INTRUSION RELATIONS OF BAHIAITE FROM SOUTHERN NORWAY

Tom. F. W. Barth,
Geologisk Museum, Oslo, Norway.

Abstract

Simple holocrystalline dikes of bahiaite (hypersthene and hornblende) cut a small body of massive hornblende norite surrounded by pre-Cambrian agmatitic gneisses. It is believed that super-critical water vapor streaming through cracks in the norite could transform the adjacent rock to bahiaite having a dike-like relation.

Bahiaite is a holocrystalline, massive rock characterized by the combination of hypersthene and hornblende. It was first described by Merrill (1895, p. 658) from Grass Creeks, Montana. Later the same combination was described by Washington (1914, p. 84) from near Maracas, Bahia, Brazil, who writes: "As the type is now shown to be widespread, I venture to suggest the name bahiaite. . . ." The Bahian rock occurs as a mass about 1 km long, 200 meters wide with distinct foliation parallel to the contact of the surrounding pre-Cambrian gneisses.

Bahiaite has been encountered within the large pre-Cambrian gneiss district of Southern Norway (Barth, 1947, p. 47). The rocks of this district are predominantly granitic in composition, but schlieren, patches, and irregular bodies of amphibolite—i.e. metamorphic, schistose combinations of plagioclase and hornblende of uncertain origin—are frequently encountered; in places they are strongly concentrated and dominate the rock composition.

Some of the larger amphibolite bodies represent metamorphic norites and contain locally, small enclaves of non-schistose rocks i.e. massive gabbroidal rocks, which by gradation pass into the surrounding amphibolite of schistose habit. Bahiaites associated with hornblendites occur at several places as special facies of the massive gabbroidal rocks. Thus the field relations indicate that such bahiaites, although completely massive, and without any obvious sign of secondary alteration, are of metamorphic-metasomatic origin. Bahiaite of other relations likewise occurs.

Figure 1 shows a map of a small part of the South-Norwegian gneiss district that was surveyed by me some years ago (Barth, 1945). The *mixed gneisses* represent a heterogeneous migmatic-anatectic rock complex in which amphibolites are present as bands, zones, schlieren, and irregular patches in a granitic matrix. The *hornblende granite* is probably younger than the gneisses, and exhibits a more igneous look, but certain facies of it are just as "gneissic" as the mixed gneisses. The contact be-

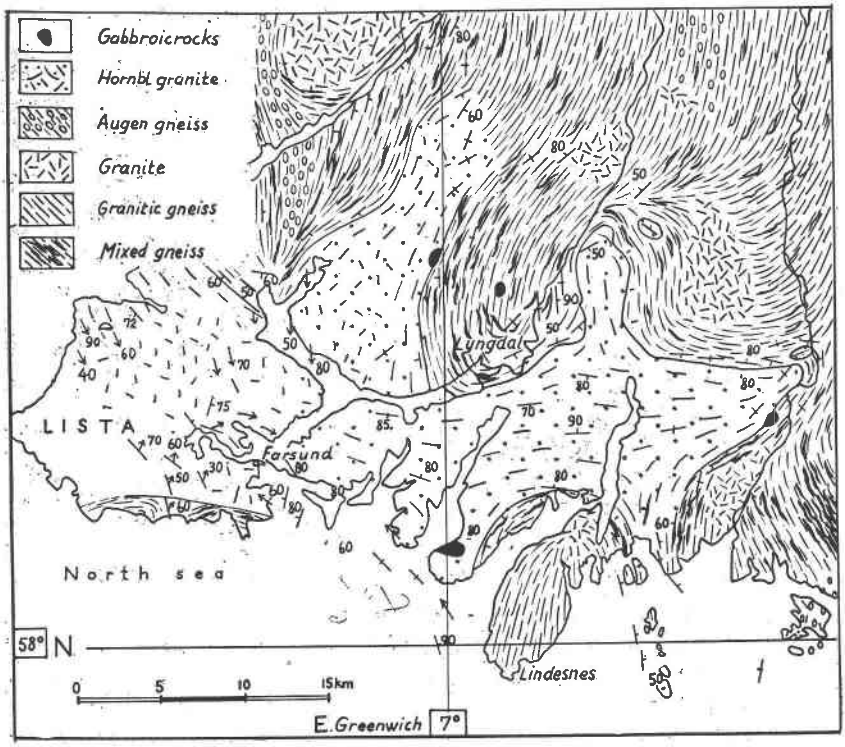

FIG. 1. Geological map of the southern tip of Norway.

