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Objekttyp: **Article**

Zeitschrift: **Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie**

Band (Jahr): **70 (1990)**

Heft 2

PDF erstellt am: **14.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-53613

SCHWEIZ. MINERAL. PETROGR. MITT. 70, 199–208, 1990

Dioritic rocks in the Nain complex, Labrador

by *R.A. Wiebe*[1]

Abstract

The Nain complex of Labrador is a typical Proterozoic complex that is dominated by large plutons of massif-type anorthosite and granite. Subordinate, Fe-rich dioritic rocks occur widely in association with the anorthosites as relatively small intrusions ranging from well-layered bodies to massive pods and dikes. Many of the occurrences of the dioritic rocks show abundant evidence for commingling and hybridization with contemporaneous granitic rocks. The compositions of dioritic liquids are well preserved in strongly chilled dioritic pilllows. The field relations, mineralogy, and chemistry of the Nain diorites strongly suggest that they are comagmatic with the anorthosites – that they crystallized from fractionated Fe-rich magmas that evolved from the mantle-derived magmas that produced the dominant anorthosites. Both anorthosites and diorites appear to have been variably affected by crustal contamination.

Keywords: Nain complex, dioritic rocks, anorthosites, magmatic differentiation, crustal contamination.

Introduction

The Nain anorthosite complex lies along the central coast of Labrador and covers an area of approximately 15,000 km^2. It is composed of large volumes of anorthositic and granitic rocks with greatly subordinate mafic rocks including troctolites, norites, gabbros and Fe-rich dioritic rocks. These plutons were emplaced into metamorphosed basement rocks of Archean and early Proterozoic ages at depths of roughly 8 to 15 km (Berg, 1977, 1979). Recent age determinations (e.g. DePaolo, 1985; Simmons et al., 1986; Carlson et al., in press) suggest that all of these plutonic rocks were emplaced in a relatively short time period about 1300 my ago. The anorthosites and most mafic rocks have largely anhydrous mineralogies and were emplaced at high temperatures (Wiebe, 1978). The magmas that produced these rocks almost surely originated within the mantle and were most probably derived by fractionation from basaltic magmas (Morse, 1982; Emslie, 1985; Wiebe, 1990). The isotopic character of many anorthositic rocks suggests that crustal contamination may have been important (Simmons et al., 1986).

The granitic rocks typically have compositions that approach those of minimum melts, have high Fe/(Fe + Mg), and have many of the characteristics of A-type (anorogenic) granites (Whalen et al., 1987; Anderson and Bender, 1989). There is a wide variety of chemical and isotopic evidence to suggest that these contemporaneous granitic rocks were produced from independent crustal melts (Morse, 1982). These melts were probably generated by the emplacement of voluminous mantle-derived magmas into the lower crust during a non-orogenic thermal event (Emslie, 1985; Wiebe, 1990).

The major occurrences of mafic rocks within a large area of the Nain complex are shown in Fig.1. There are, in addition, many small pods and dikes of Fe-rich dioritic rocks within the anorthosites. The large, dominantly troctolitic Kiglapait layered intrusion (e.g. Morse, 1979, 1981) lies immediately north of this map area. The larger bodies shown in Fig.1 are dominantly dioritic in composition, are in part well-layered, and commonly show abundant evidence for commingling between mafic and granitic magmas. Two of them, B (the Barth Island layered intrusion – de Waard, 1976) and NILI (the Newark

