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Erratum.

On p. 132, line 26, for Devonian read Ordovician.

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**NOTES ON THE GEOLOGY AND PETROGRAPHY
OF MONHEGAN ISLAND, MAINE.***

By E. C. E. LORD, Washington, D. C.

Plate XXIII.

Monhegan is the most important member of a small group of islands, situated within the depressed coastal area of Maine, about 10 miles to the south of Saint George peninsula and 12½ miles almost due east of Book Bay harbor.

The group may be considered geologically as a dissected plutonic mass forming a part of the Acadian province outlined by professor Dana† in his publications on the Archæan axis of North America.

The orographic movements resulting in the submergence and re-elevation of the Maine coast have been carefully recorded by Prof. Shaler in his study of the geology of Mount Desert,‡ and some of his observations may be duplicated, on a smaller scale, in tracing the geologic history of Monhegan. Thus we find, at various elevations marine benches and water worn caves marking periodic changes of sea-level. It seems improbable, however, judging from the present work of the

*The writer wishes to acknowledge his indebtedness to the authorities of the United States National Museum for kindly allowing him the opportunity to work up the material. He is especially indebted to Prof. Geo. P. Merrill, head curator, Dept. of Geology in the Museum for the privilege of studying the collections, and to Mr. Geo. C. Curtis, of Cambridge, Mass., for valuable suggestions concerning the physiography of the island.

†Bull. Geol. Soc. Amer., Vol. 7, p. 36 and Amer. Jour. Sci. (3rd series), Vol. 39, p. 378.

‡8th Annual Rep't U. S. G. S., 1887, p. 993.

waves, which is simply that of cutting back the salients, and slightly modifying the re-entrant features of the coast, that the topography of the island is to any great extent, the result of marine erosion.

Monhegan Island is of rectangular shape, measuring about $1\frac{3}{4}$ miles in length, by 3-5 of a mile in width. The smaller members of the group (Manana, Duck Rock, etc.) lie to the west of Monhegan and have with it a N. E.-S. W. trend, corresponding with that of the continental coast-line.

The topography of the group, as seen by the accompanying geologic map* is clearly that of a highly glaciated region but slightly modified by marine encroachment.

A very striking feature and one not hitherto noted on other islands in this vicinity, is the bold relief of the eastern headlands which rise almost perpendicularly to a height of more than 150 feet above sea-level, thus producing coastal features of great scenic beauty and grandeur. These elevations with their broad and rounded summits and gentle slopes landward, extend in an E-W direction, across the island, broadening out and gradually falling away to the western coast-line. They are separated by low, broad valleys, or by irregular, basin-shaped depressions in which surface waters collect to form small ponds and marshes.

It is of interest to note that these valleys are almost at right angles to the direction of the ice-flow, which, as imperfectly indicated by glacial groves and markings is but a few degrees east of north. This main ice-movement has resulted in the excavation of the channel separating Manana island from Monhegan, as well as of the minor longitudinal gorges so common on the island. No direct evidence of glaciation was observed in the broad transverse depressions, owing to the abundance of vegetation, but it seems probable, judging by their peculiar form and the occurrence of erratic boulders in them, that they were produced by ice-currents moving in an easterly direction across the island, along lines of structural weakness in the underlying rock.

Since the withdrawal of the ice-sheet marine erosion has

*This map is based upon a reproduction from an enlarged and corrected copy of sheet No. 312 of the U. S. Coast and Geodetic Survey prepared by Mr. Geo. C. Curtis, of Cambridge, Mass., and kindly placed at the disposal of the author.

essentially denuded the islands of all transported material, excepting the larger boulders and small areas (left open on the map) of re-assorted drift at the head of sheltered inlets.

Apart from the secular movements already noted the region has undergone excessive orographic disturbances, resulting in longitudinal and transverse faulting, as well as in a complex system of both vertical and horizontal jointing. The effect of crushing is also plainly seen in the minute fractures and rifts common in almost every hand specimen.

Ai: important fracture extending through the northern end of Manana island in a N. 55° E direction across Monhegan forms a marked topographical feature of both islands. Excessive shearing in this direction has rendered the rock in the vicinity of Manana harbor semi-schistose, or produced a highly brecciated structure (western slopes of Light House hill).

The E-W faulting is not so extensive as the longitudinal, and plainly noticeable only in the neighborhood of the transverse depressions mentioned above.

One other important line of movement, possibly of more recent date than those already mentioned, extends in a N 55°-60° W. direction, corresponding exactly with the strike of a series of granitic dikes to be discussed later.

Although varying considerably in mineral composition the Monhegan mass, as a whole, consists of a coarse grained olivine-noryte, very rich in feldspar, and resembling, in part, at least, the olivine bearing anorthosyte of the Saguenay District, Canada.*

While this rock is quite common in New Hampshire, and eastern New York,† its exact equivalent has not hitherto been found in Maine, although the gabbroitic-diorite (black granite) occurring on St. George peninsula, Addison Point and

*See F. D. Adams; *Amer. Jour. Sci.*, Vol. 50, 1895, p. 58; and *Ann. Rep't. Geol. Sur. Canada*, Vol. VIII, (J) 1895, p. 91.

