A NEW OCCURRENCE OF UNAKITE—A PRELIMINARY PAPER

By W. C. PHALEN

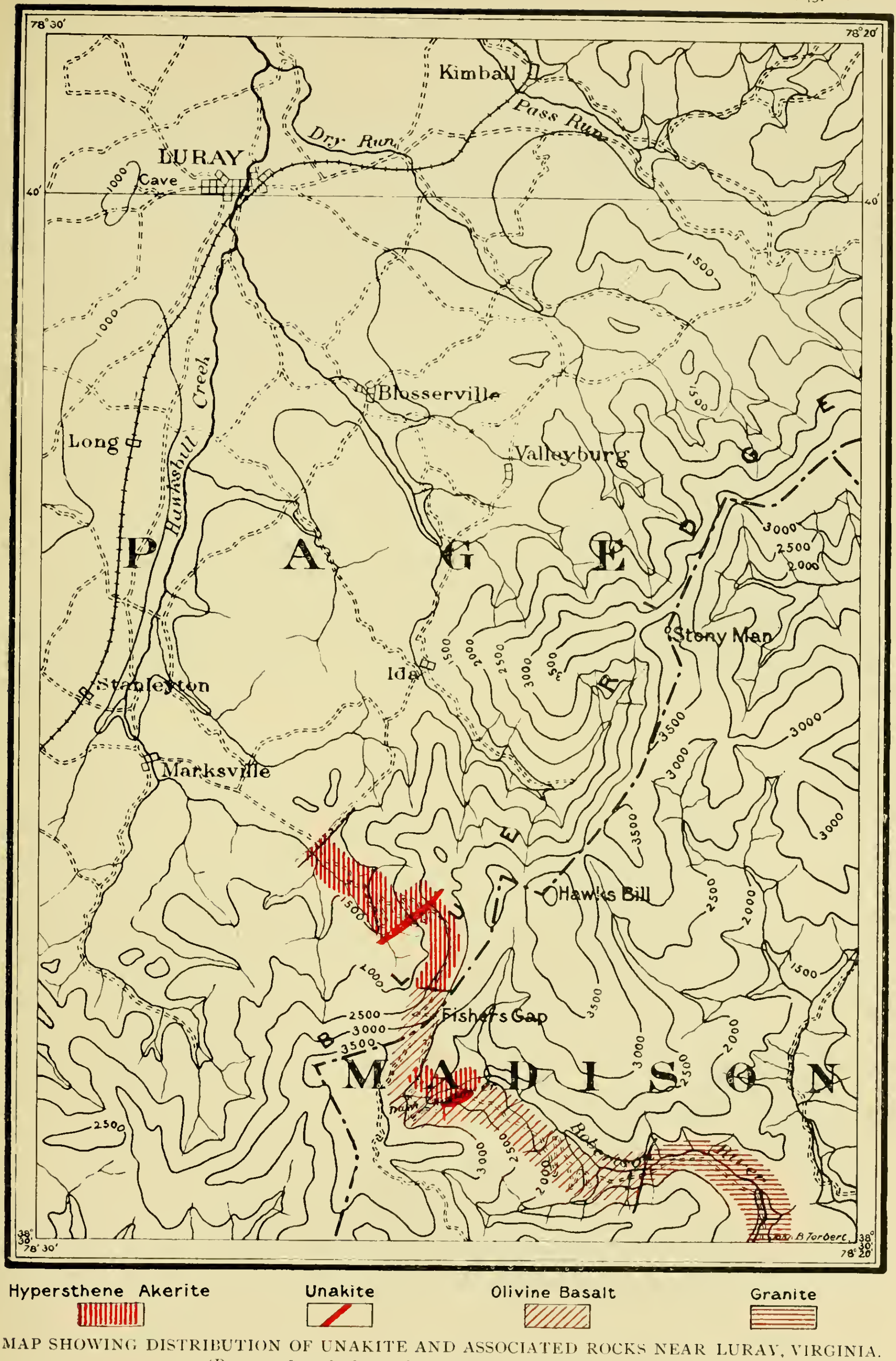
Introduction

In 1884, Prof. W. M. Fontaine, of the University of Virginia, sent to the U. S. National Museum a specimen of igneous rock of exceptional interest, occurring at Milams Gap (see Fishers Gap, pl. LXIX) at the summit of the Blue Ridge, seven miles south of Luray, Va. The rock was entered and placed among the granites under the caption unakite. In the spring of 1903, in response to a letter from Dr. G. P. Merrill, head curator of the Department of Geology, U. S. National Museum, Professor Fontaine sent another consignment of specimens with the associated country rock and at the same time a detailed description of where the unakite might be found.

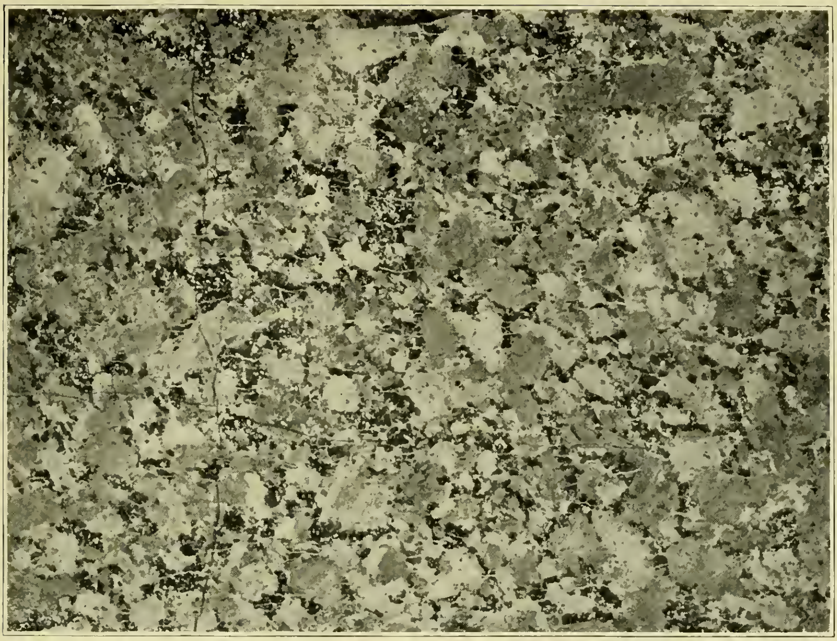
Later in the spring the writer spent a day at the locality in the company of Dr. Merrill, and in the fall he spent three days alone in the region, mapping the rocks and making collections as extensive as the limited time allowed. The following brief descriptions are the result of the two excursions.

Before describing the rocks, attention should be called to plate LXIX. It will be noticed that the boundaries of the rock masses on either side of the road, leading to and from the summit, have been left open. This was rendered necessary as it was not possible to ascertain their true extent in the limited time available; it is hoped, however, that this work may soon be accomplished. Certainly from a petrographical point of view the country is one deserving of further and detailed study.

So far as the writer is aware, this Virginia locality is the second in America where unakite occurs in appreciable quantity, the first being the Unaka mountains between North Carolina and Tennessee, whence the rock derives its name. It is highly probable, however, that the rock is not nearly so limited in distribution as this statement would seem to imply. At Marblehead Neck, Mass., for example, some rather imperfect specimens were obtained a few years ago, the unakite occurring as a dike in diorite (see pl. LXX, *b*). Here the epidotic material has undoubtedly resulted from alteration of the colored



MAP SHOWING DISTRIBUTION OF UNAKITE AND ASSOCIATED ROCKS NEAR LURAY, VIRGINIA.
(Base map from the Luray sheet of the U. S. Geological Survey.)



a. Polished section of unakite. Natural size. (Milams Gap, Va.)

b. Dike ot unakite in diorite. Natural size. (Marblehead Neck, Mass.)

components of the adjacent rock and is secondary. Such a peculiar combination of quartz, orthoclase, and epidote should not be uncommon in regions of dynamic or static metamorphism where granites or other feldspathic rocks occur, containing the colored micas, pyroxenes, amphiboles, etc.