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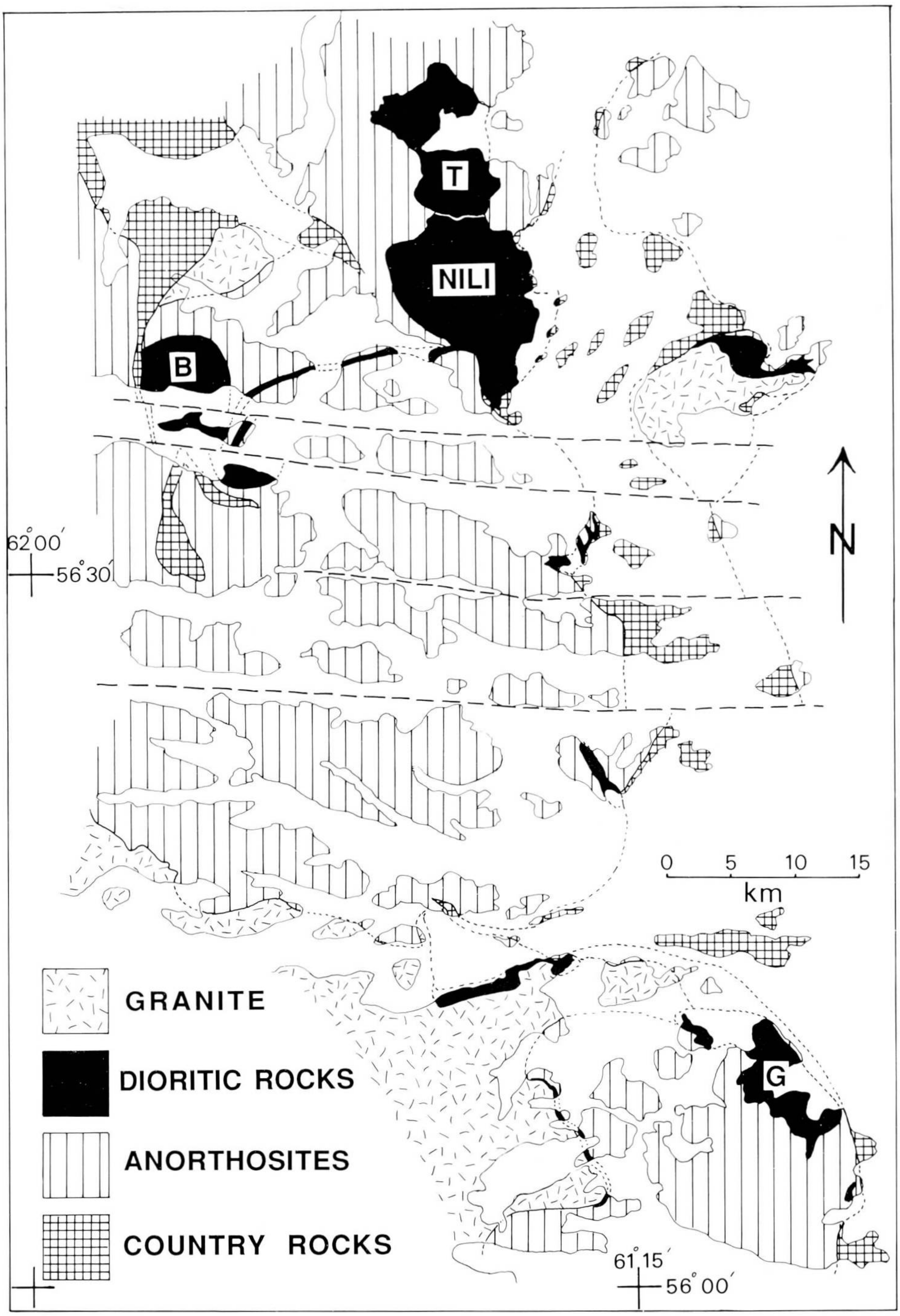


Fig. 1 Simplified geologic map of a portion of the Nain anorthosite complex. Individual dioritic plutons referred to in the text are labeled as follows: Tigalak layered intrusion (T), Newark Island layered intrusion (NILI), the Goodnews complex (G), and the Barth Island intrusion (B). The Barth Island and Newark Island intrusions have lower layered sections that are troctolitic in character.

Island layered intrusion – WIEBE, 1988), have lower sections of well-layered troctolitic rocks similar to the Kiglapait intrusion. Except for parts of those two intrusions, the remaining mafic rocks in Fig.1 have mafic minerals with high Fe/(Fe + Mg) and plagioclase compositions typically between An_{50} and An_{30}. Most of the rocks contain two pyroxenes (typically highly-exsolved subcalcic augite and inverted pigeonite); fayalite, rather than inverted pigeonite, typically occurs in diorites with highest Fe/(Fe + Mg). Ilmenite, magnetite, and apatite are ubiquitous and highly variable in abundance. Alkali-feldspar and, less commonly, quartz are important accessory phases locally; where they are relatively abundant, hornblende and biotite are also typically present. Following the IUGS classification of plutonic igneous rocks (STRECKEISEN, 1976), most of the Fe-rich mafic rocks within the Nain complex should be termed diorites. Where granitic magmas appear to have interacted with them, their compositions commonly range toward quartz monzodiorite. The dioritic rocks of the Nain complex are comparable to Fe-rich mafic rocks associated with other anorthosite complexes that have been variably termed jotunites (DE WAARD, 1970), ferrodiorites (EMSLIE, 1978), and monzonorites (DUCHESNE et al., 1985).

