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DEPARTMENT OF MINES AND TECHNICAL SURVEYS

THE ANORTHOSITE OF NORTHERN CAPE BRETON ISLAND, NOVA SCOTIA, A PETROLOGICAL ENIGMA

(Report, 2 plates and 3 figures)

S. E. Jenness

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ABSTRACT

Several small lenses of anorthosite outcrop within a band of chloritic and amphibolitic metavolcanic rocks near the northern tip of Cape Breton Island. Nearly unaltered phases of the anorthosite are pale grey, medium to coarse grained, and fractured; most of the anorthosite is considerably altered. The plagioclase is sodic andesine (An_{35-40}). Some of the anorthositic outcrops contain chloritized hornblende in amounts ranging from 5 to 30 per cent, thus passing from true anorthosite to dioritic anorthosite and anorthositic diorite.

The anorthosite is probably older than the Devonian granitic rocks in the region and younger than the metavolcanic rocks within which it occurs. A Proterozoic age for both anorthosite and metavolcanic rocks is suggested.

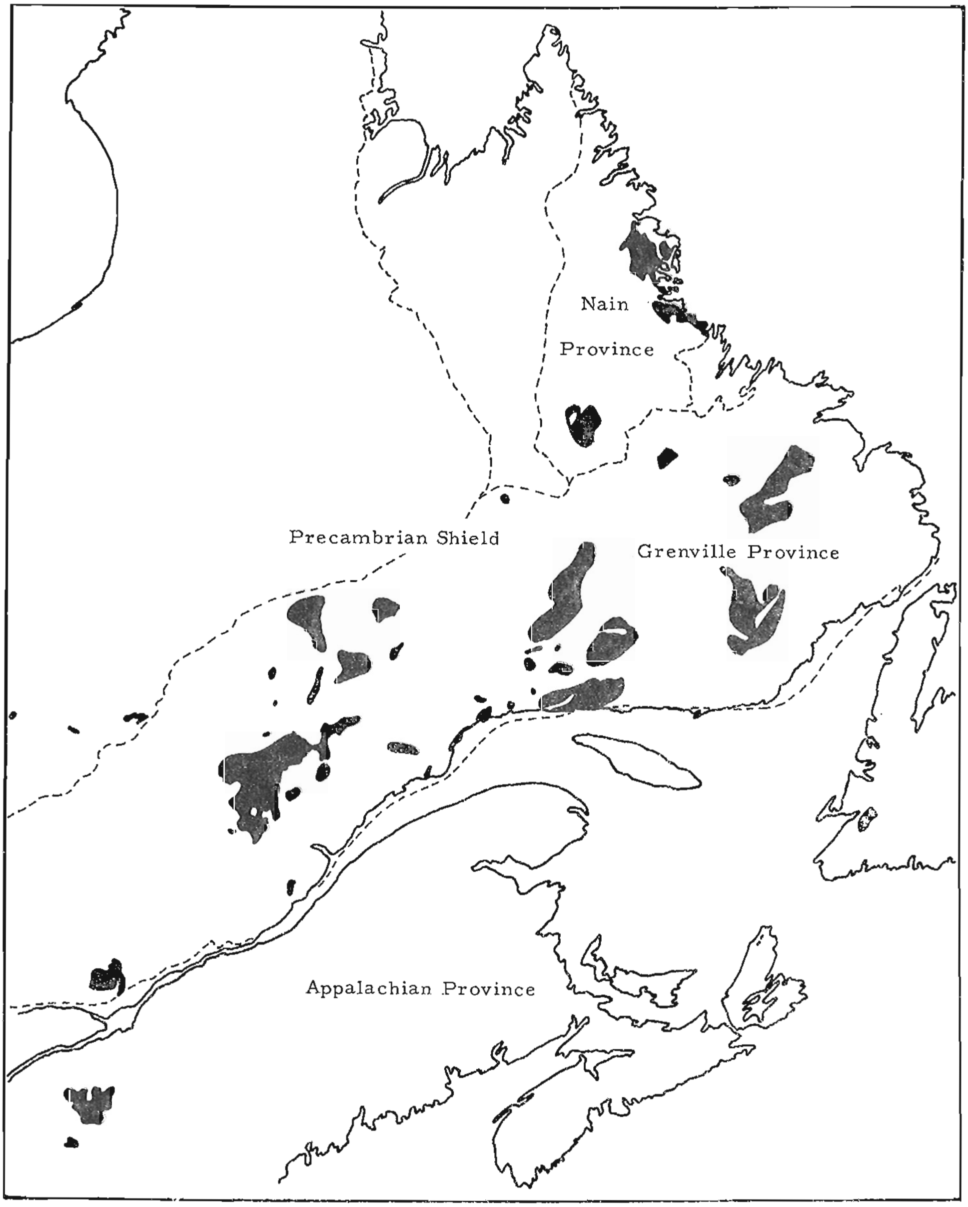

Figure 1. Distribution of anorthositic rocks in eastern Canada (after Stockwell, 1965).

THE ANORTHOSITE OF NORTHERN CAPE BRETON ISLAND, NOVA SCOTIA, A PETROLOGICAL ENIGMA

INTRODUCTION

For many years students of petrology have been taught that anorthosites occur mainly as layers in stratiform basic rock suites, such as the Bushveld or Stillwater complexes, or as large independent intrusions in Precambrian terranes. The best known example of the second type of anorthosite occurs in the Adirondacks of northern New York State, where they form the southernmost prong of the Precambrian Canadian Shield (Buddington, 1939). Other large anorthosite bodies are found north of the St. Lawrence River (Fig. 1) between the Adirondacks and Labrador (Kranck, 1961). Some of these are currently being investigated in detail by R.F. Emslie of the Geological Survey of Canada (Emslie, 1963, 1964, 1965a, b, 1966). Most of them lie near the southeasternmost part of the Precambrian Shield within the Grenville structural province, the youngest[1] part of the Precambrian Shield. The anorthosites are believed to have been intruded during the Elsonian orogeny, some 1,400 million years ago, and in most cases metamorphosed during the Grenville orogeny, approximately 900 million years ago (Stockwell, 1965). A few bodies of anorthosite lie within the adjoining western part of the Nain structural province; these also were intruded during the Elsonian orogeny (Stockwell, 1965), and hence are more or less the same age as the anorthosites in the Grenville structural province (Stockwell, 1964, p. 20).

It is therefore somewhat of a petrological enigma to find several small lensoid bodies of anorthosite in northern Cape Breton Island, Nova Scotia (Fig. 2) near the eastern margin of the Appalachian structural province. These anorthosite bodies, first recognized by Neale (1956), lie more than 300 miles southeast of the nearest anorthosite mass north of the St. Lawrence River (Fig. 1), and 150 miles southwest of the large anorthosite body near Bay St. George in western Newfoundland (Baird, 1954). The Newfoundland anorthosite, like the Cape Breton anorthosite, is within the Appalachian structural province, but has been found to be older than 900 ± 15 m.y. (Lowdon, *et al.*, 1963, p. 117) and is probably an outlier of the Grenville structural province.