The term unakite was applied originally in 1874 by F. H. Bradley,[1] who, in the reference cited below, says:

"This name unakite is proposed for a member of the granitic series from the Great Smoky Mts., a portion of the Unaka range of the Blue Ridge, which range forms the boundary between North Carolina and Tennessee.

"The specimens thus far seen are from the slopes of the peaks, known as 'The Bluff,' 'Walnut Mt.,' and 'Max's Patch' in Cocke Co., Tenn., and Madison Co., N. C. The rock is said to occur also in Yancey Co., N. C., but in a comparatively inaccessible region.

"The character relied on for the separation of the species is the constant replacement of the mica of common granite or the hornblende of syenite by epidote. The amount of this ingredient present is quite variable, in some cases even exceeding one half of the whole mass. The feldspar present is orthoclase of various shades of pink, forming from one fourth to one third of the whole. The quartz is mainly white, but occasionally smoky; its isolated portions form but a small part, say one fourth of the mass; it is veined in structure, but this is probably not a constant character. Small grains of magnetite are scattered through the rock, but not so thickly as in many granites. No other ingredients have as yet been detected. Mr. G. W. Hawes has determined the specific gravity at 2.79. The rock is very compact and takes a high polish and will doubtless prove a valuable material for ornamental architecture.

"The deep weathering of all the rocks of the southern Appalachians has caused the covering of these slopes with deep beds of debris, which conceal most of the outcrops and the dimensions of the bodies of unakite are therefore, as yet, unknown."

A perusal of the literature since Bradley's brief description in 1874 reveals nothing more than mere allusions to the name and occurrences of the rock.[2] It is not mentioned in the latest petrographical lexicon of Lœwinsson-Lessing, and, so far as the writer is aware, the only reference to the Milams Gap locality is by Merrill.[3]

Mr. F. B. Laney, who spent the last season in a survey of the building stones of North Carolina, informs me that the unakite of

[1] *Am. Jour. Science,* 3d series, VII, 1874, pp. 519–520.

[2] Dana, *Manual of Geology,* 4th ed., p. 85. Merrill, *Rocks, Rock-weathering and Soils,* 1897, p. 68. E. H. Williams, *Manual of Lithology,* N. Y., 1895, p. 128. Williams also calls attention to the occurrence of unakite in the Fichtelgebirge, Schwarzwald, and the Pyrenees.

[3] *Stones for Building and Decoration,* 1903, p. 86.

that state occurs as irregularly segregated patches in a foliated or gneissoid epidotic granite, a very different rock, at least macroscopically, from the country rock at Milams Gap, and that, so far as he is aware, it is confined to Madison county, North Carolina, and Cocke and Sevier counties, Tennessee.

Geology and Petrography

The Blue Ridge at Milams Gap, Virginia, is a single range, composed entirely of igneous rocks. Proceeding from Stanley, on the Norfolk and Western Railroad, by the public road which runs southeastward through the village of Marksville, the transported material of Hawksbill creek is finally left behind in large measure and the igneous rock in place is first encountered at an elevation of 1,260 feet.[1]

The rock, the hypersthene-akerite of the succeeding pages, continues in almost unbroken continuity to the olivine-basalt, mapped as beginning at an elevation of 2,600 feet. The first fragments of unakite were observed at 1,640 feet, but are probably not in place. The first distinct mass of the material occurs at from 80 to 125 feet below the sharp turn in the road represented on the 2,000-foot contour. Much epidosite is associated with it. No sharp lines of demarcation between it and the akerite can be distinguished, and the mass cannot be more than 10 feet wide. The mass, which is probably a continuation of that noted higher up on the road, trends north, 75° to 80° east. It is represented on the map as being rather regular, or as a dike. The masses seen, however, are too irregular to be classed as true dikes; they may more properly be termed irregular patches. The main mass of unakite occurs on the eastern slope of the ridge, where it is associated with akerite, a large mass of which is found in the basalt on this side of the ridge. Most of the material here is in the form of débris.

