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DIKE ROCKS OF THE APISHAPA QUADRANGLE COLORADO

BY

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DIKE ROCKS OF THE APISHAPA QUADRANGLE, COLORADO.

By Whitman Cross.

INTRODUCTION.

Location and field work.—The Apishapa quadrangle, the geographic relations of which are shown by Plate IV, is situated on the plains south of Arkansas River, in Colorado, about 24 miles east of the mountain front. The geology of the Pueblo, Walsenburg, Spanish Peaks, and Elmoro quadrangles, adjoining it on the northwest, west, southwest, and south, respectively, has been described in folios of the Geologic Atlas.[1] G. K. Gilbert, assisted by F. P. Gulliver and G. W. Stose, took up the survey of the Apishapa area in 1894. The Apishapa folio was completed by Stose and was issued in 1913. The rocks to be described in this paper were collected by Gilbert and his assistants, the present writer never having visited the area. The following description of the occurrence of the rocks has been kindly furnished by Mr. Stose.

Occurrence of the rocks.—Forty-three dikes have been observed in the Apishapa quadrangle. They are mostly vertical in position and trend as a rule nearly west, or somewhat to the south of west. The greater number are from 4 to 10 feet wide, but a few reach a width of 20 feet or more.

The trend of the dikes and the character of the dike rocks demonstrate clearly that they belong to the outer zone of the system of dikes radiating from the Spanish Peaks center, to the southwest. Near this center similar dikes cut the Eocene Huerfano formation, and in the Apishapa quadrangle the latest Cretaceous formation present is penetrated by some of the rocks here described. While the dikes are therefore possibly of late Eocene age, they may be considerably younger. Fragments of the dike rocks are found in the earliest terrace deposits of the quadrangle.

The dikes are most numerous, naturally, in the southwestern part of the quadrangle—the part nearest to the Spanish Peaks. The most thickly intruded tract is an elliptical upland area southeast of Bonita Cordova ranch, where 12 dikes occur within a strip about 1 mile wide. In a few places dikes were observed to intersect one another, but the relative ages were not determined, though the identification of specimens has shown that in most of these places the intersecting dikes are made up of different rocks. In Graston Butte, the dike hill east of North Rattlesnake Butte, a long branching dike of basalt is cut by a shorter one of augite vogesite.

Where the dikes penetrate shale the shale has been indurated, as a rule for several feet from the contact, and erosion has left the dike and the indurated wall rock projecting above the surface of the soft shales. No noticeable mineral change has occurred in the baked shale. A similar effect is locally found where dikes cut limestone.

The most conspicuous of these dike ridges are Mica Butte and Blue Hill. Graston Butte, east of North Rattlesnake Butte, and some others, unnamed, are nearly as large but are less conspicuous because they are less isolated.

Where the dikes cut the Dakota sandstone or the Timpas limestone (Cretaceous), they are generally attacked more readily by weathering and erosive agencies than the wall rocks and therefore are indicated by crevices or channels traversing the sedimentary formations.

[1] Gilbert, G. K., U. S., Geol. Survey Geol. Atlas, Pueblo folio (No. 36), 1897. Hills, R. C., idem, Elmoro folio (No. 58), 1899; Walsenburg folio (No. 68), 1900; Spanish Peaks folio (No. 71), 1901.

Several dikes contain xenoliths of foreign rocks brought up from lower levels and derived partly from sediments traversed by the dikes and partly from the pre-Cambrian complex below. The pre-Cambrian rocks are granites, gneisses, and schists, similar to those of the Greenhorn Mountains, to the west. No fusion or notable metamorphism of these xenoliths was observed.

General character of the rocks.—All the Apishapa dike rocks are very dense and dark in the unaltered state. The rock most easily determinable in hand specimens is a minette. Two diabases are dark gray and with a hand lens one can recognize feldspar and pyroxene in them. The largest group is that of the homogeneous-appearing aphyric aphanites; these grade into melaphyres (in the field meaning of the term) exhibiting more or less abundant and distinct small olivine and augite phenocrysts. Biotite tablets as much as 1 centimeter in diameter are sporadically developed in some rocks.

A few specimens are characterized by round or irregular white grains of analcite. Although in two specimens these grains appear like phenocrysts, it is believed that they are the filling of small pores. In one rock a fibrous zeolite occurs beside analcite partly filling vesicles. Calcite and chlorite are associates of the analcite in some rocks.

Microscopical study shows that the rocks belong to a series of lamprophyres ranging from minette to basalt. That the basalt is but one extreme of the series is shown by the gradation through several occurrences into alkali feldspar rocks carrying abundant biotite and brown hornblende, with augite and more or less olivine. The analyses to be presented confirm this characterization. The dikes of the adjacent quadrangles furnish many other lamprophyric varieties, according to Hills, making the gradation still more striking.

The Apishapa dike rocks will be described under the names minette, augite minette, tinguaite, olivine-bearing augite vogesite, augite-hornblende vogesite, sodic diabase, and olivine-plagioclase basalt.

PETROGRAPHY.

MINETTE.

Description.—The single dike of normal minette occurs west of the lower or north end of the canyon of Apishapa River. It trends east-west and is 10 feet or more in average width. Material from a point about 5 miles west of the river has a reddish or gray-brown color due to numerous leaves of glistening biotite, many of which are 2 or 3 millimeters across. A rude parallel arrangement of the biotite flakes causes a marked schistosity. The matrix is pale pinkish in tone, owing to the presence of minute biotite scales and limonite pigment. No phenocrysts of feldspar or augite can be detected.

Under the microscope the rock is seen to be a mass of interlacing leaves of fresh biotite, which form perhaps one-third of the whole, with a matrix consisting principally of clear alkali feldspar in blades, many of them arranged in sheaf-like bundles. Besides these predominant constituents, apatite is notably abundant in colorless cross-jointed prisms, the smaller of which are included in the biotite. A prismatic mineral, presumably diopside, was once an abundant element but is now almost wholly decomposed, chlorite and calcite in a very fine aggregate of indistinct outline taking its place. Magnetite is scattered through the rock in dustlike particles surrounded by limonitic stain. The feldspar is principally orthoclase, with which is associated some soda-rich plagioclase, probably oligoclase-albite.

Calcite occurs not only as one of the alteration products of the prismatic mineral but also in minute scales and irregular particles scattered through the mass. No calcite grains with distinct cleavage have been seen. The amount of calcite corresponding to the CO_2 found by analysis is much greater than the estimate from microscopical examination. This discrepancy is explained by the presence of minute seams of calcite parallel to the schistosity, representing a deposit from circulating solutions. These seams do not appear in the thin sections.

Such a control by magnesia does not exist in the Apishapa rocks, for it is in the olivine-augite vogesite with lowest actual and relative magnesia that the anorthite is entirely suppressed and in the basalt with highest actual and relative contents in magnesia that plagioclase is most abundant. Nor is it a question of the amount of normative anorthite, for the hornblende-augite vogesite, with 16.40 anorthite, has little plagioclase, while the plagioclase basalt has but 14.18 anorthite, only 1 per cent more than appears in the norm of the plagioclase-free vogesite.

Ignoring the disturbing effect of assimilation of foreign substances and assuming that the formation of a series of magmatic differentiates in a given region is a result of certain forces, known or unknown, characteristic of that region, we must also recognize that in the course of eruption and crystallization these magmas come under the influence of pressure and temperature differing from those of the site of deep-seated differentiation, causing more or less pronounced reactions. When we consider also the possibilities of the absorption by the magma of various potent substances while passing from one place to another, it seems scarcely overdrawn to say that a magmatic solution may become the plaything of conditions quite unrelated to those of the place of its origin, that these independent conditions may vary in one district from time to time, and that they surely must vary from one province to another, when magmas of the same chemical composition are involved.

When a large series of eruptions or intrusions of various differentiates has occurred in one province it is conceivable that the conditions attendant on consolidation, though independent of those regulating differentiation, may have been so constant as to permit the development of some highly characteristic mineral features of the rock series. But the fact that conditions of crystallization may vary in one region during a long series of eruptions and are not the same, unless by fortuitous coincidence, in different regions where the magmas may have been similar must lead to caution in extending over the whole world the generalizations that apply to one area.

