ALKALINE VITROPHYRE DIKE, CAPE NEDDICK, MAINE

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ABSTRACT

In this paper is presented a detailed petrographic description of an unusual alkaline vitrophyre dike intruding a mass of breccia on Nubble Island, off Cape Neddick, Maine. The rock possesses strong flow banding, skeletal crystals, several varieties of incipient spherulitic structures, and contains devitrification aggregates typical of modified pitchstones. Chemical analysis indicates its strong nordmarkitic or sölvsbergitic affinities, suggesting its relationship to the paisanitic and monchiquitic dikes which cut riebeckite granite at nearby York Beach.

INTRODUCTION

The narrow peninsula of Cape Neddick lies one-half mile southeast of York Village, Maine, and extends eastward from the coastline for about one and one-quarter miles. Separated from this peninsula by a narrow gut is a small, elongate, rocky island. Though not named on either U. S. Coast and Geodetic Survey chart (No. 228, Cape Neddick Harbor to York River) or U. S. Geological Survey map (York quadrangle, Maine-New Hampshire), this island is locally called the "Nubble." On it stand the Cape Neddick lighthouse and a few small outbuildings. The major axis of the island, which is over 800 feet long, strikes about N. 10°E. Its eastern side is penetrated by two coves, between which crops out the distinctive glassy dike that is described in this paper.

LOCAL GEOLOGIC RELATIONS

The central and western parts of the island are underlain by massive, coarse-textured, hornblende gabbro (Wandke, 1922, p. 151). Near the western side a pegmatitic facies of the gabbro is exposed the entire length of the outcrop (Fig. 1). The gabbro intrudes the Carboniferous (?) Kittery quartzite (Katz, F. J., 1918, p. 168), which latter rock is cut by many diabasic dikes. The quartzite crops out only in the southeastern part of the island and consists of alternating thin ($\frac{1}{4}''-\frac{1}{2}''$) purplish, micaceous laminae and thicker (2'–4') massive, light gray, quartzose beds. Between the quartzite and gabbro, and extending the entire length of the island, is a mass of structurally and lithologically complex breccia. This consists predominantly of quartzite and basic dike-rock fragments set in a dense, fine-textured and well indurated matrix (Haff, 1939, p. 470).
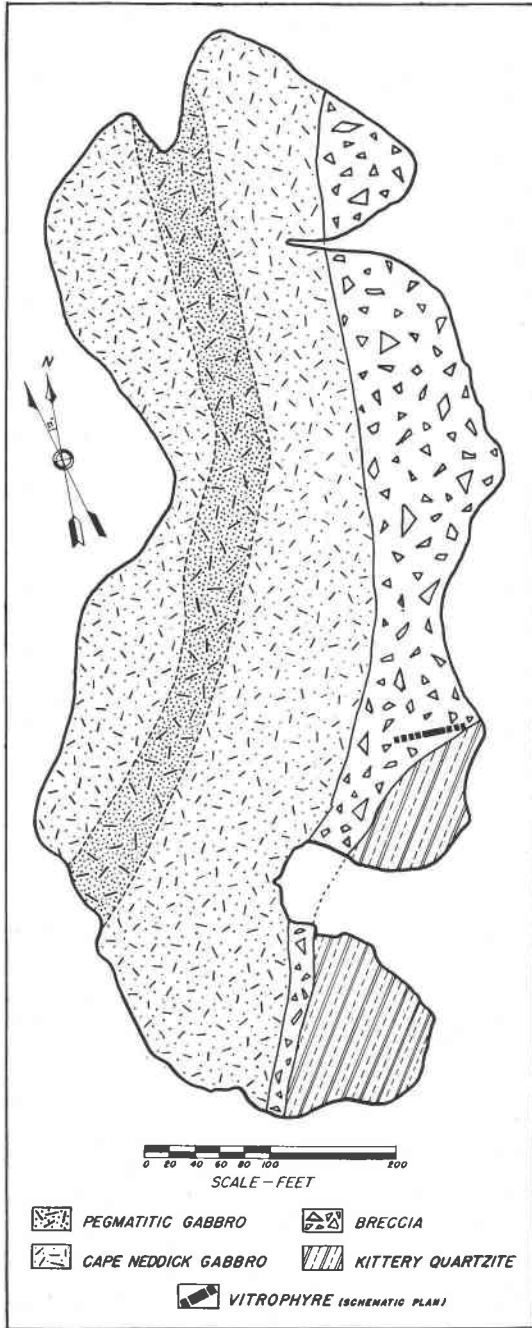
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Fig. 1. Geologic sketch map of Nubble Island, off Cape Neddick, Me., showing the areal distribution of major rock types and location of vitrophyre dike.

