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THE HONEY BROOK ANORTHOSITE

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ABSTRACT. The elliptically-shaped Honey Brook anorthosite body is located in the northern half of the Wagontown 7½ minute Quadrangle, Pennsylvania. Field mapping shows the presence from the center outward of subparallel concentric zones as follows: anorthosite (90-100 percent felsic minerals), dioritic–anorthosite (78-90 percent), anorthositic–diorite (65-78 percent), and banded diorite (40-60 percent felsic minerals). The anorthite content of the plagioclase varies from a maximum of 55 percent in the anorthosite to 35 percent in the diorite. Hornblende is the predominant mafic mineral. Chemically the rocks may be divided into three categories: anorthosite, diorite, and a transition series that includes both the dioritic–anorthosites and anorthositic–diorites. The average anorthositic rock contains more silica, alumina, and perhaps potash and less iron, magnesium, and calcium than do the dioritic rocks. A plot of all the analyses on a FeO–MgO–Alk diagram shows these rocks follow a definite trend that may be interpreted in either of two ways: if it is that of the Skaergaard intrusion, the dioritic rocks would have crystallized before the anorthositic ones; or if it is that of the Morin anorthosite, the anorthositic rocks would have crystallized before the dioritic ones.

A conventional model may be assumed for the Honey Brook anorthosite with the emplacement of a gabbroic anorthosite liquid containing a high percentage of plagioclase crystals in suspension. Flow differentiation may have concentrated the plagioclase in the core while forcing the gabbroic anorthosite liquid to the borders where it would be the last to crystallize. Or an alternate model of crystallization includes the generation of a melt of suitable amphibolitic composition which commences to crystallize under high water pressure (5000? bars) at 900°C. Though plagioclase (An_{35-42}) and pyroxene are the first minerals to crystallize, hornblende soon becomes the predominant mafic mineral. Continued cooling results in an increase in precipitation of plagioclase over hornblende to produce the transition series rocks with increasing water pressure due to concentration of volatiles in the melt leading to a shift of the plagioclase composition to An_{42-50}. Anorthosite rocks are the last to crystallize and contain few mafic minerals and abundant plagioclase of composition An_{48-55}.

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INTRODUCTION

The Honey Brook anorthosite body is located in the northern half of the Wagontown, Pennsylvania, 7½ minute Quadrangle (fig. 1). This elliptically-shaped body covers approximately 52 square km and is roughly 10 km east-west by 6 km north-south. The three dimensional shape and attitude of the body are not known, as no definitive structural data can be obtained. The aeromagnetic map of the Wagontown Quad-

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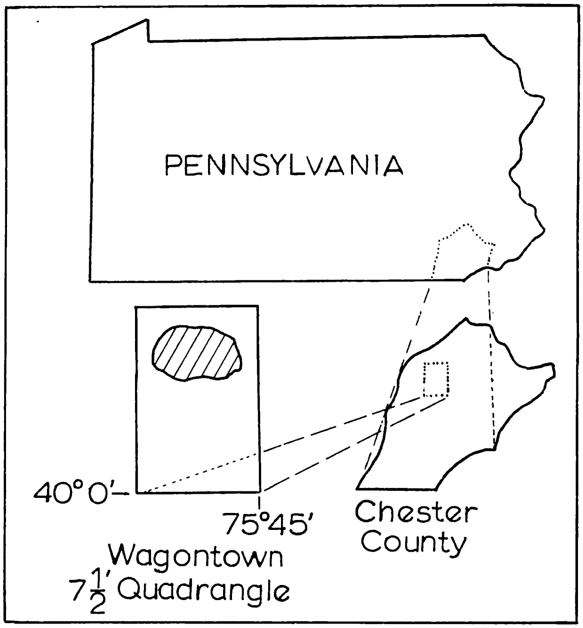

Fig. 1. Location of the Honey Brook anorthosite body shown in the striped area.

rangle (Bromery and others, 1960) indicates that the anorthosite body is a distinct rock unit of lower magnetism than the surrounding rocks and that the body extends to some depth.

The anorthosite body is almost totally surrounded by a Precambrian felsic gneiss (fig. 2), except along the southern border where it is in contact with the Cambrian Chickies quartzite (Smith, 1922). Though Bascom and Stose (1938) postulated a vertical fault along the anorthosite–quartzite contact, field relations are too obscure to determine the exact relationships. Exposures of the anorthosite and associated rocks are only in boulder fields; outcrops in place are very rare. Reliable structural data cannot be taken from these boulder field outcrops. Pegmatites are found as discrete boulders and as veins within anorthosite boulders. Precambrian diabase dikes are present, but their shape and exact location cannot be determined.