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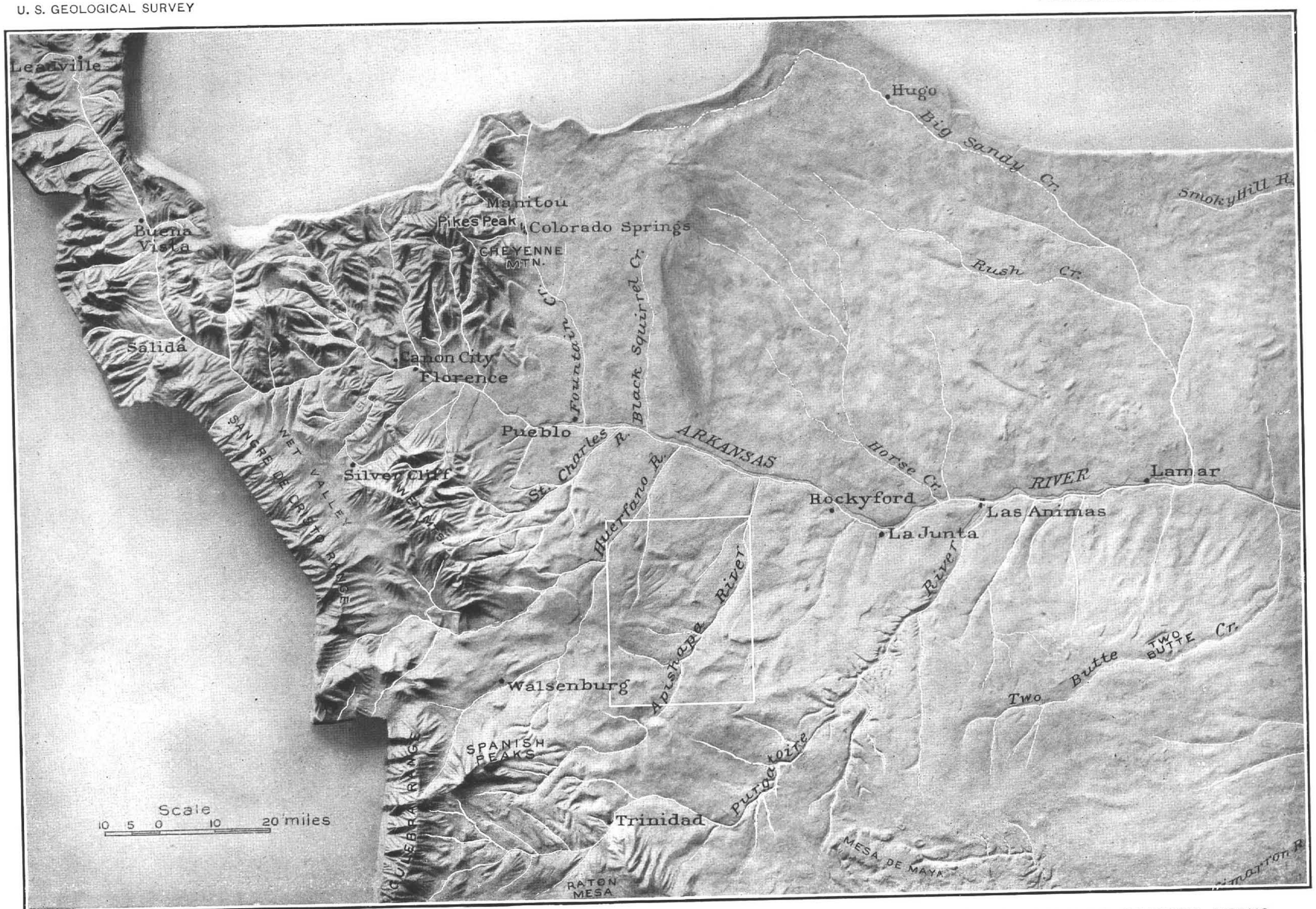


RELIEF MAP OF SOUTH-CENTRAL COLORADO, SHOWING RELATION OF THE APISHAPA QUADRANGLE TO THE SPANISH PEAKS CENTER OF ERUPTION.

The Apishapa quadrangle is outlined in white.

with adequate chemical analyses of many types, before the significance of the facts observed in this small number of rocks can be fully appreciated.

The Apishapa rocks have a considerable range in chemical composition, but very much less than is exhibited in the great series to which they belong. Those analyzed are all low in silica, but vary as to their bases from the potash-rich minette to a basalt with soda strongly dominant over potash. Lime and magnesia are very prominent, and titanic acid appears to be one of the notable chemical features.

The mafic silicates, augite and olivine, are abundant in nearly all the rock varieties; biotite is also common and is the leading constituent in the minette, and brown hornblende is strongly developed in several types. Of the felsic silicates alkali feldspar is characteristic of the greater number of the rocks and plagioclase is quantitatively important in relatively few.

The modal development of the rocks requires most of them to be classified in the current system as alkali feldspar rocks. The vogesites are soda-rich, and so apparently are the diabasic types. Even in some of the basalts alkali feldspar is abnormally developed. The persistence of alkali feldspars is probably the most notable modal feature of the whole series of intrusive rocks about the Spanish Peaks.

The prominence of the alkali feldspars must undoubtedly lead petrographers accustomed to refer all igneous rocks to either an alkalic or a calcic series to assign these rocks to the former category. But even the small group in the Apishapa quadrangle has some basalts with little alkali feldspar, and it seems altogether probable that the series ranges in fact from alkali-rich rocks to those of normal basaltic character—that is, to rocks which are intrinsically equivalent to typical basalts of the calcic, subalkalic or "Pacific series." As has been pointed out in the preceding pages, there has been some prevalent condition in the Apishapa region which has brought the alkali feldspars into great prominence and obscured for most rocks their potential anorthite. It is true of many rocks of the Apishapa quadrangle, and presumably also of the large series about the Spanish Peaks, that they are not so strongly alkali-rich rocks as they seem to be from their mode.

This brings us to the problems of greatest general and theoretical interest presented by the rocks under discussion. It has been shown that the nearest known chemical analogues of the vogesites and the associated basalt are for the most part rocks of notably different modes. This is most striking in the case of the olivine-bearing augite vogesite. These rocks emphasize anew the fact that for magmas of intermediate chemical composition, containing all the common bases in considerable quantities, there is a great possible range in the minerals which may develop on crystallization. Aside from the evident problems of classification under these circumstances, there is the more fundamental question as to the genetic significance of the observed relations. Are these facts capable of interpretation as expressing other definite natural relations, if not a dependence of mineral upon chemical characters? Are the several mineral combinations possible from such magmas as those of the Apishapa district due to conditions attending their differentiation in various regions, or are they due to variable conditions of consolidation, or to both?

For the Apishapa rocks the point of most critical interest relates to the conditions that prevented normative anorthite from entering into plagioclase, as it more commonly does in rocks of similar chemical composition, and to the place at which these conditions were effective. In the olivine-bearing augite vogesite 13 per cent of normative anorthite has been taken into other minerals, most of it going undoubtedly into augite. Such entrance of anorthite molecule into augite is common enough, but the conditions under which it takes place are not yet determined.

In his study of the variation in mineral composition of the rocks of Yogo Peak, Pirsson[1] shows that in a series of rocks ranging from granite porphyry to shonkinite, lime and alumina enter into augite apparently in proportion as magnesia acquires a molecular dominance over lime in the magmas. In a shonkinite, with 9.2 per cent MgO and 9.7 per cent CaO, there is but 10 per cent of plagioclase to 35 per cent of aluminous augite.

[1] Pirsson, L. V., chapter on petrography in Geology of the Little Belt Mountains, Montana, by W. H. Weed: U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, p. 567, 1900.

Chemical composition.—An analysis of the rock just described, made by George Steiger in the laboratory of the Geological Survey, is given in column 1 below and is accompanied by analyses of similar rocks:

Analyses of minette and related rocks.

	1	2	3	4	5	6
SiO_2	32.32	52.26	50.81	40.71	50.41	41.57
Al_2O_3	8.16	13.96	15.13	19.46	12.30	9.75
Fe_2O_3	9.46	2.76	2.40	7.46	5.71	4.06
FeO	4.10	4.45	3.52	6.83	3.06	4.47
MgO	5.97	8.21	10.64	6.21	8.69	8.65
CaO	12.60	7.06	4.96	11.83	7.08	11.10
Na_2O	.69	2.80	1.01	1.80	.97	1.57
K_2O	5.97	3.87	7.01	3.26	7.53	6.10
H_2O+	4.09	1.34	3.07	1.53	1.80	2.30
H_2O-	1.03	1.53			.46	1.54
TiO_2	4.55	.58	1.71		1.47	2.36
CO_2	6.30	.49	Trace.	.74		1.24
P_2O_5	3.78	.52	.62		.46	4.05
S	.26					
MnO	.13	.14	Trace.	.18	.15	.25
BaO	.36	.23			.23	.44
SrO	.24					.11
	100.01	100.25	100.88	100.01	100.42	[a] 99.90
Less O	.13					
	99.88					

[a] Including ZrO_2 0.02, Cl 0.04, F 0.23, Cr_2O_3 0.04, NiO 0.02, V_2O_3 0.04, FeS_2 0.06, and deducting 0.11 O for F, Cl.

