THE PETROGRAPHICAL PROVINCE OF ESSEX COUNTY, MASS. II

Essexite.—The term essexite was first introduced by Sears who applied it to a group of basic rocks composed essentially of augite, hornblende, biotite, and plagioclase, with subordinate orthoclase, nepheline. or sodalite, which he regarded as the earliest crystallized and most basic portion of the nepheline-syenite magma of Salem Neck.[1] Rosenbusch[2] enlarges the mineral list to include olivine and apatite, and erects the essexite into a group of igneous rocks of the same order as the granites or diorites. He says of them that they are related to the gabbro family as the monzonites are to the normal syenites. They may therefore be considered as essentially basic monzonitic rocks, in which both lime-soda and alkali-feldspars and feldspathoids are present, and which are usually, if not always, derived from an alkali, and especially a soda-rich, magma. In Essex county they are confined to the immediate vicinity of Salem Neck, where they occur in large masses, accompanying and cut by the nepheline-syenite. They are quite distinct from this, and, so far as I know, few transition forms into this rock have been seen. On the other hand, they grade into the diorites of the neighborhood, so that in this direction it is difficult to draw a hard and fast line. These rocks have been described by Sears[3] and by Rosenbusch.[4]

They are dark gray or almost black rocks, of a granitic structure, and usually fine-grained, though varying to some extent in this respect. Biotite and feldspar phenocrysts and small round spots of augite and hornblende are seen in most specimens, but are not prominent. Specimens from one locality

[1] SEARS, Bull. Essex Inst. Vol., XXIII, 1891.

[2] ROSENBUSCH, Elem. d. Gesteinslehre, 1898, p. 171.

[3] SEARS, loc. cit.

[4] ROSENBUSCH, Mikr. Phys., p. 247, 1896.

on Salem Neck show a marked subschistose or platy structure. Rosenbusch has described the essexites of Salem Neck in considerable detail, and in general my observations agree with his descriptions. He has, however, included among the essexites proper certain rocks with what he calls a hyperitic structure, which, it seems to me, are not essexites proper, inasmuch as they contain neither alkali-feldspar nor nepheline, but constitute a dioritic facies of it.

In thin section the structure of the essexites proper is granitic, though the plagioclase shows a tendency to tabular development. The feldspar is mostly a plagioclase, showing clear twinning lamellæ, whose extinctions vary, but which correspond to compositions ranging from Ab_1An_1 to Ab_1An_2. Rosenbusch speaks of it as "hoch idiomorph," but for my specimens this is rather strong. It is certainly much more so in the hyperitic facies, while in the more normal essexites (such as the one analyzed), it is only rarely so. An alkali-feldspar is not uncommon, generally anhedral, and often microperthitic. This, and a microcline which is occasionally met with, are apparently rich in soda. Nepheline is fairly abundant, generally interstitial, but occasionally in well shaped crystals. I could not identify with certainty any of the sodalite seen by Sears.

Rosenbusch speaks of two remarkable peculiarities of the feldspars. The first consists of the presence, in gray dusty crystals or portions of crystals, of minute biotites, or hornblendes, about which there is a dust-free zone; the other is the presence of specks and veins of a colorless substance of low refrangibility, and either isotropic or faintly birefringent, which he thinks might be either glass or nepheline. Of the first of these I could find no example in my sections, and of the second only a little here and there which did not allow me to answer the question which Rosenbusch raises as to its nature.

In the typical essexite of Sears the most common ferromagnesian mineral is a deep green or greenish-brown, highly pleochroic hornblende, basal sections of which often show prismatic planes. This occurs scattered through the mass in

highly irregular grains and prisms, and also accompanying a colorless diopside, of which it seems to be an alteration product. The hornblende in this case is not rarely bluish-green, and apparently contains some soda. The pyroxene, which is not abundant, is a colorless diopside, usually in large crystals, and nearly always altered more or less to the green hornblende. It sometimes shows such brilliant polarization colors as to suggest olivine, but the fine straight cleavage lines and the oblique extinction prove it to be a monoclinic pyroxene. Small flakes and stout tables of a greenish yellow biotite are quite common. Titanite, often showing lozenge-shaped sections as well as in irregular grains, is abundant. Small grains of titaniferous magnetite are rare, and in nearly every case form the nucleus of titanite areas, which are apparently their alteration product. Long slender prisms of apatite are very abundant.