It is to this spot that collectors should go for the material in quantity, "the best specimens being obtained along a foot-path that cuts off the first curve in the road in descending on the east side."[2] I may add that excellent specimens may also be obtained in the formerly cultivated fields lying on the right as one continues down the road, just beyond the head of the path referred to.

In order to make the discussion of the origin of the unakite more intelligible, the results of the microscopic examination of the country rock will first be presented.

[1] All elevations were determined by means of an aneroid.

[2] Fontaine's letter.

Hypersthene-akerite[1]

Akerite, the country rock of the unakite, is a very coarsely grained, dark grayish green aggregate of feldspars and black pyroxenes with here and there an occasional speck of limpid quartz. The greasy appearance of some of the constituents is strongly suggestive of the mineral nephelite, though the chemical and microscopic analyses show that none of this mineral can be present. The albite twinning of the plagioclase feldspar is plainly seen on many of the fresh fractures and an occasional Carlsbad twin is also evident.

In thin section the following minerals were noticed: Orthoclase, plagioclase, orthorhombic and monoclinic pyroxene, quartz, microcline, iron ore, apatite, and zircon, with the decomposition or alteration products, epidote, chlorite, and sericite. Hornblende is absent in most of the slides studied. In a light-colored segregation situated near the upper boundary of the akerite (a single instance, it may be observed), large masses of hornblende crystals were noticed. The microscopic features of the hornblende will be alluded to in the subsequent descriptions. The accompanying drawing (fig. 39) represents the crystallization of the hornblende in the light-colored segregation of the country rock.

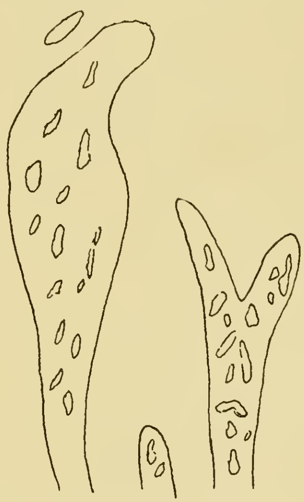


FIG. 39.—Hornblende in lighter phase of akerite. (Scale 1″ = 1′.)

The minerals are arranged in a hypautomorphic mosaic, which is strikingly clear and beautiful when fresh. By far the most abundant mineral is feldspar, which shows evidences of strain in the bent albite lamellæ and frequency of wavy extinction. It is often asso-

[1] Classified as harzose according to the quantitative scheme of Cross, Iddings, Pirsson, and Washington. For a revision of the calculation of the analyses according to the quantitative scheme, and for examining the proof, I am indebted to Dr. H. S. Washington. Dr. Washington was also kind enough to point out a discrepancy in a former paper by me on "The Rocks of Nugsuaks Peninsula, Greenland" (*Smithsonian Miscellaneous Collections*, XLV, p. 183), in which, in the calculation of the rangs, percentages instead of molecular proportions were employed. This necessitates changing omeose (p. 209) and dellenose (p. 212) to positions in the next subrangs in each instance. They are, therefore, liparose and toscanose, respectively.

ciated with quartz, producing the micrographic structure. While much of the feldspar shows albite twinning, a larger portion shows no such phenomenon, and it is evident from the frequency of the parallel extinctions that much orthoclase must be present. It does not appear to be so susceptible to kaolinization as the more basic plagioclase. The latter is generally twinned according to the albite law, and its symmetrical extinctions, ranging as high as 18.7°, indicate a feldspar intermediate between andesine and acid labradorite, more nearly the former than the latter. Perthitic intergrowths were noticed; also a curious instance of secondary feldspar twinned according to the albite law, enclosed in a feldspar of less refractive power. This is not true microperthite, and its development is undoubtedly the result of pressure, the enclosing feldspars showing the effect of strain in their wavy extinctions.