1. (Augite) minette, Apishapa quadrangle, Colo. George Steiger, analyst.
2. Augite minette, Sheep Creek, Little Belt Mountains, Mont. W. F. Hillebrand, analyst; rock described by L. V. Pirsson, U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, p. 531, 1900.
3. Augite minette, Plauensche Grund, near Dresden, Saxony. B. Doss, analyst; Min. pet. Mitt., vol. 11, p. 27, 1890.
4. Minette, Franklin Furnace, N. J. L. G. Eakins, analyst; described by J. P. Iddings, U. S. Geol. Survey Bull. 150, p. 238, 1898.
5. Syenitic lamprophyre, Two Buttes, Colo. W. F. Hillebrand, analyst; described by W. Cross, Jour. Geology, vol. 14, p. 165, 1906.
6. Apatite minette, northwest bank Columbia River, opposite Northport, Wash. W. F. Hillebrand, analyst; described by F. L. Ransome, Am. Jour. Sci., 4th ser., vol. 26, p. 337, 1908.

Analysis No. 1 shows low silica and alumina, corresponding to the dominance of biotite; potash is strongly in excess over soda; and phosphoric acid is very high, in agreement with the abundance of apatite. The decomposition of the pyroxene and especially the infiltration of calcite account for the high carbonic acid. It must be assumed that the biotite is rich in magnesia, and probably a large part of the titanic acid is to be found in the mica, as no ilmenite or titanite has been detected.

A comparison with other analyses of minette, after all due allowance has been made for the calcite present, shows the Apishapa rock to be unusually femic. While good analyses of minette are rare, the few found in literature are of rocks much richer in silica, alumina, and magnesia. None of those cited is so comparatively rich in potash. The Colorado rock has also a larger amount of titanic acid than the others. It is exceeded in phosphoric acid contents only by the apatite-rich minette of Washington (No. 6). The Washington rock is also rich in titanic acid, and it seems not improbable that these two minettes were, when unaltered, closely allied rocks.

In general mineral and chemical character this minette is about as closely related to the peculiar lamprophyric rock (prowersose) from Two Buttes, Colo. (No. 5), as it is to any of the analyzed minettes. That rock is richer in orthoclase and diopside and poorer in biotite than the minette. It has also much less normative apatite and ilmenite. The Two Buttes rock was described as "a syenitic lamprophyre allied to minette."

Classification.—The described characters of this rock clearly place it under minette in the qualitative system. It was no doubt originally an augite-bearing minette, though perhaps approaching the pure biotite variety. The rarity of minette free from augite or hornblende has been commented on by Rosenbusch.[1]

The position of this rock in the quantative system may be approximately determined in spite of its high content of carbonic acid, for, as has been pointed out, the greater part of the

[1] Rosenbusch, H., Mikroskopische Physiographie der massigen Gesteine, 4th ed., p. 666, 1907.

calcite is not due to decomposition of rock constituents. The norm and systematic position of the rock are as follows:

Norm and systematic position of minette from Apishapa quadrangle, Colo.

or	35.58
ab	6.29
C	.41
en	1.70
fo	9.24
mt	.23
hm	9.28
il	8.66
ap	9.07
	80.46
Calcite	14.30
H_2O, etc	5.38
	100.14

Class: $\frac{Sal}{Fem}=\frac{42.28}{38.18}=1.11$, salfemane, III.

Order: $\frac{L}{F}=\frac{0}{41.87}=0$, perfelic, gallare, 5.

Rang: $\frac{K_2O'+NaO'}{CaO'}=\frac{76}{0}=\infty$, peralkalic, 1, orendase.

Subrang: $\frac{K_2O'}{Na_2O'}=\frac{64}{12}=5.33$, dopotassic, (1) 2 (unnamed).

Symbol: III.5.1.(1)2.

Unless more soda has been removed than there is discernible reason to suppose this is one of the most distinctly potassic rocks known. But the degree of alteration, as well as the transitional position of the rock shown by the ratio $K_2O:Na_2O$, renders it inappropriate to name the subrang from this occurrence. The minette from Washington (No. 6) contains both nephelite and leucite and a large amount of diopside in its norm. It seems evident that the Apishapa rock may have contained so much pyroxene that normative lenads would have appeared if the analysis had been made on fresh material.

AUGITE MINETTE AND TINGUAITE.

Mica Butte, situated west of Apishapa River, in the southern portion of the quadrangle, is traversed by an east-west dike, the single specimen of which at hand exhibits two distinct rocks, one cutting the other in very intricate fashion. No recorded observations give further data on the field relations. The specimen consists chiefly of a brown, fine-grained, plainly biotite-bearing rock, much brecciated, and penetrated by dull pale-green tongues of apparently crystalline character. A poikilitic fabric is indicated in both parts by the cleavage luster of large feldspar grains, some nearly 1 centimeter across. The chadacrysts [1] are irregularly distributed through the orthoclase and all other primary constituents occur in this manner.

From the name given to the butte where this dike occurs it may be inferred that biotite is developed in much of the rock in larger crystals than in the specimen. The green material, of tinguaitic character, is so different from the minette that some considerable development must also be assumed for it.

Under the microscope the minette part of the specimen is found to consist of biotite, augite, alkali feldspar, apatite, magnetite, and brown glass. Fresh feldspar grains of various sizes inclose many augite and apatite needles of perfect crystal form and wholly irregular orientation. Some of the augite prisms betray the presence of the ægirite molecule by color and pleochroism but retain a large extinction angle. Smoky glass acts like the feldspar as matrix for the other minerals in many spots. Titanite is present in a few large grains penetrated by apatite needles.

This augite-bearing minette gives reason for the suppositon that the altered prismatic mineral of the other minette described was augite, but the latter rock is much richer in biotite than the specimen from Mica Butte.

The tinguaitic material, injected in fine veinlets all through the minette, varies greatly in texture and in the degree to which it is mixed with the minette minerals, especially biotite. Some narrow arms are coarse grained and consist of alkali feldspar, ægirite, apatite, titanite, magnetite, and glass. In such parts the ægirite occurs in irregular bunches or interstitial grains between the larger and more abundant alkali feldspars.

[1] Chadacrysts are the crystals or grains inclosed in the oikocryst, or "host": Iddings, J. P., Igneous rocks, vol. 1, p. 202, 1909.

RELATIONS OF THE APISHAPA ROCKS TO THE SPANISH PEAKS.

The dikes of the Apishapa quadrangle belong to a great system of radial dikes, with associated sills, which surround the Spanish Peaks, an eruptive center situated 25 miles southwest of the border of the quadrangle. (See Pl. IV.) The rocks of this center and of the dikes and sills, so far as they occur in the Spanish Peaks, Walsenburg, and El Moro quadrangles, have been described in a general way by R. C. Hills, in the folios dealing with these areas. No chemical analyses accompanied the descriptions by Hills. The description of the Apishapa rocks and especially the four analyses presented in this paper indicate in some measure the interest attaching to the rocks of this remarkable center of associated differentiates. A summary of the data given by Hills will make this still clearer.

At the Spanish Peaks there are three great stocks penetrating Eocene beds. The rocks of these masses are called by Hills granite porphyry, augite granite porphyry, and augite diorite. The granite porphyry is described as containing abundant large phenocrysts of orthoclase and quartz and some plagioclase. The groundmass is rich in quartz, partly in micrographic intergrowth with feldspar, presumably orthoclase. No mafic constituents are mentioned as present in this rock, but it grades within a narrow transition zone into the augite granite porphyry, which is characterized by both augite and biotite. Augite diorite is a collective name for somewhat different rocks variably rich in augite, biotite, hypersthene, plagioclase, orthoclase, and quartz.

On the map of the Spanish Peaks quadrangle Hills represents 240 dikes. A large and perhaps equal number are said to occur in the unmapped area west of the center of eruption. At 10 or 15 miles from the peaks begins a zone marked by thin sills of rocks like those which occur in dikes, and in several places dikes and sills are visibly connected. In the Walsenburg quadrangle 70 dikes and 20 sills were mapped, most of which belong to the Spanish Peaks system. Ten dikes and several sills occur in the El Moro quadrangle, south of the Apishapa.

