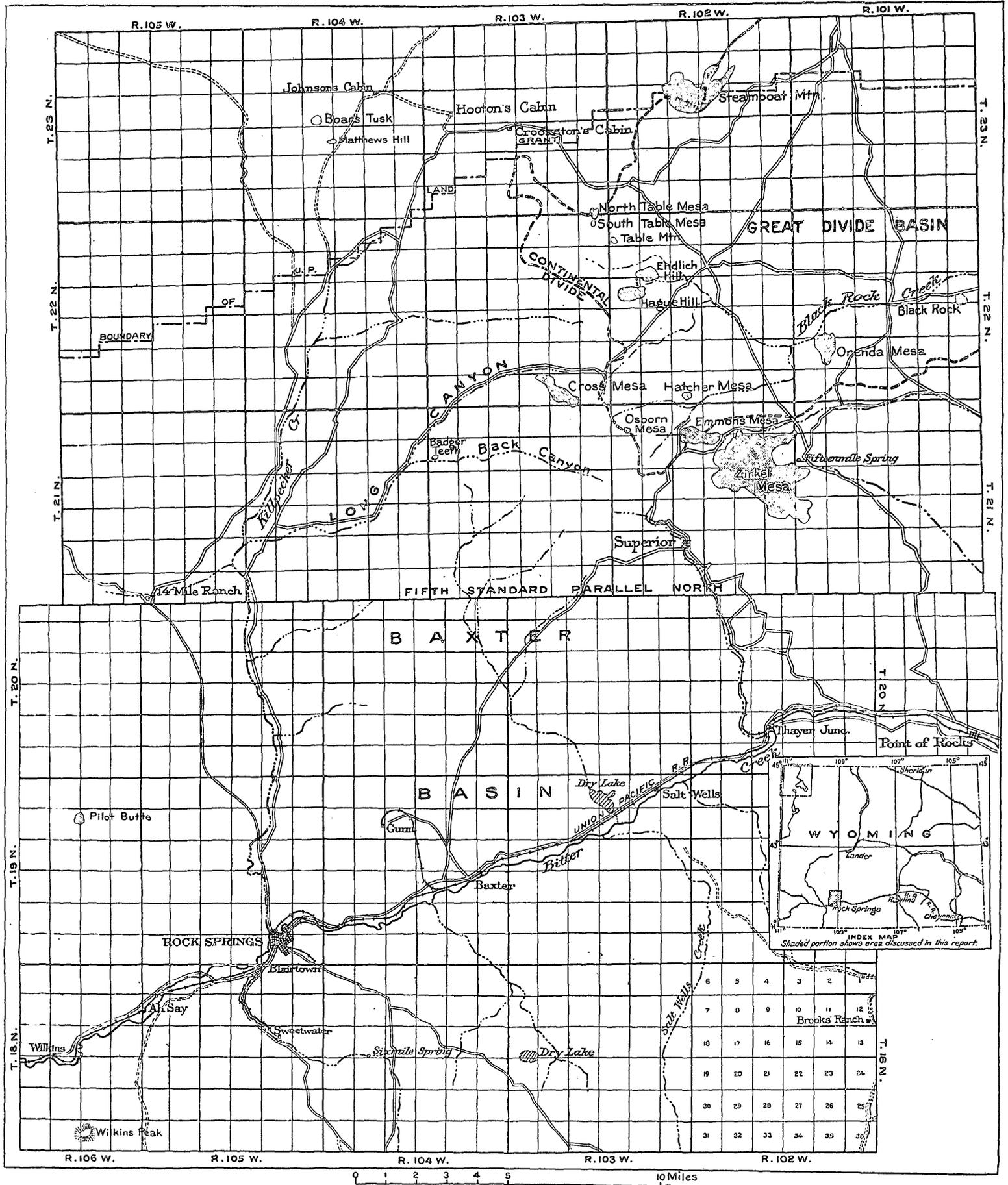


FIGURE 1.—Map showing the location and topographic relief of Pilot Butte, T. 19 N., R. 106 W. Cross-ruled areas represent lava in place; stippled areas show distribution of lava fragments.

## PILOT BUTTE.

Pilot Butte (fig. 1) is a curious flat-topped castle-like mound lying northwest of Rock Springs, in the NE.  $\frac{1}{4}$  sec. 10 and NW.  $\frac{1}{4}$  sec. 11, T. 19 N., R. 106 W. of the sixth principal meridian, Wyoming. This flat-topped mesa rises 450 feet above the plateau country of White Mountain. It is a rudely circular mass with two small indentations, one on the east and the other on the west side of the mesa. The top of this mound, approximately 1,000 feet in diameter, is bounded on all sides by abrupt, nearly perpendicular faces and slopes gently toward the east. The western crest lies approximately 50 feet higher than the crest along the east side, where the lava cap is 100 feet thick. On the west face the cap rock is approximately 150 feet thick and shows



MAP SHOWING LOCATION OF THE POTASH-BEARING ROCKS OF THE LEUCITE HILLS, SWEETWATER COUNTY, WYOMING.  
 By Alfred R. Schultz. Shaded areas represent exposures of leucite-bearing rock.

more or less distorted basaltic flow structure, suggesting proximity to the vent from which the lava exuded and spread out over the surface. On the southwest side of this castle-like mound occur several small exposures suggesting part of a dike which may be connected with the west end of the mesa. This dike appears to cut the nearly horizontal beds of the Green River formation, while the cap of the mesa or surface flow spreads out laterally over the same beds. Around this table-like mound are numerous large boulders and much fine talus, which effectually conceal the contact of the Green River formation and the lava. These float pieces are restricted to a zone around the mesa, approximately 1,900 feet in diameter. No boulders are seen outside of this narrow zonal belt. The rocks either have been entirely disintegrated or never extended beyond their present limits. A full description of the light-gray platy rock of Pilot Butte is given by Cross.<sup>1</sup>

The area of the cap rock in Pilot Butte is approximately 16 acres. One acre-foot of leucite-bearing rock, or 1 acre covered with a flow of lava 1 foot thick with a specific gravity of 2.8 would yield 3,798 tons. Assuming the average thickness of the lava flow over the 16 acres to be 100 feet (the thicker portion is restricted to the west end of the mesa), we find that the 16 acres would yield 6,076,800 tons, making the total available rock in Pilot Butte, including the boulders, small dikes, and talus-covered slope not embraced in the computations but estimated at 3,200 tons, approximately 6,080,000 tons. Assuming that the potash ( $K_2O$ ) content of this rock is equal to 8 per cent of the total mass, as given in the analysis of the rock from Pilot Butte, we would have 486,400 tons of potash stored in Pilot Butte.

#### MATTHEWS HILL.

Matthews Hill is a low rounded knoll lying in the SE.  $\frac{1}{4}$  NE.  $\frac{1}{4}$  and the NE.  $\frac{1}{4}$  SE.  $\frac{1}{4}$  sec. 21, T. 23 N., R. 104 W. (See fig. 2.) From a distance no one would suspect that this inconspicuous knoll was in any way connected with the lava exposures, as it rises only about 40 feet above the sandy waste which surrounds it. Fragments of the lava are scattered about the base and over the slopes of the elongated east-west mound. Matthews Hill is undoubtedly a volcanic neck like the Boars Tusk but, unlike it, has suffered excessive erosion in which, together with the surrounding Tertiary beds (Wasatch formation), it has been cut down to the level of Killpecker Valley. Regarding the dikes associated with the volcanic neck, Kemp and Knight<sup>2</sup> make the following statement:

On the crest of the hill there is a narrow dike 60 yards in length and having a strike nearly northeast and southwest. This is separated from a small dike having a course

<sup>1</sup> Cross, Whitman, Igneous rock of the Leucite Hills and Pilot Butte, Wyoming: *Am. Jour. Sci.*, 4th ser., vol. 4, 1897, p. 127.

<sup>2</sup> Kemp, J. F., and Knight, W. C., Leucite Hills of Wyoming: *Bull. Geol. Soc. America*, vol. 14, 1903, p. 329.

nearly at right angles to it by 15 feet of sandstone. A short distance beyond the cross dike there are two other dikes having a strike of south 10° west. \* \* \* The first one has a length of 22 yards and is separated by 10 feet of shale from the second, which extends nearly to the base of the hill. The rock from all of these dikes is mostly schistose, but there are occasional pieces of agglomerate, such as is found at the Boars Tusk and the other volcanic necks in this region. \* \* \*

The dikes are wyomingite in an advanced stage of decomposition. The slides show spots of alteration, which are not infrequently distributed through them and which are filled with some secondary and feebly refracting mineral, probably a zeolite. Leucite, diopside, and phlogopite make up the fresher portions.

The area of the Matthews Hill volcanic neck is approximately 1½ acres, and its average height above the level of Killpecker Valley is 40 feet. This neck contains roughly 228,690 tons of leucite-bearing rock. If we assume that the remainder of the elongated mound which rises above the valley bottoms and whose slopes are covered with leucite rock is made up of lava, talus blocks, and associated dikes, we will have approximately 200,000 tons in addition to that estimated above, or 428,690 tons above the level of the base of the mound. In addition to this there is below the level of the valley the downward extension of the volcanic neck, about which very little is known. The main body of the volcanic neck may expand with depth, or, on the other hand, it may become much smaller. Assuming, however, that the neck continues downward with unchanged cross section and that the rock could be mined to a depth of 3,000 feet, or the maximum workable depth assumed in reserving the better classes of coal lands at the present time, we would have 1½ acres yielding 3,798 tons of leucite-bearing rock per acre-foot, or 5,697 tons for every foot of depth, making a total for the 3,000 feet of 17,091,000 tons. The average of eight analyses of wyomingite and orendite show an average potash (K<sub>2</sub>O) content of 11.08 per cent. Assuming that the rock will average at least 10 per cent of potash, we have the following amount of leucite-bearing rock and potash stored in Matthews Hill:

*Leucite-bearing rock and potash of Matthews Hill.*

	Leucite-bearing rock in tons.	Potash (K <sub>2</sub> O) in tons.
Above level of Killpecker Valley.....	428,690	42,869
Below level of Killpecker Valley, 3,000 feet (?).....	17,091,000	1,709,100
	17,519,690	1,751,969

BOARS TUSK.