This paper presents the first detailed description of the Cape Breton anorthosite, together with a discussion of its geological setting and

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[1] Potassium-argon ages for rocks in this province range from 560 to 1,270 m.y. (Stockwell, 1963, Fig. 2).

some of the geological problems it poses. A brief preliminary report on the anorthosite appeared early in 1966 (Jenness, 1966). The paper has evolved from brief visits by the writer to northern Cape Breton in 1963 and 1965, supplemented by the use of notebooks and rock specimens from Neale's earlier study. In all, the writer has studied 41 hand specimens and 25 thin sections of anorthosite and related rocks, and many specimens of gneissic and granitic rocks associated with the anorthosite. Plagioclase compositions given in this report were determined by the Michel-Lévy statistical method using maximum extinction angles on twinned sections normal to (010), as measured in thin section. Compositional values so obtained, though not exact, have an accuracy sufficient for the conclusions reached in this paper.

General geological mapping in the area has been done by Fletcher (1885) and Neale (1964). A few other geologists have studied local stratigraphic or structural aspects of the Carboniferous rocks in the region, but only Neale (1956, 1964) recognized the anorthosite, and his description of it is brief.

The writer wishes to acknowledge the kind cooperation of the personnel of the Parks Branch, Department of Northern Affairs and National Resources, particularly the Superintendents of Cape Breton National Park, M.J. McCarron in 1963 and H.B. Webb in 1965, during the time this study was made. He is also grateful to Dr. E.R.W. Neale for suggesting the study of the Cape Breton anorthosite, and for the use of his specimens, notebooks, field maps, and airphotographs.

LOCATION AND ACCESS

The anorthositic rocks occur in Pleasant Bay map-area (National Topographic Series 11 K/15) near the northwestern tip of Cape Breton Island (Fig. 2), where they outcrop near the summit of an upland surface known as the Cape Breton Highlands, between 550 and 1,400 feet above sea-level. The surrounding terrain is densely wooded, and steep-walled precipitous streams make travel difficult. Outcrops in this region are almost entirely restricted to the beds of streams. Without helicopter transportation, access to the anorthosite bodies is possible only from the highway (the Cabot Trail), which crosses the southern end of the anorthosite belt, or from the coast, which involves lengthy and slow traverses up the precipitous stream valleys. Most of the known outcrops of anorthosite lie near the heads of these valleys.

GEOLOGICAL SETTING

The anorthosite lenses in northern Cape Breton Island lie within a northeasterly trending band of metavolcanic rocks, parallel with and 1 1/4 to 5 miles west of the major steeply dipping Aspy fault. On both sides of the metavolcanic rocks are broad bands of paragneisses and micaceous schists, derived mainly from arenaceous and argillaceous sediments metamorphosed to the almandine-amphibolite grade. Alteration minerals in both the anorthosite and the enclosing metavolcanic rocks are characteristic of the greenschist metamorphic facies, and may reflect local retrograde metamorphism. The metasediments and metavolcanics have been invaded by an assortment of granitic rocks and in places are extensively granitized. The granitic activity probably continued over a considerable period of time, for potassium-argon and rubidium-strontium mineral and whole-rock age determinations on two of the granitic bodies indicate mid-Palaeozoic ages ranging from 422 to 276 million years (Fairbairn, et al., 1960, pp. 403, 409; Fairbairn, et al., 1964, p. 256). Fairbairn, et al. (1964, p. 254) suggested the oldest significant rubidium-strontium whole-rock isochron is 373 million years, which is about mid-Devonian time. Small diabasic dykes cut the anorthosite, granites, and metamorphic rocks. Around the northern coast are a few embayments of Carboniferous sediments, in part resting upon the granitic and metamorphic rocks, in part faulted against them. Such embayments occur commonly at lower elevations than the surrounding areas of crystalline rocks. The shattered and sheared aspect of the rocks that outcrop along the Cabot Trail between the Aspy fault and Pleasant Bay, and indeed elsewhere throughout much of northern Cape Breton, suggests that faults are much more plentiful than has yet been recognized.

THE ANORTHOSITE

DISTRIBUTION

Neale (1964) mapped the anorthositic rocks as two long narrow northeast-trending lenses and seven small satellite lenses (Fig. 2). All occur within an area some 15 miles long and 4 miles wide, and lie roughly parallel with and from 1 1/4 to 5 miles west of the Aspy fault. Closely associated with the anorthosite are dioritic phases, which contain more than 10 per cent hornblende (altered in varying degrees to chlorite), and in some outcrops show vague banding (Plate IA). Some of these dioritic rocks have been shown on Neale's map as meta-diorite.

The anorthosite is best exposed in the following places: (1) several small outcrops along the Cabot Trail; (2) in Red River; (3) in South Blair River; and (4) near the head of Grande Anse River. Elsewhere it appears only in isolated outcrops or small groups of outcrops, providing less than 1 per cent exposure, in stream beds between the head of Grande Anse River and one of the headwaters of Salmon River, some 15 miles to the northeast. In all only about 105 small outcrops of anorthosite have been recorded.