The dike and sill rocks are referred by Hills to five principal groups, which at their intersections exhibit certain rather definite age relations. In the folio legends these groups are designated "early monzonite porphyry" (76 dikes), "early lamprophyre" (10 dikes), "late monzonite porphyry" (13 dikes), "late lamprophyre" (88 dikes), and "basalt" (34 dikes).

The monzonite porphyries carry both plagioclase and alkali feldspar in large amount. In the earlier group the mafic constituents are augite and brown hornblende, while in the later group these minerals are less prominent than biotite. Quartz is present in the groundmass of some of the later porphyries.

The lamprophyres exhibit great variety in composition both as to feldspars and as to mafic silicates. They range "from a near approach to the syenites, at one extremity, through the hornblende vogesites and monzonites, to the camptonitic varieties, at the other." A basic variety of the earlier group, "containing but little hornblende, shows an abundance of biotite, with more or less augite and olivine as phenocrysts, and magnetite in the groundmass." Some of the later lamprophyres are ophitic in fabric.

Under "basalt" Hills groups various rock types, some of which he says are nearly related to certain lamprophyres through abundance of hornblende and biotite and the presence of alkali feldspar. There are, however, some "normal basalts," which constitute the only exceptions to "the general statement that alkali feldspars in varying proportions range through the Spanish Peaks rocks from one end to the other." No minette is mentioned by Hills as occurring in either one of the quadrangles surveyed by him. It is evident that the Spanish Peaks area is a rich field for detailed petrographic work.

DISCUSSION OF RESULTS.

It is clear that the chemical and mineral characters of the Apishapa dike rocks illustrate some of the most puzzling and important problems of petrology. But while this is true, the great complex of associated rocks at and about the Spanish Peaks must be thoroughly studied, The classification by motex places the Apishapa rock among the olivine-plagioclase basalts. That it is not a typical feldspar basalt is shown in the discussion of norm and mode.

Comparison of norm and mode.—While the mode of the basalt of the Apishapa quadrangle is more nearly normative than those of the associated vogesites, in that anorthite is at least more fully developed in plagioclase, its norm contains a considerable amount of nephelite which probably does not appear in the mode. This nephelite shows the basalt to belong potentially with the nephelite basanites rather than with the common basalts falling in auvergnose or camptonose. The potential significance of this normative nephelite is fortunately illustrated in striking manner by the nephelite basanite of Las Planas (No. 2 of table), which is very near to the basalt of the Apishapa quadrangle in chemical composition but has less normative nephelite.

The basalts of Hünenberg (No. 3) and Wostray (No. 4) are not described in detail in the publications cited, but presumably they contain no recognized nephelite.

The lava of Matavuna volcano (No. 5) is, according to Klautsch, largely vitreous, but it contains labradorite, both in small phenocrysts and in microlites. Klautsch points out a chemical similarity between this lava and the nephelinite of Katzenbuckel and the nephelite basanite of Hundeskopf.

The basalt of Mount Terang (No. 6) is also largely glass, but shows some augite and feldspar.

SODIC DIABASE.

Three dikes of the Apishapa quadrangle have a general diabasic character in that the specimens from them are largely augite-plagioclase rocks with ophitic texture more or less distinctly developed. They are of very simple mineral composition, and their principal characteristic is the highly sodic character of the plagioclase. This appears to be oligoclase or oligoclase-albite, no andesine or labradorite having been noticed.

The rock nearest to common diabase in texture forms a dike 7 miles south-southeast of Dripping Spring. It is a gray fine-grained ophitic rock in which the fabric is more evident to the unaided eye than in any other dike of the quadrangle, yet few of its largest feldspar and augite crystals exceed 1 millimeter in length. The plagioclase crystals are more nearly euhedral than the augite crystals and often penetrate them, but the augite grains are not large enough to emphasize the ophitic fabric.

Plagioclase predominates over augite, to which the other constituents, embracing biotite, titaniferous magnetite, apatite, and probably some monoclinic alkali feldspar, are all decidedly subordinate. Chlorite, calcite, and analcite (?) are the noteworthy secondary minerals. Of these, chlorite seems to represent, in part, a former prismatic constituent, of much less abundance than augite, which is tentatively thought to have been hypersthene, for augite does not undergo visible alteration to chlorite in these rocks, nor does the brown hornblende of other dike rocks of the region. Olivine is not present and the long prisms replaced by chlorite are of a form not assumed by olivine in the associated rocks.

Plagioclase, the principal constituent of the rock, occurs in tablets of multiple albitic twinning, appearing very "dusty" in ordinary light, but it is really not much decomposed. Its refractive index in most sections is near that of Canada balsam but is prevailingly lower, and the maximum extinction from the trace of albite twinning plane is about 7°. It seems probable that oligoclase-albite is the term best expressing the composition. Some monoclinic alkali feldspar is probably present, but none was definitely identified. A colorless, isotropic mineral of low refraction occurs in small amount, in association especially with calcite and chlorite, and is referred to analcite.

One of these diabasic rocks forms a dike running east from the mesa 5 miles west of Dripping Spring. It is similar in texture and grain to the rock just described and differs from it in composition mainly in the character of the plagioclase, which is more distinctly oligoclase. Biotite and hornblende of the same deep-brown color are equally abundant, but are far subordinate to pale-green augite.

In other tongues there is a felt of ægirite needles in a fine granular mass of feldspar, and here augite of the same habit is more or less mingled with ægirite, as is also more or less biotite, in minute flakes. Sodalite or noselite in regular crystals is variably developed in some veinlets.

While this occurrence of tinguaitic character is worthy of note, the lack of observations as to its occurrence and the inadequate material at hand for its study make further description at this time undesirable.

OLIVINE-BEARING AUGITE VOGESITE.

Description.—The most abundant variety of these Apishapa dike rocks is made up principally of augite, olivine, magnetite, apatite, and a colorless matrix, which in most rocks consists mainly of alkali feldspar but in some is in part a glass. Biotite is a very common and brown hornblende an occasional constituent of small quantitative importance. All these rocks appear to be domafic[1] in general character, but the analysis of a typical rock of this group shows that the salic molecules actually predominate in the norm and they probably do so also in the mode.

Most of these vogesites are dopatic or perpatic microphyres, megaphenocrysts of olivine, augite, or biotite being rare. Both olivine and biotite sporadically reach dimensions of 1 centimeter or more. Under the microscope it is seen that olivine is commonly and augite occasionally developed in prominent phenocrysts. But the porphyritic texture is locally obscured by the seriate development of augite from the largest to the minutest particles. In a few specimens white grains of analcite are conspicuous, but these are believed to be the filling of small vesicles, and though possibly formed immediately after the consolidation of the magma, the analcite is not properly a phenocryst.

Augite is the most abundant constituent of these rocks, possibly exceeding 35 per cent in some dikes. It is pale green in color, prismoid in form, and generally of euhedral or subhedral development. In size it ranges from microphenocrysts several millimeters long to minute particles requiring a high-power lens for their identification. It is almost invariably unaltered.

Olivine was probably present in all these rocks, and in many of them it is still fresh, but in a few it is entirely altered to a chloritic or pilitic aggregate. Biotite is seldom lacking among the minute particles of the groundmass, and here and there hornblende of similar brown color is associated with it.

The brownish color of the base in some rocks is found by high magnification to be due mainly to minute scales of biotite or short prisms of hornblende, and in others it is caused by ferritic globulites. Both hornblende and biotite may be developed in equant grains of similar appearance. Magnetite occurs in many small and nearly uniform grains, but is less abundant than might be expected in such basic-looking rocks. Apatite is variable in amount but is unusually abundant in most dikes.

The felsic[2] element of these rocks plays the part of a base holding the mafic constituents. It is holocrystalline in a few rocks, partly crystalline in some, and almost or quite hyaline in others. In the most distinctly crystalline form it is anhedral and granular and consists of apparent alkali feldspar having a refractive index always distinctly less than that of balsam. More commonly the base exhibits but faint polarization and has a pale-brownish color when examined with low power. Under high magnification the mass often appears fibrous, the fibers being outlined by pale-brownish globulites between them.

The rock of this group, of which an analysis is given on page 22, is represented in Plate V. Plate V, *A* shows the appearance in ordinary light. Olivine in large crystals is represented by white areas having a rough surface. Augite is developed in clouded prisms corresponding to the olivines in size and also in many small prismoids and grains. The white irregular base is

[1] *Mafic* applies to the whole group of ferromagnesian minerals developed in rocks and to rocks in which such minerals dominate. It is distinct from *femic*, which applies properly only to normative nonaluminous ferromagnesian molecules. Cross, Iddings, Pirsson, and Washington, Jour. Geology, vol. 20, p. 561, 1912.