Between the two coves on the eastern side of the island the breccia is intruded by a narrow dike which ranges in strike from approximately west to N.60°W. in its small exposure. This dike varies from 5–8 inches in thickness, thins rapidly and possesses the dimensions given for only a few feet along the outcrop. The mass cannot be traced with certainty into either gabbro or quartzite. Definite evidence of chill against the breccia can be observed in the field. Its intrusive relation is further substantiated by the presence of conspicuous flow lines near its contacts, and of small glassy apophyses penetrating the breccia.

On the weathered surface the dike varies from a dark olive-green color to buff. White, or yellowish, tabular feldspar phenocrysts and conspicuous flow lines parallel to contacts are the only structures visible megascopically. On the fresh fracture the rock is dense, greenish-black in color, and possesses a dull, but in places slightly resinous, lustre and conchoidal fracture.

Microscopic Petrography

Microscopically this rock is conspicuously porphyritic. Fluxion structure is also prominent throughout although especially so in the chilled marginal portions.

The rock consists for the most part of haphazardly mottled, turbid, brown glass, bearing numerous crystallites and occasional relatively large euhedral plagioclase and hornblende phenocrysts. The delicate and minute, transparent, slightly greenish crystallites are usually acicular in form. They often taper or bifurcate at their extremities, are feebly birefringent, and have parallel extinction. Unmodified glass from the dike margins has an average specific gravity of 2.588 and an index of refraction of $1.535 \pm .002$. Accessory apatite occurs sparingly in minute, slender prisms and small grains of magnetite, chlorite and yellowish-green epidote are scattered throughout the groundmass. The fine, granular epidote is often associated with minor amounts of carbonate. Here and there are subhedral pyrite grains averaging 0.5 mm. across, which have in places replaced magnetite.

The brown glass is modified to varying degrees in irregular fashion. Where still wholly vitreous, as in the chilled marginal phases of the dike, it is light brown or a pale café-au-lait color. The glass in the interior of the dike is usually appreciably altered. It is extremely turbid in aspect, has a dark, greenish-brown color, in places is very feebly birefringent as the result of the presence of cryptocrystalline devitrification products, and is nearly opaque in a thin slice. Throughout the rock there is sharp color contrast, in shades of brown and greenish-brown, between flow bands. Adjacent bands nearly always show slightly different internal

structure and exhibit different degrees of modification, probably as the result of slight variations in original composition.

Near the dike margins some parts of the pale brown, glassy chill-zone show feeble anisotropic effects. These do not result from the development of devitrification aggregates but occur in streaks whose distribution is related to that of the flow bands. It seems most probable that the anomalous anisotropism in the dike selvages is caused by strain resulting from deformation subsequent to intrusion.

The turbidity of the glass in the greater part of the rock results from the presence of both secondary substances and exceedingly fine crystalline devitrification products developed at the expense of the glass. However, no individualized mineral grains sufficiently well developed to be susceptible of positive identification could be detected. At best only irregularly dispersed, microscopically irresolvable, mote-like specks and dirty brown aggregates can be seen. En masse these substances have a somewhat higher refringence than the surrounding glass and are darker brown than the unmodified portions of the mesostasis. The confused optical data obtained from these fine, disseminated products suggest that they probably consist of intimately mixed epidote and turbid carbonate. In places, small, clear, colorless areas consisting of albitic feldspar and carbonate occur in the ground-mass. In some parts of the rock several such albitized patches may show uniform optical orientation over short distances.