†See G. W. Hawes; *Geology of New Hampshire*, Vol. III (Lithology) p. 168-169; G. H. Williams: *The Gabbros and Diorites of the "Cortlandt Series," on the Hudson River near Peekskill, N. Y.*, *Amer. Jour. Sci.*, Vol. XXXV, Feb. 1888, p. 438; *ibid.* Vol. XXXII, 1886, pp. 26-41; C. H. Smyth, Jr.: *On Gabbros in the South Western Adirondack Region.* *Amer. Jour. Sci.*, III. Vol. 40, 1894, p. 55. and *Bull. Geol. Soc. America*, No. 6, 1894-5, p. 261; J. F. Kemp: *Gabbros on the Western shore of Lake Champlain, N. Y.* *Geol. Soc. Amer., Bull.*, Vol. 5, p. 213.

Vinal Haven,* resembles it very closely in mineral composition and may well be allied genetically.

The Monhegan rock is of granitoid structure, and varies in color from purplish gray to steel gray, with frequently a greenish tinge, due to the prevalence of secondary green amphibole. Weathered surfaces, are grayish brown, and present frequently a pitted appearance, owing to the more rapid decomposition of the feldspar.

The mineral constituents most readily discernible with the naked eye are feldspar, olivine, pyroxene and hornblende; which under the microscope are seen to be in the following proportions: plagioclase (50-90 %) > olivine > hypersthene > magnetite > diallage > hornblende. Fluctuations in the relative proportions of the ferro-magnesian constituents give rise to the subordinate types: troctolyte, noryte, olivine-gabbro and gabbro proper. These types represent slight phasal differences in the noritic magma, and are so intimately associated that no distinctive lines could be drawn between them in the field. They pass by gradual transition into hornblende-gabbro and gabbro-dioryte, which occupies a more limited area at the northern end of the island. Here the rock loses to some extent its gabbroitic character, being in part of finer grain and variegated color, owing to irregular inclusions of a quartz-bearing, light gray dioryte.

The petrographic continuity of the Monhegan mass is frequently interrupted by very coarse grained mineral segregations (Schlicren Gänge), and by a series of acid and basic dikes which will be discussed in a later chapter.

Of the minerals composing the olivine-noryte and allied rock-types, feldspar is by far the most important. It is of allotriomorphic development, in keeping with the granitic-granular structure of the rock. The irregular, stout, tabular crystals vary in length from two to ten mm and in breadth from one to five mm, and show in polarized light well developed polysynthetic twinning after the albite and pericline laws. Many of these composite individuals are, furthermore, united in accordance with the Karlsbader law.

*See G. P. Merrill: Proc. of the U. S. Nat. Museum, Vol. VI. No. 12, 1883; S. E. Dickerman and M. E. Wadsworth: On Olivine Bearing Database from St. George, Me., Proc. Bost. Soc. Nat. Hist., Vol. XXIII, p. 28; G. O. Smith: The Geology of the Fox Islands, Me. Dissert. Inaug. Johns Hopkins University, 1896, pp. 61-63.

The crystals cleave readily parallel P (001) and M (010), and show on these faces average extinction angles of about 24 and 33 degrees respectively. They have a specific gravity of 2.72, which, with the properties already given, would identify them as bytownite (Ab, An).

The rather high specific gravity (Ab An=2.71 normally) may be partially due to abundant inclusions, which frequently occur in such numbers as to render the crystals almost opaque in transmitted light, and gives them a purplish gray color and sub-metallic luster.

These inclusions are either in the form of a fine, ferritic dust or of delicate needles arranged according to crystallographic directions in the feldspar (parallel \bar{a} \bar{b} \bar{c}) very like those described by Chester.*

The bytownite decomposes readily to calcite and kaolin.

The chemical analysis of this feldspar (I) compared with one of bytownite from Mount Hope, Md. (II)† shows a remarkable coincidence in composition. It also differs but slightly from the theoretical composition calculated by Schuster (Miner. and petrog. Mitth., III. p. 153 1881) for a mixture of six anorthite molecules with one of albite (III).

	I	II	III
SiO ₂	48.06	46.17	46.5
Al ₂ O ₃	32.54	35.22	34.6
CaO	17.51	16.29	17.3
Na ₂ O	1.77	2.31	1.6
Total	99.88	100.00	100.00

The next mineral in order of importance is olivine. It is in varying proportions in the olivine-gabbro and noryte, and forms the sole ferro-magnesian component of the troctolyte. It is perfectly colorless and occurs in the form of irregular, allotriomorphic grains common to basic plutonics. In many specimens cleavage parallel (010) and (100) is well developed, and not infrequently the crystals are intersected by microscopic fracture planes along which magnetite is extensively developed.

*F. D. Chester: The Gabbros and Associated Rocks in Delaware. Bull. 59 U. S. Geol. Survey, p. 13-14.

†See G. H. Williams: The Gabbros and Hornblende Rocks, occurring in the Neighborhood of Baltimore, Md., Bull. No. 28, U. S. Geol. Survey, p. 20.

Inclusions of magnetite, pyroxene and feldspar are very numerous.