The more basic feldspars, it has been noted, are the more kaolinized. They contain areas of brownish, cloud-like masses, non-reactive between crossed nicols. Other inclusions consist of little tufts or fibers, which polarize brightly; these are often arranged along cracks or cleavage planes and are to be referred to the mineral sericite. Fluid inclusions are present, together with minerals of earlier crystallization, iron oxide, apatite, and zircon.

The colored constituents include the light-green monoclinic pyroxene, which, from the low extinctions and presence of characteristic partings, is to be referred to the mineral diallage. This monoclinic variety is generally associated with hypersthene, the two minerals being frequently intergrown. Many inclusions of iron oxide, both primary and secondary, are present, the hypersthene being apparently very susceptible to change. The secondary iron oxide is often present in masses simulating skeleton forms, which, coalescing, form larger masses often seamed with dark green chloritic matter. Epidote often occurs along the fissures or cleavage planes.

In but few sections studied was amphibole observed. It occurs in rather large patches (one inch and less) in a light-colored segregation of the country rock at an elevation of about 2,400 feet. It is the usual brown variety, strongly pleochroic, as follows: *C*, brown; *A*, brownish yellow; and *B*, chestnut brown with absorption scheme $B \geqq C > A$. This is rather unusual, but the difference between the absorption parallel to *B* and *C* is very slight.

The presence of primary quartz is of interest in this relatively basic rock. It occurs in large isolated masses and is also intergrown with the feldspar. Iron oxides (both hydrous and anhydrous), apatite, and zircon, together with the alteration products, chlorite, epidote, and sericite, complete the list of minerals present.

This rock has been referred to the hypersthene-akerites, a type named and described by Brögger[1] as being essentially quartzose augite-syenites, the feldspars comprising both orthoclase and plagioclase. For convenience of comparison in the subsequent discussion, a table of analyses is inserted.

	Hypersthene-akerite, Milams Gap, Va.	Hypersthene akerite, Barnekjern See, Vettakollen, Norway; Kjerulf analyst. Brögger, *Zeit. f. Crys.*, 1890, XVI, 50.	Hypersthene-andesite, Richmond Mt., Eureka Dist., Nevada; T. M Drown, analyst. Iddings, Monograph XX, U S. G. S., p. 264.	Hornblende - syenite, *Plauen'sche Grund*, Dresden. Zirkel, *Ann. der Chemie u. Physik.*, CXXXII, p 622.	Augite-syenite, E. W. Morley, analyst. H P. Cushing, *Bull. G. S A.*, x, 183.
SiO_2	60 52	59.92	61.58	59.83	63.45
Al_2O_3	16.99[2]	16.07	16.34	16.85	18.31
Fe_2O_3	.60	} 8.76	——	——	.42
FeO	6.53		6.42	7.01	3.56
MgO	1.59	2.07	2.85	2.61	.35
CaO	4.58	4.56	5.13	4.43	2.93
Na_2O	2.83	3.02	2.69	2.44	5.06
K_2O	3.91	2.82	3.65	6.57	5.15
H_2O	.88	.67	.64	1.29	.30
P_2O_5	.74	——	.28	——	Tr.
MnO	.25	——	——	——	None
BaO	——	——	——	——	0.13
TiO_2	n. d.	——	.68	Trace.	.07
ZrO_2	Tr.	——	——	——	——
Cr_2O_3	Tr.	——	——	——	——
	99.42	97.89	100.26	101.03	99.73

It will be seen that the resemblance between analysis No. 1 and that of Brögger's green, fine-grained akerite from Barnekjern is very close, and though of little import, it is of interest that the rocks agree very closely as to mineralogical content, biotite being the only component lacking in the Virginia rock to make the resemblance perfect. More specifically the name hypersthene-akerite should be applied, instead of simply akerite, and this name is here adopted. The rock is also similar to Zirkel's Plauen'sche Grund hornblende-syenite and Iddings' hypersthene-andesite from Richmond Mt., Nevada, to draw an illustration from a less perfectly crystallized magma. The types described by Cushing[3] (analysis 5), the Diana gabbro of Smythe,[4] and the Gloucester, Mass., akerite of Washington[5] are all

[1] *Zeitschrift für Crystallographie* XVI, p. 51.