The few hornblende phenocrysts present vary from 0.5–2.0 mm. in length, show excellent cleavage and are of prismatic habit. Unmodified crystals have $2V_\alpha = 86° \pm 2°$, show strong pleochroism, X, dark greenish-brown; Y, deep brown; Z, light yellow-brown; $X > Y > Z$, and have a maximum extinction angle $Z \wedge c$ of 15°–18°. Most of the hornblende originally present is represented by fibrous aggregate pseudomorphs of yellowish-green, actinolitic amphibole intergrown with magnetite, leucoxene, chlorite, and minor amounts of carbonate. There has been conspicuous selective alteration of the hornblende. In some of the dense, structurally homogeneous bands of glass it is quite fresh; in many with spherulitic structure it has been wholly replaced by granular magnetite. In pseudomorphs of this latter type the magnetite grains are often oriented along pre-existing cleavages.

A type of pseudomorph different from those after hornblende also occurs. Relicts of this second variety usually show definitely square or rectangular cross-sections, and consist of matted, fibrous amphibole, carbonate, chlorite, epidote, pyrite, magnetite and apatite euhedra. They differ essentially from those obviously after hornblende in that carbonate and apatite are everywhere much more abundant in them.

Former pyroxene, rather than olivine, is suggested by these aggregates.

The oligoclase-andesine phenocrysts (Ab_{67}–Ab_{70}) are uniformly dispersed throughout the rock but in places may show cumulophyric arrangement. When thus disposed as many as 10 to 12 sharply euhedral crystals, from 0.5–2.5 mm. in length, frequently comprise an assemblage. The plagioclase is water-clear, or at most only slightly sericitized. The phenocrysts are polysynthetically twinned on the albite, pericline and combined Carlsbad-albite laws. Zoning is usually inconspicuous and evidences of marginal resorption are rare. The larger plagioclase pheno-
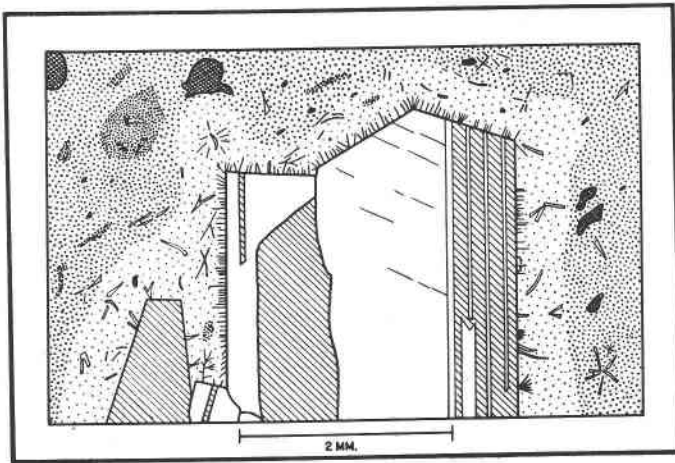

Fig. 2. Camera lucida drawing of a clarified glass zone around a plagioclase phenocryst and the characteristic fringing microlites attached to its margins. Turbid glass of groundmass is heavily stippled; cross-hatched areas are hornblende grains.

crysts show conspicuous pinacoidal development. The smaller ones tend to be more irregular in outline and, though in part tabular, often bear narrow, wedge-shaped, tapering processes extending from the corners of the crystals. Some of the incipient phenocrysts exhibit triangular cross-sections and in these the steeply pitching boundary surfaces may be seen through the translucent glass below the thin-section surface. This produces the effect of a broad, poorly defined phantom margin merging with the groundmass rather than a sharply defined contact.