The origin of dioritic and other "intermediate" rocks within the Proterozoic anorthosite massifs has been a controversial topic for many years. One possible reason for this continuing controversy is the wide range in the types of occurrences of these rocks. In the Nain complex, dioritic rocks occur as (1) well-layered rocks of cumulate origin, (2) chilled pillows that preserve liquid compositions, and (3) hybrid rocks that have formed by the interaction of mafic and granitic magmas. In addition, many massive, apparently homogeneous dioritic rocks, including dikes, show some evidence of having been affected by both crystal accumulation and contamination by granitic material. Even well layered dioritic cumulates commonly contain clear petrographic evidence of incorporation of crystals derived from coexisting granitic melts. Obviously, any attempt to determine the relationship of a diorite to its associated rocks must take into account its specific mode of occurrence (e.g. cumulate vs. chilled liquid) and the processes (e.g. con-

Tab. 1 Representative modes[1] of diorites from the Nain complex

	Chilled pillows and dikes		layered rocks			hybrid rocks		
Spec	276	133	527	195D	312A	140	306	114A
Quartz	-	4.5	0.6	2.2	6.4	9.8	18.9	8.9
K-spar	0.6	11.0	0.4	6.1	4.8	14.2	10.7	12.1
Plag	53.5	52.2	60.0	50.0	51.0	45.1	50.6	47.2
Pyroxene[2]	26.8	23.7	28.8	31.6	20.5	14.2	7.6	5.8
Fayalite	7.3	-	-	-	-	4.1	-	5.2
Hornblende	-	3.0	-	3.6	9.8	7.4	8.8	16.3
Biotite	0.9	2.6	-	1.1	0.7	1.7	1.5	1.4
Opaques[3]	7.7	2.4	6.9	4.3	5.4	2.6	1.7	2.6
Apatite	3.2	0.6	3.3	1.1	1.4	0.9	0.2	0.5
%An[4]	37	33	42	38	38	29	23	29

1 Between 1000 and 1400 points counted per sample on a grid, 1/2 by 1 mm.

2 Includes augite, inverted pigeonite and orthopyroxene.

3 Mainly ilmenite and magnetite.

4 Determined by dispersion (MORSE, 1968).

tamination) that may have acted locally. The purpose of this paper is to describe the dioritic rocks that occur within the Nain anorthosite complex and to present a model for their origin. The available data from the Nain complex suggest that the dioritic rocks have largely crystallized from residual magmas related to the anorthosites and that contamination from crustal granitic magmas has been locally important.

Petrography

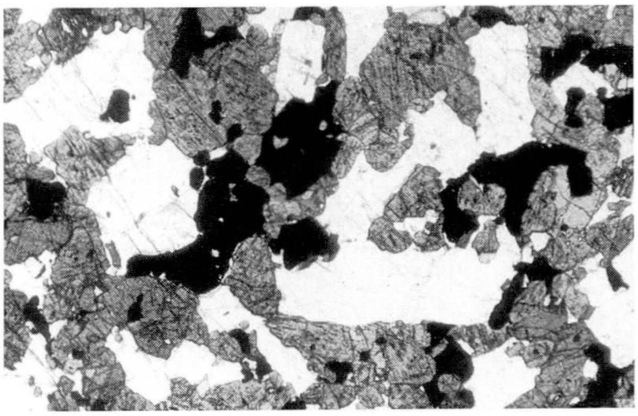
Representative modes of dioritic rocks from the Nain complex are given along with the percent An of plagioclase in Tab. 1. Except in dioritic rocks that display some petrographic evidence of hybridization with granitic material, quartz and alkali-feldspar are generally less than 10 percent. The two modes of the chilled rocks represent relatively well the range of modes of these rocks, especially in terms of the typical modal abundances of apatite and oxide minerals. In contrast, modes of the layered diorites range far beyond the three modes given in Tab. 1 with, for example, the percentages of apatite and oxide minerals ranging respectively between 0–10 and 0–20 percent. Other modes of dioritic rocks from the Nain complex are included in WIEBE (1979) and WIEBE and WILD (1983).