Field mapping suggests the presence of subparallel concentric zones based on the quantity and arrangement of the mafic minerals of the rocks, and the zoning follows Buddington's anorthosite series classification except that the mineralogy requires the use of the term diorite instead of gabbro (Buddington, 1939). For the sake of clarity, the body has been subdivided into approximate zones (table 1 and fig. 2) although sharp contacts between zones is highly doubtful. Since the distinction between zones on the basis of field data is somewhat arbitrary due to lack of significant outcrops, contact relationships between zones are necessarily

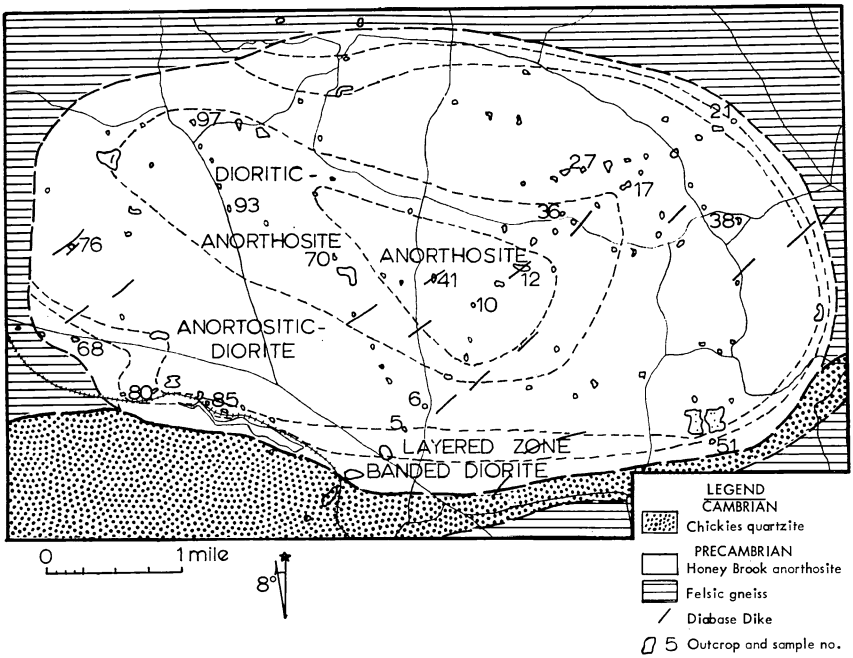

Fig. 2. Geologic map of a portion of the Wagontown, Pennsylvania, 7½ minute Quadrangle. All outcrops indicated by approximate outline. Those outcrops from which samples for analysis were collected and those mentioned in the text are numbered.

TABLE 1
Zonal classification
(see fig. 2 also)

Rock name	Plagioclase % An	Felsic content	Mafic content	Remarks
Anorthosite	48-55	90-100	10-0	Found with highest frequency in the central portion of the body and may be considered a central core.
Dioritic-anorthosite	42-50	78-90	22-10	Generally found in a zone that completely surrounds the central anorthosite.
Anorthositic-diorite	40-45	65-78	35-22	The last completely continuous zone. It completely encloses the dioritic–anorthosite and the anorthosite.
Layered zone	35-45			Not a continuous zone. The discontinuity occurs along the northwest border.
Anorthosite		90-100	10-0	
Diorite		40-60	60-40	
Banded diorite	35-42	40-60	60-40	Confined principally to the outer border area.

of an indefinite nature. When boulders of two or more different anorthositic rock types are found in one locality, that locality is placed within the zone of the predominating rock type, based on field estimates of mafic content.

PETROGRAPHY

The characteristics common to the rocks of the Honey Brook anorthosite series are:

1. A hypidiomorphic granular texture.
2. Ubiquitous presence of plagioclase feldspar, common hornblende, magnetite, apatite, and biotite.
3. Various stages of alteration ranging from very minor uralitization and sericitization to total alteration. Except for the alteration products, the mineralogy of the unaltered variety and the totally altered variety is essentially identical.
4. Various degrees of granulation, the most occurring in the border zone of banded diorite.
5. Absence of zonal growth in the plagioclase.

The chief differences among the several petrologic zones are the quantities of the mafic minerals, the arrangement of the mafic constituents, and the degree of granulation. The mineralogical variation between the zones and the optical properties of the minerals are presented in tables 2 and 3.

TABLE 2
Mineralogical variation between zones
(mode percentages)

Mineral	Anorthosite	Dioritic anorthosite	Anorthosite diorite	Layered zone: Anorthosite	Layered zone: Diorite	Banded diorite
Plagioclase*	90-100	78-90	65-78	90-100	40-60	40-60
Hornblende	0-8	10-15	10-20	0-8	35-55	15-25
Uralite	—	5-10	5-10	0-1	5-10	7-12
Biotite	<2	1-2	2-5	<1	3	3-6
Garnet	—	—	1	—	—	4-6
Apatite	1	1	1-3	1	1-3	3
Magnetite	<0.5	1	1-3	<0.5	1-3	5
Quartz	<2	—	—	—	—	tr
Microcline	—	—	—	—	—	1-3
Sphene	—	—	0-1	—	—	—
Augite	—	—	—	—	—	1
Calcite	—	—	0-1	—	—	0-1
Epidote	—	—	<1	—	—	—
Plagioclase An %	48-55	42-50	40-45	35-45		35-42
Modal Counts	5	4	9	2		4
Percentage Estimates	20	17	30	8		3

* Plagioclase percentages include alteration products of plagioclase (clinozoisite, zoisite, sericite). Plagioclase compositions were determined with the flat stage using curves in Deer, Howie, and Zussman (1966) and were occasionally checked by universal stage methods (Slemmons, 1962).