Specimens of the schistose variety vary a good deal. In a specimen given me by Mr. Sears the feldspars are largely in small anhedra, and the structure is microgranitic. Most of them are simple, perthites are not very common, twinning lamellæ rare. They have a brecciated structure and sometimes undulatory extinction, suggesting that the tendency to schistosity is due to pressure. Nepheline is present in considerable amount. Small irregular anhedra of a bright green aegirine-augite are scattered abundantly through the mass. A few large pale fawn-colored augites are seen, always more or less altered to a granular aegirite-augite. Small flakes of greenish-brown biotite and grains of titanite, often highly automorphic, are abundant, hornblende is almost wanting, and apatite scarce.

In other specimens the granitic groundmass is on a larger scale, the feldspars tabular and microperthite common, and interstitial nepheline abundant. An olive-green hornblende in beautifully automorphic crystals takes the place of the aegirite-augite, which is absent; large diopsides are rare, biotite almost wanting, titanite and apatite not abundant, and magnetite extremely scarce. No olivine was found by me in any of the varieties of the normal essexite.

The hyperitic variety is represented by two specimens from the southwestern part of Salem Neck, which only differ from Sears' type in being a little more coarsely crystalline, but much less so than the hyperitic diorites to be described later. The structure is somewhat ophitic, the feldspars being thick tabular, and the ferromagnesian minerals frequently xenomorphic towards them. At the same time these occupy bays and form inclusions in the feldspars, so that the crystallization must have been to a certain extent simultaneous. The chief peculiarity of the structure is the zonal growth of the biotite and hornblende about the pyroxene, olivine, and magnetite.

The feldspars are almost exclusively plagioclase, which is usually fresh, and with rather thick twinning lamellæ, whose extinction angles correspond to a basic labradorite, about $Ab_1 An_3$. Only a few grains of alkali-feldspar could be seen, and nothing which could be identified with nepheline. Olivine is present in some quantity, as rather large grains, usually automorphic though corroded. They are generally fresh, but sometimes partially serpentinized. A colorless or pale fawn-colored augite is present which shows high extinction angles. A reddish-brown barkevikitic hornblende is very abundant, showing the usual pleochroism; $\mathfrak{c}$=deep red-brown, $\mathfrak{b}$=deep red-brown, $\mathfrak{a}$=light brownish yellow, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. It seldom forms independent individuals, but nearly always occurs as a border about the pyroxene and olivine. This border, which is usually of the nature of a reaction rim between the pyroxene or olivine and the feldspar, is highly irregular, often of great relative thickness, and in many cases almost entirely replaces the pyroxene. A brown biotite which is present in less amount also occasionally plays the same rôle. Magnetite and ilmenite grains are abundant, and about them is almost constantly found a hornblende rim when they are included in pyroxene, while, if they are included in feldspar, this is less common. Apatite is rare.

An analysis was made of a specimen from Salem Neck which was given me by Mr. Sears as representing his type. An analysis of a similar specimen, made by M. Dittrich for Professor Rosenbusch is given in II.

	I	II		I	II
SiO^2	46.99	47.94	BaO	none	....
TiO_2	2.92	0.20	Na_2O	6.35	5.63
Al_2O_3	17.94	17.44	K_2O	2.62	2.79
Fe_2O_3	2.56	6.84	H_2O	0.65	2.04
FeO	7.56	6.51	P_2O_5	0.94	1.04
MnO	trace	....		——	——
MgO	3.22	2.07		99.60	99.92
CaO	7.85	7.47			

I. Essexite. Salem Neck. H. S. Washington anal.

II. Essexite. Salem Neck. M. Dittrich anal. (Rosenbusch. Elem. d. Gesteinslehre, 1898, p. 172. No. 1.)

The resemblance between the two analyses is close, the greatest differences being in ferric oxide, titanium oxide, and magnesia. It is possible that the low titanium oxide in Dittrich's analysis is due to the fact that it represents only the residue left after evaporation of the silica with hydrofluoric acid, while in mine, where the similar residue amounted to only 0.72 per cent., the titanium oxide was determined directly. The low silica and high lime and alkalies will be noticed, showing the basic monzonitic character of these rocks. Magnesia is rather lower than might be expected, a point which will be discussed later on.