The extraordinary volcanic neck known as the Boars Tusk is one of the most striking exposures in the region. The main mass, with its double spire, lies in the SE. ¼ SW. ¼ sec. 16, T. 23 N., R. 104 W., near the middle of Killpecker Valley, just south of the shifting sand dunes.

(See fig. 2.) It penetrates the basal beds of the Wasatch, but the contact is concealed by talus blocks. The Boars Tusk consists of three parts. The basal portion resembles a frustum of a very flat cone covered with fine talus. This frustum is approximately 100 feet high, and on it rests a frustum of a steeper cone composed of coarser talus. This frustum is approximately 100 feet high and consists of huge fallen boulders from the Tusk, mixed with some finer material. On top of this frustum rises the main rock of the Tusk, which is the remnant of a plug occupying one of the conduits through which the potash-rich magma rose to the surface. Cross<sup>1</sup> states:

The mass of the column is partly a compact breccia and partly massive rock. On the southern and western sides is a breccia made up of the same rock type, which in massive form reaches to the top of the column on the east and north and is apparently separated from the breccia by fissures.

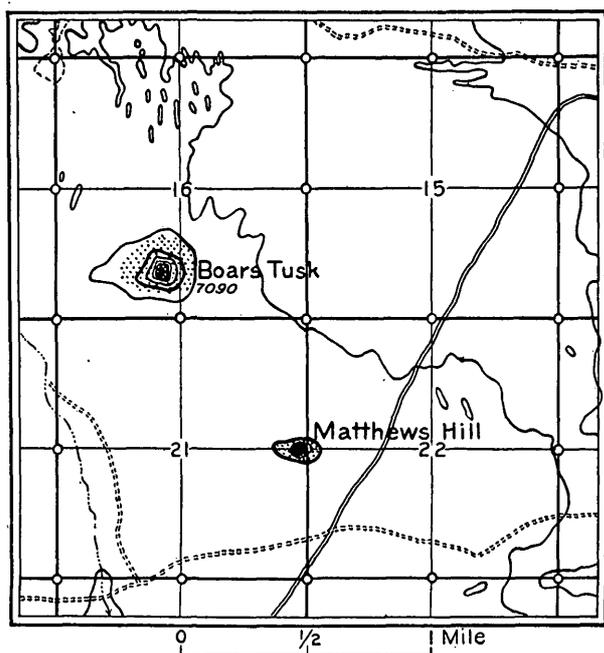


FIGURE 2.—Map showing the location and topographic relief of Boars Tusk and Matthews Hill, T. 23 N., R. 104 W. Cross-ruled areas represent lava in place; stippled areas show distribution of lava fragments.

Kemp<sup>2</sup> makes the following statement regarding the rock of the Boars Tusk:

The material of the Tusk is chiefly eruptive agglomerate and tuff, but the whole mass is penetrated by the north and south dike, whose width is from 30 to 50 feet and

<sup>1</sup> Cross, Whitman, *Igneous rock of the Leucite Hills and Pilot Butte, Wyoming*: Am. Jour. Sci., 4th ser., vol. 4, 1897, p. 119.

<sup>2</sup> Kemp, J. F., and Knight, W. C., *Leucite Hills of Wyoming*: Bull. Geol. Soc. America, vol. 14, 1903, p. 328.

which is sheeted by the fault. The dike itself contains many inclusions and much resembles a hardened tuff. The boulders of the agglomerate are partly a cellular, eruptive rock and partly fragments of shale and sandstone.

The amount of rock in the Boars Tusk is somewhat difficult to compute, as all of the contacts are concealed beneath the talus surrounding the main spire of the Tusk. The area covered by the spire or Tusk proper above the frustum of the upper cone is approximately 1.6 acres. Assuming that the plug will not decrease in size from the base of the upper cone, or Tusk proper, down to the level of the valley, and that the exposed massive part of the Tusk is approximately equal to the volume of a cone whose base is 1.6 acres and whose altitude is that of the Tusk above the frustum of the upper cone, or 140 feet, we have available in the plug of the Boars Tusk approximately 1,866,384 tons of leucite-bearing rock above the level of Killpecker Valley. In the frustum of the cones surrounding the volcanic plug, which are composed largely of talus and boulders, we have approximately 8,900,000 tons, on the assumption that all of the mass in the frustum of the cones is made up of this material. Assuming that the volcanic plug will have at least the same area below the level of Killpecker Valley as it has where the talus-covered slope conceals the main volcanic plug of the Tusk, we would have 1.6 acres yielding 3,798 tons of leucite-bearing rock per acre-foot, or 6,076 tons for every foot in depth, making a total of 18,228,000 tons for a total depth of 3,000 feet. Using in our computations 10 per cent potash content for this rock as in other cases, we have for the Boars Tusk the following results:

*Leucite-bearing rock and potash of Boars Tusk.*

	Leucite-bearing rock, in tons.	Potash (K <sub>2</sub> O), in tons.
In volcanic plug of Tusk above level of Killpecker Valley.....	1,866,384	186,638
Portion of frustum of cones surrounding volcanic plug above level of valley..	8,900,000	890,000
Below level of Killpecker Valley to 3,000 feet depth.....	18,228,000	1,822,800
	28,994,384	2,999,438

**BADGER TEETH.**

The Badger Teeth exposures are the remnants of an old volcanic neck lying in the SE.  $\frac{1}{4}$  NW.  $\frac{1}{4}$  sec. 7, T. 21 N., R. 103 W. (See fig. 3.) They consist of five projecting toothlike masses arranged along an east-west line, the two largest being on the east, near the crest of the knoll, and the other three on the west slope. A somewhat conical platform of sandstone of Montana age rises about 65 feet above the bottom of Back Canyon. On this platform rises a conical mass of talus to a height of 75 feet, above which the two larger teeth project, the highest reaching an elevation of 7,023 feet, or 173 feet

above the valley bottom. Regarding the material in the Badger Teeth, Kemp<sup>1</sup> makes the following statement:

The projecting masses consist partly of a green volcanic agglomerate and partly of solid eruptive rock. The mass of the two larger teeth consists of about half of each. Before the explosive activity which gave rise to the agglomerate there must have been a solid dike, because the bowlders of the agglomerate are chiefly of eruptive rock themselves, and the interstices are filled with tuff or mud precisely as at the Boars Tusk. The dike is a dense drab rock, which in places is amygdaloidal. The amygdules contain crystals of aragonite, which, except for the chalcedony of Steamboat Mesa and the niter observed by Dr. Cross, is the only secondary mineral we have observed in the amygdules. The aragonite occurs in platy crystals and in tufts of needles. In the field we thought the needles to be some zeolite, but they were kindly determined to be aragonite by Dr. Austin F. Rogers, of the department of mineralogy, Columbia University. The dike also contains many inclusions of sandstone and shale. \* \* \*

The extremely limited character of the exposure brings one irresistibly to the conclusion that it is an elongated volcanic neck built up in a short fissure. \* \* \*

The dike is wyomingite and one of the best examples of this rock in the hills. The leucites are large and abundant. The diopsides are also unusually large and well formed. The phlogopite has its own six-sided boundaries. There is abundance of a yellow glass present in which the other minerals are embedded. A very few stray sanidines were detected, so that it can not be said that the rock lacks this mineral entirely. Apatite is also present. The rock is practically identical with that at the Boars Tusk and Wortman dike.

The amount of rock in the Badger Teeth above the sandstone platform of Montana age is approximately equal to the volume of a cone whose base covers 4 acres and whose height is 75 feet, or about 379,800 tons. Assuming that the area of the volcanic neck below the talus cone remains the same as at the surface and is at least 1½ acres, we would have 17,461,305 tons of rock in the plug below the sandstone platform of Montana age to a depth of 3,000 feet below the bottom of the valley of Back Canyon.

*Leucite-bearing rock and potash in the Badger Teeth.*

	Leucite-bearing rock, in tons.	Potash (K <sub>2</sub> O), in tons.
Badger Teeth and talus cone above sandstone platform of Montana age. . . . .	379,800	37,980
Volcanic neck below sandstone platform of Montana age to a depth of 3,000 feet below bottom of Back Canyon . . . . .	17,461,305	1,746,130
	17,841,105	1,784,110

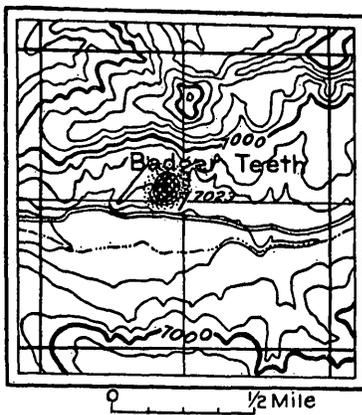


FIGURE 3.—Map showing the location and topographic relief of the Badger Teeth, T. 21 N., R. 103 W. Cross-ruled areas represent lava in place; stippled areas show distribution of lava fragments.