Table 3
Optical properties

Mineral	Color	Pleochroism	Absorption formula	Birefringence	Extinction angle	Optic angle	Remarks
Hornblende	Brown and green	X = yellow to blue-green Y = green Z = brown	Z > Y > X	0.021 (±) 0.005	$Z \wedge c = 21°$ ± 3°	(—) 65° (±) 5°	
Augite	Light brown	Colorless to light brown	X > Y > Z	0.025	*$Z \wedge c = 42°$	*(+) 54°	*Universal stage determination 3 grains
Alteration products:							
Uralite	Blue-green	Blue-green to pale blue	—	0.028 (±) 0.002	—	—	Fibrous habit
Clinozoisite	Colorless	—	—	0.013 (±) 0.005	—	—	Anomalous interference colors, "ultra blue"
Zoisite	Colorless	—	—	0.006	Parallel		Anomalous interference colors, "ultra blue"
Sericite	Colorless	—	—	0.032	Nearly parallel	(—) 50°	

Anorthosite.—In hand specimen, the fresh anorthosite is coarse grained and varies in color from dark blue gray through light gray to light pinkish gray. In places, large (2 to 4 cm) white nodules of highly altered plagioclase occur in a blue gray matrix. Mafic minerals occur as small segregated patches of grains and as well disseminated grains.

Microscopic examination of the blue gray anorthosite shows that even the freshest-appearing specimens are partially altered. Along fractures in the rock and in the nodules, alteration of the plagioclase is total. Chief alteration products are zoisite, clinozoisite, and sericite. Straining of the quartz is common.

Individual grains of plagioclase are subhedral to euhedral and are generally twinned. Albite twinning is the predominant form, although albite twinning combined with pericline or Carlsbad twinning is not uncommon. Common hornblende, the primary mafic constituent, occurs as both fresh and altered grains which are always well disseminated throughout the anorthosite. It is possible that the apparently altered hornblende is really an alteration product of pyroxene and only the fresh hornblende is primary. The euhedral to subhedral grains of hornblende are commonly rimmed by a substance of unknown composition (possibly uralite). Uralite refers to a light blue-green pleochroic amphibole of unknown composition which rims many of the hornblende grains and also occurs as isolated anhedral grains. Accessory minerals in the anorthosite include biotite, quartz, apatite, and magnetite. The biotite occurs as small crystals in segregated patches and is generally associated with magnetite.

Dioritic anorthosite.—In hand specimens, the dioritic anorthosite is coarse grained with a "peppered" light gray to blue-gray appearance due to the highly disseminated nature of the mafic minerals which occur both as isolated grains and as small patches. Variation in the composition of the plagioclase indicates an increase in the sodic content in this zone over the anorthosite core. In thin section, granulation is evident but not pronounced. The major mafic minerals are hornblende, uralite, biotite, and magnetite.

Anorthositic diorite.—This is the largest zone of the anorthosite body. In hand specimen, it is distinguished from other zones by its color variation from a light gray to a definite pink. It contains subparallel lenses (1 to 3 cm thick) and stringers of mafic material comprised of biotite, hornblende, or garnet or a combination of these three. At locality number 38 (fig. 2) on the eastern edge of this zone large well developed crystals of allanite (up to 2½ cm) were found along a fracture wall in anorthositic diorite boulder. Though most rocks from this zone are light gray to pinkish gray in color, specimens collected from localities 27 and 97 (fig. 2) were a deep pink. The typical white alteration product of plagioclase occurs along fractures in the deep pink dioritic–anorthosite together with, for this area, an atypical alteration product of yellow-green epidote.

Microscopic examination of the anorthositic–diorite indicates the degree of granulation here is highest of all the zones. The anhedral plagioclase grains that are pink in hand specimen are similar under the microscope to those of the light gray to pinkish gray varieties; the only apparent difference is in hand specimen color. Common hornblende, uralite, biotite, garnet, and magnetite comprise the mafic fraction of the rocks of this zone. The biotite grains are noticeably larger than in the other zones. Euhedral grains of apatite and sphene account for the bulk of the accessory fraction of the rock (table 2). The secondary minerals include not only zoisite, clinozoisite, and sericite, but also calcite and epidote. Epidote is found only along fracture zones and occurs as minute anhedral grains with a distinctive greenish-yellow pleochroism. The anhedral grains of calcite are generally in association with hornblende.

Garnet occurs both as disseminated euhedral to subhedral grains and as lens-shaped aggregates (up to 5 cm in diam). The garnet has a refractive index of 1.785 ± 0.003 and a specific gravity of 3.95 suggesting a composition of Alm_{56} Py_{27} And_3 Gr_{14} (after Winchell and Winchell, 1959). A Laue photograph of the garnet indicates it is unstrained.

Layered zone.—The coarsely crystalline layered zone constitutes only a small fraction of the total bulk of the Honey Brook body; it does not extend around the northwestern part of the body (fig. 2). In this zone, thick layers (5 cm to several meters) of generally dark gray (with some variation from light gray to blue gray), very pure anorthosite alternate with moderately thick (2 to 10 cm) layers of diorite. Granulation is nearly as strong in this zone as it is in the anorthositic–diorite. Once again, alteration of the plagioclase is strongest along fractures.

As in all the other zones, the mafic minerals in the diorite layers are common hornblende, uralite, magnetite, and very minor biotite; the only difference between the layered zone and the anorthositic–diorite is in the arrangement of the mafic minerals into true layers rather than subparallel lenses.

Banded diorite.—The banded diorite of the border facies is rarely found as fresh material. The minerals comprising this zone are similar to those found in the anorthositic–diorite zone, but the mafic minerals and plagioclase occur in regularly spaced alternating bands giving the rock a gneissic structure. Disseminated grains of garnet occur along with rare aggregates.

In thin section myrmekitic plagioclase occurs with microcline perthite. Quartz is not only associated with the plagioclase but is found as partial rims around several of the garnet grains. Augite (table 3) occurs in minor amounts.