Textures of the chilled pillows and fine-grained dikes range from granular to subophitic with randomly oriented plagioclase of high aspect ratio (Fig. 2A). Such rocks are characterized by an even distribution of disseminated opaque minerals and apatite. Layered cumulate rocks typically have grain-sizes between 0.5 and 3 mm and cumulus minerals with subhedral form (Fig. 2B). The least evolved rocks contain cumulus orthopyroxene or inverted pigeonite and plagioclase. The most evolved cumulates contain cumulus ilmenite, magnetite, and apatite.

Hybrid rocks are characterized by great textural variation even in small samples, a very irregular distribution of all phases – especially quartz and alkali-feldspar, and a wide range in grain-size (Fig. 2C). In hybrid rocks the ratio of hornblende to pyroxene commonly varies greatly even within distances of a few cm. Xenocrystic alkali-feldspar crystals up to 1 cm in length are commonly present and generally rimmed by sodic plagioclase. In some hybrid rocks xenocrystic equant quartz is enclosed within mafic rims.

The average An-content of plagioclase is highest in the cumulate layered rocks, intermediate in the chilled rocks, and least in hybrid dioritic rocks. Plagioclase typically shows strong normal zoning and some patchy zoning (VANCE, 1965). Plagioclase phenocrysts with cores as calcic as An_{50} occur in some chilled dikes and pillows; some of these are iridescent and, hence,

(A)



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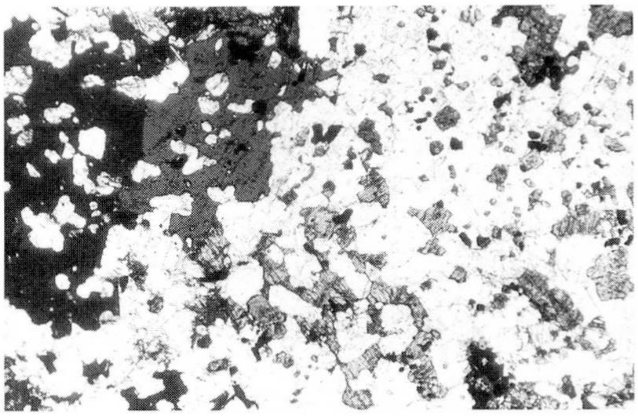
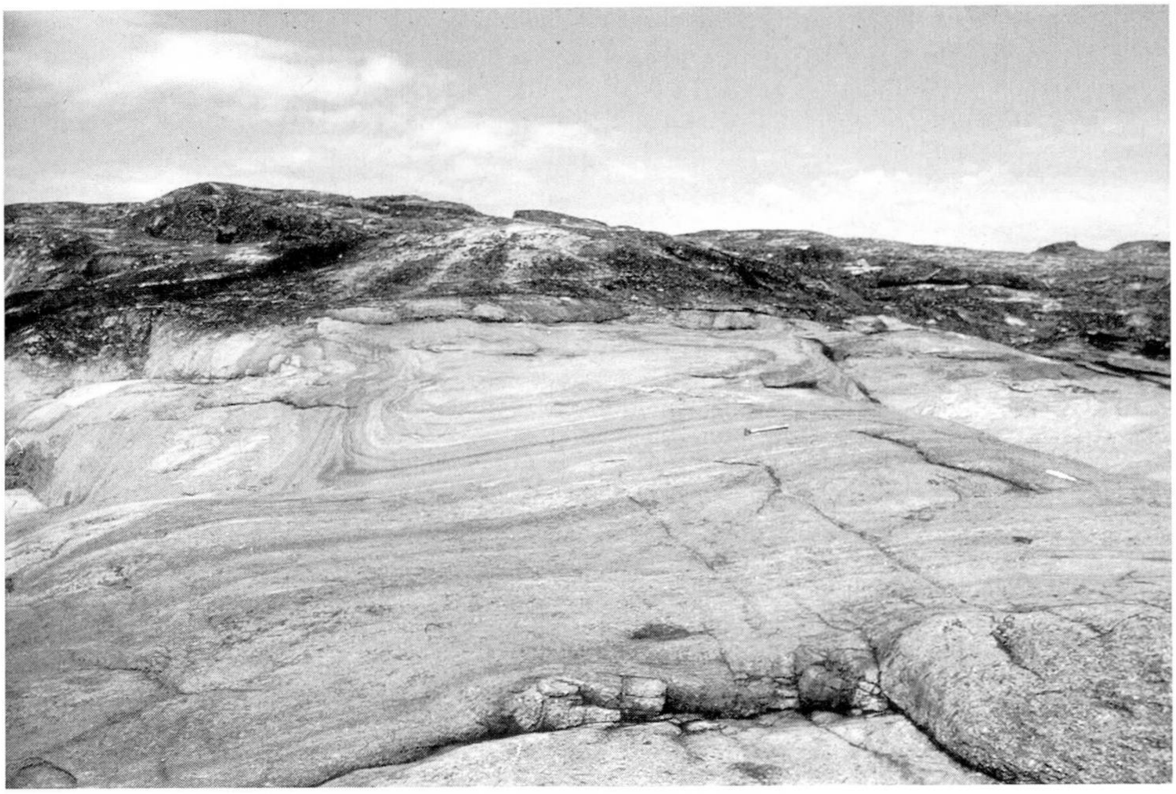