The olivine decomposes readily to serpentine and brown iron ore, and is in many instances surrounded, or entirely replaced, by secondary growths of amphibole, chlorite and mica. These secondary products are characteristic of feldspathic gabbros and norites wherever olivine is in direct contact with a basic plagioclase, and have been variously interpreted.*

It seems probable in the case of the Monhegan norites that they are due to the effects of regional metamorphism rather than to magmatic corrosion. Where metamorphism is not so far advanced as to destroy the original structure of the rock, the olivine is seen to be separated from the bytownite by three distinct mineral zones. The inner zone adjoining the olivine is about $\frac{1}{16}$ mm wide, and consists of tremolite prismatically developed normal to the surface of the olivine; the crude prisms are perfectly colorless and extinguish at an angle ($c:c$) of about 18° . Following this zone occurs a very narrow one (.05-.1 mm.) of a colorless, or pale green slightly pleochroitic

*See A. E. Tornebohm: *Über die wichtigsten Diabas und Gabbrogesteine Schwedens*, L. J. 1877, p. 383.

Fried. Becke. *Eruptivgesteine aus der Gneissformation des oesterreichischen Waldviertels*. T. M. P. M., 1882, IV, pp. 352-65, and *Gesteine der Columbreten*. Min. und Pet. Mitth., Vol. 16, 1896, pp. 327-336.

A. Lacroix: *Contributions à l'étude des gneiss à pyroxene et des roches à wernerite*. Bull. Soc. min. Fr., 1889, p. 245.

G. H. Williams: *The Peridotites of the Cortlandt Series on the Hudson River near Peekskill, N. Y.* Amer. Jour. Sci., 1886, Vol. XXXI, p. 35, and Bull. U. S. G. S., No. 28, p. 25.

W. S. Bayley: *Fibrous Intergrowths of Augite and Plagioclase in a Minnesota Gabbro*. Amer. Jour. Sci., Series III, Vol. 43, 1892, pp. 516-520.

H. B. Patton: *Microscopic Study of some Michigan Rocks*. Rep't State Board of Geol. Survey for 1891-92, p. 186.

F. D. Adams: *Über das Norian und Ober-Laurentian von Canada*. L. J. B-B. VIII, 1893, pp. 466-470.

J. F. Kemp: *op. cit.*, p. 221.

W. D. Matthews: *The Intrusive Rocks of St. John N. B.* Trans. N. Y. Acad. Sci., Vol. XIII, 1894, pp. 193-201.

H. Rosenbusch: *Micros. Physiog.* II, 1896, p. 315.

R. W. Schaefer: *Die basische Gesteine von Ivrea*. Min. und pet. Mitth., Vol. 17, 1898 pp. 495-517.

J. M. Clements: *A Study of Some Examples of Rock Variation*. Jour. of Geol., Vol. 6, 1898, pp. 384-386.

A. H. Elftman: *The Geology of the Keweenaw Area in North-eastern Minnesota (III)*. Am. Geol., vol. XXII, Sept., 1898, p. 139.

mineral resembling chlorite, which terminates abruptly in an outer fringe of bluish-green actinolitic hornblende. This outer zone is usually from $\frac{1}{10}$ -1 mm. thick and is formed of a dense interlocking mass of actinolite fibers. In many specimens, where the effects of orogenetic processes are more apparent, actinolite needles extend out in all directions, frequently wholly replacing the feldspar.

The actinolite is strongly pleochroitic (parallel *c*=bluish green, parallel *b*=grass green, parallel *a*=pale yellow) and shows on prismatic sections a maximum extinction of 22° (*c:c* = 22°).

In many cases the olivine is itself altered to a pilitic* mass consisting of fibrous tremolite, actinolite, chlorite and flakes of brown mica.

The olivine is normally the first ferro-magnesian constituent to crystallize, but it was found in some sections to contain large feldspar inclusions indicating a later period of crystallization. These inclusions are surrounded by rims of secondary hornblende and chlorite identical with those formed on the outer contact with the olivine, thus indicating that the minerals of both zones are of similar origin, and formed after the rock magma had reached a state of solidity.

Hypersthene is a constant accompaniment of the olivine in the Monhegan norytes. It occurs, either in the form of irregular grains, often surrounding the olivine, or as well developed crystals evenly distributed through the rock. The granules are in some instances associated with the olivine in such a manner as to suggest a resorption rim, but careful examination leads to the conclusion that the minerals are of separate origin, and their proximity due simply to mechanical segregation during the solidification of the rock.

In the noryte proper the orthorhombic pyroxene is the predominating ferro-magnesian constituent. It occurs here in well developed prismatic crystals with distinct cleavage parallel (100) (010) and (110) and strong pleochroism; parallel (*a*) purplish to reddish brown, parallel (*b*) light brownish yellow, parallel (*c*) pale green. It is, furthermore, easily recognized by the characteristic metallic luster (schillerization) produced by original inclusions of thin, rectangular plates of brown titanite

*See P. Becke., *op. cit.*, p. 355.

iron ore, arranged parallel to the brachypinacoid (010), with their longer sides coinciding with the axis *a* of the hypersthene. These inclusions are identical in origin with those in the hypersthene of the Baltimore gabbros, as described by Williams* and cannot be considered as products of decomposition.† The hypersthene is not infrequently surrounded by a fringe of uralitic hornblende, which in many cases, replaces the entire crystal, and is optically hardly distinguishable from the actinolite resulting from the olivine.