[2] Including TiO_2.

[3] *Bull. Geol. Soc. Am.*, x, 183.

[4] *Ibid.*, VI, 271–274.

[5] *Jour. Geol.*, VI, 796–798.

too rich in the more acid feldspars to admit of close comparison. All, however, show general relationship to the Virginia type and it is probable that more alkalic phases of the latter rock exist.

Unakite[1] (Cat. No. 75,518)

This rock is an irregular crystallization of old-rose feldspar and green epidote, the latter generally occupying the spaces between the feldspar. The peculiar green of the epidote, together with the old-rose hue of the feldspar, make a striking and beautiful combination, and were the rock sufficiently abundant to justify exploitation, its quarrying must certainly prove a profitable venture. As the case now stands, the working of the deposit is out of the question for the reason that there is not enough of it. Its use for outside decoration cannot be considered, owing to the relative ease with which the rose-colored feldspar bleaches to a white product.

It has been noted that the crystallization of the feldspar, quartz, and epidote is very irregular. In some specimens gathered from the type locality on the eastern slope of the ridge, the red feldspar constitutes fully three-fourths of the mass, and from this ultra-feldspathic phase, all phases through to the quartz-epidote (epidosite) combination may be seen.

Rarely an automorphic outline of a feldspar may be seen with a slightly resorbed margin. The largest phenocryst noted was 2.5 cm. The feldspar is specked with epidote and quartz, the former occupying the fissures and cleavage cracks. Where the epidote forms cloud-like masses, the feldspar appears to have been bleached.

Quartz is distributed in the spaces between the other minerals, also in the body of the feldspar and epidote. It is generally clear, perhaps inclined to the smoky type. It presents no unusual features, and with mention of an occasional piece of iron oxide, the list of macroscopic constituents ends.

In thin section epidote, feldspar, quartz, iron oxides, zircon, and apatite were seen. Epidote occurs in large granular aggregates. Frequently such masses have curved boundaries. It also appears as minute isolated dots in the mass of the feldspar and as stringers along the cleavage planes of this mineral. This occurrence is well represented in plate LXXI, *a*. The specks of epidote representing

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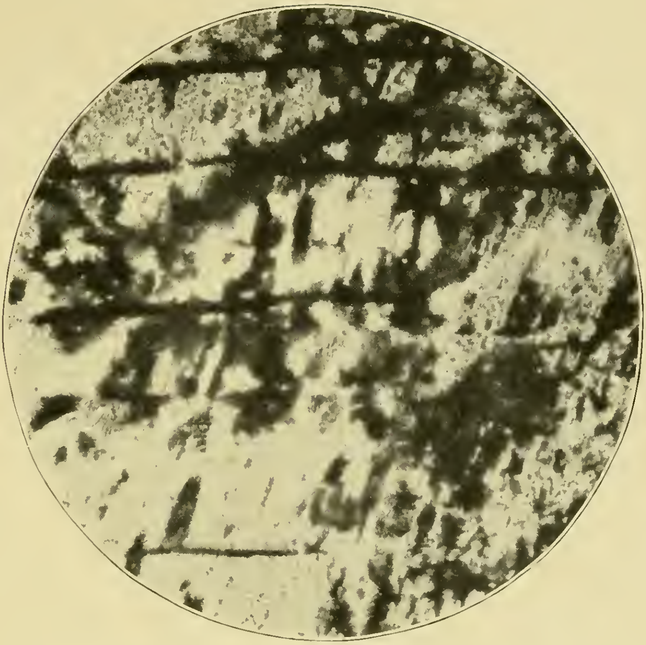
[1] Although the secondary nature of this rock excludes it from proper classification according to the quantitative system of Cross, Iddings, Pirsson, and Washington, and although it is uncertain whether the original magmatic characters are retained or not, it may be mentioned that a magma of this composition would fall under the head of sagamose.