<sup>1</sup> Kemp, J. F., and Knight, W. C., *Leucite Hills of Wyoming*: Bull. Geol. Soc. America, vol. 14, 1903, pp. 326-327.

## CROSS MESA.

Cross Mesa (see fig. 4), which is capped by one of the principal flows, lies just west of the Continental Divide, in sec. 35 and the NE.  $\frac{1}{4}$  sec. 34, T. 22 N., R. 103 W., and extends into the NE.  $\frac{1}{4}$  sec. 2, T. 21 N., R. 103 W. The mesa is half a mile wide and extends  $1\frac{1}{2}$  miles

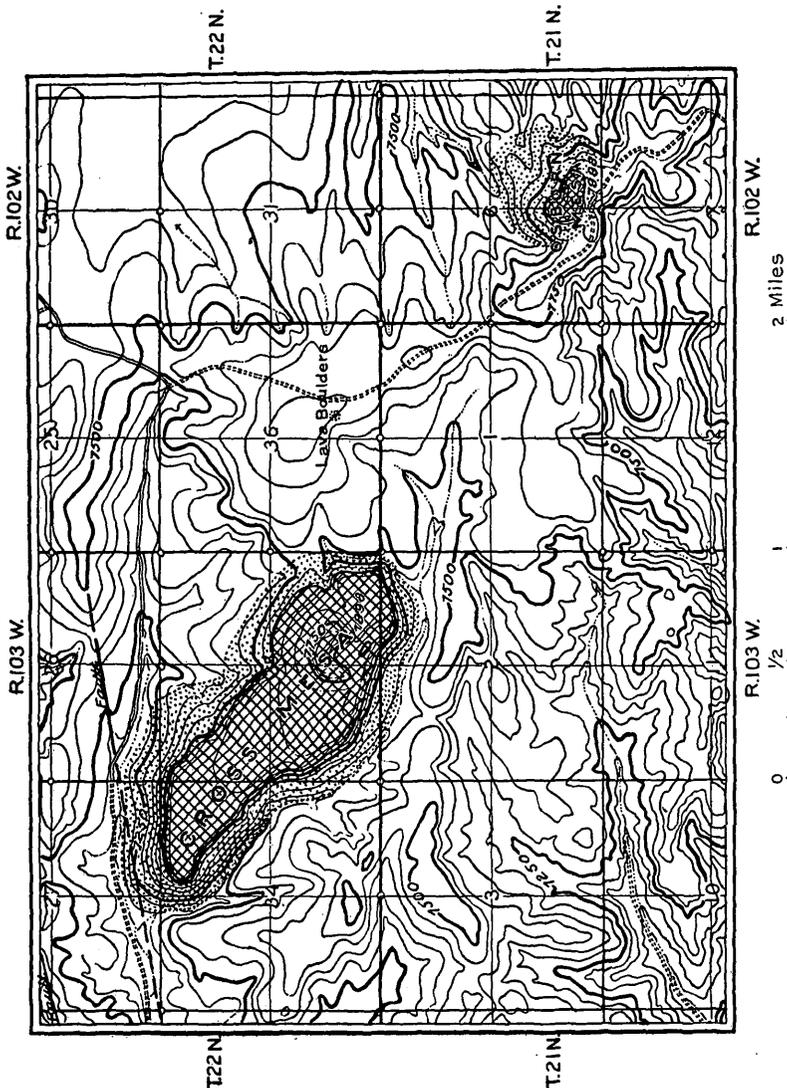


FIGURE 4.—Map showing the location and topographic relief of Cross and Osborn mesas and their relation to the lava-boulder locality. Cross-ruled areas represent lava in place; stippled areas show distribution of lava fragments.

in a northwest-southeast direction. The lava sheet overlying the rocks of Montana age is about 50 feet thick and stands about 400 feet above the valley of Long Canyon, which lies a quarter of a mile to the north. The mesa slopes gently in all directions from the remnant of an old cone that rises to an elevation of 7,898 feet a quar-

ter of a mile south of the center of sec. 35. The longest tongue of lava extends toward the northwest for more than a mile and drops approximately 100 feet in this distance. The cone is the north half of an old ring whose south half was destroyed at the time of eruption or has subsequently been eroded. It is built up of fragments of reddish pumice. The rock of the mesa is composed of orendite, leucite, sanidine, diopside, hornblende, phlogopite, and rutile. Outside of the material composing the cone, the escarpment and top of the mesa appear to be made up of one flow. The entire mass of rock back from the cone, where there is probably a volcanic conduit, is made up of this surface flow and no leucite-bearing rock occurs beneath the capping bed.

The amount of rock in this surface flow is approximately 70,832,700 tons and it contains about 7,083,270 tons of potash ( $K_2O$ ). Rising on top of this surface lava sheet is the cone of pumice south of the center of section 35. The amount of rock in the cone lying above the surface flow may be estimated at 7,899,840 tons, containing about 789,984 tons of potash, making a total of 78,732,540 tons of rock, or 7,873,254 tons of potash, above the surface of the underlying sedimentary rock. No attempt is made to estimate the tonnage that may exist in the volcanic conduit beneath the cone through which the material of the mesa no doubt was derived.

#### OSBORN MESA.

Osborn Mesa (fig. 4) lies on the highest point of the west ridge of the Continental Divide south of Steamboat Mountain and reaches an elevation of 7,998 feet. Although a commanding mesa, it is not of great superficial area. The longer axis of the flow is about a quarter of a mile long and extends in a southeast-northwest direction along the Continental Divide. The exposure is about an eighth of a mile in width and is surrounded on the slope of the hill by talus blocks or boulders that extend more than a quarter of a mile back from the vertical edge of the cap rock, which is approximately 100 feet thick. The source of the material composing this mesa is no doubt a dike or vent associated with the flow which may be concealed beneath its surface. No dike or volcanic neck was seen during the examination, but from the relations at the mesa and along the Continental Divide, which slopes from the mesa both to the southeast and the northwest, it appears that the lava was forced to the surface in the locality of the mesa. About  $1\frac{1}{2}$  miles to the northwest, on the Continental Divide, in the SW.  $\frac{1}{4}$  SE.  $\frac{1}{4}$  sec. 36, T. 22 N., R. 103 W., occur four large boulders, with associated fragments of smaller rock, lying at an elevation of about 7,700 feet, or approximately 200 feet lower than the base of the flow at Osborn Mesa and 100 feet higher

than the base of the lava at the east end of Cross Mesa, half a mile to the west. These boulders probably represent the remnants of an old flow which at one time was continuous from Osborn Mesa to the boulder locality and may have extended some distance toward the northwest. The topographic relations along this part of the divide, as well as the small remnants of lava and altered sandstones, suggest that it was at one time capped by a tongue of lava extending northwestward from Osborn Mesa much as the tongue now extends northwestward from Cross Mesa. This lava surface flow may also have extended northeastward and joined with the lava at Hatcher Mesa. The slope from Osborn Mesa northwestward along the divide to the four boulders is comparable to the slope of the lava flow on Cross Mesa and probably represents part of the same surface, which in turn may be a part of the nearly base-leveled plain upon which the Bishop conglomerate and the lava flows rest.

Osborn Mesa lies in the SW.  $\frac{1}{4}$  SE.  $\frac{1}{4}$  and the SE.  $\frac{1}{4}$  SW.  $\frac{1}{4}$  sec. 6, T. 21 N., R. 102 W. The area of the lava cap is about 15 acres, and as the rock is a typical orendite, its mass is approximately 5,697,000 tons, and it contains about 569,700 tons of potash. This computation does not take into consideration the talus blocks nor the rock which may occur in a dike or vent through which the lava reached the surface.

#### HATCHER MESA.

Hatcher Mesa is in the S.  $\frac{1}{2}$  sec. 33, T. 22 N., R. 102 W., about a quarter of a mile south of the center of the section. (See fig. 5.) It is a conspicuous flat-topped hill, approximately a quarter of a mile in diameter, and is bounded by a high vertical scarp. The talus blocks scattered along the slope below the scarp extend down to the valley and are distributed over an area whose diameter is equal to about half a mile. The top of the lava cap is 7,670 feet above sea level, or 420 feet above the bottom of the valley. The thickness of the lava sheet is about 50 feet. The general appearance of the lava on this mesa and its nearness to Emmons Cone suggest that it may be the remnant of a once continuous flow extending from Emmons Cone, on Emmons Mesa, about a mile to the south, northward to Hatcher Mesa or to some point beyond.

The elevation of the base of the lava cap at Hatcher Mesa is, however, nearly 100 feet higher than the base of the lava along the northwestern part of Emmons Mesa, and as there has been no displacement by faulting, the source of the lava can not be Emmons Cone. It is more probable that it is a remnant of a surface flow that spread out over the surface from Osborn Mesa, 2 miles to the southwest, connecting Osborn Mesa, Hatcher Mesa, and the boulder locality. The slope from Osborn Mesa to Hatcher Mesa is approximately the same

as that from Osborn Mesa to the boulder locality and is similar to that on Cross Mesa. It is of interest to note in this connection that the old surface must have sloped toward the north along the crest of the divide, with a corresponding slope toward the east and west on the two sides, as seen in the lava surfaces in Cross and Emmons mesas. Whether it marks the location of an earlier Continental Divide or only a minor irregularity on the nearly base-leveled plain is a matter of conjecture.

The present area of the lava-capped mesa is 27 acres, its mass about 5,127,300 tons, and its potash content about 512,730 tons.