Diorite.—This group is quite extensively represented in Essex county, the main occurrence being a long area with a general northeast-southwest trend in the western part, in Danvers, Topsfield, and Ipswich, a smaller area occurring about Salem and Marblehead and extending north into Beverly. From the large western area I have no specimens, all of mine coming from localities in the smaller areas about Salem and Marblehead. These rocks have been partially described by Sears[1] and are quite diversified in character.

Megascopically these are very dark, almost black, rocks, though a few are quite light, especially the main rock at Fort Sewall, Marblehead, which is a mottled light gray. This mass, by the way, is notable for the great number of "schlieren" and rounded masses of a dark, more basic diorite which it contains.

[1] SEARS, Bull. Essex. Inst., Vol. XXIII, 1891.

In structure they are always granitic, and in texture vary from rather fine to coarse-grain, the last looking like a typical diorite. The only minerals visible are white feldspars and black hornblende, biotite and augite.

Under the microscope it is seen that these rocks are essentially monzonitic in character, in Brögger's sense, orthoclase or an alkali-feldspar being almost invariably present along with the plagioclase, and that they vary from rather basic rocks rich in plagioclase and poor in orthoclase to more acid ones in which the orthoclase largely predominates over the plagioclase and where quartz also appears. The former closely approach the hyperitic varieties of the essexites, and, in fact, are only distinguished from these by their greater coarseness of grain and more dioritic appearance megascopically. The latter closely approach the akerites and perhaps should be described with them, but, on account of their intimate association with the dioritic rocks, and also because of their distinctly different megascopical character, they are placed here. Between these two extremes are found many transition types. The structure is always granitic or hypautomorphic, the dark minerals usually, but not always, having crystallized before the feldspars, the plagioclase generally before the orthoclase, and the quartz, if present, being always interstitial. None of the specimens are quite fresh, the best in this respect being some from near Collin's Cove, Salem Neck, which are hyperitic in structure.

The plagioclase, which has a tendency to stout tabular forms, is highly, and in many cases beautifully, twinned, according to the albite and pericline laws. It varies considerably in composition from an oligoclase, Ab_2An_1, to a basic labradorite, Ab_1An_3, the former being more abundant in the more acid orthoclase-rich varieties and the latter in the more basic, especially in specimens from Salem Neck. It is usually xenomorphic toward the ferromagnesian minerals, but not always, and is also met with as inclusions in the latter, so that it seems that, although the latter began to crystallize first, during a later stage the crystallization was simultaneous. Inclusions of augite,

magnetite and apatite are not rare. A quite common feature is the presence of numerous minute black rods which are square or long in section and are probably magnetite. In the specimen from Peach's Neck which was analyzed a reaction between augite and plagioclase has produced small flakes of brown biotite along the edges of the latter and extending into its substance. The alkali-feldspar is less automorphic than the plagioclase, and is often microperthitic. The quartz, which is abundant only in the main rock of Fort Sewall, is always interstitial and clear, with minute glass or liquid inclusions.

The ferromagnesian minerals vary much not only in amount but in kind. A colorless or almost colorless monoclinic pyroxene is most abundant. This corresponds in general to diopside, but in certain specimens, Peach's Neck, and in black "schlieren" at Fort Sewall, it has the habit of diallage, a parting parallel to (100) and (010) being prominent. The diopside shows high extinction angles and carries few inclusions. The diallage, which has a tendency to light brownish hues, is frequently crowded with minute magnetite (?) rods, which in sections parallel to (010) are arranged parallel with the direction of extinction, at an angle of 34° with the cleavage cracks. They also carry the small brown or opaque plates which are so frequent in the hypersthene of gabbros. These are not pleochroic and are apparently isotropic. In the hyperitic facies from Salem Neck the pyroxene is a light violet augite. The pyroxenes alter easily to uralite, brown hornblende, and biotite.

Primary hornblende is not abundant and is to be referred to two varieties. In the main rock of Fort Sewall and in specimens from Peach's Neck it is pale green or olive-green, not very pleochroic, and automorphic as well as fragmentary. In the basic hyperitic rocks of Salem Neck it is brown, much more highly pleochroic, and is apparently a barkevikite. Biotite, when primary, is greenish yellow or brown, the latter especially in the hyperitic forms. Secondary hornblende and biotite are extremely common, formed usually at the expense of the pyroxenes, and often in the form of reaction rims. A few crystals of

olivine entirely altered to serpentine were seen, but they are too rare to be of any importance. Magnetite is abundant in all the specimens, usually in large rounded grains. There seems to be a tendency for biotite to be produced from it when included in feldspar and hornblende when in augite, but this rule is not constant. Apatite is abundant in fair-sized stout crystals, more so in the basic than in the acid varieties.