Attached to the margins of many plagioclase phenocrysts are delicate, transparent or slightly greenish crystallites (longulites). These have grown as individuals or as clusters of minute prisms radiating from points on the crystal margin. Individual crystallites tend to be nearly uniform in length on a given crystal, stand perpendicular to the crystal margins, and form conspicuous comb-like fringes (Fig. 2). So far as can be deter-

mined the crystallites attached to plagioclase are identical with those scattered elsewhere throughout the glass. The formation of these fringing crystallites has caused the glass immediately surrounding the phenocrysts to be depleted of certain substances (cf. Tyrrell 1928, p. 225–226). Hence around each phenocryst bearing such a fringe is a narrow zone of glass of lighter color than that found elsewhere in the rock. Further, these lighter zones are relatively free from the granular alteration products often so abundant in the glass. The outer limits of the clarified areas are demarcated by narrow, quasi-continuous zones congested with dark-colored secondary products. At the corners of the fringed plagioclase crystals the light-colored zone widens and protrudes beyond its general limits roughly parallel to the enclosed phenocryst.

Opaque, dark brown to black, skeletal crystal growths, which may approach in overall dimensions the larger phenocrysts, occur in the glass, usually in or near the chilled selvages. These growths consist of magnetite, rutile (?), and leucoxene with some associated epidote. They have no definite boundaries (Pl. I C). In them, thin plates, rods and granules of opaque minerals are arranged in uniformly spaced parallel rows which are variable in length within a single skeletal unit. Transverse, rod-like members usually connect the long parallel rows and thereby form a reticulate network. The parallel rows in an individual skeletal growth have no common orientation with respect to nearby growths, nor is their disposition related to flow structures. These skeletal structures sometimes indiscriminately traverse spherulitic structures in the rock and one network may embrace several of the latter. No semblance of suggestive crystal form or cleavage could be detected in them, although such structures may possibly represent incipient pyroxene.

All the phenocrysts are definitely intratelluric. The flow lines in the glass uninterruptedly swirl around and arch over both individual phenocrysts and glomeroporphyritic aggregates. The plagioclase phenocrysts are consistently oriented with their long axes closely conformable in direction with that of the local fluxion structure. Many plagioclase phenocrysts in the chilled selvages have been much fractured and in some cumulophyric groups the crystals have been reduced to a jumble of shattered and irregularly oriented fragments (Pl. I D). Such structures might conceivably result either from relief of stresses upon cooling, or from post-consolidation movements. In either case the surrounding glass itself should likewise show some evidences of strain. However, the glass enclosing these shattered crystals is not fractured and continuous flow lines pass around the fractured crystals and aggregates. It seems more likely that these phenocrysts were broken by flowage of the viscous magma during its intrusion rather than by any later mechanical dislocation of the solidified glass.
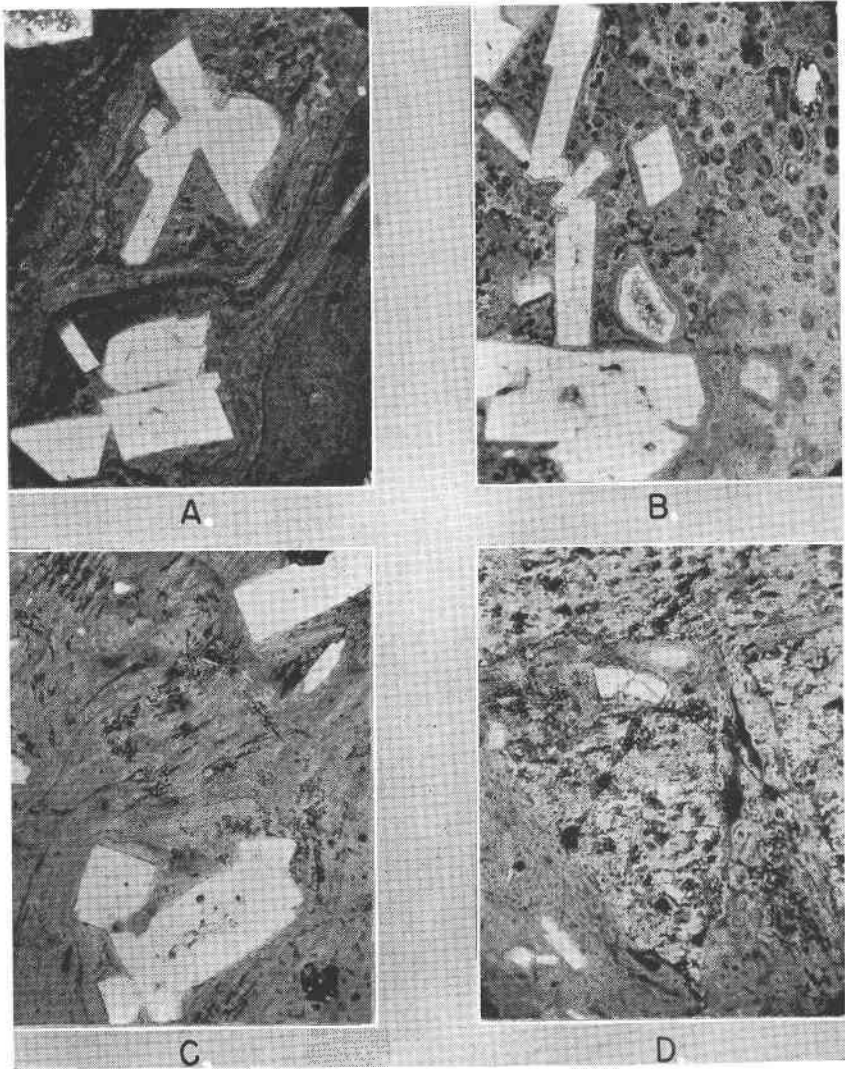
PLATE I