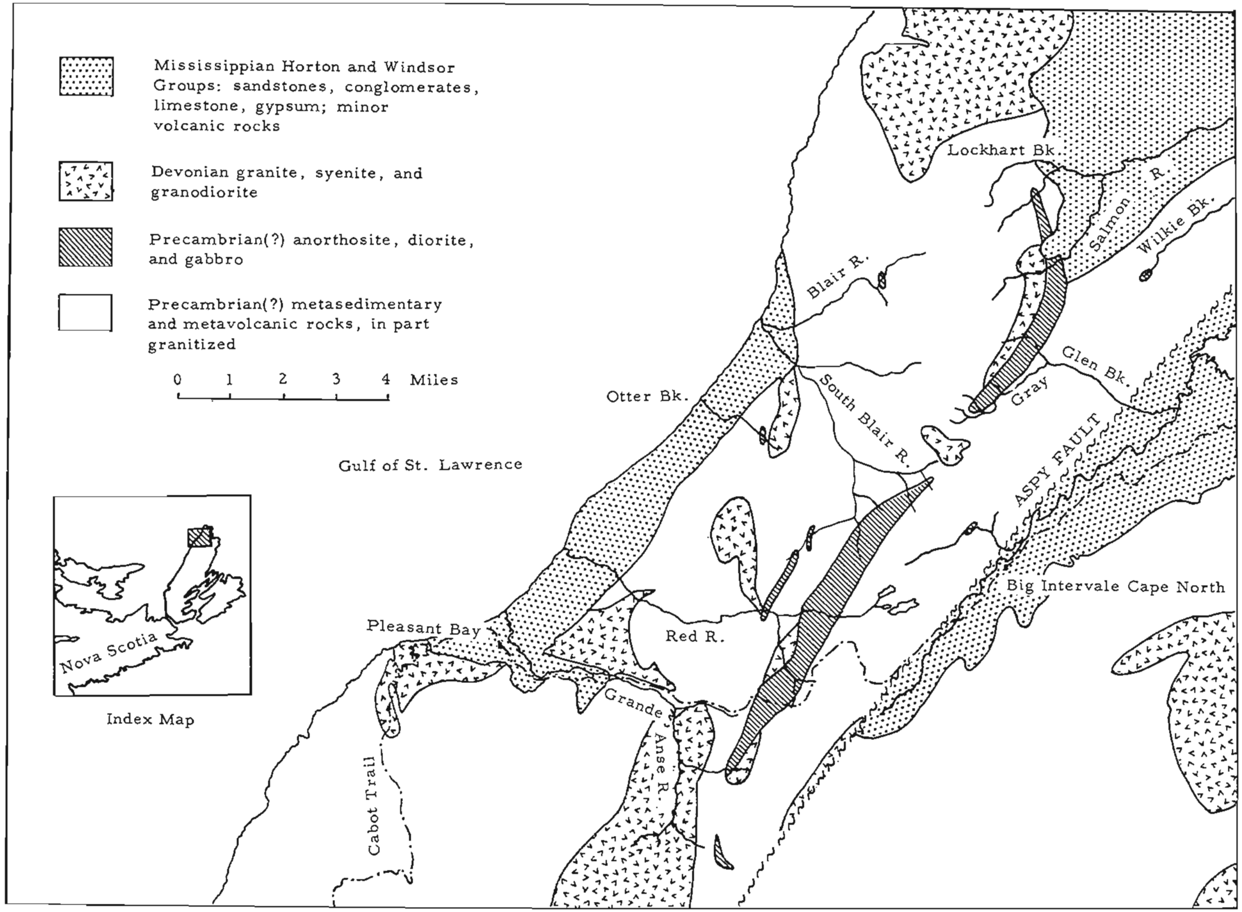

Figure 2. Geological map showing the distribution of anorthositic bodies in northern Cape Breton (simplified from G.S.C. Map 1119A by Neale, 1964).

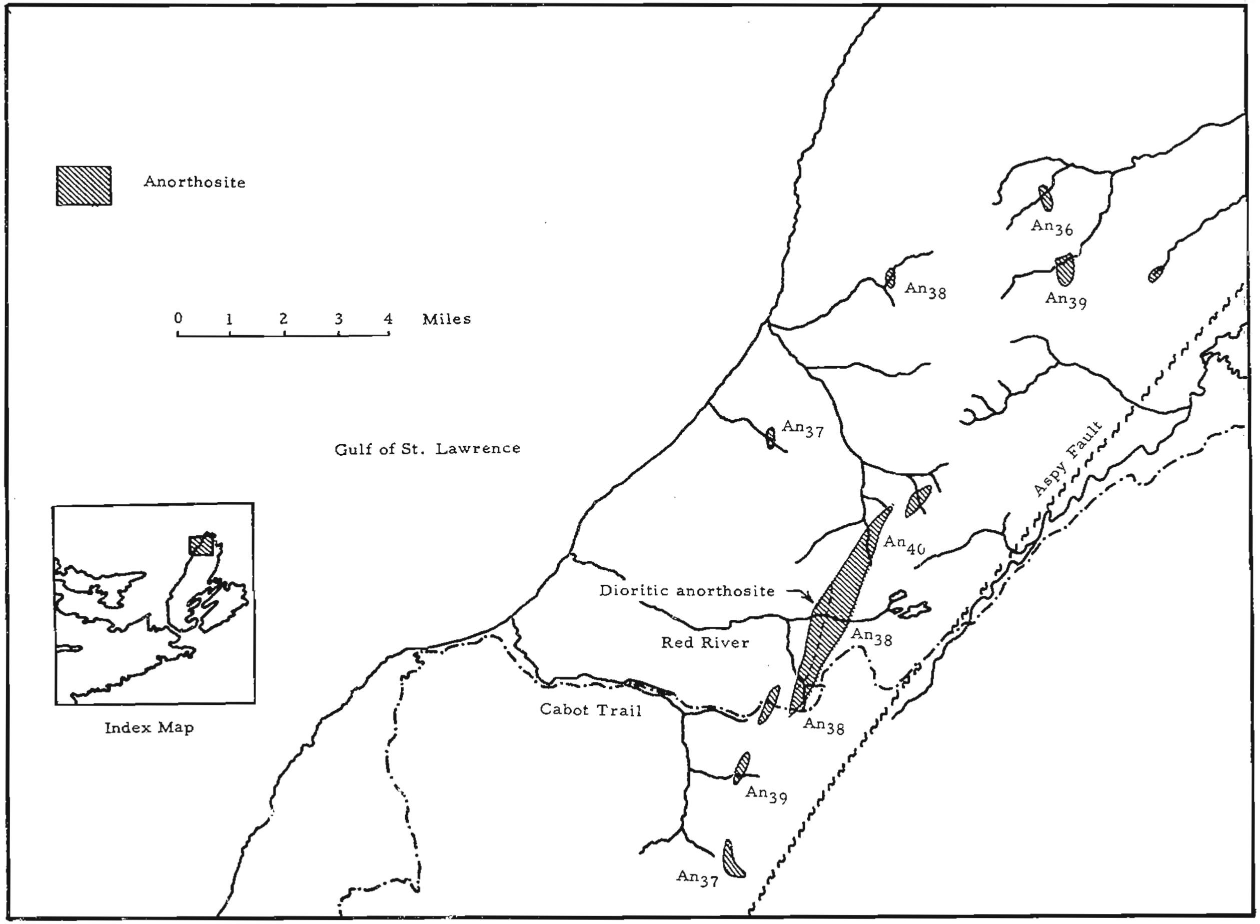

Figure 3. Sketch map showing suggested distribution of anorthosite and approximate compositions of plagioclase.

none of which exceeds 100 feet in length or width, obviously a meagre amount of field material with which to work. Furthermore the extent of overburden in this part of Cape Breton precludes the likelihood of any important new outcrop areas being found. The writer has found only six small outcrops not known to Neale, and they are on the Cabot Trail in roadcuts made since Neale was last in the area.

The scarcity of outcrops makes interpretation of the continuity of the anorthosite between some adjoining stream channels questionable. Neale (1964) joined the various outcrops into two elongate bodies and seven small lenses (see Fig. 2); the writer, taking a more conservative approach, suggests one elongate body and nine small lenses (Fig. 3).

The largest anorthosite body mapped by Neale (1964), which the writer for easy reference calls the Red River anorthosite body, trends northeasterly across the Cabot Trail from the headwaters of Grande Anse River to the headwaters of Blair River, a distance of 7 miles. Its width ranges from 1/8 to 3/4 mile. Neale and the writer have recorded some 68 anorthosite outcrops in this body, well over half the total number of anorthosite outcrops found to date in northern Cape Breton. Of these, 43 are in the headwaters of Red River. These outcrops, together with those along Cabot Trail, were examined by the writer.

PETROGRAPHY

The writer collected 21 anorthositic specimens from the headwaters of Red River and the Cabot Trail from which 14 thin sections were prepared. In addition, Neale's collections contained 6 specimens and 2 thin sections from the same area, as well as an additional 14 specimens and 9 thin sections from the other anorthosite outcrop areas. After studying these 41 anorthosite specimens and 25 thin sections, the writer has concluded that the Red River anorthosite body is typical and reasonably representative of all the Cape Breton anorthosite, and that petrographic descriptions of it are probably applicable in large part to the other anorthosite bodies.

The Red River Anorthosite Body

Outcrops in Red River and its Tributaries

The anorthosite exposed in and near the headwaters of Red River is generally medium grained (1-5 mm) and equigranular, and weathers white. In all outcrops examined it is somewhat altered; the less altered phases are pale bluish grey, pale grey, or greyish white on fresh surfaces, with visible crystal faces, whereas the more altered phases are generally whitish or pinkish, and individual crystal faces are not readily recognized. A relatively fresh looking pale bluish grey variety is exposed in a small outcrop on the north side of Cabot Trail between two small tributaries of Red River, whereas chalky white anorthosite outcrops just across the highway at the same locality (Plate IB).