tween gneiss and hornblende granite is interesting: As indicated by the map at the end of the long offshoot that extends northward, the contact is transitional and indefinite. Everywhere else the contact is sharp and conformable; both the hornblende granite and the surrounding gneisses are strongly foliated parallel to the common border.

Gabbroic rocks are represented by four small bodies within the map area. They are massive without foliated borders. Bahiaite is associated with the most northern of these bodies and will form the subject of the following description.

The field relations are shown by Fig. 2. A massive body of hornblende norite that is situated right on the border between hornblende granite and mixed gneiss is dissected by a number of small dikes of massive bahiaite. Small patches of hornblende norite, detached from the main body, are scattered around. In this place numerous small, unsystematically distributed, angular inclusions of amphibolite make the mixed gneisses look like agmatite, i.e. a gneissified breccia.

The hornblende norite: Plagioclase forms clear, homogeneous, polygonal crystals, several millimeters long, of composition 57An. Hypersthene forms clusters of equidimensional small crystals; (several tenths of a millimeter long). They are distinctly pleochroic; indices of refraction are $\alpha=1.715$ (red), $\beta=1.727$ (yellow), $\gamma=1.731$ (green,) $(-)2V=54°$; corresponding to 51 Fs (according to the diagram of Poldervaart

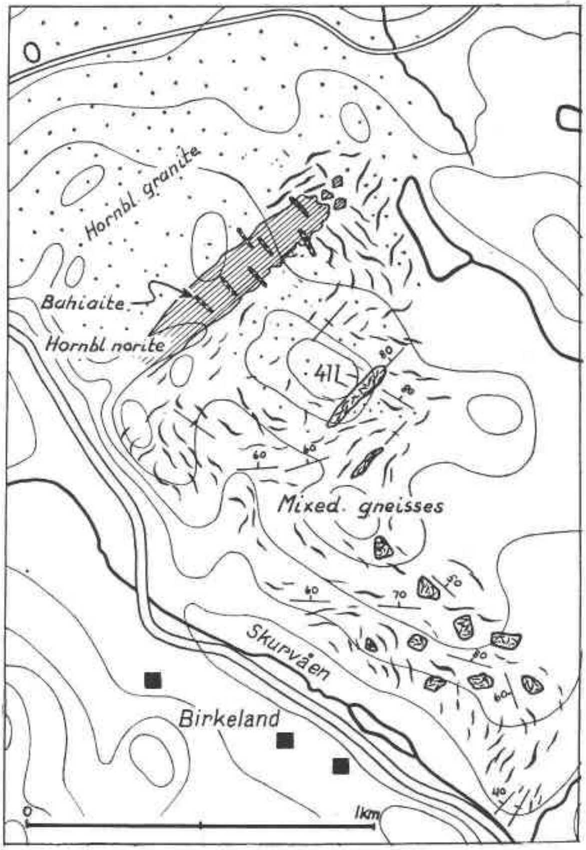

FIG. 2. Geological map of the hornblende-norite—bahiaite occurrence near Lyngdal, Southern Norway.

1947, p. 167). Hornblende is hypidiomorphic homogeneous, and shows rather large, prismatic crystals, several millimeters long; pleochroism is brown-greenish, brown-light yellow.

The bahiaite contains no feldspar. Hypersthene and hornblende are similar to those of the norite. Hypersthene shows $\alpha=1.706$, $\beta=1.718$, $\gamma=1.722$, $(-)2V=58°$ corresponding to 44 Fs.