A. Photomicrograph taken to show the strong flow structure in the glass and the cumulophyric arrangement of plagioclase phenocrysts. The variability in color and microstructure in the different flow bands and the tendency for incipient spherulitic structures to be developed in the clearer glassy portions are quite evident. Mag. 13×, plane polarized light.

B. Photomicrograph showing the clarified rims developed about the euhedral plagioclase phenocrysts and the rudimentary spherulitic structures which are dispersed throughout the lighter-colored portions of the glass. Mag. 18×, plane polarized light.

FLUXION STRUCTURES

A most conspicuous feature of this rock is its fluxion structure. Under the microscope individual flow bands in the glass, which are usually from 0.8–1.00 mm. wide, are manifestly variable in both composition and internal structure (Pl. I A). Some are crowded with stellate crystallite aggregates and incipient spherulites. The latter are especially abundant in the glassy marginal phases of the dike although they occur generally throughout the entire rock. Almost the entire area of some flow bands is so densely crowded with spherical growths of circular cross section that the groundmass glass is virtually excluded. In such instances polygonal cross-sections through the rudimentary spherulites are often encountered because of the mutual interference of the contiguous spheroids. The thin and attenuated flow lines, such as are evident in spherulitic bands because of parallel alignment of crystallites and streaked coloration effects, are not diverted by the spherulitic growths. Often the fluxion lines terminate abruptly against the boundaries of the spherulites; a relationship indicating that the formation of some of these followed intrusion. Where the spherulites occur in flow bands which have been deflected around phenocrysts, the former also appear to have developed *in situ*. The termination against spherulitic structures of subsidiary streaks and lines within the curved flow band itself substantiates this.

There is much variation in size and mode of distribution of spherulites within a single flow band. They may be randomly dispersed, strung out singly in rows, or several in contact may form bead-like assemblages. Spherulitic bands are not sharply demarcated from contiguous bands exhibiting different structure but often merge into them horizontally. Spherulitic zones near the dike margins are extremely vitreous, have a high content of relatively unmodified glass, and extend to the actual contacts. It is in such zones that the glass interstitial to the spherulites has the anomalous doubly refractive character to which allusion has been made.