Many outcrops are intensely fractured (Plates IB, IIA), and along the eastern flank of the Red River body in the east-trending branch of Red River, the anorthosite is visibly granulated and sheared. Outcrops farther west in the same stream are less fractured and only locally sheared.

Many outcrops contain several per cent or more of mafic mineral, chiefly chloritized hornblende. The alteration products are typically greenschist facies minerals of the epidote, clay, mica, and chlorite families. Patches of green mafic mineral are rare in the eastern outcrops along the east-trending branch of Red River, but become increasingly abundant to the west, where outcrops of anorthosite alternate with chloritic schists. Along the southwestern branch of Red River a similar gradation westward (or northwestward) occurs from relatively pure anorthosite, with little or no visible mafic mineral content, into a more mafic variety (dioritic anorthosite or anorthositic diorite), which contains 10 to 30 per cent hornblende in patches, broadly disseminated, or in fairly distinct layers or segregations (Plate IA). Layers of hornblende strike S75°E and dip 60°S in a stream bed outcrop near the highway, a few yards south of the junction of the two small tributaries of the southwestern branch of Red River. Outcrops along this branch are discontinuous, but the writer suggests that the anorthosite and the hornblende-enriched phase (shown as meta-diorite by Neale, 1964, and as dioritic anorthosite on Fig. 3 in the present report) are part of the same anorthositic body, because the two phases appear to be gradational and somewhat interspersed, and can be separated only in a general manner owing to the irregular distribution of the hornblende.

The only place where the hornblendic phase appears with regularity in successive outcrops is on the west side of the Red River body, in Red River and its southern tributary (Fig. 3). Elsewhere it is either absent or occurs with no apparent pattern in one or two outcrops associated with anorthosite. If the plagioclase composition were more calcic (labradorite or bytownite), this rock would be called gabbroic anorthosite, the name given to rocks with 10 to 22 1/2 per cent mafic minerals (Turner and Verhoogen, 1960, p. 322) commonly associated with anorthosites in the Grenville structural province. Gabbroic anorthosite, however, generally contains pyroxene rather than hornblende, in addition to the more calcic plagioclase, so that the term is not strictly applicable to the mafic phases just described.

As seen in thin section the anorthosite is granulated and altered to varying degrees. The plagioclase composition in 6 of the 15 thin sections of specimens from Red River and the Cabot Trail nearby is andesine (An_{36-39}); in the other nine sections alteration is too extensive for composition determination. Hornblende present in some of the thin sections, forms with apatite and an opaque mineral (probably magnetite), the primary minerals in the rock. Most hornblende is partly altered to pale green or colourless chlorite. Other alteration or introduced minerals in the anorthosite include epidote, clinozoisite, secondary mica, clay minerals, carbonate, and pyrite, all typically products of low-grade metamorphism. Table IV gives modal analyses of 4 hornblende-free specimens of anorthosite from the Red River body. Most hand specimens have a clayey smell when breathed upon, and the plagioclase is commonly liberally dusted with clayey alteration minerals.

Outcrops along the eastern margin of the anorthosite in Red River are granulated, and fractures and shear phenomena are apparent in many other outcrops. It seems probable, therefore, that faults are present both along the eastern margin and within the anorthosite body in this region. Such structures may account in part for the mixture of rock types from outcrop to outcrop in Red River. The existence of several small faults would not be surprising in this region, however, for it is only 1 1/2 miles from the major northeast-trending Aspy fault.

Outcrops in South Blair River

At least 16 outcrops of anorthosite are present near the sources of four small tributary streams of South Blair River, and lie between 1 1/2 and 2 3/4 miles northeast of the outcrops of anorthosite in Red River. Of these 16, 13 occur in the southernmost of the four streams. The outcrops are near the northern end of the Red River anorthosite body (Fig. 2). Although the writer has not seen them, he has determined from Neale's (unpublished) field notes, maps, airphotos, and four hand specimens, that the anorthosite resembles that in Red River and on the Cabot Trail. They range from sheared to unsheared, from altered chalky white to relatively fresh pinkish or pale bluish grey, and from leucocratic phases with little mafic mineral content to varieties carrying from 10 to 20 per cent hornblende. White, chloritized varieties are apparently the most abundant. The four specimens were too altered to secondary clay minerals to permit determinations of the plagioclase composition. Alteration minerals are similar to those in Red River outcrops—secondary mica, chlorite, clinozoisite, and carbonate.

Other Anorthosite Bodies

The presence of volcanic rocks in new roadcuts on the Cabot Trail in the area shown by Neale (1964) as anorthosite suggests that the southern end of the Red River anorthosite body lenses out near the old section of the highway. This would mean that outcrops of anorthosite farther west along the highway and also farther south are two separate lenses, and that the Red River body is considerably smaller than shown by Neale (see Fig. 3). The present study of specimens and field notes pertaining to eight other lenses shown on Neale's (1964) map as anorthosite or related gabbroic rocks has indicated that only three are in fact anorthosite. One important exposure is described below and a summary of data on the others is given in Table 1.

Anorthosite Contact on the Cabot Trail

As far as the writer is aware, the only easily accessible exposed contact between anorthosite and the adjoining rocks is located on the Cabot Trail, where the steep descent westward to Pleasant Bay begins. Both the anorthosite and adjoining volcanic rocks at this locality are intensely fractured (Plate IIA), making it difficult to interpret the exact nature of the contact. From field relationships and examination of three thin sections, however, the writer has interpreted it as a nearly vertical fault zone, about 30 feet wide, and trending north-northwest. A comparatively massive andesite, about 25 feet thick, adjoins the fault zone on the west side, and is in turn succeeded westward by a succession of chloritic volcanic rocks with variable amounts of pink feldspar. Most of the rocks exposed along the Cabot Trail for another mile towards Pleasant Bay are intensely fractured chloritic volcanic rocks.

The anorthosite in this contact exposure is pale greyish white weathering, resembling the exposures about a mile eastward alongside the highway. A specimen from the more massive part of the outcrop (about the position of the figure on Plate IIB) is considerably fractured and veined, and the feldspar is intensely altered to a dusty brownish matte of clay minerals, iron oxide, epidote, secondary mica flakes and veinlets, and veinlets of almost colourless chlorite. A specimen from the crushed zone (just left of the figure on Plate IIB) is highly brecciated, with shattered brownish dusty feldspar fragments in a matrix of finely ground plagioclase and its alteration products. Because of the extent of brecciation and alteration, compositions of the plagioclase could not be determined.