[2] *Felsic*, a term complementary to mafic, has been proposed for the group of modal feldspar, feldspathoids, and quartz, to which the normative term *salic* is often incorrectly applied. Cross, Iddings, Pirsson, and Washington, idem.

alkali feldspar, some of the radiating and branching groups of needles being visible in the center of the figure. Biotite is here very subordinate and its small flakes can not be distinguished from magnetite in the photograph.

Plate V, *B* brings out the rather prominent bundles of alkali feldspar needles and the irregularly granular, anisotropic character of the rest of the white base of Plate V, *A*.

In a few of these augite vogesites there is some isotropic or very faintly polarizing substance that plays the same textural part as the feldspar aggregate of the rock illustrated by Plate V. Some alkali feldspar accompanies this base, which is supposed to be glass. It is clouded by minute brownish particles.

In several rocks there is also another isotropic substance, of dusty appearance and low refractive index, which is usually associated with chlorite and calcite and is believed to be secondary analcite.

Indications of plagioclase are entirely lacking in most of these olivine-bearing augite vogesites. Nephelite is possibly present in small amount in the very fine grained base, which consists largely of alkali feldspar, but it nowhere assumes a distinctly recognizable form.

Chemical composition.—An analysis of a fresh typical olivine-bearing augite vogesite is given in column 1 below, together with analyses of chemically analogous rocks, for comparison.

Analyses of olivine-bearing augite vogesite and related rocks.

	1	2	3	4	5	6	7
SiO_2	44.31	44.39	44.87	43.64	42.80	44.66	44.52
Al_2O_3	14.10	13.12	14.05	13.12	12.49	12.97	14.28
Fe_2O_3	4.75	4.19	2.03	6.40	4.32	3.84	6.36
FeO	6.02	7.38	7.79	5.52	6.06	7.55	5.39
MgO	7.80	9.54	8.87	9.36	7.62	9.35	7.13
CaO	9.66	9.55	9.76	9.52	10.43	8.82	10.20
Na_2O	3.74	4.17	4.65	3.89	4.33	4.24	3.76
K_2O	2.83	2.22	2.31	2.18	2.75	2.78	2.59
H_2O+	3.29	1.96	.62	.49	4.92	.69	3.53
H_2O-	.88	......	......	.16	......	.48	
TiO_2	2.10	2.40	4.71	4.55	2.36	2.76	2.04
P_2O_5	.53	.93	.27	.74	1.77	1.10	.56
S	.10	......	.23	......	......	......	......
MnO	.18	......	.07	......	......	.20	......
BaO	.10	......	......	......	......	......	......
SrO	.10	......	......	.03	......	......	......
	100.49	100.18	[a] 100.23	99.60	99.85	[b] 99.71	100.36
Less O	.05						
	100.44						

[a] Including Co_2, 0.16. [b] Including Cr_2O_3, 0.01, and NiO, 0.26.

1. Olivine-bearing augite vogesite, dike south-southeast of Dripping Spring, Apishapa quadrangle, Colo. Analyst, George Steiger.
2. Feldspar basalt, Friedrichstolln, Der Meissner, Allendorf, Hesse. Cited by F. Beyschlag, Erläuterungen zur geologischen Spezialkarte von Preussen, Blatt Allendorf, p. 47, 1886.
3. Essexite, Haselbach, Passau, Bayrischer Wald, Bavaria. Analyst, G. Vervuert. Described by A. Frentzel, Geogn. Jahresheften, vol. 24, p. 162, 1911.
4. Nephelite basanite, La Garrinada, Olot, Spain. Analysis and description by H. S. Washington, Am. Jour. Sci., 4th ser., vol. 24, pp. 233–240, 1907.
5. Leucite basalt, Hertinghausen, Hesse-Nassau, Germany. Analyst, Dittrich. Described by R. Bernges, Neues Jahrb., Beil. Band 31, p. 633, 1911.
6. Basalt (trachydolerite), Sverres Fjeld volcano, Bock Bay, Spitzenbergen. Analyst, Dittrich. Described by V. M., Goldschmidt, Videnskapsselsk. Skr.-naturv. Kl., 1911, No. 9.
7. Nephelite basanite. Jesserken Berg, Bohemian Mittelgebirge. Analyst, C. Fr. Eichleiter. Described by G. Irgang, Min. pet. Mitt., vol. 28, pp. 55–57, 1909.

The agreement in chemical character among these rocks is notable, yet the names assigned to them show how greatly the conditions of consolidation affect the mode. The seemingly small variations of the different oxides have in fact an important effect on the normative or potential mineral character of these magmas, as appears from the table of norms given below. Titanic acid is notably high.

Classification.—The norms of the rocks whose analyses have been quoted will be found in the table below. Those for the cited rocks of this and succeeding tables have been calculated by H. S. Washington.[1]

[1] Dr. Washington has kindly given me free access to the extensive material he has compiled for a new edition of his invaluable tables of rock analyses, now nearly ready for publication.

Analyses of olivine plagioclase basalt and related rocks.

	1	2	3	4	5	6
SiO_2	44.64	44.29	44.78	45.80	43.76	45.15
Al_2O_3	12.82	12.62	12.76	13.41	11.58	12.93
Fe_2O_3	3.64	3.61	5.42	6.89	4.39	5.26
FeO	8.34	8.84	8.34	5.69	7.57	6.88
MgO	10.05	10.06	10.17	12.82	12.97	11.35
CaO	10.09	9.23	10.23	9.91	9.64	9.97
Na_2O	3.39	3.25	3.56	3.57	3.03	2.90
K_2O	1.76	1.82	1.81	1.41	1.84	1.76
H_2O+	1.20	.21	1.42	......	.47	.32
H_2O-	.36	.09	......	......	......	.29
CO_2	......	......	.93	......	.38	......
TiO_2	1.99	4.92	.25	......	3.41	2.65
P_2O_5	.90	.57	.92	.46	.45	.73
SO_3	......	.05	......	......	.14	......
ZrO_2	......	.02	......	......	......	......
S	......	......	......	......	.15	......
NiO	......	......	......	......	......	.01
MnO	.16	(a)	......	......	......	.16
BaO	.14	.06	......	......	......	......
SrO	.09	.04	......	......	......	......
	99.57	99.68	100.59	99.96	99.78	100.36

[a] Not determined.

1. Olivine-plagioclase basalt dike 8 miles east-northeast of North Rattlesnake Butte, Apishapa quadrangle, Colorado. Analyst, George Steiger.
2. Nephelite basanite, Las Planas, south of Olot, Catalonia, Spain. Analysis and description by H. S. Washington, Am. Jour. Sci., 4th ser., vol. 24, p. 217, 1907.
3. Basalt, Hünenberg, Blatt Melsungen, Prussia. Analyst, Steffen. Described by F. Beyschlag, Erläuterungen zur geologischen Spezialkarte von Preussen, Blatt Melsungen, p. 20, 1891.
4. Basalt, Wostray, near Milleschau, Bohemia. Analyst, J. Hanamann. Cited by J. E. Hibsch, Min. pet. Mitt., vol. 24, p. 274, 1905.
5. Basalt, Matavuna, flow of 1905–6, Savaii, Samoan Islands. Analyst, Heuseler. Described by A. Klautsch, Preuss. geol. Landesanstalt Jahrb., vol. 27 (1907), p. 174, 1910.
6. Basalt, Mount Terang, Camperdown district, Victoria, Australia. Analyst, A. A. Topp. Rock described by H. J. Grayson, Geol. Survey Victoria Mem. 9, p. 22, 1910.

The basalt of the Apishapa quadrangle has a composition similar to that of the vogesites but is slightly richer in magnesia and richer in soda relative to potash. The total of the alkalies is high and the silica low for an average feldspar basalt.

Classification.—The norms of the basalt of the Apishapa quadrangle and the analogous rocks are as follows:

Norms of olivine-plagioclase basalt and related rocks.