Other bands consisting of dense, brownish, structurally homogeneous glass contain mere traces of streaked fluidal structures internally. Except for sporadic phenocrysts such bands are quite uniform despite the presence of irregularly distributed, turbid patches through which may be scattered a few crystallites.

C. Photomicrograph showing the skeletal crystals consisting of black, opaque rods and plates in parallel arrangement. The orientation of these skeletal units shows complete disregard for flow structures in the glass. Mag. 13×, plane polarized light.

D. Photomicrograph of a minute glass apophysis penetrating a fragment of quartzite in the enclosing breccia. The greenish-brown glass contains a few shattered plagioclase phenocrysts, prominent flow structures and several incipient spherulites with conspicuous nuclei. Mag. 18×, plane polarized light.

Bands containing swarms of minute, pale-green, oriented crystallites (longulites) set in brown glass also occur. The longulites, although showing minor variations in direction within a given band, rarely depart much from parallelism with respect to its general direction. Bands carrying crystallites in abundance are lighter in color and less turbid than some others because of a relative lack of alteration aggregates in the vitreous matrix. It is in bands such as these that the greenish crystallites·fringing the plagioclase phenocrysts are especially conspicuous.

Irrespective of their different structural characteristics none of the flow bands is continuous for appreciable distances. The boundaries between contiguous bands of contrasting structure usually remain parallel for a few centimeters and then converge; thus the bands pass laterally into others with different internal structures. However, the spherulitic zones in the chilled selvages are much more persistent and apparently continuous along the entire outcrop of the dike.

INCIPIENT SPHERULITIC STRUCTURES

The spherulitic growths in the rock range from 0.2–0.5 mm. in diameter and nearly all of them are definitely rudimentary as regards perfection of internal structure. The majority have almost perfectly circular outlines but a few are oval or elliptical in cross section. Where several have coalesced more complex lobate outlines are presented. Though the spherulites within a given flow band may be approximately uniform in dimensions, there is considerable size variation between those in different bands.

Several growth stages in the development of these incipient spherulites or orbicules can be observed. Primitive ones, invariably small, simply consist of one or more narrow, concentric rings (shells) of dark, finely granular material enclosing lighter colored areas of glass. At the center of these circular areas there is usually a nucleus of material exactly like that forming the periphery. The nuclei may be mere pin-points or may occupy as much as one-third of the total cross-sectional area. The substances forming both the dark annulae and the nuclei do not differ in appearance from the secondary aggregates found elsewhere throughout the rock (Pl. I B).

In these rudimentary structures the lighter colored parts between the nucleus and the outer ring or rings are sometimes feebly polarizing. In certain flow bands the material in the outer ring of these spheroidal growths has been replaced by vermicular chlorite. In some parts of the glass even more simple, merely spherical aggregates were developed, but have been replaced by epidote and carbonate.

Somewhat maturer structures, approaching more closely the true

spherulitic forms, have a glassy center at which microlites have developed. In these structures both the dark nuclei and concentric rings are absent. The microlites in the more abundant of these radiate directly from a center which is coincident with that of the spherulite itself. In others microlites radiate from several centers all eccentric with respect to the structure as a whole. Where several stout radiating microlites occur within the growth, a typical axial cross may be readily apparent under crossed nicols with high illumination. In places large microlites are arranged in the form of a simple cross from whose limbs smaller microlites have grown perpendicularly. Spherulitic structures of oval or elliptical cross section often contain a single large microlite, whose long axis lies parallel to the elongation of the oval, to which are attached smaller microlites set normal to its long axis.

Where the spherulitic forms are dispersed in narrow bands consisting of a single row of spheroids, the adjacent glass matrix has a sharply scalloped configuration. In bands congested with these structures the interstitial glass is clearer than that in adjacent areas and identical with that surrounding the feldspar phenocrysts bearing fringes of microlites. The incipient spherulitic structures which contain no nuclei are most abundant in the chilled margins of the dike and are often developed in the delicate apophyses of glass penetrating the breccia. These spherulites carry no microlites and in this respect differ from those in the interior parts of the dike which underwent a longer cooling period.