This anorthosite is shown on Figure 3 as a lens separated from the main Red River body for three reasons: (1) two small outcrops of basic volcanic rocks occur on the Cabot Trail between this anorthosite and that in the southeastern tributary of Red River; (2) the degree of shattering near the

TABLE I

DATA ON SOME ANORTHOSITE OCCURRENCES, NORTHERN CAPE BRETON ISLAND

Location	No. outcrops	Colour	Comp. Plag.	Remarks
1. Near head of Grande Anse River	3	Greenish white	An_{39}	Much fractured, altered to chlorite, epidote, clay minerals; associated with volcanics (trachytic tuff?), minor grey fine-crystalline limestone, and small diabase dykes.
2. 1 1/2 miles southwest of Red River anorthosite body	5	Chalky white	An_{37}	Altered to clay minerals, secondary mica, and epidote similar to alteration of Red River anorthosite body; associated with sheared injection gneiss.
3. Lockhart Brook	3	Light grey	An_{36}	Intensely fractured and sheared; altered to clay minerals, secondary mica, epidote, chlorite, minor carbonate; flanked by northerly striking gneissic rocks.
4. Salmon Brook	5	Pale greenish pink	An_{39}	Altered to dusty brownish clay minerals, epidote, chlorite, and carbonate; anorthosite outcrops alternate with outcrops of gneiss and hornblende schist, which have northwesterly foliations and are overlain by Carboniferous sediments.
5. Otter Brook, 1 1/2 miles above mouth	1	Pinkish buff	An_{37}	Much altered to dusty brownish clay minerals and aggregates of epidote; minor veinlets and grains of carbonate; nearest outcrops about 200 feet distant are gneissic biotite and hornblende-rich rocks locally feldspathized.
6. Blair River, 2 miles from coast	1	Pale greenish grey	An_{38}	Crushed plagioclase veined by epidote and clay minerals; adjacent outcrops are schistose chloritic and feldspathic (volcanic?) rocks.

contact suggests local structural control; and (3) the anorthosite at the contact and in several small exposures in the drainage ditches on both sides of the highway a few yards uphill (to the east) contains little mafic mineral, thus resembling the anorthosite on the east side of the Red River body rather than the dioritic anorthosite on the west side. If the larger body is partly differentiated, as is suggested on its western side by the abundance of ferromagnesian mineral and by the dip of the poorly defined layering in some outcrops, then the anorthosite by the contact on the highway is akin to the eastern (upper?) side of the Red River body, and hence is structurally out of position as now exposed. This third reason is necessarily a very tenuous interpretation, owing to the meagreness of exposed field relationships, but it does not appear unreasonable.

Reinterpretation of Rocks Formerly Considered Related to the Anorthosite

Neale's 1964 map shows five small lenses of metamorphosed basic rocks as part of the same map-unit as the anorthosite (see also Fig. 2). The writer's examination of Neale's specimens from these five small lenses has led him to conclude that most are chloritic or amphibolitic rocks, and that none are anorthosites. A summary of known petrographic data is shown in Table II.

Neale (1964) has shown a lens of 'syenite' along the northwest flank of the dioritic anorthosite in the tributary of Red River. The rocks there exposed, however, consist mainly of variable amounts of pink feldspar grains (1-4 mm) in a fine-grained chloritic matrix. The writer observed vague colour banding in three outcrops and an absence of pink feldspar in others. One outcrop consisted of fine-grained quartz, white feldspar, and biotite, and appeared to be a metasediment or metamorphosed tuff. The writer therefore believes that the 'syenite' along this stream is actually feldspathized metavolcanic and metasedimentary rocks, the metavolcanic rocks being dominant. If this interpretation is correct no relationship exists between the 'syenite' and the anorthosite, as one might have otherwise suspected.

CHEMICAL AND MODAL ANALYSES

Table III presents analyses of anorthosites from Cape Breton (Nos. 1-4), the Morin anorthosite, Quebec (Nos. 5-8), an average of four analyses of Marcy-type anorthosite from northern New York (No. 9), and three analyses from the large Michikamau intrusion in Labrador (Nos. 10-12). With the exception of No. 9, these constitute most of the analyses on Canadian anorthosites made by the Geological Survey of Canada and by the Quebec Department of Mines. Analyses 1 to 4 were made for the writer in

TABLE II

DATA ON SOME NON-ANORTHOSITIC ROCKS, NORTHERN CAPE BRETON ISLAND

Location	No. outcrops	Shown on Neale's 1964 Map as:	Remarks
1. Three headwater tributaries of Gray Glen Brook	10 plus	anorthosite and meta-diorite	Seven specimens from these streams are granitic rocks and chloritic and amphibolitic metamorphic rocks, with varying amounts of pink feldspar, probably feldspathized meta-volcanic and metasedimentary rocks. No anorthosite.
2. Head of Wilkie Brook	2	anorthosite	Outcrops contain blebs and stringers of potassium feldspar and are associated with chloritic and granitic rocks. May be felds-pathized acidic volcanic rocks. No anorthosite.
3. 1 mile north-west of Big Intervale Cape North	2	meta-diorite	On basis of two specimens, interpreted as gneisses injected by granitic dykes; not related to anorthosite or dioritic anorthosite.
4. Outcrops 1 mile west of Red River anorthosite body	8 plus	meta-gabbro	On basis of two specimens, interpreted as chloritized amphibolites, probably of sedimentary origin; not related to anorthosite.

1964 in the Analytical Chemistry Laboratories of the Geological Survey of Canada by a combination of X-ray fluorescence and rapid chemical methods. Na_2O, P_2O_5, H_2O, CO_2, and FeO were determined chemically; total Fe and all other oxides were determined by X-ray fluorescence; Fe_2O_3 was calculated by difference from total Fe and FeO. Analyses numbers 5 and 10 to 12 were prepared in the same manner in the same laboratories for E.R. Rose and R.F. Emslie, respectively. Analyses 6 to 9 are from Faessler (1962) and Buddington (1939).

Analyses 1 to 4 (Table III) are of anorthosite samples from the Red River body near the Cabot Trail. Two analyses (2, 3) are on partly altered anorthosite, the other two (1, 4) are on much altered anorthosite.

A perusal of the analyses in Table III reveals several similarities between the Cape Breton data and those for the Morin, Adirondack, and Michikamau anorthosites, but also several significant differences. Similar, for example, are the silica, alumina, manganese oxide, and possibly ferric iron content, but notably different are the ferrous iron, magnesia, soda, and potash contents, and lime is appreciably lower than that in analyses 6 to 9 and 10 to 12, though similar to analysis 5 from Ste. Agathe. The lower iron and magnesia contents of the Cape Breton anorthosites may simply reflect a lower ferromagnesian mineral content of the samples analyzed, and perhaps also less FeO entrapped in the plagioclase. The lower CaO content coupled with the higher Na_2O and K_2O contents in analyses 1 to 4 can be attributed to the composition of the plagioclase, which is sodic andesine, whereas the plagioclase is labradorite in the Morin and Michikamau anorthosites and calcic andesine in the Marcy anorthosite. It is somewhat curious that the most altered sample of anorthosite from Cape Breton (No. 4) has the lowest potash content, and that this is similar to the potash content in the fresh Morin anorthosite. Were it not for this similarity the writer would probably have suggested that the potash in analysis No. 4 had been leached by weathering or alteration. It is also possible that the lower percentage K_2O in analysis 4 as compared with analyses 1 to 3 is not geologically significant. This same sample also has the lowest Fe_2O_3 content of the four Cape Breton samples.