A distinctive mineralogical feature of the Monhegan rocks is the subordinate position occupied by the monoclinic pyroxene. In the noritic types it is usually absent or distributed sporadically in the form of irregular grains heavily charged with magmatic inclusions. It is in the gabbroitic facies only that this mineral assumes larger proportions. The greenish brown, thick, tabular crystals are of irregular outline, and but slightly pleochroitic. They show well developed prismatic cleavage and the orthopinacoidal parting characteristic of diallage. On sections parallel to the plane of symmetry these crystals extinguish at an angle (*c:c*) of about 38° with the trace of the prismatic cleavage. The diallage is replete with ferritic inclusions, quite similar in character to those of the hypersthene, and is in general considerably uralitized.

Magnetite and apatite are common in the Monhegan rock types—the former fluctuating quantitatively in direct proportion to the bi-silicates.

Apart from the fibrous aggregations of uralitic hornblende and actinolite already mentioned, the microscope reveals in nearly every instance small grains of a brown, primary hornblende. This mineral can best be described in the hornblende-gabbro which forms mineralogically a connecting link between the olivine-noryte and gabbro-dioryte. The rock is dark gray, almost black, and porphyritic in structure. Phenocrysts of bytownite and hornblende are embedded in a dense, coarse-grained ground mass composed of hornblende, diallage, hypersthene, bytownite, and magnetite in about equal proportions, and all, excepting the hornblende, pan-idiomorphically

*Bull. 28, U. S. G. S., 1886, pp. 23-24.

†See J. W. Judd: *Tertiary Peridotites of the Western Islands of Scotland*, Q. J. Geol. Soc., Vol. 41, p. 383, August, 1885.

developed. This latter mineral (of both generations) is poikilotically intergrown with pyroxene, magnetite and feldspar crystals, which in thin sections gives it a very characteristic mottled appearance. The hornblende is of dark brown color and strongly pleochroitic: parallel **b** and **c**—chestnut brown, parallel **a**—yellow. Absorption is $c > b > a$

The poorly developed crystals vary in size from 1 mm-2 cm and have well defined prismatic cleavage, against which a maximum extinction ($c:c$) of 14° was determined. The above physical properties correspond almost exactly with those of a brown hornblende from the hornblende-gabbro near Pavone, Upper Italy, described by van Horn* and regarded by him to be syntagmatite† plus a normal-orthosilicate molecule ($R:SiO_2$) with the constitutional formula: $(H, K, Na)_2(Mg, Fe, Ca)_2(Al, Fe)_2Si_2O_{10}$.

It will be remembered that in discussing the mineral components of the olivine-noryte, attention was called to the fact that in many cases olivine and feldspar were more or less completely replaced by secondary amphibole (tremolite and actinolite) accompanied by chlorite and sometimes biotite. This highly metamorphosed rock may be termed, altered, or amphibolized noryte in contrast to the amphibole bearing gabbro-diorite, which is genetically more directly connected with the gabbroitic phase of the noryte proper, and can only be distinguished macroscopically from this rock by its dark green or grayish green color and variable coarseness of grain (see p. 332).

With the aid of the microscope the gabbro-diorite is seen to be composed of basic feldspar, green hornblende, magnetite, biotite, apatite and frequently diallage more or less uralitized.

The alteration of diallage to green hornblende (uralite) by paramorphism has, thanks to Williams, Chester ‡ and others, been so well described that it needs no special mention here. It may, however, be of interest to note that many of the sections contained, besides this fibrous amphibole, another of massive structure and idiomorphic form. These crystals are

*Pet. Untersuchungen ueber die nortische Gesteine der Umgebung von Ivrea in Oberitalien. Min. u. pet. Mitth., XVII B., 5 Heft, 1897, pp. 19-23.

†See R. Scharizer, neues Jahrb., 1884, II, p. 142.

‡Bull. 59, U. S. G. S., pp. 25-27.

of prismatic habit and dark green color. Pleochroism is strong: parallel c and b =dark brownish green, parallel a =greenish yellow. Absorption ($c > b > a$), and an extinction angle ($c:c$) of about 18° are characteristic of dioritic hornblende.

With the increase of this primary amphibole the gabbroitic character of the rock changes until finally a rock is reached composed entirely of this mineral, associated with plagioclase, reddish brown mica, magnetite, apatite and some little quartz. This is the most acid rock of the area studied, and differs from a typical diorite solely in the basic character of the plagioclase.

A specific gravity determination of this feldspar gave about the same result as that obtained for the bytownite (sp. gr. 2.681). With the aid of the microscope, however, it was found to consist of a larger interior portion, with the optical properties of bytownite and a narrow outer shell, perfectly free from inclusions, and having the small extinction angles of andesine ($a:a$ —about 4° on (001) and 9° on (010).

A striking feature in the geology of Monhegan are the dike-like masses (segregation veins) already referred to (p. 332). Intrusions of this kind are very common in gabbro areas generally and have been treated at length by various authors.*

On Monhegan two distinct types were readily recognized; one composed almost entirely of bytownite (labradorfelse)—being by far the most common in the region, and

*See G. H. Williams: Bull. 28, U. S. G. S., p. 25.