	1	2	3	4	5	6
or	10.56	11.12	10.56	8.34	11.12	10.56
ab	12.58	15.20	14.67	13.10	8.91	14.67
an	14.18	14.18	13.62	16.12	12.79	16.96
ne	8.52	6.82	8.24	9.37	8.80	5.40
di	24.53	22.02	21.04	23.89	25.41	22.14
ol	16.24	14.10	18.62	18.16	17.78	15.75
mt	5.34	5.34	7.89	9.98	6.50	7.66
il	3.80	9.42	.48	......	6.54	5.02
ap	2.12	1.34	2.12	1.01	1.01	1.68
	97.87	99.54	97.24	99.97	98.86	99.84
Rest	1.56	.47	3.54	.00	1.14	.62
	99.36	100.01	100.78	99.97	100.00	100.46

The quantitative classification of No. 1 is shown by the ratios cited below:

Class: $\frac{Sal}{Fem}=\frac{45.84}{52.03}=0.881=III$, salfemane.

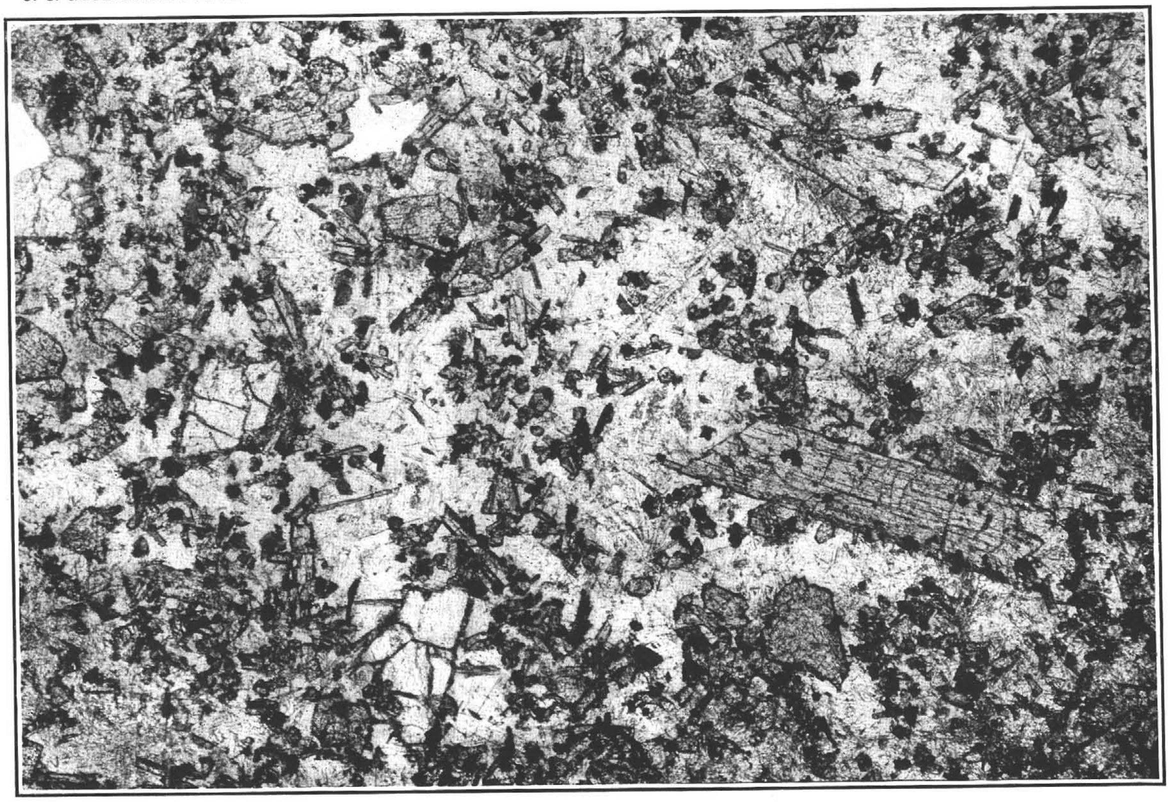
Order: $\frac{L}{F}=\frac{8.52}{37.32}=0.228={}'6$, portugare.

Rang: $\frac{K_2O'+Na_2O'}{CaO'}=\frac{74}{51}=1.45={}'3$, limburgase.

Subrang: $\frac{K_2O'}{Na_2O'}=\frac{19}{55}=0.345=4$, limburgose.

The symbols of the rocks express the degree of normative resemblance between them.

1.... III.′6.′3.4.
2.... III.(5)6.′3.4.
3.... III.′6.(2)3.4.
4.... III.6.3.4.
5.... III.6.(2)3.4.
6.... III.5(6).3.4.

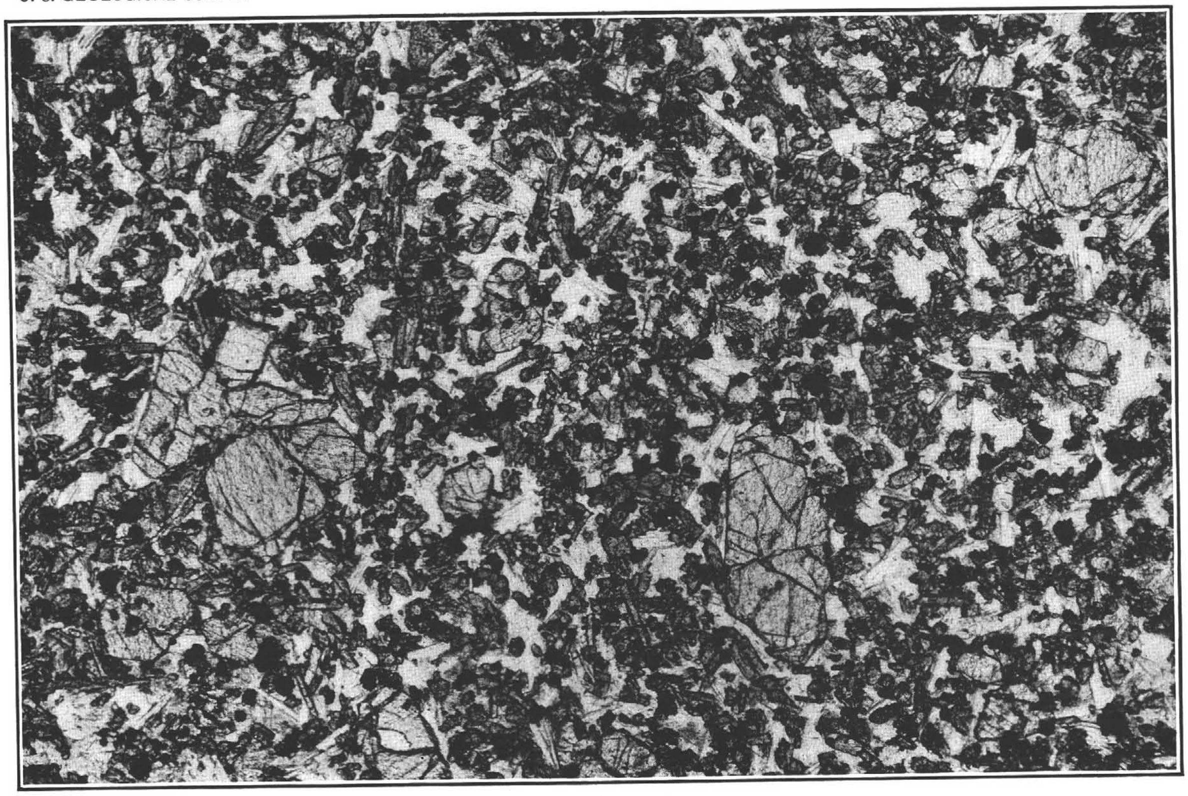


A.

B.

PHOTOMICROGRAPHS OF ANALYZED AUGITE VOGESITE.

A, With one nicol; *B*, with crossed nicols. Magnified 51 diameters.



A.

B.

PHOTOMICROGRAPHS OF ANALYZED PLAGIOCLASE BASALT.

A, With one nicol; *B*, with crossed nicols. Magnified 51 diameters.

Norms of olivine-bearing augite vogesite and related rocks.

	1	2	3	4	5	6	7
or	16.68	12.79	13.34	12.79	16.12	16.68	15.57
ab	7.60	10.74	7.07	15.58	7.86	9.96	10.48
an	13.07	10.56	10.84	11.95	6.95	7.51	14.18
ne	13.20	13.49	17.46	11.08	15.34	13.92	11.64
di	25.32	24.12	28.23	23.76	26.46	23.12	25.68
ol	8.08	13.25	9.78	8.68	6.81	13.66	4.93
mt	6.96	6.03	3.02	4.64	6.26	5.57	9.23
il	4.00	4.56	8.97	8.66	6.38	5.32	3.95
hm	....	....	....	3.20	....	....	....
ap	1.24	2.35	.67	1.68	4.02	2.69	1.34

The position of the Apishapa rock (No. 1) in the quantitative system is determined by the following data:

Class: $\frac{\text{Sal}}{\text{Fem}}=\frac{50.55}{45.60}=1.11$ =III, salfemane.