It is evident that the rocks which are grouped under the heading of diorite are highly varied and that they represent transition forms from the essexites to the akerites. This is true at least for the area under examination; of the larger Danvers-Ipswich area I can say nothing. For the satisfactory study of these rocks several analyses will be necessary, but at present only one is available. The rock chosen for analysis was a specimen from the south side of Peach's Neck, a coarse-grained dark rock which shows under the microscope plagioclase, less orthoclase, no quartz, diopside, diallage, magnetite, apatite, and secondary hornblende and biotite. It is not quite fresh, but not altered enough to affect the result seriously.

SiO_2	51.82	CaO	8.59
TiO_2	2.15	Na_2O	3.44
Al_2O_3	17.06	K_2O	1.77
Fe_2O_3	1.97	H_2O (110°)	0.11
FeO	8.60	H_2O (ignit.)	0.20
MnO	none		100.58
MgO	4.87		

This is evidently the analysis of a diorite, though a basic one, the silica and alkalies being too high for a gabbro. It will be discussed later.

Quartz-augite-diorite.—The rocks which Sears calls by this name occupy a narrow area west of the rocks described in the preceding pages, which stretches through the county in a northeast-southwest direction from Andover to Newburyport and the New Hampshire line. Representing them I have only three specimens from Newburyport, given me by Mr. Sears, by whom they have been briefly described.[1] They are light gray, medium-

[1] SEARS, Bull. Essex Inst., Vol. XXVII, p. 7, 1895.

grained, granitic rocks, showing feldspars, augite, and a few quartz grains. The feldspars are apt to be epidotized. In thin section they show a granitic structure, and are composed of a rather basic plagioclase, about Ab_1An_2, nearly as much orthoclase, considerable quartz, stout prisms of pale green diopside which is commonly uralitized, some pale green biotite also altered, little or no magnetite, and rare small apatites. As all the specimens were badly decomposed I made no analysis of them, but they presumably approach in composition the nordmarkites.

Porphyritic diorite.—A peculiar rock which may be called a diorite is found, along with the orbicular syenite, in similar rounded masses enclosed in granite, near Bass Rock. It is dark-brown, with a rather fine-grained granitic groundmass of white feldspar tables and hornblendes, often surrounded by white feldspar zones, lying in a finer-grained matrix. Through this are scattered large phenocrysts of labradorite, up to 5^{cm} in length, of a peculiar clove-brown color and thick tabular habit. The cleavage of these is very good, and on basal cleavage surfaces fine twinning striations are visible.

Under the microscope the groundmass shows a granitic structure, composed largely of alkali-feldspar, with some plagioclase, small grains of colorless diopside, pale brownish-green hornblende, rare biotite flakes, considerable magnetite in grains and small stout rods, quite abundant apatite and no quartz. The large phenocrysts show well developed twinning lamellæ, which give extinctions corresponding to a labradorite of the composition Ab_2An_3. They are dusty with minute liquid inclusions holding movable bubbles, and also carry inclusions of diopside, hornblende, and magnetite. An analysis was made of a rather coarse-grained piece which was chiefly phenocryst, and this gave:

SiO_2	54.99	CaO	9.87
TiO_2	0.29	BaO	none
Al_2O_3	25.58	Na_2O	4.95
Fe_2O_3	0.43	K_2O	1.11
FeO	2.70	H_2O	0.38
MnO	trace		
MgO	0.72		101.02

This may be calculated roughly to represent:

Orthoclase,	6.5	Diopside,	2.1
Albite,	42.0	Hornblende,	3.2
Anorthite,	44.2	Magnetite,	2.1

Here the albite and anorthite molecules are in the ratio of 1 : 1, but since the microscope shows that the plagioclase has the composition of about Ab_2An_3, it is evident that the alkali-feldspar is rich in soda, and has approximately the composition Or_1Ab_2. The analysis, however, does not represent the composition of the rock as a whole, and for most purposes is of little or no use.