F. D. Adams: loc. cit., p. 449.

W. S. Bailey: The Basic Massive Rocks of the Lake Superior region. Jour. of Geol.; Vol. III, pp. 815-24.

A. C. Lawson: Rept. on the Geology of the Rainy Lake Region. Geol. Survey of Canada, Ann. Rept., 1887, Vol. III, Appendix L, p. 73.

A. H. Elftman: Notes upon the Bedded and Banded Structures of the Gabbro, etc. Geol. & Nat. Hist. Survey of Minn., 23rd Rept., 1894, pp. 224-30, and Amer. Geol., 1898, Vol. XXII, pp. 135-43.

Alfred Harker: Carrock Fell: A study in the Variation of Igneous Rockmasses. Quart. Jour. Geol. Soc., London, 1894, p. 316.

J. W. Judd: op. cit., p. 49.

A. Geikie and J. J. Teall: On the Banded structures of some Tertiary Gabbros in the Isle of Skye, Q. J. G. S., 1894, pp. 652-53.

C. Chelius: Lucitporphyrit, ein Ganggestein von Ernsthofen und seine Beziehungen zu den anderen Diorit und Gabbro Ganggesteinen des Odenwaldes. Notizbl. d. ver. f. Erdk. d. Grossh. geol. Landesanst. zu Darmstadt, IV, Folge 18, pp. 14-22.

C. F. Kolderup: Die Labradorfelse des westlichen Norwegens. Neues Jahrb., 1899, Vol. 1, p. 451.

the other made up of pyroxene with some little bytownite, magnetite and apatite (gabbro-pyroxenite). Bands of extremely coarse grained norite occupy mineralogically and geologically an intermediate position between the two. These dike-like masses have an irregular lenticular form without persistency in strike or dip. They can rarely be followed for more than 20-30 yards, and terminate generally in narrow veins and stringers while merging laterally into the surrounding rock without definite planes of contact.

The mineralogical interest of these rocks is confined chiefly to the pyroxenite, which is of a dark gray color in contrast to the lighter purplish gray of the feldspar aggregates.

The pyroxene of the one dark vein critically examined is a brownish green augite resembling diopside. It is of crude prismatic habit and has well defined cleavage parallel (110). It is furthermore characterized by the unusual position of the optical constants; the axis of greater elasticity (**a**) being nearer the crystallographic axis **c** (parallel to the cleavage) than that of least elasticity; as is generally the case $\wedge a:c \approx 38^\circ$ in maximo. Dispersion of the bisectrices is recognizable: the angle $c : a < c : a$. Pleochroism is strong: parallel **c** apple green parallel **b** greenish yellow, parallel **a** purplish brown. Absorption: $a > b > c$.

A diopside-like pyroxene of almost identical physical properties, has been described by Broegger* from some of the coarse grained dikes near Frederiksvärn, Norway, but there the mineral appears to grade into aegirine, which is not the case in the Monhegan dike. Microlitic inclusions of opaque ilmenite needles, arranged crystallographically very much like those in the bytownite, are very plentiful in this pyroxene.

The chemical relationship of the rocks just described is shown by the following analyses:

I. Olivine-noryte.†

*W. C. Broegger: Min. der sudnorweg. Augitsyenite. Zeit. für Kryst., 1890, Vol. 16, p. 656.

†In order to secure material representing as nearly as possible the average composition of the rock-types described under this heading, 6 specimens were selected that united yielded a mass composed (by volume) of approximately 60 per cent bytownite, 20 per cent olivine, 10 per cent hypersthene, 10 per cent actinolite+diאלללל+magnetite+apatite.

- II. Hornblende-gabbro from near Seal Ledge.
 III. Gabbro-dioryte from Green Point.*
 IV. Labradorfels from Burnt Head.
 V. Gabbro-pyroxenite from Burnt Head.
 VI. Diopside from No. V.
 VII. Green augite from the Cape Verde Islands.
 (Praya San Thiago).†

	I	II	III	IV	V	VI	VII
SiO ₂	40.61	44.79	47.2	45.78	43.17	42.55	43.99
TiO ₂ .....	.65	1.84	.84		1.56	1.66	
Al ₂ O ₃	25.90	15.18	18.64	30.39	9.93	11.72	14.01
Fe ₂ O ₃	2.18	4.13	1.96	1.33	8.78	3.75	2.09
FeO	5.37	8.21	6.82	1.22	6.88	6.74	8.84
MgO	7.69	7.93	8.28	2.14	6.80	8.88	10.88
CaO	14.50	14.10	11.52	16.66	20.96	22.51	19.42
Na ₂ O	2.31	2.18	2.91	1.66	1.77	1.55	1.09
K ₂ O .....	.25	.30	.28	.10	.16	.05	
Ign. ....	.78	1.33	1.44	.51	.31	.49	
	100.24	99.99	99.89	99.79	100.30	99.90	100.32
Spec. gr.	2.91	3.04	2.02	2.83	3.28	3.36	

The above analyses reveal the general character of the rock very clearly. Differences in the chemical composition of the various types are quite in keeping with their mineralogical fluctuations. Thus we find the hornblende-gabbro (II), rich in pyroxene (hypersthene and diallage) and brown hornblende, contains more iron (4.79 per cent) and SiO₂ (4.13), and less Al₂O₃ (10.72 per cent) than the olivine bearing feldspathic norite (I). The high per cent of SiO₂ (47.2) in the gabbro-dioryte (III) combined with 18.64 per cent Al₂O₃ and but 11.52 CaO may be explained by the presence of some quartz and acid feldspar (andesine) in this rock. (See p. 338.)