#### EMMONS MESA.

Emmons Cone is one of the prominent landmarks in this vicinity. The cone lies on the northwestern part of the mesa of the same name and from its peculiar color may be easily distinguished from all points of view. The mesa from which the cone rises is a nearly flat-topped prominence a little over-half a mile in width and about  $1\frac{1}{2}$  miles long, extending in an east-west direction. The thickness of the lava cap is approximately 50 feet, and the surface slopes gradually toward the east. This mesa may at one time have been connected with Zirkel Mesa, from which it is now separated by a narrow gulch or ravine eroded into the underlying sandstone of Montana age. The lava of Emmons Mesa was derived from the vent at Emmons Cone; that of Zirkel Mesa came from one or more of the vents on it. The cone on Emmons Mesa rises approximately 162 feet above the top of the mesa, or to an elevation of 7,862 feet, and its base is approximately three-eighths of a mile in diameter. Emmons Mesa lies in secs. 3, 4, 9, and 10, T. 21 N., R. 102 W., and its relation to Hatcher and Zirkel mesas may be seen in figure 5. The area of the lava cap is 440 acres; it contains approximately 83,556,000 tons of rock and the potash content is about 8,355,600 tons. The cone that rises above the level of the mesa contains approximately 11,074,968 tons of rock, or 1,107,496 tons of potash, making a total for this mesa, exclusive of the boulders surrounding the mesa and any associated volcanic necks or plugs, of 94,630,968 tons of rock, or 9,463,096 tons of potash.

#### ZIRKEL MESA.

Zirkel Mesa, by far the largest exposure of lava in the Leucite Hills, lies chiefly in the east half of T. 21 N., R. 102 W., but extends into the western part of T. 21 N., R. 101 W. It consists of lava flows with high and nearly vertical escarpments, more or less dissected and indented at various places about the margin. The mesa is built up of a complex of several flows whose material came, in part, at least, from separate vents. The entire mass of lava rests on rocks of

Montana age which have been cut by at least three prominent faults, none of which affect the lava, thereby proving that the age of the lava flow is later than the faulting. (See fig. 5.) The surface of the mesa is very irregular in some places, but in others it is nearly flat. From the top of the mesa rise five prominent cones, four of which consist of fragments of pumice, and the other, with its smaller asso-

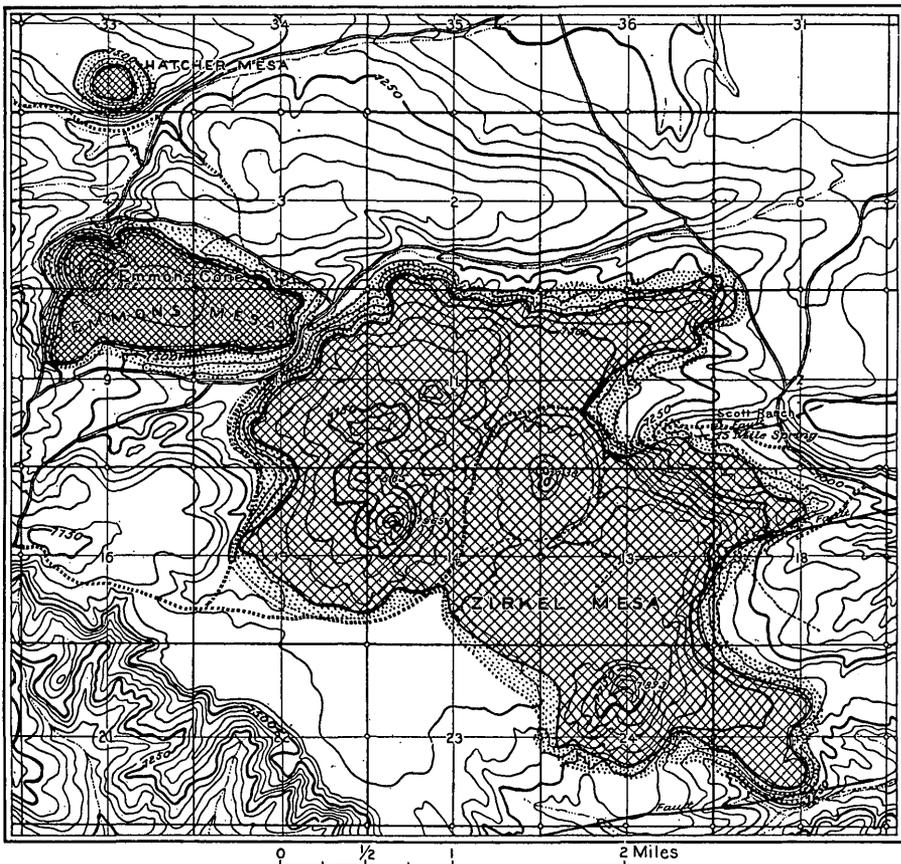


FIGURE 5.—Map showing the location and topographic relief of Hatcher, Emmons, and Zirkel mesas, Tps. 21 and 22 N., R. 102 W. Cross-ruled areas represent lava in place; stippled areas show distribution of lava fragments.

ciated blisters, is made up of solid lava similar to the cones on Steamboat Mountain.

Because of the irregularity of the surface and the varying thickness of the flows from the several vents, it is difficult to compute the tonnage in Zirkel Mesa. No attempt will be made to estimate the amount of rock that may occur in the vents from which the lava exuded or that is distributed about the mesa in the form of talus and boulder blocks. The mesa covers approximately 3,300 acres and the average total thickness of the flows is 75 feet. The amount

of rock in this more nearly horizontal part of the mesa is equal to 940,005,000 tons, with approximately 94,000,500 tons of potash. The irregularities on the mesa, including the cones and protuberances, contain approximately 102,336,276 tons of leucite-bearing rock, in which are stored 10,233,627 tons of potash, making a total of 1,042-341,276 tons of rock, or 104,234,127 tons of potash.

## ORENDA MESA.

Orenda is one of the larger mesas and lies  $2\frac{1}{2}$  miles northeast of Zirkel Mesa, in secs. 19, 20, 29, and 30, T. 22 N., R. 102 W. The rock is orendite, named from this locality, and in some respects resembles that of Zirkel Mesa. The main trend of the exposure is north and south. (See fig. 6.) The rock mass is made up of several irregular flows or series of flows, as is the case at Zirkel Mesa, but here the flows appear to have a common source or vent located more nearly at the center of the mesa. The cones, three in number, consist of fragmental reddish-yellow pumice. The south cone is much higher than the two at the north and reaches an elevation of 7,560 feet. The entire mesa is limited laterally by a high scarp, beyond which is found the customary zone of talus and broken boulders.

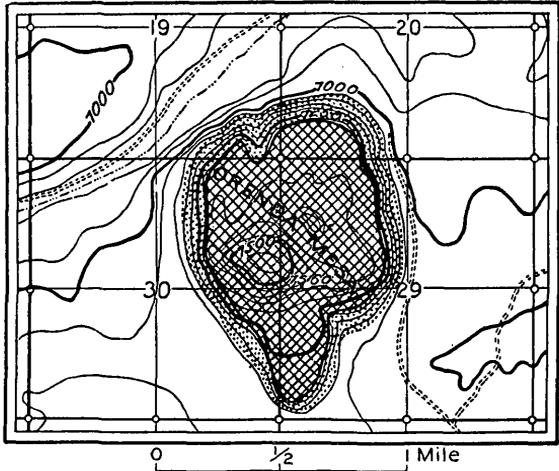


FIGURE 6.—Map showing the location and topographic relief of Orenda Mesa, T. 22 N., R. 101 W. Cross-ruled areas represent lava in place; stippled areas show distribution of lava fragments.

The Orenda Mesa area contains approximately 369 acres. While the scarp is in general rather high, there are several points near the heads of little gulches where it is indented and the abrupt wall is comparatively low. The surface of part of the mesa is undulating and rises toward the cones. The average thickness of the flow to the base of the three cones may be taken as 100 feet. This thickness applied to the area gives approximately 140,355,600 tons of rock, or 14,035,560 tons of potash. Above this mass rise the three cones, which contain approximately 9,320,584 tons of rock, or 932,058 tons of potash, making a total in the mesa, outside of the talus and the volcanic vents below the base of the lava flow, of 149,676,184 tons of leucite-bearing rock containing potash approximating 14,967,618 tons.

## BLACK ROCK MESA.

Black Rock is the most eastern exposure of the Leucite Hills and lies in secs. 13 and 24, T. 22 N., R. 101 W. It is roughly circular in outline, but is broken on the north side by a semicircular reentrant. The mesa rises 450 feet above the level of the valley on its north side and the nearly flat top has a broad east-west depression near the center, by virtue of which the north and south sides of the scarp rise considerably above the average level, reaching a maximum height of 7,200 feet along the south crest.

The slopes are covered by talus, above which rises the nearly vertical scarp of leucite-bearing lava. This lava exhibits a suggestion of

basaltic structure, having a roughly columnar surface, due to a system of nearly vertical joints which give it the general appearance of an old volcanic neck or stock. Near the north base of the scarp the rock is soft and porous and in many places resembles a tuff. Numerous other factors suggest that this is an old neck rather than a surface flow, as previously reported. The main scarp of the mesa is about 100 feet high, but in places it extends much farther down the hillside, particularly on the northeast side, thus giving it a greater thickness at this point. The top, as seen from a distance, appears to be nearly horizontal, but on closer examination it is seen to have a slight slope toward the center of the mesa. The general appearance of the hill may be inferred from figure 7.