Gabbro.—Rocks which belong to this group are found in typical development only at Nahant, and are called norites by Sears, who has briefly noticed them.[1] According to Wadsworth[2] and Sears, gabbros also occur at various localities in Essex county, especially at Davis' Neck, Cape Ann, and Woodbury Point, Beverly. These, however, judging from the somewhat unsatisfactory specimens in my possession, are rather diorites in Brögger's sense, but will not be described further.

The gabbro of Nahant, as represented by the few specimens collected by myself, are dark, coarse-grained rocks composed of plagioclase, which even in the freshest specimens are dull or waxy and greenish through epidotization and black augite, besides titaniferous magnetite grains. They show both megascopically and in thin section a typically granitic structure.

The abundant plagioclase, although rather decomposed, shows twinning lamellæ whose extinctions correspond to those of a basic labradorite about Ab_1An_3. A little orthoclase is also present. A pale gray augite is abundant, which is often automorphic and shows constantly high extinction angles. In my specimens I could find none of the hypersthene mentioned by Sears. Large titaniferous magnetite grains are common and are often surrounded by borders of leucoxene. With the exception of limonite, epidote, chlorite, and a few other decomposi-

[1] SEARS, Bull. Essex Inst., Vol. XXVI, 1894.

[2] WADSWORTH, Geol. Mag., 1895, p. 208.

tion products, these are the only minerals present. An analysis was made of the freshest specimen, which was slightly altered, from near a cove on the north shore of Nahant, east of the village.

SiO_2	43.73	Na_2O	2.42
TiO_2	4.23	K_2O	1.45
Al_2O_3	20.17	H_2O (110°—)	0.08
Fe_2O_3	4.32	H_2O (110°+)	1.02
FeO	6.93	P_2O_5	0.15
MnO	none		
MgO	3.91		99.40
CaO	10.99		

It is low in silica, rich in lime, but rather poor in magnesia, high in titanium oxide and alumina, and rather high in alkalies for such a rock, which is evidently a true gabbro.

ADDENDUM

"*Hyperitic diorite.*" — Since the description of this rock was put in type an analysis has been made, which renders necessary some corrections and additions. The analysis is given here.

	I	II
SiO_2	45.32	49.25
TiO_2	1.94	1.41
Al_2O_3	18.99	16.97
Fe_2O_3	3.78	15.21
FeO	9.78	
MnO	....	trace
MgO	4.68	about 3.00
CaO	9.19	7.17
Na_2O	3.78	4.91
K_2O	2.12	2.01
P_2O_5	....	0.76
H_2O (110°)	0.09	about 0.30
H_2O (ignit.)	0.31	
	99.98	100.99

I. Hornblende-gabbro, Salem Neck. H. S. Washington anal.

II. Olivine-gabbro-diabase, Dignæs, Gran. A. Damm and L. Schmelck anal. (W. C. Brögger. Quart. Jour. Geol. Soc., Vol. L, p. 19, 1894.)

It will be seen that the rock is decidedly more basic than the other diorites of the region, so far as I am acquainted with them. The silica in fact is lower than that of the diabase and essexite, and closely approaches that of the gabbro from Nahant. This being the case, and the characters otherwise corresponding, the rock is not a diorite in the proper sense, as used by Brögger,[1] but should be called a hornblende-gabbro. It was thought at the time of the microscopical examination that the rock was basic, but it was not expected that it would turn out to be so low in silica as the analysis shows. At the same time the character of the hornblende, which is essentially a barkevikite, the rather high alkalies, and the association with essexite and foyaite show that these hornblende-gabbros ("hyperitic diorites") are decidedly distinct from the other diorites, and approach more closely the essexites and the more soda-rich rocks of the region. Attention has already been called to the fact that they grade into the essexites, and that Rosenbusch grouped them with these, but their decidedly lower alkali content and lack of orthoclase and nepheline sufficiently distinguish them.

It is to be remarked that these rocks resemble very closely under the microscope some of the gabbros of Norway, especially those from the district of Gran, and above all, some from the Viksfjeld. This is seen on microscopical comparison of sections of the rocks, some being mutually indistinguishable, and is also shown by the analyses, one of those of the Gran rocks being given in II for comparison.

H. S. WASHINGTON.

[1] W. C. BRÖGGER, Die Eruptivgesteine des Kristianiagebietes, Vol. I, p. 93, 1894, and Vol. II, p. 35, 1895.