Chemical analyses of both hornblende norite and bahiaite are entered in Table 1. The simple mineral composition of these two rocks may easily be calculated from the analyses. The quantitative mineral assemblages thus calculated are listed in Table 2.

The compositions of the two hornblendes, that of the norite and that of the bahiaite, as calculated from the corresponding rock analyses are respectively:

$$[Na_{0.8}Ca_{1.9}Mn_{0.1}]_{2.8}[Mg_{2.0}Fe_{1.6}''Ti_{0.6}Fe_{0.5}'''Al_{0.3}]_5[Al_{2.9}Si_{5.1}]_8O_{23}\cdot H_2O \quad \text{and}$$

$$[Na_{0.7}Ca_{1.8}Mn_{0.1}]_{2.6}[Mg_{2.5}Fe_{1.4}''Ti_{0.4}Fe_{0.3}'''Al_{0.4}]_5[Al_{2.3}Si_{5.7}]_8O_{23}\cdot H_2O.$$

The two hornblendes are rather similar in composition. The iron: magnesia relations i.e. $\frac{Fe}{Fe+Mg}$, expressed in terms of molecular percentage of iron are for hypersthene and hornblende respectively: in norite 50 and 49, in bahiaite 44 and 40.

It is worth noticing that in both rocks hornblende is enriched in magnesia relative to the hypersthene with which it is in contact. In hornblende-bearing basalts the opposite relation exists.

TABLE 1. CHEMICAL ANALYSES

	1	2	3	2′	3′
SiO_2	44.38	43.57	42.78	41.3	40.6
TiO_2	1.98	2.49	2.95	1.8	2.1
Al_2O_3	15.46	16.33	9.14	18.3	10.2
Fe_2O_3	3.27	3.01	2.79	2.2	2.0
FeO	10.17	14.17	18.94	11.3	14.9
MnO	0.26	0.22	0.33	0.2	0.3
MgO	7.27	7.75	13.64	11.0	20.6
CaO	9.24	8.52	6.24	8.7	6.3
Na_2O	3.31	2.38	1.33	4.4	2.4
K_2O	0.90	0.29	0.21	0.3	0.2
H_2O^+	3.48	0.98	1.04	3.1	3.3
H_2O^-		0.02	0.05		
P_2O_5	0.28	0.22	0.46	0.2	0.3
CO_2		0.27	0.05	0.3	0.1
S		0.22	0.07		
F		0.04			
Cl			0.06		
Total	100.00	100.48	100.08	100.0	100.0

1. Average of six crinanites, after Daly (1933, p. 22).
2. Hornblende norite. Near Lyngdal, Southern Norway (Bruun analyst).
3. Bahiaite. Near Lyngdal, Southern Norway (Bruun analyst).

2′ and 3′. The corresponding rocks in terms of equivalent molecular percentage, or per cent of cations.

The field relations and the similarity of the mineralogy strongly indicate that the two rocks are congenetic. Let us accept without argument that the rocks are magmatic and let us make a routine petrochemical interpretation of the analyses: The composition of the hornblende norite, although unusually high in iron, is not far from that of an olivine basalt; Table 1 demonstrates that it is close to the crinanites or analcime-

Table 2. Molecular Norm and Mode

Hornblende norite				*Bahiaite*			
Norms							
		Wo	2.6			Wo	4.0
Or	1.5	Hy	10.6	Or	1.0	Hy	65.8
Ab	22.0	Ol	21.0	Ab	12.0		
An	34.0	Mt	3.3	An	19.0	Mt	3.0
		Il	3.6			Il	4.2
	57.5	Ap	0.6		32.0	Ap	0.8
		Cc	0.6			Cc	0.2
			42.3				78.0
Modes							
Plagioclase (57An)			35.0				
Hypersthene (51Fs)			26.5	Hypersthene (44Fs)			43.2
Hornblende			34.7	Hornblende			53.6
Ore*			2.8	Ore**			2.2
Apatite and calcite			1.0	Apatite and calcite			1.0
			100.0				100.0

* Composition: $FeTiO_3=1.0$, $Fe_3O_4=1.5$, $FeS=0.3$.
** Composition: $FeTiO_3=1.2$, $Fe_3O_4=0.9$, $FeS=0.1$.

olivine diabases from Scotland. The composition of the bahiaite is slightly more magnesian and approaches that of an ultramafic rock which may be regarded as an early differentiate, or an accumulative phase of the olivine-diabase magma.