a. Unakite showing replacement of feldspar by epidote between crossed nicols (× 53).

b. Microstructure of hypersthene-akerite showing curved albite lamellæ between crossed nicols (× 53).

replaced feldspar, in addition to their occurrence in the body of this mineral, form a fringe about the massive feldspar, and thus the gradual replacement of this mineral may be plainly seen.

The epidote is usually of a transparent yellowish green, but occasionally becomes dark green and opaque in the vicinity of the iron oxide, due perhaps to chloritic matter or to a larger content of iron oxide, most probably the former. The iron oxides show fractures filled with the same green pigment mentioned above; I judge them from this fact to be secondary and to have resulted from the same processes which have given rise to the green pigment. Some of the epidote is nearly colorless; other portions are striped by a darker variety along the cleavage cracks. These cleavages, when present, are very poorly developed, as is to be expected in secondary epidote, and for the same reason this origin interferes with the normal coloring. Hence vibrations may vary in different parts of the rock, but those noted are shades of yellowish green with absorption $B > C > A$.

The feldspar seems to be all orthoclase. It is almost perfectly clear in part, but when epidotization has begun, it is translucent. It is not colored in thin section, and the old-rose color noted in hand specimens is to be explained by microscopic inclusions of flakes of brown iron oxide, occurring in cloud-like masses more or less concentrated along the cleavage cracks.

The remaining constituents are quartz, brown and black iron ore, brown zircons, and apatites.

For convenience in comparison the analysis of unakite is given with that of hypersthene-akerite.

	Unakite, Milams Gap. Phalen, analyst.	Hypersthene-akerite, Milams Gap. Phalen, analyst.
SiO_2	58.32	60.52
Al_2O_3 (1)	15.77	16.99
Fe_2O_3	6.56	.60
FeO	.89	6.53
MgO	.09	1.59
CaO	11.68	4.58
Na_2O	.32	2.83
K_2O	4.01	3.91
H_2O	1.73	.88
P_2O_5	.48	.74
MnO	.13	.25
Cr_2O_3	——	trace.
ZrO_2	trace.	trace.
	99.98	99.42

[1] Including TiO_2.

Origin of Unakite

The two rocks have originated from the same magma, and the constituents necessary to produce the epidote are present in the hypersthene-akerite. These are the pyroxenes and plagioclase. In some sections, as already noted, under hypersthene-akerite, hornblende is present. Its very limited occurrence, however, precludes the possibility of its having been the chief source of the iron of the epidote. It is a well-known fact that epidote is a common mineral in regions which have undergone dynamic metamorphism,[1] and such influence may have had its effect in the present instance, for the wavy extinction and bent albite lamellæ (pl. LXXI, *b*) indicate that the region has been subjected to some stress. The relatively large content of water in the akerite is suggestive. But the chief cause of epidotization is perhaps due to the action of percolating meteoric waters (hydrometamorphism). The change of the pyroxenes to epidote may be seen in many of the sections studied. It begins along the cleavage cracks and on the edges of the minerals, gradually replacing them, thence extending to the plagioclase and ultimately replacing this mineral and orthoclase (pl. LXXI, *a*). It is accompanied by a separation of iron oxide in skeleton forms which gradually coalesce, producing the massive fractured forms noted under unakite. It was thought that this fractured phase of the iron oxide might be due to a partial removal of its mass to form epidote, but the resistance of this mineral to alteration precludes this possibility. The presence of much potash does not militate against this origin by percolating waters, for the potash varieties of feldspar, as is well known, are far more resistant than the soda-lime varieties.[2]

Magnesium is also frequently removed in greater proportion than lime.[3] In this connection, the presence even of small amounts of soda and magnesia is suggestive, for it indicates the former presence of those minerals involved in the formation of the epidote.