It is probably not practical to compare chemical compositions of sodic andesine anorthosite in small lenses, such as the anorthositic bodies in Cape Breton, with those of more calcic anorthosite in large batholithic masses, such as the Morin, Michikamau, or Adirondack anorthosites, but the scarcity of similar small lens-like bodies of anorthosite in Eastern Canada, coupled with the scarcity of analyses of anorthosites in general, prevents comparisons with anorthosites more closely resembling the curious Cape Breton bodies. Possibly the much altered white andesine anorthosite at Lac Chibougamau, 300 miles north of Montreal (Graham, 1956) bears the closest resemblance to the Cape Breton anorthosite. However, to the

TABLE III

CHEMICAL ANALYSES* OF ANORTHOSITES

	Cape Breton Anorthosite				Morin Anorthosite				Average Adirondack Anorthosite	Michikamau Anorthosite		
	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	52.9	53.9	55.0	53.1	53.9	55.00	55.25	53.65	54.54	51.9	53.6	52.2
Al_2O_3	26.0	26.7	25.5	25.9	23.3	23.08	25.05	27.18	25.61	25.6	24.5	23.2
Fe_2O_3	1.8	1.1	1.2	0.7	1.2	1.28	0.49	0.33	1.00	0.6	1.4	0.2
FeO	0.4	0.1	0.1	0.2	3.0	2.71	2.24	1.44	1.26	0.9	2.0	3.2
CaO	8.8	7.5	6.1	7.6	6.7	10.64	10.23	11.27	9.92	9.2	9.0	9.5
MgO	< 0.5	< 0.5	< 0.5	0.7	3.7	2.14	1.36	0.51	1.03	0.7	< 0.5	3.9
Na_2O	5.7	6.0	6.5	6.2	4.5	3.39	3.87	3.83	4.58	5.5	5.4	3.9
K_2O	1.4	1.2	1.7	0.6	0.6	0.46	0.58	0.68	1.01	0.7	0.5	0.3
H_2O +)							0.65	0.75)				
)	1.1	0.9	0.8	1.2	0.66	0.90		)	0.55	0.9	0.4	0.3
H_2O -)							0.25	0.20)				
CO_2	0.4	0.1	0.1	0.1	0.54	nil	tr	nil	--		not determined	
TiO_2	0.14	0.09	0.15	0.06	1.1	0.21	0.16	0.08	0.67	0.1	1.2	0.2
MnO	0.01	< 0.01	< 0.01	< 0.01	0.01	tr	tr	--	--	< 0.01	0.04	0.08
P_2O_5	0.06	0.07	0.04	0.06	0.09	tr	tr	--	--	0.03	0.03	0.03
S		not determined				--	--	--	--		not determined	

% An**	40	37	38	38	50	50?	50?	?	35-52	52-55
S.G.					2.9					

* Analyses 1-5, and 10-12 are rapid X-ray fluorescence and chemical analyses by the Analytical Chemistry Section, Geological Survey of Canada.
** Determined petrographically.

1. Lab. analysis 1111-64; altered whitish anorthosite, near eastern margin of body, Red River, northern Cape Breton.
2. Lab. analysis 1112-64; slightly altered anorthosite, light pink, Red River, few yards west of analysis 1, northern Cape Breton.
3. Lab. analysis 1113-64; slightly altered bluish white anorthosite, outcrop on north side of Cabot Trail, northern Cape Breton.
4. Lab. analysis 1114-64; much altered chalky white anorthosite, outcrop on south side of Cabot Trail, northern Cape Breton.
5. Spec. RG-60-8; fresh dark brown Morin anorthosite, Ste. Agathe, Quebec (from E.R.Rose, in press, Table VIII).
6. Analysis 212, in Faessler (1962). Morin anorthosite, Ashton facies.
7. Analysis 217, in Faessler (1962). Morin anorthosite, Chertsey facies, mylonite.
8. Analysis 223, in Faessler (1962). White Morin anorthosite, from near New Glasgow.
9. Average of 4 analyses, Marcy type anorthosite, core of Adirondack massif (Buddington, 1939, p. 30).
10. Spec. EC-62-134, in Emslie (1965b); anorthosite, Michikamau intrusion.
11. Spec. EC-62-34, in Emslie (1965b); anorthosite, Michikamau intrusion.
12. Spec. EC-62-52, in Emslie (1965b); leuconorite, Michikamau intrusion.

writer's knowledge, no chemical analyses of it have ever been made. The grey to white andesine anorthosite in the St. Urbain area (Mawdsley, 1927) has plagioclase in the An_{30-40} compositional range, but differs from the Cape Breton anorthosite in that it contains an appreciable amount of orthoclase intergrown with the plagioclase and its ferromagnesian mineral is hypersthene. Mawdsley includes chemical analysis of the plagioclase but not of the anorthosite, thus no direct analytical comparison can be made with the Cape Breton anorthosite.

Table IV shows the results of point-counter analyses of the thin sections cut from the same specimens as provided chemical analyses 1 to 4 on Table III. The analyses are based on 2,400 to 2,500 mineral counts per slide and give a reasonable indication of the percentages of each mineral. Specimens 2 and 3 verify that these rocks are properly termed anorthosites (more than 90 per cent plagioclase). Specimens 1 and 4 show the effects of extensive alteration, with lower plagioclase values and higher epidote and mica or chlorite contents than the less altered samples. These analyses also support the writer's field impressions that the pale bluish anorthosite (specimen 3) is the least altered variety in northern Cape Breton.

TABLE IV

MODAL ANALYSES OF CAPE BRETON ANORTHOSITE

	1	2	3	4
Plagioclase	79.0	90.5	93.5	61.5
Secondary mica (sericite)	5.4	1.8	1.5	1.9
Epidote (incl. clinozoisite)	14.4	6.1	3.1	21.4
Chlorite	0.2	0.2	0.5	14.7
Opaque	0.5	0.8	1.1	0.3
Carbonate	0.3	0.1	0.2	-
Apatite	0.2	0.5	0.1	-
Quartz(?)	-	-	-	0.2
	100 %	100 %	100 %	100 %
	2435 - counts	2424 - counts	2508 - counts	2473 - counts

1. altered whitish anorthosite, Red River (analysis 1, Table I)
2. light pink anorthosite, Red River (analysis 2, Table I)
3. bluish white anorthosite, Cabot Trail (analysis 3, Table I)
4. chalky greyish white anorthosite, Cabot Trail (analysis 4, Table I)

DISCUSSION

The writer was originally sceptical about the existence of anorthosite in this eastern part of the Appalachian mountain system. He is now convinced that several small bodies of anorthosite and dioritic anorthosite are in fact present, but their presence creates several new problems, for which there are as yet no apparent answers, or for which only partial answers can be found. The main problems are as follows:

1. What is the origin of the anorthosite?
2. What is its age?
3. Where are the gabbroic and syenitic rocks that generally accompany anorthosites?
4. When and how was the anorthosite altered?
5. What is the significance of the relatively high soda and potash contents?
6. What connection exists, if any, between the location of the anorthosite and the Aspy fault?
7. What significance can be attached to the presence of anorthosite in northern Cape Breton Island?

By discussing briefly some of these problems, the writer hopes to stimulate others to seek and find the answers that have eluded him.