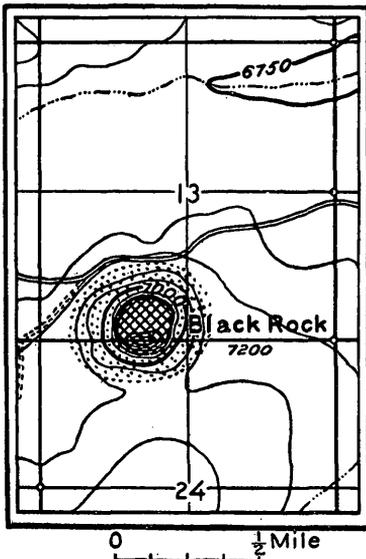


FIGURE 7.—Map showing the location and topographic relief of Black Rock Mesa, T. 22 N., R. 101 W. Cross-ruled areas represent lava in place; stippled areas show distribution of lava fragments.

Black Rock Mesa stands above the basal beds of the Wasatch formation, or what has been called the Black Rock coal group in the coal reports on this region. There is no indication of the existence of sedimentary rock underneath or in contact with the lava of the mesa. On the extreme south side the rock at the base is very scoriaceous, being composed largely of fragments of all sizes, which are more or less angular and are held together by a vesicular lava mass. Two-thirds of the way up the cliff is a 20-foot band of heavy massive lava, but the top is scoriaceous. At the top there is a fairly pronounced horizontal flow structure, layers of dense lava alternating with more porous layers.

The area of Black Rock Mesa is about 12 acres. As this rock is the variety called wyomingite, its weight is approximately 3,798 tons per acre-foot, or 45,576 tons for every foot of rock over the entire area. As there are at least 100 feet exposed, the amount of rock available is about 4,557,600 tons, containing 455,760 tons of potash. These figures do not include any rock below a plane 100 feet beneath the top of the mesa. The exact location and size of the volcanic conduit are not known, and an estimate made at present of the leucite rock available from Black Rock below the upper 100 feet is a mere guess. However, if this proves to be the stock of an old volcanic neck and retains the same dimensions to a depth of 3,000 feet below the surface of the valley, it will contain approximately 152,679,600 tons of rock, or 15,267,960 tons of potash, making a total for the Black Rock locality of 157,237,200 tons of leucite-bearing rock, or 15,723,720 tons of potash.

#### STEAMBOAT MOUNTAIN.

Steamboat Mountain is the second largest exposure in the Leucite Hills region, being surpassed only by Zirkel Mesa. The lava capping here rests on beds of Green River age. These, together with the underlying Wasatch formation, form the south face of the semicircular mountain which rises 1,200 feet above the sand-dune country to the south and more than 1,000 feet above the west limb of the Continental Divide north of Table Mountain. (See fig. 8.)

The southern face of the escarpment is very regular and consists of a vertical semicircular cliff rising from 50 to 60 feet above the underlying sedimentary beds, whereas on the north side, where the lava is considerably thinner, it is deeply dissected by ravines that head near the south side of the mesa. At the base of the cliffs the contacts with the underlying sediments are concealed by talus, which forms 25° to 35° slopes. The surface of the mesa, which slopes gently toward the north, is very rough and irregular.

On the top of the mesa are three hills or "cones." The northern and lower of these is perfectly conical in outline; the other two are less perfect cones, being flatter and more rounded on top, but they are higher, reaching elevations of about 8,610 feet. Just east of the northern conical mass is a low mound which may be the remnant of a fourth cone. These cones, unlike most of those in the group, are not made up of fragmental pumice but consist of hard lava flows like the one on Zirkel Mesa and may mark the positions of vents or volcanic conduits above which huge blisters of lava have been built up.

Regarding the rock of Steamboat Mountain, Kemp and Knight<sup>1</sup> make the following statement:

The lava occurs in two distinct and easily recognizable flows, each of which is about 30 feet thick. The contact is marked by a black scoriaceous crust on the lower sur-

<sup>1</sup> Kemp, J. F., and Knight, W. C., *Leucite Hills of Wyoming*: Bull. Geol. Soc. America, vol. 14, 1903, pp. 325-326.

face of the upper flow, which gives all desirable evidence of a quick chill. Iridescent hues play over the dark scoria, just as on the Vesuvian lavas, and remind the observer most strongly of some of the familiar phenomena of the Neapolitan volcano. It would appear as if the second flow had followed the first after a comparatively brief interval of time. The flows are not otherwise greatly contrasted. They each have amygdaloidal and dense bands. The amygdules are sometimes of altogether extraordinary size, being 3 to 6 inches long and half as broad. They are occasionally lined with beautiful crusts of chalcedony.

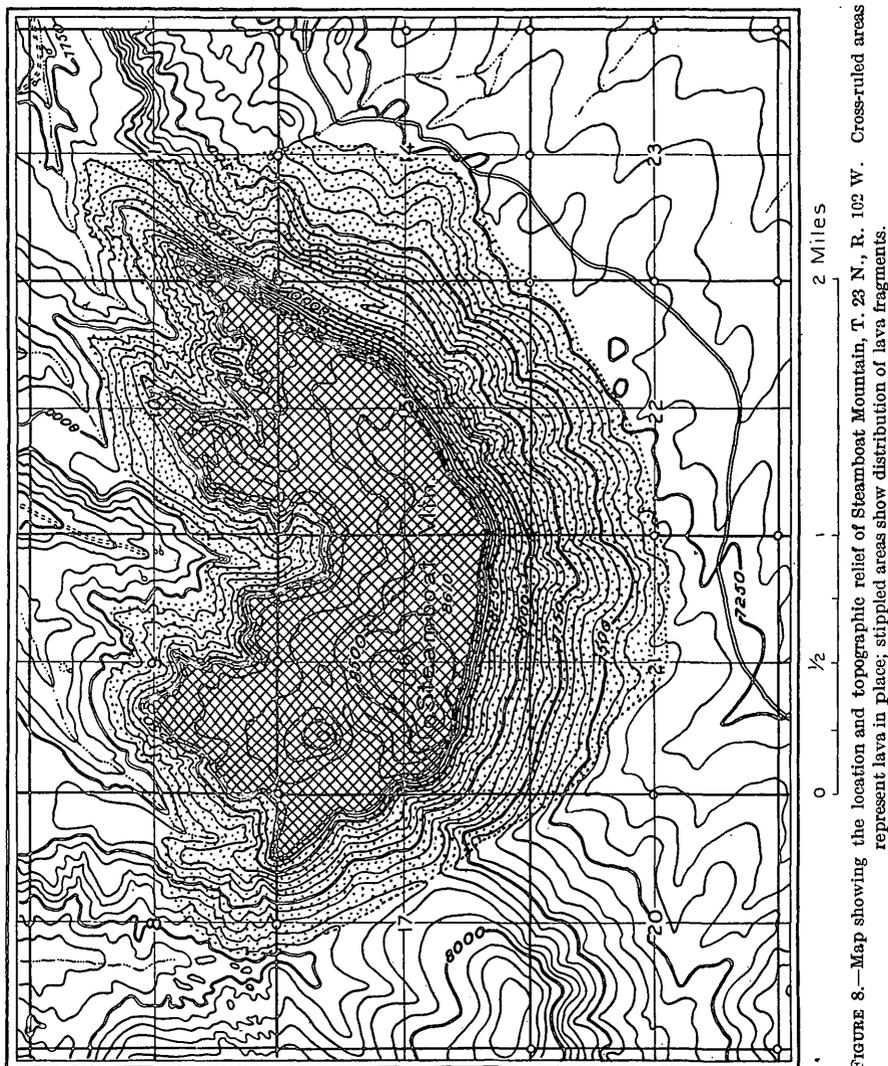


FIGURE 8.—Map showing the location and topographic relief of Steamboat Mountain, T. 23 N., R. 102 W. Cross-ruled areas represent lava in place; stippled areas show distribution of lava fragments.

The rock of this mesa is prevailingly if not entirely wyomingite. Our specimens, gathered from the east and west ends and from cone No. 1, are of this type. There may be a little sanidine at the southwest point, but it is rare and doubtful. Leucites are in great richness; diopside is comparatively scarce. There is a little hornblende and considerable phlogopite. Rutile and apatite complete the list. Calcite appears rarely in the amygdules. The black scoria is of great interest. In thin section it presents a gray-green glass with myriads of little leucites scattered through it, pre-

cisely as in some Vesuvian scorias. We have seen no similar rock anywhere in the hills. It has doubtless been caused by the quick chill at the underside of the flow. The scoria may be collected along the old and partially completed road at the southwest corner of the mesa.

On the east side of the mesa no evidence of two flows was seen unless the presence of scoriaceous zones is to be regarded as such evidence. The scoriæ seem, however, to be distributed irregularly through the lava mass. Below the lava lie 100 feet or more of brown sandstones and shales. At the contact and for some distance below it the sandstones and shales are burned or baked to a brick-red, becoming lighter as their distance from the contact increases.

Steamboat Mountain lies in secs. 8, 9, 10, 11, 15, 16, and 17, T. 23 N., R. 102 W. The area covered by the lava flow capping the mountain is about 1,019 acres. At an earlier date no doubt the mesa extended farther out on the great table-land of shales belonging to the Green River formation that now forms the west limb of the Continental Divide north of Steamboat Mountain. In this connection it may be of interest to call attention to the fact that the lava cap on Table Mountain,  $4\frac{1}{2}$  miles to the southwest, is approximately at the same elevation as that on Steamboat Mountain, and is only a little more than twice as far from the southern cone of Steamboat Mountain as the farthest point on the northeastern tongue of lava on Steamboat Mountain is from the same source.