Epidosite

The term epidosite has been used in the previous pages for a quartz-epidote combination—the non-feldspathic phase of the una-

[1] Lindgren, Metasomatic Processes in Fissure Veins, *Trans. A. I. M. E.*, XXX, 611.

[2] "Among the feldspars, the potash varieties are, as a rule, more refractory than the soda-lime or plagioclase varieties. This is shown not merely by our own observations, but by those of others as well. Roth shows from analyses of fresh and weathered phonolite, nepheline-basalt, and dolerites that the loss of soda is almost invariably greater than that of potash."—Merrill, *Rocks, Rock-weathering and Soil*, p. 236.

[3] Ibid., p. 239.

kite—as it proves when examined macroscopically. Though feldspar is not readily apparent to the naked eye, it may be seen in thin sections largely replaced by epidote. A small amount of untwinned plagioclase is also present. The remaining minerals are zircon, hydrous and anhydrous iron ore, and apatite. The derivation of this rather rare rock from the unakite is very apparent; it represents an advanced stage of epidotization.

Olivine-basalt

The mass of the rock constituting the ridge in this vicinity, and to whose resistance the ridge owes its superior height, is a dull green aphanatic mass whose constituents, excepting an occasional speck of epidote and partially altered olivine, cannot be determined with the naked eye. This olivine-basalt is younger than the granite lying to the east, and may be later than the boss of akerite, though future work only will settle this point definitely. Its intrusion in the granite has resulted in profound metamorphism of the latter rock in the border zones, the ordinarily massive rock having become decidedly gneissoid. Large fragments of basalt, generally epidotized, occur near the contact, which appear as though they had solidified, had been wrenched from the wall, and had then fallen back into the magma in its upward motion. Columnar joining in the basalt is well developed north of the Gap at Franklin Cliff.

The olivine of the basalt occurs as phenocrysts, sometimes 3 or 4 mm. in diameter, and generally presents a thoroughly corroded periphery, surrounding a tolerably fresh nucleus. At times even this has disappeared, leaving a brownish red mass to mark its former position. The results of the microscopic examination indicate almost complete alteration, and the determinable constituents are few in number, consisting chiefly of feldspar, pyroxene, olivine, magnetite, with chlorite, epidote, and iron ore. The feldspar and pyroxene constitute the mass of the rock. Imbedded here and there in the mass occurs the olivine, partially filled with a network of brown decomposition products, mostly iron oxide. Besides this ocherous material, there are amorphous, cloud-like masses scattered about in abundance, generally associated with the ferruginous constituents and evidently produced as a result of their decomposition. There are present in addition, epidote and chlorite, the latter in scales or shreds polarizing with dull-gray or bluish tints. In some green phases, epidote constitutes the bulk of the rock.

Summary

1. Four rocks are described, namely, hypersthene-akerite, unakite, epidosite, and altered olivine-basalt. The first two mentioned are of more than ordinary interest, owing to their rather restricted distribution.

2. The term unakite has been applied to a rock whose mineral components would place it among the granites, with epidote as an essential constituent, but whose analysis is relatively basic for this type of rock. This name was applied by Bradley in 1874 to a similar rock from the Unaka mountains, North Carolina, and so far as the writer is aware, its occurrence at other places has not been referred to.

3. The name hypersthene-akerite has been applied to a hypersthene-quartz-diallage-syenite in the sense originally proposed by Brögger.

4. The unakite has originated from the akerite by the process of hydrometamorphism, aided and perhaps induced by dynamic disturbances.

5. The relative ages of the akerite and basalt are not given, since they could not be determined with certainty in the limited time available for field work. It is hoped that in the near future opportunity for more extended study will be presented. The basalt is younger than the granite on the eastern slope.