ORIGIN OF THE ANORTHOSITE

Over the past several decades it has become generally accepted that anorthosites are differentiates of basic magmas. Some may well originate from liquid gabbroic anorthosite magmas, as was suggested by Buddington (1939) for the Adirondack anorthosite; others, however, appear to have been derived from basaltic magma, a derivation indicated by compositional trends and structural phenomena with related more salic rocks. Emslie (1965b) favoured basaltic magma as the parent of the large Michikamau anorthosite in central Labrador, and considered it typical of the major anorthosite plutons in Eastern Canada. Such bodies generally have syenitic rocks associated with them, rocks long regarded as late magmatic differentiates of the anorthosites. The Cape Breton anorthosite is dissimilar to the typical Eastern Canadian anorthosites, however, in size, composition, and associated rock types, for it apparently occurs in small isolated bodies, somewhat like the small alpine-type ultrabasic bodies in the Appalachians, is more sodic, has no gabbroic phase accompanying it, and has no apparently true syenite or other similarly salic granitoid differentiate associated with it. The syenite shown on Neale's (1964) geological map to adjoin the anorthosite in several places is now interpreted as feldspathized volcanic rocks and, hence, is unrelated to the anorthosite.

Field evidence in Cape Breton offers only a little data that can be used in resolving the problem of origin of these peculiar small bodies. These data are as follows: (1) the lenses are mainly anorthosite, with only minor amounts of dioritic anorthosite; (2) the plagioclase composition seems to fall consistently between An_{35} and An_{40}, and shows no recognizable variation pattern (Fig. 3); (3) the type of low-grade metamorphic alteration displayed by the anorthosite is similar in all outcrops sampled, though the extent of alteration shows considerable variation; (4) most outcrops are intensely fractured, and some show indications of granulation; (5) the enclosing rocks are probably mainly volcanics, of intermediate to basic composition, in places considerably feldspathized, with much epidote and chlorite; these rocks are considered retrograde metamorphic products from a regional amphibolite metamorphic grade. Regional metamorphism in northern Cape Breton locally produced rocks of the staurolite-almandine subfacies of the almandine-amphibolite facies, but is too low grade to have permitted the development of the anorthosite from a sedimentary rock, by recrystallization or some other metamorphic process, a process invoked to explain the formation of anorthosite in Boehls Butte quadrangle, Idaho (Hietenan, 1963). Furthermore, the irregular distribution and composition of the anorthosite within metamorphosed basic volcanic rocks do not support any suggestion of metamorphism from an argillaceous limestone or similar sedimentary rock, or from some volcanic rock type within the enclosing band of basic volcanic rocks. No definite origin can be suggested, but the writer favours injection along zones of structural weakness of a partly crystalline, partly hydrous melt. Contact chilling would not be expected because the surrounding rocks have apparently undergone retrograde metamorphism, which would probably erase any positive evidence of thermal metamorphism; furthermore the anorthosite is much too fractured in the one exposed contact to permit recognition of a chilled border facies were it present.

If the anorthosite is of magmatic origin, why is there so little evidence of differentiation, and where are the generally associated and related basic and more salic rocks? No basic intrusive rocks (other than small dykes) outcrop within 11 miles of the anorthosite, according to current (1966) geological maps, and aeromagnetic data reveal no recognizable body of basic to intermediate intrusive rocks within 13 miles of the anorthosite in the northern part of the island. Several small syenitic bodies lie within a few miles of the anorthositic bodies, but all appear to be heterogeneous complexes of chloritic and hornblendic rocks with granitic gneisses and are more likely feldspathized or granitized phases of the metavolcanic or metasedimentary basement rocks than magmatic differentiates related to the anorthosite. It does not appear, therefore, that any sizeable differentiated basic or salic bodies related to the anorthosite are present within northern Cape Breton.

AGE OF THE ANORTHOSITE

The age of the Cape Breton anorthosite poses an interesting problem. Because all other anorthosites in Eastern Canada, with the possible exception of some Lower Palaeozoic anorthositic gabbro at St. Stephen, New Brunswick (Chamberlain, 1965; McCartney, 1965), are of Middle to Late Proterozoic age, it is natural to suspect the Cape Breton anorthosite to be the same age. But does this necessarily follow, for the latter anorthosite is quite unlike the anorthosites north of the St. Lawrence River or in Newfoundland?

The anorthosite in Cape Breton contains no suitable isotopic minerals for age determination analysis, and its age cannot yet be determined reliably from any relations with adjoining rocks, for in its only known contact, the anorthosite is faulted against volcanic rocks, the age of which is not known. Only the nearby granitic rocks have been dated, and they yield potassium-argon and strontium-rubidium ages ranging from 276 to 422 million years (Fairbairn et al., 1960, 1964). The writer regards the anorthosite as older than the granitic rocks, and also suspects that the regional metamorphism of the sediments and volcanics associated with the anorthosite occurred at the time of formation of the granitic rocks, though an older metamorphism is possible. Contact relations and isotopic dating at present offer little hope for determining the age of the anorthosite, other than indicating a probable age older than 422 million years.

A clue to the age of the anorthosite may be obtained if the age of the enclosing volcanic rocks can be established. Volcanic rocks elsewhere on Cape Breton Island are restricted to Precambrian, Cambrian, and Mississippian strata. The Precambrian and Cambrian volcanics occur in the southeastern part of the island (Weeks, 1954) and the Mississippian volcanics in the Lake Ainslie-Margaree River area on the west side of the island (Kelley and Mackasey, 1965). Volcanic rocks below the base of the Mississippian Horton Group in Pleasant Bay map-area are also probably Mississippian. These are rhyolitic rocks associated with red clastic sediments or occurring as small dykes cutting the country rocks inland from the areas of Mississippian rocks, and are certainly much younger than the metamorphosed volcanics associated with the anorthosite. Cambrian volcanic rocks and their accompanying clastic sediments of the Bourinot Group in southeastern Cape Breton are virtually unmetamorphosed and contain no carbonate members, and so seem unlikely candidates for correlation with the metavolcanics and metasediments in northern Cape Breton.

Elimination of Mississippian and Cambrian volcanic sequences for correlation purposes leaves only the Precambrian volcanics, and though the evidence is certainly inconclusive, correlation of the metavolcanics and metasediments associated with the anorthosite in northern Cape Breton with the volcanic-bearing Precambrian George River Group in southeastern Cape Breton is certainly possible. Both consist of regionally metamorphosed argillaceous and arenaceous sediments with limestone and volcanic rocks, now forming paragneisses, crystalline limestone, and chloritic rocks. The presence of an abundance of crystalline limestone in southern Cape Breton has in the past suggested correlation of these strata with those in the Grenville structural province. Only a few outcrops of crystalline limestone have been found in northern Cape Breton, but these resemble those in the George River Group rather than the black cone-in-cone-structured limestone of the Upper Cambrian of southern Cape Breton.

The foregoing tenuous lines of evidence thus suggest a Precambrian age for the metamorphic rocks enclosing the anorthosite in the Pleasant Bay area, possibly comparable to the Proterozoic age of similar rocks in the Grenville structural province. The anorthosite may also be interpreted as Proterozoic, similar to the anorthosites in the Grenville structural province, but such a suggestion is really not much more than a calculated guess, and the age of the anorthosite must still be regarded as an unsolved problem.

CONCLUDING REMARKS

The only known contact of the anorthosite with the surrounding rocks is a probable fault zone. Similarly shattered anorthosite has been seen in several other outcrops, suggesting the presence of other as yet unrecognized faults amongst the anorthosite outcrops. This possibility is further strengthened by the nearby presence of the major Aspy fault, which forms a scarp front for more than 25 miles along the northeastern side of Cape Breton, and the exposures of several small offshoot faults along Cabot Trail immediately west of the scarp face. The degree of rock shattering in most exposures of basement rocks in northern Cape Breton further attests to the probability of extensive faulting. It is not difficult therefore to suspect that the present distribution of anorthosite lenses in northern Cape Breton may be the result of a complex of vertical or near-vertical faults, of which the Aspy is the major one, producing many small isolated slices from what may have once been a more extensive anorthositic body at depth.