Owing to the irregularity of the surface and the variations in the thickness of the lava, it is somewhat difficult to estimate the tonnage of rock in Steamboat Mountain. Assuming, however, that the average thickness of the lava exclusive of the cones is 50 feet, for every foot in depth over the entire area we have 3,870,162 tons, making a total for 50 feet of 193,508,100 tons of leucite-bearing rock, or 19,350,810 tons of potash. In addition to the mass of rock in the mesa, the material in the cones above the general level is equal to approximately 12,573,700 tons, containing 1,257,370 tons of potash, giving a total amount of rock capping Steamboat Mountain of 206,181,800 tons, containing 20,618,180 tons of potash.

#### NORTH TABLE MESA.

North Table Mesa lies in the south center of sec. 36, T. 23 N., R. 103 W., and in the north center of sec. 1, T. 22 N., R. 103 W. (See fig. 9.) It is a flat-topped mesa rising to an elevation of 7,900 feet, or approximately 700 feet above the valleys lying on its north and southeast sides. The top of this mesa is at least 400 feet lower than the top of Table Mountain. The mesa, which covers about 80 acres, is rimmed by a prominent scarp ranging in height from 40 to 60 feet and averaging approximately 50 feet. At the base of this scarp is the customary highly inclined slope, such as surrounds each of the other mesas.

Near the west base of North Table Mesa, in the SE.  $\frac{1}{4}$  SE.  $\frac{1}{4}$  sec. 35, T. 23 N., R. 103 W., there is a small dike, about 15 feet wide, which is

exposed for a distance of 50 feet. For the southwest 20 feet it extends in a direction N. 30° W., the rest of the dike striking N. 60° E., at a right angle to this portion. The outer part of this dike weathers into forms resembling extrusive bombs and spherulites. Computed in the same way as for the other localities, North Table Mesa contains about 15,192,000 tons of rock, in which the potash content approximates 1,519,200 tons.

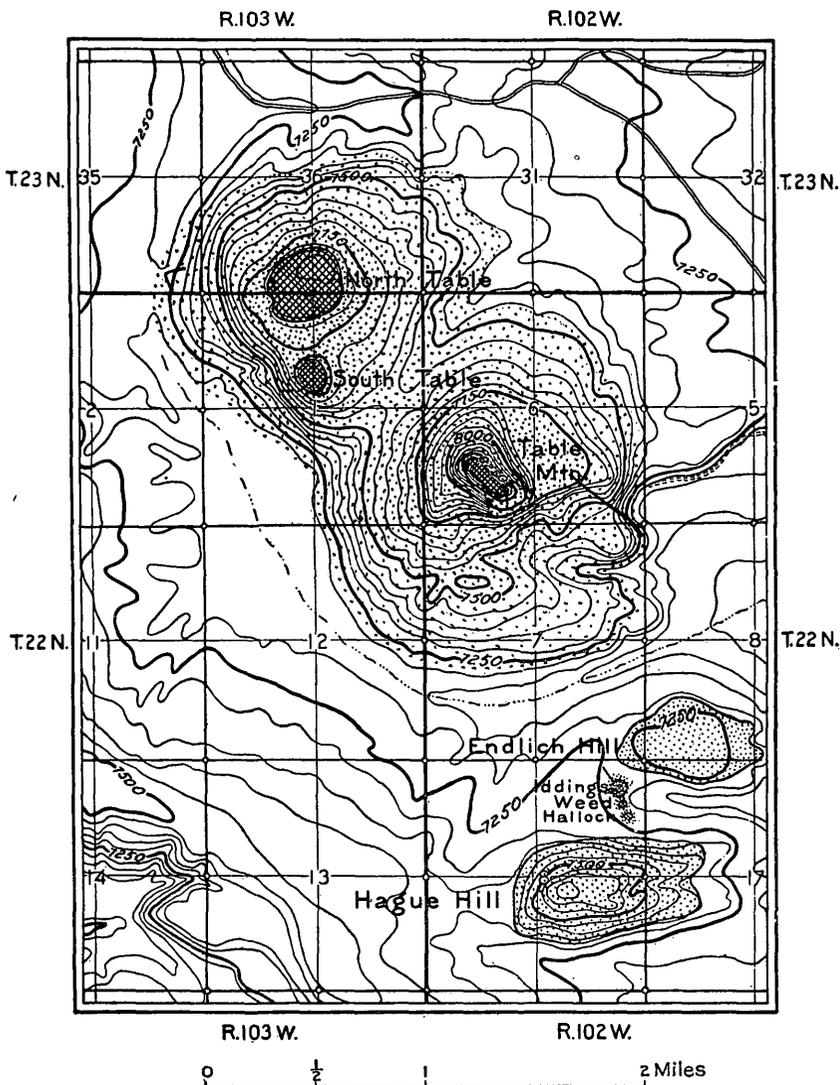


FIGURE 9.—Map showing the location and topographic relief of North Table and South Table mesas, Table Mountain, Iddings, Weed, and Hallock buttes, Endlich and Hague hills, and their associated dikes. Cross-ruled areas represent lava in place; stippled areas show distribution of lava fragments.

#### SOUTH TABLE MESA.

About an eighth of a mile south of North Table Mesa, on its south slope, lies South Table. (See fig. 9.) This is the smallest flat-topped

mesa in the field. The top lies approximately 250 feet lower than the top of North Table and is surrounded by a prominent scarp nearly 200 feet high. This mass is a remnant of a volcanic neck and exhibits a poorly developed columnar structure. The rock is dense and platy and is largely schistose, the planes of schistosity being about vertical. It resembles the material of the dikes much more strongly than it does the material of the surface flows. Many of its characteristics are similar to those observed at Black Rock, in sec. 13, T. 22 N., R. 101 W.

The lava at South Table covers about 8 acres, and the upper 100 feet of the intruded mass contains about 3,038,400 tons of rock and 303,840 tons of potash. If the diameter of the volcanic neck remains uniform in size to a depth of 3,000 feet below the level of the valley the core of the volcanic neck would contain an additional amount of 105,736,320 tons of rock, or 10,573,632 tons of potash, making a total for South Table of 108,774,720 tons of potash-bearing magma, or 10,877,472 tons of potash.

#### TABLE MOUNTAIN.

Table Mountain (fig. 9) lies in the SW.  $\frac{1}{4}$  sec. 6, T. 22 N., R. 102 W., and is the most conspicuous of all the exposures in the Leucite Hills locality. It has also been called North Pilot Mesa, because it is so conspicuous a landmark and may be seen so readily from any direction on entering this region.

The top of this mesa has an elevation of 8,300 feet, and is therefore as high as Steamboat Mountain. The lava cap on North Table lies approximately 1,300 feet above the bottom of the valley, near its east base. The mesa is surrounded by a vertical scarp, varying in height from 30 to 60 feet, with an average of about 50 feet. The topmost layer of the mesa is much more vesicular and porous than the lower part of the flow and, when seen from a distance, has a somewhat lighter appearance. On the north side of the mesa, at a point near the center, in a cavity or recess on the east side of the cleft through which the top may readily be gained, Dr. Cross found potassium nitrate in 1884.

Southeast of Table Mountain, in the SE.  $\frac{1}{4}$  SE.  $\frac{1}{4}$  sec. 6, T. 22 N., R. 102 W., near the base of this slope, is a dike extending N.  $30^\circ$  W. Its maximum thickness is 16 feet, but it varies greatly along the strike, in places pinching down to a few inches, in others expanding to nearly the maximum. The longest single exposure covers about 700 feet. Many inclusions were seen in the dike, and the carbonaceous shale at the contact seems to have been baked slightly for a distance of 1 to 2 inches back from the igneous mass. The rock weathers a light gray and is schistose in habit, the schistosity being due chiefly to the parallel arrangement of the phlogopite minerals.

The area of the capping rock of Table Mountain is approximately 22 acres. Computations similar to those made at the other localities show that this mesa contains 4,177,800 tons of leucite-bearing rock having a potash content of 417,780 tons.

#### OTHER EXPOSURES OF LEUCITE-BEARING ROCKS.

Southeast of Table Mountain, in secs. 7, 8, 17, and 18, are two talus-covered hills, the northern one known as Endlich and the southern one as Hague. (See fig. 9.) The blocks of lava are very large and have the appearance of remnants of a lava sheet. No rock of the former flow was found in place in the small areas examined.

Between the two talus-covered hills, in the NE.  $\frac{1}{4}$  sec. 18, T. 22 N., R. 102 W., are three volcanic necks with their associated dikes. The three volcanic necks, called Iddings, Weed, and Hallock buttes, lie in a line extending a little east of south. Hallock and Weed buttes are both low mounds and can not be seen from a great distance. Hallock lies on the north slope of Hague Hill and Weed lies in the depression between Hallock and Iddings buttes and is the lowest of the three. Iddings Butte is the northernmost, the highest, and the largest. It is an elliptical butte about 300 feet long and 120 feet wide, from which rises a volcanic mass of rock resembling in miniature the exposure at the Boars Tusk. Northwest of Iddings Butte is a dike 52 inches wide, extending N.  $40^{\circ}$  W. and resembling in occurrence and appearance the dike in sec. 6, southeast of Table Mountain. Extending west from the volcanic core that forms the mass of Iddings Butte is a dike 90 inches wide, composed of dense bluish rock containing many inclusions. Two small dikes, about 2 feet wide, were observed near the volcanic plug just north of the 90-inch dike. On the south side of Iddings Butte is another dike, approximately 30 inches wide. It extends S.  $30^{\circ}$  E. for a distance of 250 feet from the neck with which it seems to be connected. The general relations of these exposures and their distribution are shown in figure 9. The amount of leucite-bearing rock available from the five exposures just described, but exclusive of the associated dikes, is given approximately in the following table:

*Leucite-bearing rock and potash content in secs. 7, 8, 17, and 18, T. 22 N., R. 102 W. of the sixth principal meridian, Wyoming.*