Order: $\frac{\text{L}}{\text{F}}=\frac{13.20}{37.35}=0.376=6$, portugare.

Rang: $\frac{K_2O'+Na_2O'}{CaO'}=\frac{91}{47}=1.936=2'$, monchiquase.

Subrang: $\frac{K_2O'}{Na_2O'}=\frac{30}{61}=0.49$ ='4, monchiquose.

The other rocks have the following symbols:

2....III.6.2.4
3....III.6(7).2.4
4....III.6.2'.4
5....III.6'.2.4
6....III.6.2.4
7....III.6.2(3)'.4

The Apishapa rock comes well within the central parts of the salfemane class and its lendofelic order, portugare. It is domalkalic but intermediate toward the alkalicalcic rang limburgase. As to subrang it is dosodic but intermediate toward the sodipotassic shonkinose. With regard to the femic elements it is dopolic, prepyric, premiric, and premagnesic, and in these respects the rocks compared with it are closely analogous.

In the mineralogic or qualitative system the Apishapa rock must be called an olivine-bearing augite vogesite, for it has no plagioclase. Manifestly its feldspar is highly sodic and hence the rock is not a typical vogesite.

Bearing the name vogesite, the Apishapa rock parts company with its chemical analogues so far that no suggestion of close similarity with them is conveyed by their current names.

Comparison of norm and mode.—In the vogesite from Colorado norm and mode do not agree at all closely in some important respects. That rock is purely of an alkali feldspar type, yet it has more normative anorthite than most of the chemically analogous rocks containing plagioclase. It has a large amount of normative nephelite but little in the mode, while the reverse is true of augite and olivine. No doubt the augite contains much of the lime and alumina of the normative anorthite, and the abnormative amounts of olivine and augite release some silica, which presumably served to decrease the nephelite and increase the albite of the rock.

It is interesting to note that the rocks compared with this vogesite also exhibit differences of norm and mode. The basalt of the Meissner (No. 2) is a well-known rock cited by Rosenbusch, Zirkel, and others as typical of the doleritic basalts of intersertal texture, without mention of nephelite as a constituent. Beyschlag, however, notes that among the petrographers who have studied the Meissner basalt Senft and Möhl have reported nephelite, a determination which he regards as requiring confirmation. The quoted analysis of the Meissner basalt seems clearly to be the most reliable of those cited by Beyschlag, but he unfortunately gives no special description of the material analyzed. Alkali feldspar is present, though not in large amount, in a section of rock from the Meissner given to me many years ago by Prof. Zirkel, but I have not been able to find nephelite in it. The norm of the Meissner basalt shows that it has potential nephelite, and if conditions in some parts of the mass were favorable to its development nephelite might well assume locally an important rôle.

The essexite (No. 3) of the above table has abundant andesine, though its normative anorthite is less than that of the vogesite. In spite of the name essexite Frentzel does not mention nephelite as a constituent, although 17.46 per cent is shown in the norm. The nephelite basanite of La Garrinada (No. 4) has abundant labradorite and some nephelite, but orthoclase is not mentioned by Washington. The leucite basalt (No. 5) has so much glass that its holocrystalline mode can not be safely inferred, but its abnormative leucite is certainly not due to low silica or high potash contents.

The basalt of Bock Bay (No. 6) appears from the full description of Goldschmidt to have nephelite in its groundmass, though in particles so minute that he regards the determination as questionable. Although containing practically the same potash and more soda than the vogesite, this basalt has no determinable alkali feldspar. With less lime and much less normative anorthite than the vogesite, it has considerable plagioclase, richer in soda than in lime.

The nephelite basanite of Jesserken Berg (No. 7) presents curious relations of norm and mode, particularly when compared with the vogesite (No. 1) and the basalt of Spitzbergen (No. 6). It is a sanidine-bearing nephelite-hauyne basanite with oligoclase as its lime-soda feldspar, yet it has nearly twice as much normative anorthite as the basalt from Spitzbergen and is not so rich in the alkali molecules. It agrees closely with the vogesite in chemical composition but has both plagioclase and lenads much more prominently developed.

HORNBLENDE-AUGITE VOGESITE.

Description.—A group of vogesites differing but little from the group just described in megascopic appearance is characterized by an abundance of camptonitic brown hornblende, equaling or exceeding augite in amount, with biotite of the same brown color, and a variable development of plagioclase, which is always subordinate to alkali feldspar. Olivine is or was a constituent of less importance than in the other group, and it is commonly decomposed to a pilitic aggregate, while the other mafic silicates are fresh. Apatite and magnetite are abundant.

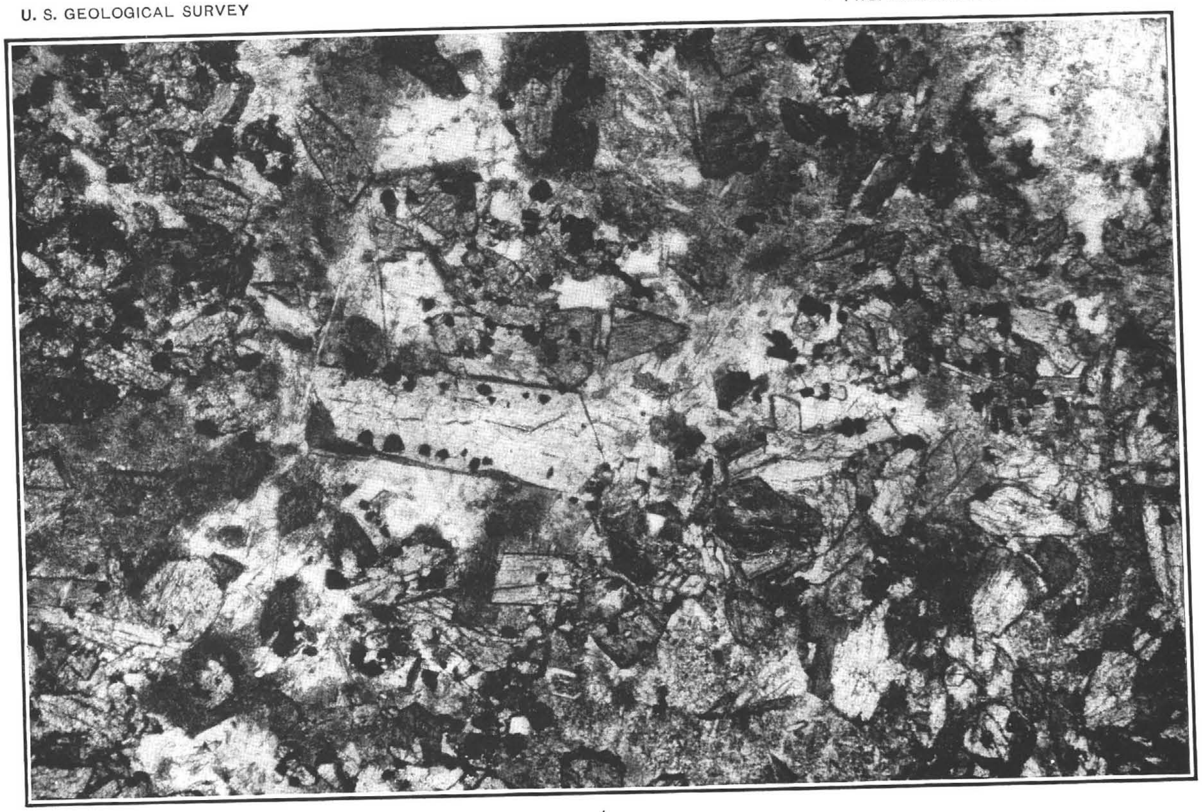
Some of these vogesites are unevenly panautomorphic, granular except for the alkali feldspars, and so coarse that their texture can almost be recognized by the unaided eye. Others are microphyres, and in these hornblende and biotite are chiefly or wholly in the groundmass, while a part of the augite appears in distinct microphenocrysts along with olivine.

The mafic silicates predominate somewhat, but feldspars are more abundant than they seem to be, because of the occurrence of the alkali feldspars as the matrix. Plagioclase is most commonly developed in stout crystals of imperfect form and is labradorite or andesine.

Analcite occurs in round phenocrystic grains and some of it seems as if it might be primary, but this is questioned because small pores of the same size containing chlorite, calcite, and sometimes analcite are present in the same rocks.