The labradorfels (IV) and gabbro-pyroxenite (V) representing the products of extreme differentiation of the noritic magma, show the most pronounced chemical differences. Thus No. IV, composed almost entirely of bytownite (see An. p. 333) has considerable more SiO₂, Al₂O₃, CaO and over 10 per cent

*No. III is a mass analysis of six specimens of gabbro-dioryte containing approximately 45 per cent actinolite (uralite) 20 per cent bytownite, 5 per cent andesine, 20 per cent primary green hornblende, 10 per cent magnetite+apatite+quartz+mica.

† See Hinze: Handb. der Min., p. 1112 (CCCVIII).

less iron and magnesia than the olivine-noryte (I); while No. V, being chiefly pure diopside. VI contains over 7 per cent more iron and magnesia and nearly 16 per cent less Al_2O_3 than the same rock. It is of interest, to note that both of the derived rock-types are appreciably more acid than the noryte magma (I).

The composition of the diopside (VI) from the gabbro-pyroxenite (V) presents some interesting features which may be discussed somewhat more critically. For comparison the analysis of a grass green augite from the augite-phonolyte of the Cape Verde islands is given (VII).* Both these minerals contain an unusually high per cent of $\text{CaO} + \text{Al}_2\text{O}_3$ (34.26 and 33.45) combined with but 42.55 and 43.99 SiO_2 ; leaving only about 22% for the remaining elements. These facts indicate the presence of an alumosilicate ($\text{H}_2 \text{Al}_2 \text{SiO}_6$)* in the constitution of the pyroxene, and enables the analysis to be interpreted as follows:

SiO ₂	26.62%				
FeO	6.74				
MgO	5.12				
CaO	12.50				
	50.99				
				Ca (Mg, Fe) Si ₂ O ₆	
SiO ₂	6.78				
Al ₂ O ₃	11.52				
MgO .....	.83				
CaO	5.15				
	24.28				
				(Ca, Mg) Al ₂ SiO ₆	
SiO ₂	4.39				
CaO	4.09				
MgO	2.93				
	11.41				
				Ca Mg SiO ₃	
SiO ₂	5.60				
Fe ₂ O ₃	3.75				
Na ₂ O	1.46				
	10.81				
				Na ₂ Fe ₂ Si ₄ O ₁₂	
SiO ₂ .....	.47				
Al ₂ O ₃ .....	.20				
Na ₂ O .....	.12				
	.79				
				Na ₂ Al ₂ Si ₄ O ₁₂	

98.27 Pyroxene

*See Naumann-Zirkel: Elemente der Min., 1898, p. 686.

Residue: .83% CaO+.49% ignition+.41% (1.66 TiO₂ less equivalent SiO₂)=1.73%.

Acid and Basic Dikes of the Region.

As has already been stated (p.332) fissure intrusions are of common occurrence in the Monhegan mass. They are indeed so numerous that it was not attempted to represent all on the map. These dikes belong to two great systems of intrusions, differing in time of eruption, as well as in mineral composition. To one system belong all the basic dikes closely allied geologically and mineralogically with the basic rock of the region; and to the other the granitic and aplitic types belonging to a later period of eruption and in no way connected genetically with the Monhegan mass. It is of interest to note that the basic dikes are confined almost exclusively to the island, and have little or no uniformity in strike; whereas those of granitic character, with but one or two exceptions, extend uninterruptedly in a N. 50°-60°W. direction across the island, and could be identified again on the main land some twelve miles distant. These acid dikes vary in width from 6 inches to as many feet, and in texture from a fine grained soda-alyte composed of albite, muscovite, quartz and accessory garnet, cordierite and magnetite, to a coarse granular pegmatitic granite made up principally of albite > quartz > muscovite > orthoclase > garnet > apatite > magnetite.

The exceptions referred to are of two dikes from 6 in. to a foot in thickness outcropping along the eastern face of Burnt Head, and continuing in a northerly direction to White Head; a distance of about ½ mile. The rock is characterized by the presence of biotite and blue and black tourmaline graphically intergrown with quartz.

The texture of these dikes is usually quite uniform, but in some instances rocks of granitic and aplitic character occur within the same vein. Here the alyte occupies the central part of the dike mass in such a manner as to suggest a later intrusion. The results of a chemical analysis of this alyte (No. 17) is given under I, and under II that of a similar rock

(soda-ganulyte) from near Mariposa, California,* is reproduced for comparison.

	I	II
SiO ₂	74.78	74.21
TiO ₂ .....		.30
Al ₂ O ₃	14.56	14.47
Fe ₂ O ₃	3.04	.35
FeO .....		.50
CaO .....	.69	1.71
MgO	trace	.28
Na ₂ O	6.02	7.62
K ₂ O .....	.59	.10
Ign .....	.42	.38
P ₂ O ₅ .....		.07
Total	100.10	99.99
Spec. gr.	2.64	

The rather large amount of iron in I may be attributed to the presence of garnet and cordierite; the latter mineral being frequently altered to a fibrous mass (pinite?) strongly impregnated with limonite.