	Leucite-bearing rock, in tons.		Potash ( $K_2O$ ), in tons.	
	Above surface.	Below surface to 3,000 feet depth.	Above surface.	Below surface to 3,000 feet depth.
Iddings Butte.....	132,930	11,394,000	13,293	1,139,400
Weed Butte.....	37,980	11,394,000	3,798	1,139,400
Hallock Butte.....	56,970	11,394,000	5,697	1,139,400
Endlich Hill.....	206,584	.....	20,658	.....
Hague Hill.....	376,712	.....	37,671	.....
	811,176	34,182,000	81,117	3,418,200

## SUMMARY OF AVAILABLE LEUCITE-BEARING ROCK.

The potash contained in the lava is not all found in the mineral leucite, but occurs also in the phlogopite, sanidine, glass, and to a small degree in diopside. The greater portion, however, is found in the two minerals, leucite and phlogopite. The chemical analyses of the leucite-bearing rock samples show that the potash ( $K_2O$ ) content of all the minerals in the rock ranges from 7.99 per cent in the madupite rock from Pilot Butte to 11.91 per cent in the orendite rock from Table Mountain, averaging for the nine analyses 10.74 per cent and for the eight samples of wyomingite and orendite 11.08 per cent. In addition to the potash, these rocks contain a large percentage of alumina ( $Al_2O_3$ ), which, were it possible of extraction, might prove of commercial value. In the nine samples analyzed the alumina ranges from 9.14 per cent in the madupite from Pilot Butte to 13.37 per cent in the wyomingite from Zirkel Mesa, averaging for the nine samples 10.82 per cent. Taking 10 per cent of  $K_2O$  and 10 per cent of  $Al_2O_3$  as a moderate average of the content of potash and alumina in the leucite-bearing rocks, we have stored in the lavas in the Leucite Hills of Wyoming the amounts of leucite-bearing rock, potash, and alumina given in the following table:

*Summary of the available leucite-bearing rock, alumina, and potash from the several exposures of the Leucite Hills, Wyoming.*

	Leucite-bearing rock, in tons.	Alumina ( $Al_2O_3$ ), in tons.	Potash ( $K_2O$ ), in tons.
Badger Teeth.....	17,841,105	1,784,110	1,784,110
Black Rock Mesa.....	157,237,200	15,723,720	15,723,720
Boars Tusk.....	28,994,384	2,899,438	2,899,438
Cross Mesa.....	78,732,540	7,873,254	7,873,254
Emmons Mesa.....	94,630,000	9,463,000	9,463,000
Endlich Hill.....	206,584	20,658	20,658
Hague Hill.....	376,712	37,671	37,671
Hallock Butte.....	11,450,970	1,145,097	1,145,097
Hatcher Mesa.....	5,127,300	512,730	512,730
Iddings Butte.....	11,526,932	1,152,693	1,152,693
Matthew Mesa.....	17,519,690	1,751,969	1,751,969
North Table Mesa.....	15,192,000	1,519,200	1,519,200
Orenda Mesa.....	149,976,184	14,997,618	14,997,618
Osborn Mesa.....	5,697,000	569,700	569,700
Pilot Butte.....	6,080,000	608,000	608,000
South Table Mesa.....	108,774,720	10,877,472	10,877,472
Steamboat Mountain.....	206,181,800	20,618,180	20,618,180
Table Mountain.....	4,177,800	417,780	417,780
Weed Butte.....	11,431,980	1,143,198	1,143,198
Zirkel Mesa.....	1,042,341,276	104,234,127	104,234,127
	1,973,496,177	197,349,617	197,349,617

These figures do not take into consideration the rock that occurs in the dikes associated with the volcanic necks and surface flows, nor the material underlying the mesas which has not been estimated in the discussion of the separate exposures. If the volcanic cones on Emmons, Zirkel, and Orenda mesas and Steamboat Mountain represent volcanic conduits or necks similar to the volcanic necks

seen at Boars Tusk, Badger Teeth, and Iddings Butte, there is considerable leucite-bearing rock in these localities that has not been included in the estimate. Some idea of the amount of material below the mesa for each conduit may be obtained by comparison with the amount estimated for the portions of the Boars Tusk and Badger Teeth lying below the level of the valley.

The figures in the above table for Pilot Butte are based on a 10 per cent potash content, the amount assumed for all the other localities, whereas in the computations used in the discussion under the heading of Pilot Butte, 8 per cent potash, the result as determined by one analysis of this rock, was used.

#### TRANSPORTATION.

The most accessible routes for railroad transportation and those of easiest grade in the northern part of the Rock Springs field lie along the larger valleys or main tributaries of Bitter Creek, namely, Nine-mile and Tenmile creeks, Horse Thief Canyon, Killpecker Valley, and its tributaries. Railroad tracks built along any of these valleys would become feeders to the main Union Pacific line along Bitter Creek and would thus afford an easy means of transportation, as gravity could be utilized in part in running the loaded cars from the mines to the nearest point on the main line.

Thus far the Union Pacific is the only railroad crossing this area, and all points in the northern part of the Rock Springs field are readily accessible from its main line. Several projected lines have been surveyed across the north end of the field, but no other line has begun active construction. The location of the Union Pacific Railroad, with its spur tracks on either side of its main line, places it in a position to control the future development of the entire field. The grade along its main line is moderate, and by short branch spurs with easy grade similar to the branches built along Horse Thief Canyon to Superior, Wyo., along the west side of Baxter Basin to Gunn, Wyo., and up Killpecker Valley, it will be comparatively easy to reach any part of the field. As many of the lavas occur on high mesas or divides, it may be necessary, if it is ever demonstrated that this rock will furnish large quantities of commercially available potash and alumina, to transport the quarried rock from these high elevations to some point where it may be treated by a local plant or loaded on cars along the line of one of the railroad branches. For this purpose aerial tramways or ore chutes may be readily installed.

Zirkel Mesa, the largest of the lava localities, lies only 2 miles from the Superior branch of the Union Pacific Railroad, but it will not be practicable to extend this branch to any of the exposures, as between Horse Thief Canyon, along which the railroad track lies, and Osborn, Emmons, and Zirkel mesas there rises a very abrupt

scarp, whose crest lies approximately halfway between the railroad track and the southern exposure of the leucite rock on Zirkel Mesa. The rise from the railroad track in Horse Thief Canyon to the crest of the escarpment is over 700 feet, while the surface on top of the escarpment is nearly level from the crest back to the mesa, the entire table-land sloping gently toward the north and east.

#### STATUS OF THE LANDS CONTAINING POTASH-BEARING ROCKS.

Prior to 1907 and 1908, when the coal examinations were made in the Rock Springs field, no attempt had been made to utilize the leucite-bearing rock in the Leucite Hills, and it was considered of importance only from a scientist's point of view. Since that time, however, conditions have somewhat changed. As yet the United States has developed no potash industry and is dependent entirely on foreign countries for its supply of this valuable material, the imports of which in 1910 amounted to 1,798,391,012 pounds, valued at \$11,615,134, and during the first nine months of 1911 were 1,601,659,217 pounds, valued at \$11,665,367, amounting to more than \$1,250,000 a month. At present every effort is being made to locate valuable potash deposits in the United States so as to supply, if possible, the constantly increasing demand from our own resources. Since the recent stimulation of interest in the possibility of finding potash in this country a number of companies have been formed for the purpose of exploiting or developing the deposits in various forms. It is reported that an attempt will be made to extract the potash ( $K_2O$ ) and alumina ( $Al_2O_3$ ) from the rock of the Leucite Hills in the vicinity of Zirkel Mesa. The problem of devising methods to extract all or any part of the potash and alumina from the lavas of the Leucite Hills is one whose solution rests entirely with the chemical and industrial engineers. The approximate amount of potash and alumina these rocks contain is well known, and the point to be determined is merely whether the extraction process to be used will separate enough of the minerals at a sufficiently low cost to make it a commercial success.

So far as known, no final patent has been granted by the United States to any of the lands in which the lava occurs except the odd sections within a distance of 20 miles of the Union Pacific main line, which were included in that company's original grant. The total number of 40-acre tracts in the Rock Springs field in which exposures of potash-bearing rock occur number 290, containing approximately 11,600 acres. Of this amount, 154 tracts, or 6,160 acres, still belong to the Government, and 136 tracts, or 5,440 acres, belong to the Union Pacific Railroad Co., unless that company has disposed of its title subsequent to receipt of final patent.

It is reported that the Union Pacific Railroad Co. has agreed to lease, under certain conditions and for certain royalties, the right, beginning September 1, 1912, to take rock for potash and its by-products from the following-described lands, all of which lie on Zirkel Mesa:

- T. 21 N., R. 101 W., sec. 19, W.  $\frac{1}{2}$ .  
 T. 21 N., R. 102 W., sec. 9, NE.  $\frac{1}{4}$ ;  
     sec. 11, all;  
     sec. 13, all;  
     sec. 15, NE.  $\frac{1}{4}$ , E.  $\frac{1}{2}$  NW.  $\frac{1}{4}$ , N.  $\frac{1}{2}$  SE.  $\frac{1}{4}$ .