Pegmatite.—Coarsely crystalline light gray pegmatite occurs as small veins and large (1-3 m) boulders. The primary minerals of the pegmatite are microcline perthite (45 percent), quartz (45 percent), and myrmekitic plagioclase (5 percent); accessories are hornblende with uralite, biotite, garnet, and magnetite. In the northwest part of the anorthosite body, the pegmatite contains a small fraction of mafic minerals (10 to 20 percent). Alteration of the pegmatite varies and is extensive in some samples.

Diabase.—Fine grained and more commonly porphyritic, dark charcoal gray, diabase boulders are scattered throughout this body as in many other Precambrian localities in southeastern Pennsylvania (Bascom and Stose, 1938). The primary minerals are augite and plagioclase (An_{55}), although much of the plagioclase is replaced by zoisite. Augite is altered to hornblende and biotite along its borders.

Chickies quartzite.—The Cambrian Chickies quartzite consists of fine grained interlocking quartz with some granulation of larger quartz grains. Minor opaque ores, including hematite and probably magnetite, along with rare flakes of muscovite and an intergranular iron stain complete the mineralogy of this rock.

Felsic gneiss.—The Precambrian felsic gneiss varies considerably in composition and appearance. Megascopically, the texture of the light-colored rock varies from granoblastic to lepidoblastic. Medium grained quartz-rich portions with sericitized plagioclase are accompanied by fine grained biotite, chlorite, and tourmaline. Other portions are comprised of medium grained allotriomorphic-granular microcline, perthite, and quartz with minor hornblende and accessory magnetite rimmed by sphene, zircon, and apatite. Smith (1922, p. 44) includes a chemical analysis in her description of the felsic gneiss which she termed a quartz-monzonite.

CHEMISTRY

The samples selected for analysis were collected from numbered sites located on figure 2. They include two anorthosites from the core region; seven samples of the anorthositic-diorite and dioritic-anorthosite zones; three anorthosites and one diorite of the layered zone plus one of the banded diorite zone; and one sample of the pegmatite rock. The analyses, modes, and CIPW norms are arranged in table 4 in order of increasing total iron content calculated as FeO. The data are plotted on figure 3. The FeO–MgO–Alk diagram (fig. 4) for the Honey Brook anorthosite illustrates the presence of four chemically distinct rock types. They are diorite comprised of the diorite of the layered zone and the banded diorite zone; the transitional rocks composed of the rocks of the dioritic-anorthosite and anorthositic-diorite zones; anorthosite composed of the anorthosites from the core of the body and the anorthositic layers of the layered zone; and pegmatite. The trend depicted in this diagram is very similar to that presented by Papezik (1965, p. 705) for the Morin anorthositic pluton, particularly the Mauve facies. This trend is also similar to the estimated liquid trend shown for the late differentiates of the Skaergaard intrusion (Wager and Brown, 1967, p. 238). Note the Honey Brook diorite rocks plot near the beginning of the late differentiate trend, and the anorthosite and pegmatite rocks plot near the completion of the late differentiate trend.