In other respects both analyses are essentially identical.

The abnormally high percentage of soda and silica combined with but .69% CaO clearly indicates an acid member of the albite group (Ab₁₂:An₁) as the principal constituent of the rock.

The basic dikes of the area are of special interest as they may be taken to represent products of deep seated differentiation peculiar to the norite magma. Dikes of quite similar character are by no means rare and have received careful treatment by various authors.†

*See H. W. Turner: 17th Ann. Rept., U. S. G. S., Part I, p. 721.

†See F. D. Adams: op. cit., p. 434, Rept. on the Geology of the Laurentian Area of Montreal. Ann. Rept., Geol. Soc. Canada, Vol. VIII, 1895, pp. 134-139.

G. H. Williams: The Gabbros and Diorites of the "Cortlandt Series." op. cit., p. 442.

J. F. Kemp: Gabbros on the Western Shore of Lake Champlain op. cit., p. 223, and A Diorite Dike at Forest of Dean, Orange Co., N. Y.. Amer. Jour. Sci., XXXV, 1888, p. 331.

W. D. Matthews: op. cit., p. 197.

W. S. Bayley: The Eruptive and Sedimentary Rocks of Pigeon Pt., Minn., U. S. G. S. Bull., 109, 1893, p. 44.

A glance at the map will make clear the irregular distribution of these dikes. They are all of contemporaneous origin, occupying probably original fissures in the Monhegan mass which are in no wise connected with subsequent zones of fracture. The dikes are themselves sheared and faulted to as great a degree as the rock in which they are intruded, and they are intersected by the granite dikes, already mentioned, which are consequently of more recent age.

These dikes vary in thickness from a few inches to not more than three feet. They have but little persistency in strike, and only in rare instances could be traced for a considerable distance from the shore. The rock varies in color from dark steel gray to brownish or purplish gray, and in texture from aphanitic to medium granular. The structure is pandidiomorphic granular throughout; in contrast to that of the porphyritic diabase and camptonite dikes, on the main-land.*

The rock is remarkably fresh and exhibits none of the pronounced effects of erosion characteristic of the camptonites. While showing, macroscopically, unappreciable differences, under the microscope, the mineral composition of these dikes is seen to lie between that of a hypersthene-gabbro on the one hand and gabbro-dioryte on the other—both extremes being connected by types resembling hornblende-gabbro. Adopting the classification of Chelius and Osann, the

A. C. Lawson: op. cit., pp. 154-157, (F), and *Amer. Geol.*, VII, 1891, p. 153.

U. S. Grant: *The Geology of the Gabbro Lake Plate*, *Geol. and Nat. Hist. Survey of Minn.*, Vol. 4, 1896-98, p. 409.

H. B. Patton: op. cit., p. 185.

A. H. Elftman: loc. cit.

H. W. Fairbanks: *The Geol. of Point Sal, Cal.*, *Bull. Dept. Geol. Univ. of Cal.*, Vol. II, No. 1, 1896, pp. 50-74.

C. Chelius: *Das Granitmassiv des Melibocus und seine Ganggesteine*. *Notiz. d. Ver. für Erdk.*, Darmstadt, 1892, IV, Folge, 13 Heft, pp. 1-13, and 1894, IV Folge, 15 Heft, pp. 16-33.

A. Osann: *Ueber die dioritische Ganggesteine im Odenwald*. *Mitth. d. Gross. Bad. Geol. Landesanstalt*, 1892, II, p. 380.

C. F. Kolderup: op. cit., p. 451.

J. A. L. Henderson: *Pet. and Geol. Investigations on certain Transvaal Norites etc.*, London, 1898. (Dulau & Co., 37 Soho Sq.) p. 51.

T. H. Holland: *Basic Dikes in Norite from Southern India*. *Neues Jahrb.*, Bd. II, Heft 3, 1898, pp. 441-83; and on *Augite-Diorites with Micropegmatite*. *Q. J. G. Soc.*, 1897, pp. 403-417.

*See E. C. E. Lord: *On the Dikes in the Vicinity of Portland, Me.* *Am. Geol.*, Vol. XXII, Dec., 1898, p. 339.

gabbroitic intrusions have been termed beerbachyte (aplitic gabbro), and the dioritic, malchyte, (aplitic dioryte).

It is of interest to note that olivine, the prevailing ferromagnesian constituent of the olivine-noryte, is lacking in the dike rocks, and, further, that feldspar no longer preponderates over other ingredients.