According to the records of the General Land Office only one entry is on file at the present time within the lava areas of the Leucite Hills, namely, that in the E.  $\frac{1}{2}$  SW.  $\frac{1}{4}$  and the S.  $\frac{1}{2}$  SE.  $\frac{1}{4}$ , sec. 12, T. 21 N., R. 102 W., on the northeast side of Zirkel Mesa. This homestead entry was made March 12, 1907, but final certificate has not yet been issued. Mineral claims at some of the exposures may have been staked out on the ground, later applied for by the discoverer, and legally recorded by the proper county officers at Rock Springs, Wyo., but thus far none of these lands have gone to patent, and title therefore still rests with the Government. It is to be noted that no provision exists in the present law which permits the withdrawal or reservation of lands from the appropriate forms of mineral entry for the sake of potash or, in fact, for any minerals other than coal, gas, oil, or phosphate.

The following table shows the location of the areas of the leucite-bearing rocks by township, range, and section, and indicates what tracts are still part of the public domain:

*Locations of leucite-rich rock on Government and Union Pacific Railroad lands.*

Location.	Name.	Government.	Union Pacific.
T. 21 N., R. 101 W. ....	Zirkel Mesa .....	Sec. 6, SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ ..... Sec. 18, W. $\frac{1}{2}$ NE. $\frac{1}{4}$ , NW. $\frac{1}{4}$ , NW. $\frac{1}{4}$ SW. $\frac{1}{4}$ .....	Sec. 19, W. $\frac{1}{2}$ , W. $\frac{1}{2}$ E. $\frac{1}{2}$ .
T. 22 N., R. 101 W. ....	Orenda Mesa .....	Sec. 20, S. $\frac{1}{2}$ SW. $\frac{1}{4}$ ..... Sec. 30, NE. $\frac{1}{4}$ , N. $\frac{1}{2}$ SW. $\frac{1}{4}$ , SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ .....	Sec. 19, S. $\frac{1}{2}$ SE. $\frac{1}{4}$ ..... Sec. 29, NW. $\frac{1}{4}$ , NE. $\frac{1}{4}$ SW. $\frac{1}{4}$ , W. $\frac{1}{2}$ SW. $\frac{1}{4}$ .....
Do .....	Black Rock Mesa .....	Sec. 24, NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ , N. $\frac{1}{2}$ NW. $\frac{1}{4}$ .....	Sec. 13, S. $\frac{1}{2}$ SW. $\frac{1}{4}$ , SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ .....
T. 21 N., R. 102 W. ....	Osborn Mesa .....	Sec. 6, SE. $\frac{1}{4}$ SW. $\frac{1}{4}$ , SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ .....	
Do .....	Emmons Mesa .....	Sec. 4, S. $\frac{1}{2}$ .....	Sec. 3, S. $\frac{1}{2}$ SW. $\frac{1}{4}$ , SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ , N. $\frac{1}{2}$ .....
Do .....	Zirkel Mesa .....	Sec. 2, S. $\frac{1}{2}$ SW. $\frac{1}{4}$ ..... Sec. 10, E. $\frac{1}{2}$ , NW. $\frac{1}{4}$ , E. $\frac{1}{2}$ SW. $\frac{1}{4}$ ..... Sec. 12, NE. $\frac{1}{4}$ , W. $\frac{1}{2}$ , S. $\frac{1}{2}$ SE. $\frac{1}{4}$ ..... Sec. 14, all. .... Sec. 24, N. $\frac{1}{2}$ , N. $\frac{1}{2}$ S. $\frac{1}{2}$ .....	Sec. 1, SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ ..... Sec. 11, all. .... Sec. 13, all. .... Sec. 15, E. $\frac{1}{2}$ , E. $\frac{1}{2}$ NW. $\frac{1}{4}$ , NE. $\frac{1}{4}$ SW. $\frac{1}{4}$ ..... Sec. 23, N. $\frac{1}{2}$ NE. $\frac{1}{4}$ .....
T. 22 N., R. 102 W. ....	Hatcher Mesa .....		Sec. 33, E. $\frac{1}{2}$ SW. $\frac{1}{4}$ , W. $\frac{1}{2}$ SE. $\frac{1}{4}$ .....
Do .....	Hague Hill .....	Sec. 18, S. $\frac{1}{2}$ NE. $\frac{1}{4}$ , SE. $\frac{1}{4}$ NW. $\frac{1}{4}$ , E. $\frac{1}{2}$ SW. $\frac{1}{4}$ , SE. $\frac{1}{4}$ .....	Sec. 17, S. $\frac{1}{2}$ NW. $\frac{1}{4}$ , N. $\frac{1}{2}$ SW. $\frac{1}{4}$ .....
Do .....	Hallock Butte, Weed Butte, Iddings Butte, and dikes.	Sec. 18, E. $\frac{1}{2}$ NE. $\frac{1}{4}$ .....	

*Locations of leucite-rich rock on Government and Union Pacific Railroad lands—Contd.*

Location.	Name.	Government.	Union Pacific.
T. 22 N., R. 102 W. ....	Endlich Hill.....	Sec. 8, S. $\frac{1}{2}$ SW. $\frac{1}{2}$ , SW. $\frac{1}{2}$ SE. $\frac{1}{2}$ .	Sec. 7, SE. $\frac{1}{2}$ SE. $\frac{1}{2}$ .
Do. ....	Table Mountain and dikes.	Sec. 18, NE. $\frac{1}{2}$ NE. $\frac{1}{2}$ .	Sec. 17, NW. $\frac{1}{2}$ NE. $\frac{1}{2}$ , N. $\frac{1}{2}$ NW. $\frac{1}{2}$ .
T. 23 N., R. 102 W. ....	Steamboat Mountain..	Sec. 6, SW. $\frac{1}{2}$ , NW. $\frac{1}{2}$ SE. $\frac{1}{2}$ S. $\frac{1}{2}$ SE. $\frac{1}{2}$ .	Sec. 9, SE. $\frac{1}{2}$ NW. $\frac{1}{2}$ , SW. $\frac{1}{2}$ , W. $\frac{1}{2}$ SE. $\frac{1}{2}$ .
		Sec. 8, SE. $\frac{1}{2}$ SE. $\frac{1}{2}$ .....	Sec. 11, NW. $\frac{1}{2}$ SW. $\frac{1}{2}$ .
		Sec. 10, SW. $\frac{1}{2}$ NE. $\frac{1}{2}$ , S. $\frac{1}{2}$	Sec. 15, N. $\frac{1}{2}$ NE. $\frac{1}{2}$ , SW. $\frac{1}{2}$
		Sec. 16, N. $\frac{1}{2}$ , N. $\frac{1}{2}$ SW. $\frac{1}{2}$ , SE. $\frac{1}{2}$ .	NE. $\frac{1}{2}$ , NW. $\frac{1}{2}$ , N. $\frac{1}{2}$ SW. $\frac{1}{2}$ , SW. $\frac{1}{2}$ SW. $\frac{1}{2}$ , NW. $\frac{1}{2}$ SE. $\frac{1}{2}$ .
T. 21 N., R. 103 W. ....	Badger Teeth.....		Sec. 17, E. $\frac{1}{2}$ NW. $\frac{1}{2}$ .
Do. ....	Cross Mesa.....	Sec. 2, N. $\frac{1}{2}$ NE. $\frac{1}{2}$ .	Sec. 7, SE. $\frac{1}{2}$ NW. $\frac{1}{2}$ , NE. $\frac{1}{2}$ SW. $\frac{1}{2}$ .
T. 22 N., R. 103 W. ....	do.....	Sec. 34, N. $\frac{1}{2}$ NE. $\frac{1}{2}$ , SE. $\frac{1}{2}$ NE. $\frac{1}{2}$ .	Sec. 35, NW. $\frac{1}{2}$ NW. $\frac{1}{2}$ , S. $\frac{1}{2}$ NW. $\frac{1}{2}$ , SW. $\frac{1}{2}$ SE. $\frac{1}{2}$ .
Do. ....	Boulders.....	Sec. 36, SW. $\frac{1}{2}$ SE. $\frac{1}{2}$ .....	Sec. 1, SW. $\frac{1}{2}$ NE. $\frac{1}{2}$ , SE. $\frac{1}{2}$ NW. $\frac{1}{2}$ .
Do. ....	South Table.....		Sec. 1, NW. $\frac{1}{2}$ NE. $\frac{1}{2}$ , N. $\frac{1}{2}$ NW. $\frac{1}{2}$ .
Do. ....	North Table.....		
T. 23 N., R. 103 W. ....	do.....	Sec. 36, SW. $\frac{1}{2}$ , W. $\frac{1}{2}$ SE. $\frac{1}{2}$ .	
T. 23 N., R. 104 W. ....	Boars Tusk.....	Sec. 16, E. $\frac{1}{2}$ SW. $\frac{1}{2}$ , W. $\frac{1}{2}$ SE. $\frac{1}{2}$ .	
Do. ....	Matthew Hill.....	Sec. 22, SW. $\frac{1}{2}$ NW. $\frac{1}{2}$ , NW. $\frac{1}{2}$ SW. $\frac{1}{2}$ .	Sec. 21, SE. $\frac{1}{2}$ NE. $\frac{1}{2}$ , NE. $\frac{1}{2}$ SE. $\frac{1}{2}$ .
T. 19 N., R. 106 W. ....	Pilot Butte.....	Sec. 10, E. $\frac{1}{2}$ NE. $\frac{1}{2}$ .....	Sec. 11, W. $\frac{1}{2}$ NW. $\frac{1}{2}$ .

The United States Government, realizing the great present and the greater future need of potash as a fertilizer, has been active in recent years in its search for sources of this compound. Both the Department of the Interior and the Department of Agriculture are taking part in this search and all possible mineral and organic sources are being sought and tested. The Geological Survey's activities are confined to the possible geologic sources and are inspired by a desire to place at the service of the public the special training of its staff of geologists. This paper has been prepared in furtherance of this end and others similar in tenor will appear from time to time.