(C)

Fig. 2 Photomicrographs of dioritic rocks. The length of each photomicrograph is 9 mm. (A) Typical texture of a chilled dioritic pillow with moderately tabular plagioclase, two pyroxenes, and disseminated ilmenite, magnetite and apatite. (B) Cumulate diorite from the Tigalak layered intrusion with cumulus plagioclase, inverted pigeonite, augite, and ilmenite. (C) An example of a hybrid dioritic rock. Note the very large range and irregular distribution of grain size. Pyroxenes are the dominant mafics in the left half of the view, hornblende in the right half.



(A)

(B)

Fig. 3 Photographs of outcrops showing the relation of dioritic rocks to the anorthosites. (A) Well-layered diorites from the eastern margin of the Goodnews complex rest conformably on and alternate with anorthosite (leuconorite). (B) The hammer rests on a basalt dike that cuts anorthosite and is, in turn, cut by diorite that appears to have been filter-pressed from the anorthosite. The diorite vein wanders irregularly away from the basalt dike and grades into the interstices of the anorthosite near the lower part of the photograph. This relationship provides direct evidence that diorite is comagmatic with the anorthosite.

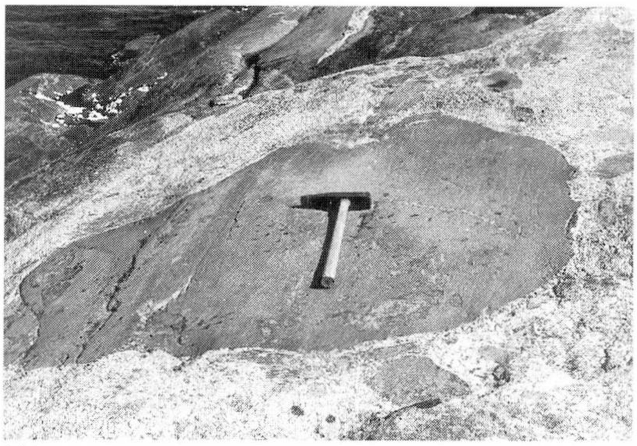
provide a clear link to nearby anorthosites with similar plagioclase. In some layered rocks, a small percentage of cumulus plagioclase crystals may contain a large irregular to angular inclusion of alkali-feldspar or, less commonly, sodic plagioclase. The fact that similar inclusions are common in plagioclase from hybrid rocks strongly suggests that the alkali-feldspar cores are xenocrystic in origin and that even well layered diorites have been affected by contamination. Large alkali-feldspars with fretted margins and plagioclase overgrowths also occur in some of the chilled dioritic rocks; these also appear to be xenocrysts incorporated from partly crystallized granitic magmas (HIBBARD, 1981).

Inverted pigeonite and sub-calcic augite are the dominant pyroxenes in dioritic rocks. They are typically unzoned in terms of Mg/(Mg + Fe), but the distribution of exsolution lamellae indicate that some low-Ca pyroxenes had cores of orthopyroxene and rims of pigeonite. Mg/(Mg + Fe) ranges between 0.5 and 0.3 with cumulates typically having higher values and hybrids having the lowest. Representative analyses of pyroxenes from all types of dioritic rocks are given in WIEBE and WILD (1983). Fayalitic olivine is a common interstitial mineral in the more Fe-rich varieties of all three types of diorite. Hornblende commonly occurs as rims on pyroxenes. Its abundance is greatest in the hybrid diorites and in chilled dioritic pillows that are enclosed by contemporaneous hydrous granitic material. This association, along with the generally higher Rb-content of hornblende-rich diorites, suggests that the water needed to stabilize hornblende was contributed by contemporaneous granitic magmas.