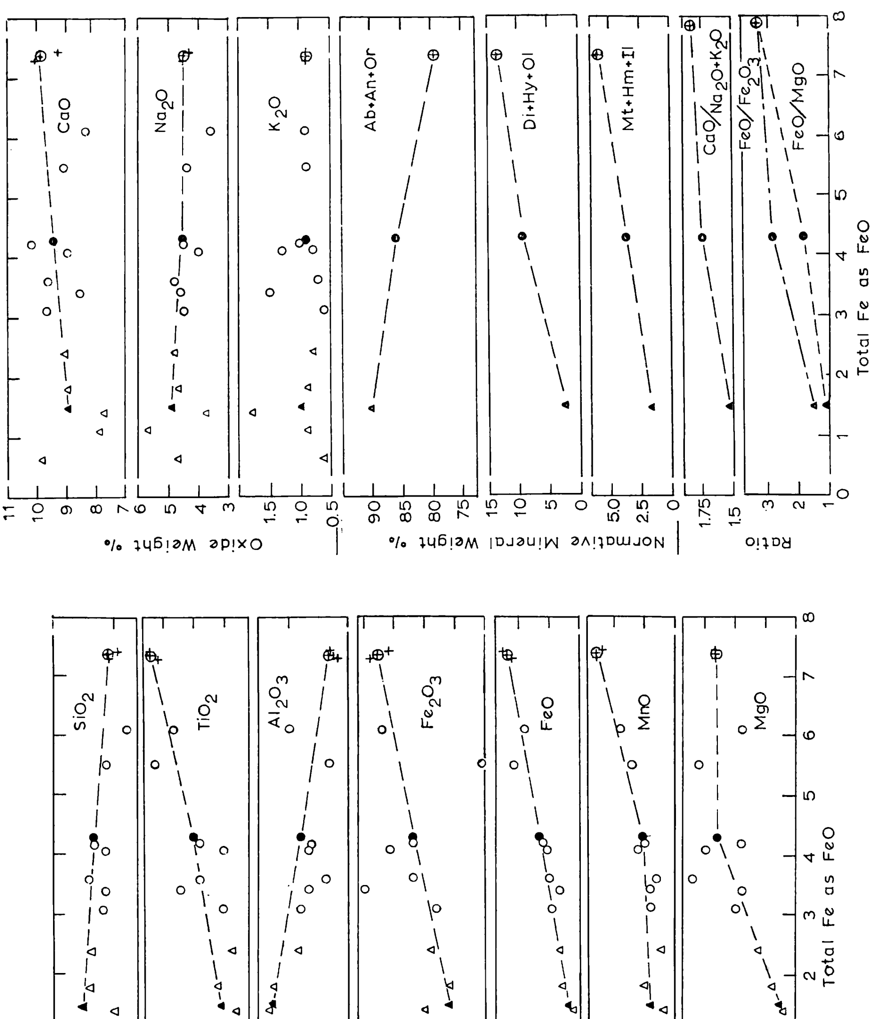

Fig. 3. Oxide weight percentages versus total iron as FeO. Normative mineral weight percentages versus total iron as FeO. Selected ratios of oxides versus total iron as FeO. Anorthosite (open triangle), average anorthosite (closed triangle), transition series (circle), average transition series (closed circle), diorite (+), and average diorite (circle with plus sign).

Table 4

Analyses for SiO_2, TiO_2, Al_2O_3, Fe as Fe_2O_3, and P_2O_5 done by spectrophotometric means. Analyses for MnO, MgO, CaO, Na_2O, and K_2O done by atomic absorption. FeO, $H_2O(+)$, and $H_2O(-)$ by wet chemical methods. Modal percentages based on at least 1000 counts per thin section.

Anorthosites

	Sample number	21	51	12	85	41
Oxide Weight Percentages	Fe_T as FeO	(0.6)	(1.1)	(1.4)	(1.8)	(2.4)
	SiO_2	54.1	57.3	49.8	54.2	54.2
	TiO_2	0.2	0.3	0.3	0.6	0.4
	Al_2O_3	26.7	24.4	26.7	26.1	24.2
	Fe_2O_3	0.3	0.4	1.0	0.6	0.9
	FeO	0.4	0.7	0.5	1.3	1.6
	MnO	0.02	0.07	0.02	0.05	0.02
	MgO	0.6	0.6	0.7	0.9	1.1
	CaO	9.9	7.9	7.8	9.0	9.1
	Na_2O	4.7	5.7	3.8	4.7	4.8
	K_2O	0.6	0.9	1.8	0.9	0.8
	P_2O_5	0.0	0.8	0.3	0.05	0.2
	H_2O^+	1.3	0.5	4.4	0.4	1.3
	H_2O^-	0.1	0.1	2.3	0.1	0.1
	Total	98.9	99.7	99.4	98.9	98.7
Mode	Plagioclase	—	99.8	95.6	97.1	—
	Mafic	—	—	4.4	2.3	—
	Accessory	—	0.2	—	0.6	—
	Garnet	—	—	—	—	—
Norm	Quartz	2.3	4.8	3.9	2.5	2.3
	Corundum	0.3	1.6	5.0	1.2	—
	Orthoclase	3.5	5.3	10.6	5.3	4.7
	Albite	39.8	48.2	32.2	39.8	40.6
	Anorthite	49.1	34.0	36.8	44.3	42.1
	Nepheline	—	—	—	—	—
	Diopside	—	—	—	—	(1.4)
	wo	—	—	—	—	0.7
	en	—	—	—	—	0.4
	fs	—	—	—	—	0.3
	Hypersthene	(1.7)	(2.1)	(1.7)	(3.2)	(3.6)
	en	1.5	1.5	1.7	2.2	2.3
	fs	0.2	0.6	—	1.0	1.3
	Olivine	—	—	—	—	—
	fo	—	—	—	—	—
	fa	—	—	—	—	—
	Magnetite	0.4	0.6	0.8	0.9	1.3
	Hematite	—	—	0.4	—	—
	Ilmenite	—	0.6	0.6	1.1	0.8
	Apatite	—	1.9	0.7	0.1	0.5
	P(di+hy+ol)	1.7	2.1	1.7	3.2	5.0
	F(or+ab+an)	92.4	87.5	79.6	89.4	87.4
	M(mg+hm+il)	0.4	1.2	1.8	2.0	2.1