Plate VI reproduces photomicrographs of the hornblende-augite vogesite of which an analysis is submitted below. This rock came from a dike 3 miles west of the upper end of Apishapa Canyon and east of Mica Butte. Plate VI, *A*, taken in with one nicol, shows the general texture very well. The large prism to the left of the center and nearly all other prisms and grains of the same shade of gray are augite. Many darker-gray crystals are brown hornblende, which is intergrown with augite at one end of the large prism and in many other crystals. Three decomposed olivine crystals appear near the center. Biotite is very subordinate in this rock. The black grains of Plate VI, *A*, are all magnetite, and several long needles of apatite appear in the left-hand portion. The feldspathic base is resolvable only in polarized light between crossed nicols. Plate VI, *B*, brings out the multiple twinning (albite and pericline laws) of a stout crystal near the upper border, and albite twinning appears in a few other grains but is less easily distinguished in the illustration. Some clear alkali feldspar needles, which are also visible in *A*, appear more sharply defined in *B*, lying in a fine aggregate of feldspathic character.

Chemical composition.—The augite-hornblende vogesite of a dike 4 miles west of Apishapa Canyon has the composition given in column 1 on page 25, according to an analysis by George Steiger. Analyses of some of the most closely allied rocks are given for comparison.



A.

B.

PHOTOMICROGRAPHS OF ANALYZED HORNBLENDE-AUGITE VOGESITE.

A, With one nicol· *B*, with crossed nicols. Magnified 51 diameters.

The Apishapa rock is near the center of the salfemanes and by its low nephelite falls in the perfelic order gallare, but it is transitional to portugare, in which the hornblende-free vogesite comes. Through low alumina and consequent lower anorthite this vogesite is alkalicalcic and through less preponderant soda it is sodipotassic.

Kentallenose and ourose have even fewer known representatives than monchiquose and the Apishapa rock has few very close analogues, as the above table shows.

The motex [1] of this rock places it in the mineralogic system as a lamprophyre of dominant alkali feldspar with hornblende, augite, and olivine as its mafic silicates. By the appearance of plagioclase the rock approaches the monzonitic series of lamprophyres.

Comparison of norm and mode.—In this rock, as in the olivine-bearing vogesite, the most notable discrepancy between norm and mode is in the lime feldspar. With 16.4 per cent normative anorthite the rock has but little plagioclase, while its nearest chemical analogues are characterized by plagioclase.

OLIVINE-PLAGIOCLASE BASALT.

Description.—The basalts of the Apishapa quadrangle are dark, dense rocks, differing from the vogesites because of their more distinctly crystalline appearance, due to the development of feldspar. Yet these rocks are so fine grained that only a few crystals of olivine, augite, or plagioclase can be clearly recognized by the unaided eye even in the coarsest specimens.

The microscope shows that the olivine, augite, plagioclase, magnetite, and apatite have a development like that most commonly found in typical basalts of dense and nearly holocrystalline texture. Olivine exhibits a tendency to form small phenocrysts, while augite and plagioclase are less commonly prominent in this way. But a seriate gradation from largest to smallest grains diminishes or destroys the porphyritic appearance. The ophitic relation of plagioclase and augite is seldom pronounced.

Biotite in small leaves is sparingly present in some of these basalts. Brown hornblende has not been noted. The interstitial feldspar is orthoclase or an alkali feldspar containing both potash and soda. In some dikes this alkali feldspar is almost lacking and in others it has a development similar in character though not in importance to that in the olivine-bearing augite vogesite. Glass is present in some dikes in clear colorless areas penetrated by mineral grains or prisms, but does not assume the rôle, common in basalts, of a base of smoky color and globulitic interpositions.

Plate VII, *A*, represents the appearance of the basalt of which an analysis is given below, as seen in ordinary light. The large phenocrysts of rough surface are olivine. Augite appears only in the prismoids and grains of much smaller size but forms a large part of the rock. The interstitial white areas represent abundant plagioclase laths and irregular grains of plagioclase or alkali feldspar, which are not readily distinguished except when seen in polarized light. The greater part of the black areas represent dark-brown biotite and the remainder magnetite.

Plate VII, *B*, represents the same area as seen in polarized light, the plagioclase laths being here much more distinct.

Chemical composition.—The chemical analysis of the basalt is given in the subjoined table, together with those of the nearest chemical analogues of which I have found mention:

[1] *Motex* is a convenient term by which to refer to the mode and texture of any rock. See H. S. Washington, Am. Jour. Sci., 4th ser., vol. 24, p. 230, 1907.

Analyses of augite-hornblende vogesite and related rocks.

	1	2	3	4	5
SiO_2	43.49	43.58	50.35	44.20	44.82
Al_2O_3	12.76	11.46	15.76	13.96	14.06
Fe_2O_3	5.92	3.40	2.32	3.19	4.56
FeO	5.18	9.13	7.30	8.41	7.27
MgO	9.23	10.80	7.40	8.03	8.60
CaO	10.54	9.88	10.12	9.79	9.56
Na_2O	2.40	2.18	2.75	3.66	3.69
K_2O	2.53	2.13	3.89	2.35	2.30
H_2O+	3.05	2.40	.45	.76	.30
H_2O-	1.86	.47	....	.12	.05
CO_2	....	....	....	....	....
TiO_2	2.10	3.32	.30	4.10	4.25
P_2O_5	.75	.95	.39	.62	.67
S	.11	....	....	....	....
Cl	....	Trace.	....		....
FeS_2	....	....	....	....	....
NiO		....	....	.14	....
MnO	.10	....	.35	.51	None.
BaO	.13	....	....	....	....
SrO	.12	....	....	....	....
	100.52	99.70	101.38	99.84	100.13

1. Augite-hornblende vogesite, Apishapa quadrångle, Colorado.
2. Limburgite, Woodend, Macedon, Victoria, Australia. Skeats and Summers, Geol. Survey Victoria Bull. 24, p. 28, 1912.
3. Olivine monzonite. Smalingen, Fahlun, Sweden. Analyst, L. Schmelck. Described by W. C. Brögger, Die Eruptivgesteine Kristianiagebietes, vol. 2, p. 46, 1895.
4. Nephelite basanite, Cruzcat, south of Olot, Spain. Analysis and description by H. S. Washington, Am. Jour. Sci., 4th ser., vol. 24, pp. 233-240, 1907.
5. Nephelite basanite, Montsacopa, near Olot, Spain. Analysis and description by H. S. Washington, loc. cit.

This type is more basic than the vogesite described above, having less silica, alumina, and alkalies and more magnesia and lime, but these differences are not enough to obscure the general similarity of the two rocks. The cumulative effect of the differences is best appreciated by a comparison of the norms of the two rocks.

Classification.—The norms of the hornblendic vogesite and the correlated rocks are as follows:

Norms of augite-hornblende vogesite and related rocks.[a]

	1	2	3	4	5
or	15.01	12.23	22.8	13.90	13.34
ab	11.00	13.10	11.0	9.43	14.15
an	16.40	15.29	18.3	14.73	15.01
ne	5.11	2.84	6.5	11.64	9.37
di	23.48	21.99	23.6	24.28	21.86
ol	9.48	17.79	13.1	11.11	9.73
mt	8.58	4.87	3.5	4.64	6.73
il	3.95	6.38	.6	7.75	8.06
ap	1.78	2.35	1.0	1.34	1.68
	94.79	96.84	100.4	98.82	99.93
Rest	5.62	2.87	.5	.88	.35
	100.41	99.71	100.9	99.70	100.28

[a] The norms of Nos. 2 to 5 are as calculated by Dr. Washington. Nos. 4 and 5 differ slightly from those originally published by him (loc. cit.).

The position of the vogesite in the quantitative system is indicated by these data:

Class: $\frac{\text{Sal}}{\text{Fem}}=\frac{47.52}{47.27}=1.+=\text{III}$, salfemane.

Order: $\frac{L}{F}=\frac{5.11}{42.41}=0.120+=5(6)$, portugare-gallare.

Rang: $\frac{K_2O'+Na_2O'}{CaO'}=\frac{66}{59}=1.12=3$, camptonase-limburgase.

Subrang: $\frac{K_2O'}{Na_2O'}=\frac{27}{39}=0.69=3'$, ourose-kentallenose.

The symbols of the analogous rocks are:

2.... III. 5′. 3. 3(4).
3.... III. 5(6). 3. 3.
4.... III. 6.(2)3.4.
5.... III.′6.(2)3.4.