These facts indicate the following intrusive history:

(1) A forceful intrusion of a homogeneous magma highly charged with vapor into a narrow vent (shattering of the surrounding rocks—formation of agmatite).

(2) The congealing at low temperature of this magma to hornblende norite. Normally the magma should have given the combination plagioclase-pyroxene-olivine which corresponds to a much higher temperature.

Water vapor and other gases were responsible for the low temperature.

(3) The formation of cross joints and the subsequent intrusion of a hot, plastic stiff mud composed of antecedent crystals of hypersthene and hornblende which had accumulated at the bottom of the reservoir. This last assumption is necessary for two reasons. Bahiaite is an *early* differentiate of the norite and cannot have been intruded as a magma posterior to the formation of norite. A bahiaitic magma, i.e. an ultramafic magma does not exist at a reasonable temperature.

The interpretation does not tally too well with the field relations although it seems to be the only possible one, if we assume an igneous rock formed by crystal fractionation in a magma and subsequent intrusion.

One fact that makes any magmatic interpretation difficult is the isolated location of the small gabbro bodies. Where is the magma reservoir in which the differentiation is supposed to have occurred? There is certainly no geological evidence of it in the neighborhood.

Secondly the intrusion mechanism of the bahiaite: stiff masses of crystals lubricated by thin films of liquid being forced through narrow openings, should have resulted in crushing and grinding of the crystals, friction striae on the walls, and an oriented arrangement of splinters and elongated crystals of hornblende. No such effects can be seen.

It may be necessary, then, to consider a metasomatic mode of origin. The norite body lies on the contact hornblende granite—mixed gneiss. The gneiss in the immediate neighborhood is unusual in that it is developed as an agmatite. The evidence is strong that the place once was a chimney or blow-hole through which vapors and emanations were expelled.

The metasomatic action of these emanations on the existing rocks (for example on a large amphibolitic inclusion) resulted in the formation of the hornblende norite (the temperature was probably slightly higher than that of the metamorphism of the surrounding amphibolites). By further pneumatolytic action the bahiaite dikes were formed according to a mechanism suggested by Bowen and Tuttle in 1949 (p. 459): water vapor charged with various rock-making oxides streaming through a crack in the hot hornblende norite could convert the adjacent rock to bahiaite which might appear to be a dike in the hornblende norite.

References

Barth, T. F. W. (1945), Geological map of the Western Sörland: *Norsk Geol. Tidsskr.*, **25**, 1–9.

Barth, T. F. W. (1947), The nickeliferous Iveland-Evje amphibolite and its relations: *Norges Geol. Undersøk.*, No. **168a**, 71 pp.

Bowen, N. L., and Tuttle, O. F. (1949), The system MgO-SiO_2-H_2O: *Bull. Geol. Soc. Am.*, **60**, 439–460.

Daly, R. A. (1933), Igneous rocks and the depths of the earth: McGraw-Hill, New York and London.

Merrill, G. P. (1894), Notes on some eruptive rocks from Gallatin, Jefferson and Madison Counties, Montana: *Proc. Nat. Mus.*, **17**, 656–658, Washington.

Poldervaart, A. (1947), The relationship of orthopyroxene to pigeonite; *Mineral. Mag.*, **28**, 164–172.

Washington, H. S. (1914), An occurrence of pyroxenite and hornblendite in Bahia, Brazil: *Am. Jour. Sci.*, **38**, 79–90.