TABLE 4

Transitional series

	Sample number	80	70	76	93	17	36	10
Oxide Weight Percentages	Fe_T as Fe	(3.1)	(3.4)	(3.6)	(4.1)	(4.2)	(5.5)	(6.1)
	SiO_2	51.8	51.3	54.2	51.3	53.4	51.1	48.0
	TiO_2	0.5	1.2	0.9	0.5	0.9	1.6	1.3
	Al_2O_3	24.0	23.3	22.0	23.3	23.2	21.7	24.8
	Fe_2O_3	0.8	2.0	1.2	1.6	1.2	0.01	1.7
	FeO	2.3	1.6	2.5	2.7	3.1	5.5	4.6
	MnO	0.04	0.04	0.03	0.06	0.05	0.07	0.09
	MgO	1.5	1.4	2.2	2.0	1.4	2.1	1.4
	CaO	9.7	8.6	9.7	9.0	10.2	9.1	8.4
	Na_2O	4.5	4.6	4.8	4.0	4.5	4.4	3.6
	K_2O	0.6	1.5	0.7	0.8	1.0	0.9	0.9
	P_2O_5	0.3	0.01	0.2	0.03	0.3	0.3	0.5
	H_2O^+	1.3	4.4	0.4	1.2	0.9	1.2	3.1
	H_2O^-	0.2	0.1	0.1	0.1	0.1	0.1	2.1
	Total	97.5	100.1	98.9	96.6	100.3	98.1	100.5
Mode	Plagioclase	78.0	85.7	83.7	61.6	65.3	80.7	78.3
	Mafic	20.9	12.8	14.2	36.3	32.1	16.8	16.3
	Accessory	1.0	1.5	2.1	—	2.6	2.6	4.6
	Garnet	—	—	—	2.1	—	—	0.8
Norm	Quartz	0.4	—	1.4	1.7	0.6	—	2.6
	Corundum	—	—	—	—	—	—	3.8
	Orthoclase	3.5	8.9	4.1	4.7	5.9	5.3	5.3
	Albite	38.1	38.5	40.6	33.8	38.1	37.2	30.5
	Anorthite	43.5	38.5	36.4	43.2	40.1	36.8	38.4
	Nepheline	—	0.2	—	—	—	—	—
	Diopside	(2.2)	(3.2)	(8.4)	(1.0)	(7.0)	(5.4)	—
	wo	1.1	1.7	4.4	0.5	3.5	2.7	—
	en	0.6	1.5	2.9	0.3	1.8	1.1	—
	fs	0.5	—	1.1	0.2	1.7	1.6	—
	Hypersthene	(5.5)	—	(3.6)	(7.4)	(3.3)	(3.1)	(8.6)
	en	3.1	—	2.6	4.7	1.7	1.3	3.5
	fs	2.4	—	1.0	2.7	1.6	1.8	5.1
	Olivine	—	(1.4)	—	—	—	(5.2)	—
	fo	—	1.4	—	—	—	2.0	—
	fa	—	—	—	—	—	3.2	—
	Magnetite	1.2	1.8	1.7	2.3	1.7	0.01	2.5
	Hematite	—	0.8	—	—	—	—	—
	Ilmenite	1.0	2.3	1.7	1.0	1.7	3.0	2.5
	Apatite	0.7	—	0.5	0.1	0.7	0.7	1.2
	P(di+hy+ol)	7.7	4.6	12.0	8.4	10.3	13.7	8.6
	F(or+ab+an)	85.1	85.9	81.1	81.7	84.1	79.3	74.1
	M(mg+hm+il)	2.2	4.9	3.4	3.3	3.4	3.01	5.0

TABLE 4 (continued)

		Diorite		Pegmatite	Average anorthosite	Average transitional series	Average diorite
	Sample number	6	5	68			
Oxide Weight Percentages	Fe_T as FeO	(7.3)	(7.4)	(0.8)	(1.46)	(4.3)	(7.35)
	SiO_2	50.6	49.5	69.2	55.7	53.4	51.0
	TiO_2	1.6	1.7	0.1	0.4	1.0	1.7
	Al_2O_3	20.8	21.5	14.4	26.4	24.0	21.6
	Fe_2O_3	1.9	1.6	0.7	0.6	1.2	1.8
	FeO	5.6	6.3	0.2	0.9	3.4	6.1
	MnO	0.13	0.12	0.02	0.04	0.05	0.10
	MgO	1.8	1.8	0.6	0.8	1.8	1.8
	CaO	10.1	9.3	0.8	9.0	9.5	9.9
	Na_2O	4.5	4.3	1.7	4.9	4.5	4.5
	K_2O	0.9	0.9	7.9	1.0	0.9	0.9
	P_2O_5	0.6	0.6	0.0	0.3	0.2	0.6
	H_2O^+	0.0	0.5	0.4			
	H_2O^-	0.6	0.1	0.1			
	Total	99.1	98.2	96.1	100.04	99.95	100.03
Mode	Plagioclase	—	66.0	—	97.5	76.2	66.0
	Mafic	—	20.5	—	2.2	21.3	20.5
	Accessory	—	6.8	—	0.3	1.5	6.8
	Garnet	—	6.7	—	—	1.0	6.7
Norm	Quartz	—	—	26.5	3.5	0.3	—
	Corundum	—	—	1.6	1.6	—	—
	Orthoclase	5.3	5.3	46.7	5.9	5.3	5.3
	Albite	37.1	36.4	14.4	41.5	38.1	37.8
	Anorthite	33.9	36.7	4.0	42.7	42.6	36.1
	Nepheline	0.5	—	—	—	—	0.2
	Diopside	(10.3)	(4.7)	—	—	(2.6)	(7.7)
	wo	5.2	2.3	—	—	1.3	3.8
	en	2.1	0.9	—	—	0.7	1.5
	fs	3.0	1.5	—	—	0.6	2.4
	Hypersthene	—	(1.2)	(1.5)	(2.6)	(6.9)	—
	en	—	0.4	1.5	2.0	3.8	—
	fs	—	0.8	—	0.6	3.1	—
	Olivine	(4.2)	(6.4)	—	—	—	(5.7)
	fo	1.6	2.2	—	—	—	2.1
	fa	2.6	4.2	—	—	—	3.6
	Magnetite	2.8	2.3	0.4	0.9	1.7	2.6
	Hematite	—	—	0.4	—	—	—
	Ilmenite	3.0	3.2	1.9	0.8	1.9	3.2
	Apatite	1.4	1.4	—	0.7	0.5	1.4
	P(di+hy+ol)	14.5	12.3	1.5	2.6	9.5	13.4
	F(or+ab+an)	76.3	78.4	65.1	90.1	86.0	79.2
	M(mg+hm+il)	5.8	5.5	2.3	1.7	3.6	5.8
Ratio	CaO/Na_2O+K_2O				1.53	1.76	1.84
	FeO/MgO				1.12	1.89	3.39
	FeO/Fe_2O_3				1.50	2.84	3.39

The analyses of the rocks from each major type have been averaged and recalculated to 100 percent and water free (table 4); the average trends are as indicated in figure 3. The ratios used by Papezik (1965) are presented for the average major rock types on figure 3. Systematic changes with decreasing FeO_T content do occur. Silica and alumina increase along with a slight increase in potash over soda and titanium over total iron; these are accompanied by a definite decrease of calcium versus the alkalis and a decrease in FeO over both MgO and Fe_2O_3.