Field relations

The dioritic rocks shown in Fig. 1 occur in a wide range of settings, and many smaller dikes and pods are found throughout the anorthosites. Most large bodies of diorite either lie within or along the margins of the anorthositic intrusions. Some occurrences appear to have formed by multiple injections of Fe-rich magmas into the partially solid, fractured margins of large anorthosite plutons. Gradational contacts between diorite and anorthosite are common, and up to 100 meters of transitional noritic and gabbroic rocks occur along the margins of some larger dioritic bodies where they are in contact with anorthosite. The gently-dipping bases of some layered dioritic bodies rest directly on underlying leuconorite, and similar coarse-grained leuconorite occurs as layers within some of the lower portions of these diorites (Fig. 3A).

In some settings field relations strongly suggest that diorite has formed from residual liquid related to the anorthosites. Dioritic rocks along the eastern margin of the Tigalak layered intrusion (T in Fig. 1) locally grade through norite to the adjacent anorthosite. Near its contact with the Tigalak intrusion, the anorthosite contains many dioritic dikes that become less distinct as one moves away from the Tigalak. These dikes ultimately appear to merge into the interstitial matrix of the anorthosite. Fortuitously, a basaltic dike has cut this anorthosite before it became


(A)

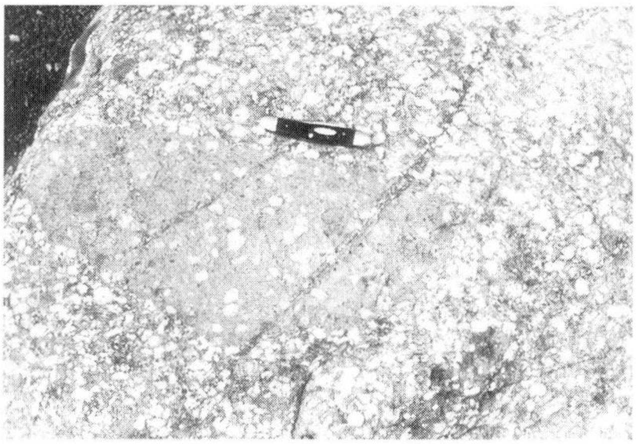

(B)

Fig. 4 Photographs of outcrops showing the relations between dioritic and granitic rocks. (A) The hammer rests on a strongly chilled pillow of Fe-rich diorite contained within texturally heterogeneous granitic rocks with smaller, variably digested inclusions of diorite. (B) A small dioritic inclusion (lacking a chilled margin and containing scattered xenocrysts of alkali-feldspar) occurs within a coarser-grained hybrid dioritic rock with abundant xenocrysts of alkali-feldspar and scarce quartz. Most alkali-feldspar xenocrysts are surrounded by plagioclase rims of variable thickness. These relations require multi-stage mixing between dioritic and granitic magmas.

completely solidified. Residual liquid (of diorite composition) appears to have flowed from the interstices of the anorthosite and broken across (back-veined) the then-solidified basaltic dike (Fig. 3B).

Nearly all of the diorites in Figure 1 contain some evidence for commingling or hybridization with granitic magmas. Large pillowlike masses like that shown in Fig. 4A are common in the larger diorite bodies and especially abundant where diorite occurs along the margins between anorthositic and granitic plutons. The matrix to these pillows is commonly extremely heterogeneous, both texturally and mineralogically, and appears to represent a more intimiate, but still incomplete, mixing between partially crystallized dioritic and granitic magmas. Most mafic inclusions that have strongly chilled margins, as shown in Fig. 4A, have proven to retain the compositions of chilled liquids (WIEBE, 1979). However, in many areas of hybrid rocks, mafic inclusions may lack chilled margins and show signs of prior contamination. Figure 4B shows a typical fine-grained dioritic inclusion that has included

Tab. 2 Representative Chemical Analyses of Dioritic Rocks from the Nain Complex.