CHEMICAL COMPOSITION OF THE DIKE

As regards chemical composition, this glassy rock is apparently closely allied to nordmarkite and perhaps even more so to some of the hypabyssal derivatives of such magmas. It contains however somewhat less combined alkalies and slightly more ferrous iron than typical nordmarkite, nordmarkite-porphyry or sölvsbergite (Table 1). Except as regards its appreciably lower CaO content it is chemically very similar to windsorite. As in windsorite the greater part of the calcium in this dike magma has evidently been expended in the formation of oligoclase-andesine.

It may be inferred from the norm that appreciable quartz and orthoclase have both remained occult in the mesostasis, although a small amount of the potassium can probably be accounted for by the rudimentary spherulitic growths. In view of its structure and mineralogy this rock is considered to be a partially devitrified, spherulitic pitchstone or vitrophyre of rather unusual alkaline affinities. In this connection it is interesting to note the presence of other conspicuously alkaline rocks, to which this vitrophyre is probably genetically related, in the vicinity of Cape Neddick. At York Beach, less than one mile west of the occurrence

herein described, there crops out a riebeckite granite stock cut by several diaschistic dikes of paisanite and monchiquite.

TABLE 1

	A	B	C	D	Normative Minerals of rock A		Niggli values Analysis A	
SiO_2	64.98	64.76	66.86	64.62				
TiO_2	.46	.70	.21	.81	Q	13.44	si	274.0
Al_2O_3	17.61	17.13	16.34	16.46	or	26.69	ti	1.5
Fe_2O_3	1.82	1.87	2.24	1.82	ab	44.54	p	0.3
FeO	2.53	1.25	1.99	2.14	an	3.61		
MnO	trace	.19	trace	.12	C	2.75	al	43.7
MgO	.69	.33	.22	1.10	hy	4.08	fm	18.7
CaO	.90	1.48	.92	2.39	mt	2.55	c	4.0
Na_2O	5.26	5.80	6.01	4.57	il	.91	alk	33.6
K_2O	4.53	5.70	4.07	5.21	ap	.34		
H_2O+	.94	.20	.41	.39			k	.36
$H_2O(-)$		.21	.18	.13	$I''.4(5) .1''.3(4)$		mg	.23
P_2O_5	.16	.11	trace	.21				
CO_2				.11			nordmarkitisch	
FeS_2				.19				
CuO				trace	*Mode of Rock A* (Vol. %)			
BaO	.02	.09		.03				
SrO	none			trace	Glass	93.00		
ZrO_2		.11		.03	Hornblende	2.00		
Cl		.02		.05	Plagioclase	4.00		
SO_3	.04		none		Rest	.20		
S		.06						
						99.20		
Sum	99.94	100.01	99.59	100.38				

A. *Alkaline Vitrophyre*, Nubble Island, Cape Neddick, Maine. F. A. Gonyer, analyst, 1942.

B. *Nordmarkite*, Tonsenås, Aker, Nordmark, Norway. A. Rödland, analyst. Brögger, W. C., Die Eruptivgesteine des Oslogebietes, VII. Die chemische Zusammensetzung der Eruptivgesteine des Oslogebietes: *Skr. Vidensk.-Selsk. Kristiania* M.-N. Kl. No. 1, p. 87 (**1933**).

C. *Sölvsbergite*, Brock's Monument, Macedon, Victoria. A. G. Hall, analyst. Skeats and Summers: *Bull. Geol. Surv. Victoria*, **24**, p. 22 (1912).

D. *Windsorite*, Little Ascutney Mountain, Vermont. W. F. Hillebrand, analyst. Daly, R. A., The geology of Ascutney Mountain, Vermont; *U. S. Geol. Surv., Bull.* **209**, 47 (1903).

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