The FeO–MgO–Alk diagram (fig. 4), the oxide weight percentages (fig. 3), the selected oxide–FeO_T ratios (fig. 3), and the normative mineral percentages (fig. 3) all seem to point to the following conclusions:

1. The average anorthositic rock contains more silica, alumina, and perhaps potash, and certainly less iron, magnesium, and calcium than do the dioritic rocks.

2. The chemistry of the rocks of the Honey Brook anorthosite does follow a definite trend on the FeO–MgO–Alk diagram.

A. If this trend is that of Wager and Brown for the Skaergaard intrusion, the dioritic rocks would have crystallized before the anorthositic ones.

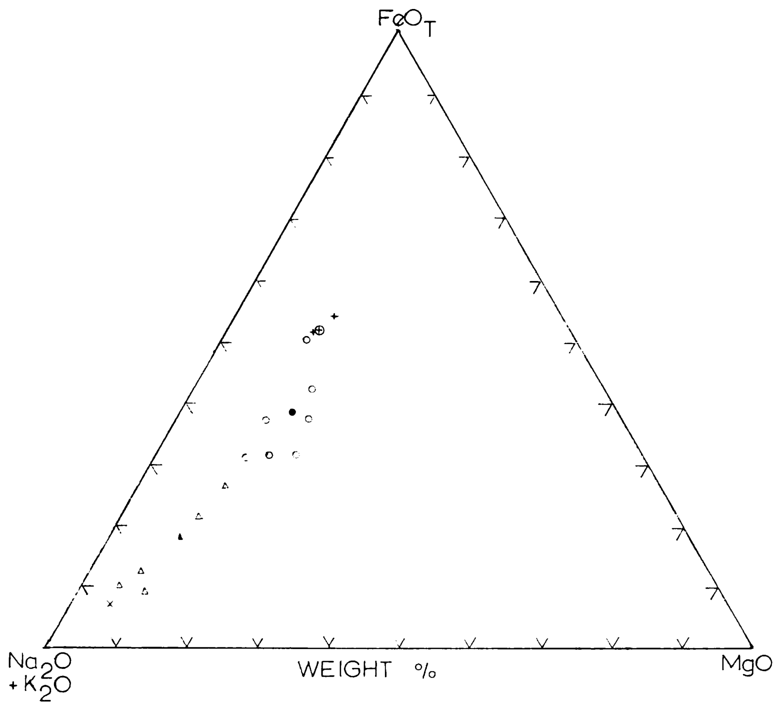

Fig. 4. FeO_T–MgO–Alk diagram for the Honey Brook anorthosite body. Anorthosite (open triangle), average anorthosite (closed triangle), transition series (circle), average transition series (closed circle), diorite (+), average diorite (circle with plus sign), and pegmatite (X).

B. If this trend is that of Papezik for the Marin anorthosite, the anorthositic rocks would have crystallized before the dioritic ones.

DISCUSSION

Conventional model.—The Honey Brook anorthosite body exhibits many features that lend themselves to a conventional interpretation for its origin, that is, anorthosite precipitated as a crystal cumulate, further cooling crystallizing the transition series with the diorite as an end product. These features include:

1. A differentiation trend toward strong iron enrichment (see figs. 3 and 4).
2. An increase in the Ab/An ratio from anorthosite to diorite.
3. An increase in the ratio of opaque ores to other minerals from anorthosite to diorite.

A plot of the various oxide weight percentages versus the differentiation index of Thornton and Tuttle (1960) (wt percentage of normative quartz + orthoclase + albite) for the Honey Brook rocks is very similar to those given in de Waard (1969) for the Marcy and Morin massifs.

The data are thus consistent with the emplacement of a gabbroic anorthosite liquid containing a high percentage of plagioclase crystals in suspension (Buddington, 1939). Flow differentiation may have con-

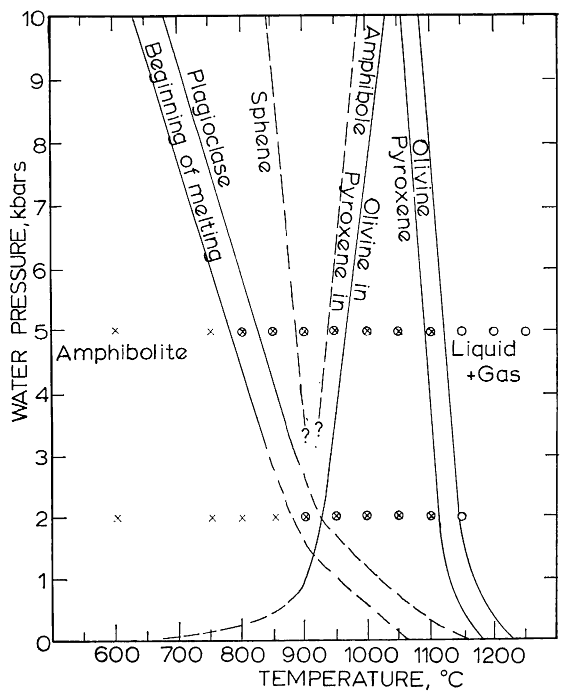

Fig. 5. The olivine tholeiite-water system (Yoder and Tilley, 1962).

centrated the plagioclase in the core while forcing the gabbroic–anorthosite liquid to the borders where it would be the last to crystallize.