Beerbachyte (5, 6, 10, 16) consists of an even granular mass of diopside, hypersthene and bytownite, in about equal proportions, associated with magnetite and a few scattering grains of apatite. These ingredients differ only structurally from those described in connection with the olivine-noryte. In many of the specimens (1, 2, 3, 13, 14, 24, 26, 27) brown hornblende, identical with that of the hornblende gabbro, enters into the composition of the rock; sometimes to the almost complete exclusion of the pyroxene (2, 24, 26). This brown hornblende and more especially the pyroxene, is, furthermore, frequently replaced by green hornblende, as a result of uralitization, which is not readily distinguished from the primary amphibole of the malchyte. (See below)

A peculiar feature of the beerbachyte as well as of other rocks of the region is the frequent occurrence of veins and seams of secondary green hornblende. These were at first supposed to be magmatic segregations, but on close inspection they were found to follow continuously the joint and rift planes in the rock, which would indicate that uralitic hornblende is not necessarily of prescribed local development, but may, under favorable conditions, occur along independent zones of fracture metamorphic agencies have been most active.

Chlorite and limonite are the principal products of atmospheric weathering of these rocks.

Malchyte (4, 7, 9, 11, 20, 21, 23, 25, 28, 29) is dark steel gray in color, and of even granular structure, very similar to beerbachyte. The rock is composed essentially of dark green hornblende and bytownite, with accessory biotite, magnetite (pyrite) and apatite. The hornblende is of short prismatic form, with the large angle of extinction (angle c : c —about 18°), pleochroism (parallel c —green, parallel b —brownish green, parallel a —greenish yellow) and absorption ($c > b > a$) characterizing the primary hornblende of the gabbrodioryte. (p. 338).

Products of weathering and metamorphism are similar to those of the beerbachyte.

No distinct line of demarcation could be drawn between these two rock-types. Beerbachyte grades into malchyte through an increase in green hornblende with a proportional decrease of the pyroxenes in the same manner that hornblende-gabbro merges into gabbro-dioryte. The parallelism in the mineral composition of the dike rocks with their deep-seated prototypes is further emphasized by the fact that some specimens of malchyte (22, 23) contains quartz, andesine and biotite, as is the case in the more acid varieties of gabbro-dioryte (see p. 338). These specimens may be referable to the luciite of Chelius,* although no analysis has been made of them.

The chemical relation of these basic dikes with the gabbrotic facies of the noritic magma is brought out by the following analyses.

The average chemical composition of beerbachyte is given under I and that of malchytè under II.† For comparison the analysis of hornblende-gabbro (III) and gabbro-dioryte (IV) have been reproduced, and the average composition of III-IV and I-II given under V and VI respectively.

	I	II	III	IV	V	VI
SiO ₂	46.29	45.66	44.79	47.20	45.99	45.97
TiO ₂	1.21	1.39	1.84	.84	1.34	1.30
Al ₂ O ₃	17.16	16.26	15.18	18.64	16.91	16.71
Fe ₂ O ₃	2.57	2.97	4.13	1.96	3.04	2.77
FeO	9.87	8.51	8.21	6.82	7.51	9.17
MgO	7.79	10.21	7.93	8.28	8.13	9.00
CaO	12.04	12.25	14.10	11.52	12.81	12.14
Na ₂ O	2.21	1.34	2.18	2.91	2.54	1.77
K ₂ O .....	.16	.31	.30	.28	.29	.13
Ign .....	.51	.92	1.33	1.44	1.38	.74
Total	99.81	99.82	99.99	99.89	99.94	99.81
Spec. gr.	3.06	3.04	3.04	3.02	3.05	3.03

It will be noticed at a glance at the above tables that, excepting slight differences in the proportions of FeO and MgO,

* Notizbl. des Ver f. Erdkh., 1894, IV Folge, p. 32.

†The material for these analyses was obtained by uniting an equal amount (by volume) of rock powder from six specimens of beerbachyte (3, 5, 6, 10, 14, 16) and five of malchyte (4, 7, 23, 20, 21)).

beerbachyte (I) and malchyte (II) have essentially the same composition. The mean of these two analyses (VI) is seen, to correspond almost exactly with that of gabbro-dioryte and hornblende-gabbro (V)—the only appreciable difference being in MgO, FeO, which is 2.53% larger in the dike rocks (VI) than in the gabbro and gabbrodioryte (V).

From this striking chemical as well as mineralogical analogy it is apparent that these dikes represent but another form of the same gabbroitic magma which, fluctuating within the limits of columns III and IV, has itself reached an advanced stage of differentiation from that of the common magma. (See Analysis I p. 340.)

It is also probable judging by the intimate geological as well as mineralogical relations of the main rock types that this differentiation was caused by slight local changes in the physical and chemical conditions during the solidification of the liquid mass after it had reached essentially its present geological position. The presence of numerous dikes, exhibiting the same mineralogical variations as occurred in the main rock mass itself, substantiates this view, and points, furthermore, to the very gradual and uniform character of the magmatic fluctuations.

Monhegan has participated in the principal orographic and epirogenetic movements of the adjoining province, and may well be considered a part of it (see p. 329), although rocks of similar description were not found on the neighboring islands, nor in the immediate vicinity on the mainland.

Owing to the isolated position of the island and the absence of sedimentary rocks upon it, but little more can be said of its geologic age than that the intrusion antedated that of the granitic dikes.

Very similar conditions are found on the island of Vinal Haven* where the diabasic gabbro, (black granite), of post-Niagara age is intersected by younger granitic intrusions. If this diabase is indeed a geological equivalent of the Monhegan rock, which on purely petrographic grounds seems probable, both intrusions would be of late Devonian age.

*See G. O. Smith, *op. cit.*, p. 64-65.