The anorthosite may occur as sills along lines of structural weakness that developed early in the tectonic history of the region in association with an ancestral Aspy fault, preceding the intrusion of the granites. The present erosion level appears to have left the gneisses, schists, and anorthosite as a capping above the main granite mass.

Alteration of the anorthosite is characteristic of rocks in the greenschist facies and is comparable to that in the surrounding rocks. Some outcrops are almost totally altered, others are relatively unaltered, but there seems to be no pattern for the distribution of the alteration, other than that the more severely shattered outcrops are more extensively altered. This suggests that alteration followed emplacement, which could mean that the alteration occurred during early to middle Palaeozoic times, perhaps when the granitic rocks were emplaced, at which time a general soaking of the country rocks by water, potash, and silica may have been responsible for the extensive feldspathization of many of the country rocks. To the writer's knowledge, no potash feldspar has been produced in the anorthosite.

The anorthosite in Cape Breton seems to be a petrological enigma, occurring as it does within the Appalachian structural province, tens of miles from the nearest Grenville outlier. Although it resembles anorthosites in the Grenville structural province in some mineralogical and petrographic aspects, it differs from them sufficiently to suggest that it may have had a different origin and tectonic history. In brief, the Cape Breton anorthosite may well be a curious breed all its own.

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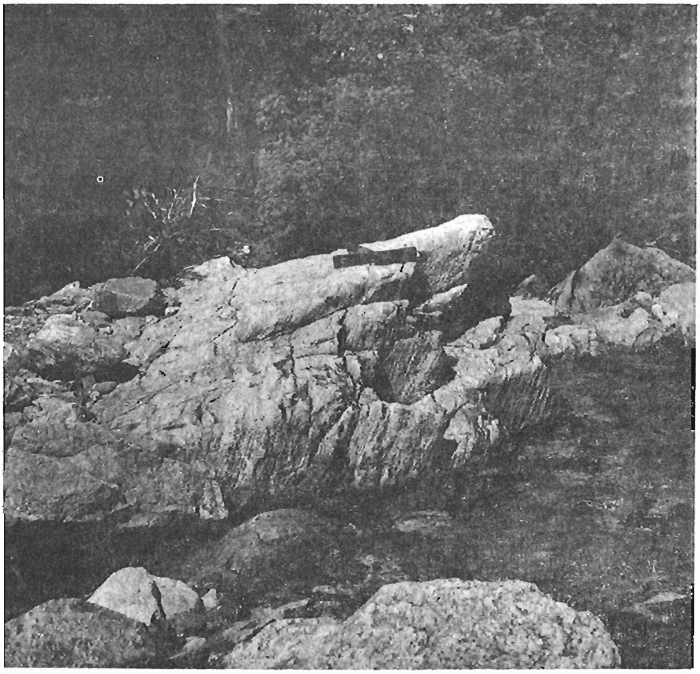

Plate 1 A.

Banding in dioritic anorthosite, caused by segregation of amphibole. Tributary to Red River, 5 3/4 miles east of Pleasant Bay post office. (S.E.J. 1-3-65)

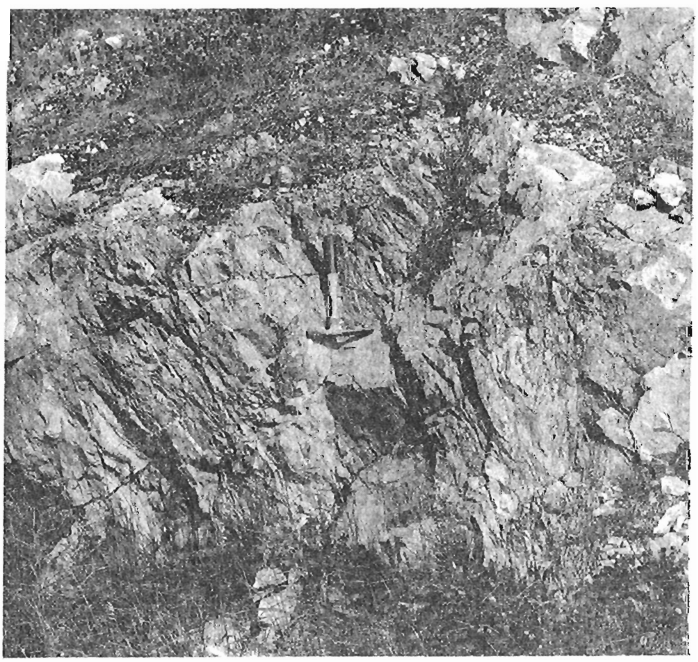

Plate 1 B.

Closely fractured, chalky greyish white anorthosite on south side of Cabot Trail, 5 3/4 miles east of Pleasant Bay post office. (S.E.J. 2-9-63)

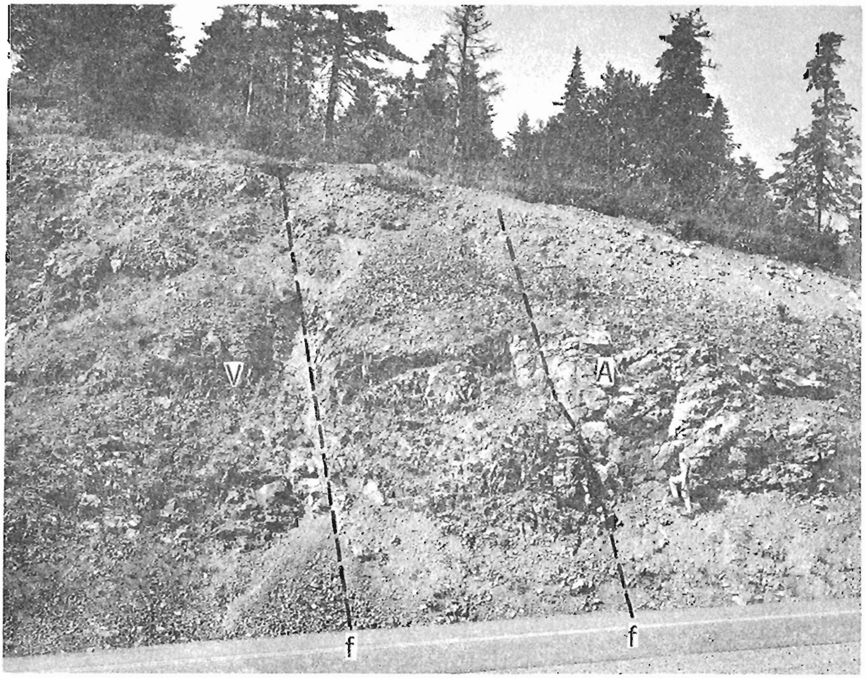

Plate II A.

Contact between anorthosite (A) and volcanic rocks (V), showing brecciated zone of anorthosite between two probable faults, and the unstable talus slope. North side of Cabot Trail, 5 miles east of Pleasant Bay post office. (S.E.J. 1-1-65)

Plate II B.

Detail view of right half of Plate II A, showing brecciated anorthosite in fault zone (left half of picture) in contact with more massive anorthosite. (S.E.J. 1-2-65)