Alternative model.—Some features of the Honey Brook anorthosite do not readily lend themselves to a conventional interpretation. A theoretically possible alternative model is discussed below.

Yoder and Tilley (1962) and Yoder (1969, p. 16) present the diagram included here as figure 5. At 5000 bars water pressure a melt of amphibolite composition first precipitates olivine and pyroxenes followed by amphiboles and finally plagioclase. In the Honey Brook anorthosite the only remnant pyroxene is in the banded diorite which plots at the early differentiation stage on the FeO–MgO–Alk diagram (fig. 4). However, those rocks of the transition series that contain the most hornblende and other mafic minerals are also found along the FeO rich end of the differentiation line.

From figure 3, calcium is seen to decrease in absolute abundance and in relative abundance to alkalis from diorite to anorthosite, even though the An content of the plagioclase increases from diorite to anorthosite. From Yoder (1969, p. 20) figure 6 illustrates a tendency for plagioclase composition to become more calcic with increasing water pressure; this may occur as crystallization continues by concentration of volatiles in the melt. The presence of fresh and most probably primary hornblende crystals may also be indicative of high water pressure during crystallization of the melt. The silica content of the Honey Brook anorthosite rocks increases from diorite to anorthosite. Roeder and Osborne (1966) state that the presence of water in a magma will influence liquid compositions to change toward higher SiO_2 contents,

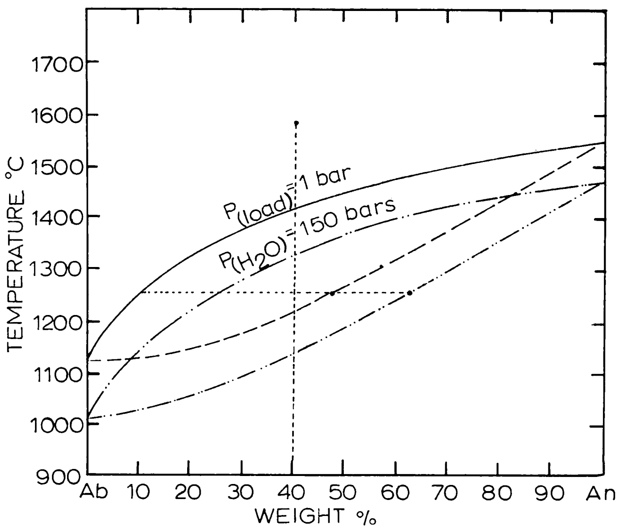

Fig. 6. The albite–anorthite system at 1 bar (load) and 150 bars (water pressure) (after fig. 9, Yoder, 1969).

if during fractional crystallization temperatures drop low enough for crystallization of amphiboles and biotites. The plot of FeO/Fe_2O_3 shows an increase in Fe_2O_3 from diorite to anorthosite and is indicative of a relative increase in partial pressure of oxygen during crystallization.

1. Assume a melt of suitable amphibolitic composition. This melt may be primary or the result of partial melting of the lower crystal material; its mode of generation is beyond the scope of this paper.

2. Commence crystallization under high water pressure (5000 bars?) at moderate temperatures for lower crustal conditions (900°C). The first minerals are pyroxene and plagioclase (An_{35-42}). Soon hornblende and more plagioclase follow while the earlier pyroxene may react to form hornblendes. These rocks now form the dioritic zone or outer portion of the Honey Brook body.

3. Continue cooling and crystallization with the proportion of plagioclase increasing to form rocks of the transition series (dioritic-anorthosites and anorthositic-diorites). Increasing water pressure due to concentration of volatiles in the melt leads to a shift of the plagioclase composition toward an increase in calcium (An_{42-50}).

4. Continue cooling with the formation of the anorthosite zone of the core containing few mafic minerals and a plagioclase of composition An_{48-55}.

5. Crystallize the last dregs of the melt to form the pegmatite rocks that are rich in silica, potash, and alumina.

6. Develop the present alteration or metamorphic mineralogy of uralite, sericite clinozoisite, zoisite, garnet, and rare epidote and allanite by either autometamorphism upon further cooling or later metamorphism.

7. Respond to magmatic stresses or later tectonic movements by granulation.

8. Intrude the Precambrian diabase dikes.

CONCLUSIONS

1. The Honey Brook anorthosite body is probably magmatic in origin.

2. A crude zoning or banding of the body from pure anorthosite to banded diorite through a transitional series of dioritic-anorthosites and anorthositic-diorites does exist. This zonation is further exemplified by the following mineralogical and chemical characteristics from diorite to anorthosite:

   A. Increase in plagioclase content of the rocks from 40 to 50 percent to 90 to 100 percent and plagioclase composition from a minimum of An_{35} to a maximum of An_{55}.

   B. Increase in silica, alumina, and possibly potash content.

   C. Decrease in iron, magnesium, manganese, titanium, and calcium content.

3. Most of the hornblende found in these rocks may be primary and indicative of high water pressure during crystallization.

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