		Chilled Pillows				Layered Rocks		
Spec	P67B	P102	P63	P32	P66	P18	P2A	P3E
SiO_2	51.86	47.39	46.88	45.58	50.37	49.18	46.31	42.16
TiO_2	2.88	3.19	3.55	3.84	2.39	2.90	3.67	4.51
Al_2O_3	13.75	13.13	13.41	12.80	15.52	14.01	12.73	13.48
Fe_2O_3	1.69	2.82	5.03	7.36	4.99	3.44	5.73	5.48
FeO	13.30	13.53	13.62	12.53	9.48	12.12	13.28	13.40
MnO	0.22	0.27	0.28	0.27	0.20	0.21	0.27	0.27
MgO	3.65	4.27	4.74	3.76	4.77	4.85	6.16	5.05
CaO	7.04	8.01	8.84	8.46	7.31	7.09	8.25	10.24
Na_2O	3.44	3.57	2.86	3.02	3.57	2.82	2.82	2.23
K_2O	1.49	0.89	0.52	0.71	0.72	1.14	0.47	0.31
P_2O_5	0.62	0.83	0.75	0.87	0.52	0.28	0.44	2.23
LOI	1.25	1.21	0.96	1.07	0.77	1.41	1.05	0.99
TOTAL	101.19	99.11	101.44	100.27	100.61	99.45	101.18	100.35
Rb	11	6	12	16	7	30	7	2
Sr	366	450	392	337	537	393	335	405
Ba	1162	1285	626	636	771	610	387	307
Zr	370	480	140	265	223	215	82	60
V	172	181	226	175	186	264	318	221
Ni	22	22	32	18	22	56	44	18
				CIPW Norms				
qtz	1.71	-	0.90	2.65	2.99	2.39	-	1.06
or	8.81	5.37	3.06	4.23	4.26	6.87	2.77	1.84
ab	29.12	30.85	24.08	25.74	30.25	24.34	23.83	18.98
an	17.69	17.54	22.01	19.43	24.23	22.65	20.66	26.01
di	11.23	14.78	13.95	14.32	7.16	9.49	14.33	8.77
hy	22.09	12.05	20.21	13.48	18.10	22.90	21.61	21.51
ol	-'7.07	-	-	-	-	0.51	-	
mag	2.45	4.18	7.26	10.76	7.25	5.09	8.30	7.99
ilm	5.47	6.19	6.71	7.35	4.55	5.62	6.96	8.62
ap	1.44	1.97	1.73	2.04	1.21	0.66	1.02	5.21
Mg/(Mg+FeT)	0.31	0.32	0.32	0.26	0.38	0.36	0.37	0.33
An/(An+Ab)	0.38	0.36	0.48	0.43	0.44	0.48	0.46	0.58

alkali-feldspar xenocrysts and some scarce quartz xenocrysts prior to coming to rest in a hybrid material consisting of medium-grained dioritic material with a much larger proportion of alkali-feldspar xenocrysts.

In contrast with the field relations of associated diorite and anorthosite, no evidence for a continuous, homogeneous transition between diorite and granite has been found. If granite were related to the diorite by fractional crystallization, it seems most probable that the upper portions of well-layered dioritic intrusions would grade toward granite. No such gradations exist.

Geochemistry

Representative analyses of dioritic rocks from the Nain complex are given in Tab. 2. Chilled rocks approximate the compositions of liquids, and layered rocks are cumulates. Chemical analyses of other Nain diorites are reported in WIEBE (1979) and WIEBE and WILD (1983). Besides being characterized by high Fe, the compositions of the dioritic rocks typically trend toward high TiO_2 and P_2O_5. Cumulates have higher normative An and higher Mg# (= Mg / [Mg + Fe_T]) than associated chilled rocks. The chilled rocks all have much higher Ba/Sr than associated layered rocks. These and other chemical data indicate that the chilled diorites have compositions that are appropriate for liquids that could have produced the layered cumulate rocks (WIEBE, 1979). The layered rocks show much greater overall compositional variation than the chilled rocks because their compositions depend strongly upon the proportions and identities of the cumulus phases.

Where chilled dioritic rocks (representing liquids) are closely associated with anorthositic bodies, they have trace-element (as well as major-element) compositions that are consistent with their representing residual liquids from the anorthosites. This can clearly be seen in terms of Sr and Ba plotted against CaO (Fig. 5). Sr is greatly depleted and Ba greatly enriched in dioritic liquids that, on the basis of field relations and major-element chemistry, appear to be appropriate residual liquids related to the anorthosites. These simple relationships would be obscured if dioritic rocks of cumulate origin were also included in the plots-Sr would be increased in diorites to the extent that plagioclase was a cumulus phase and Ba would be depleted because it would tend to be excluded from all cumulus phases.

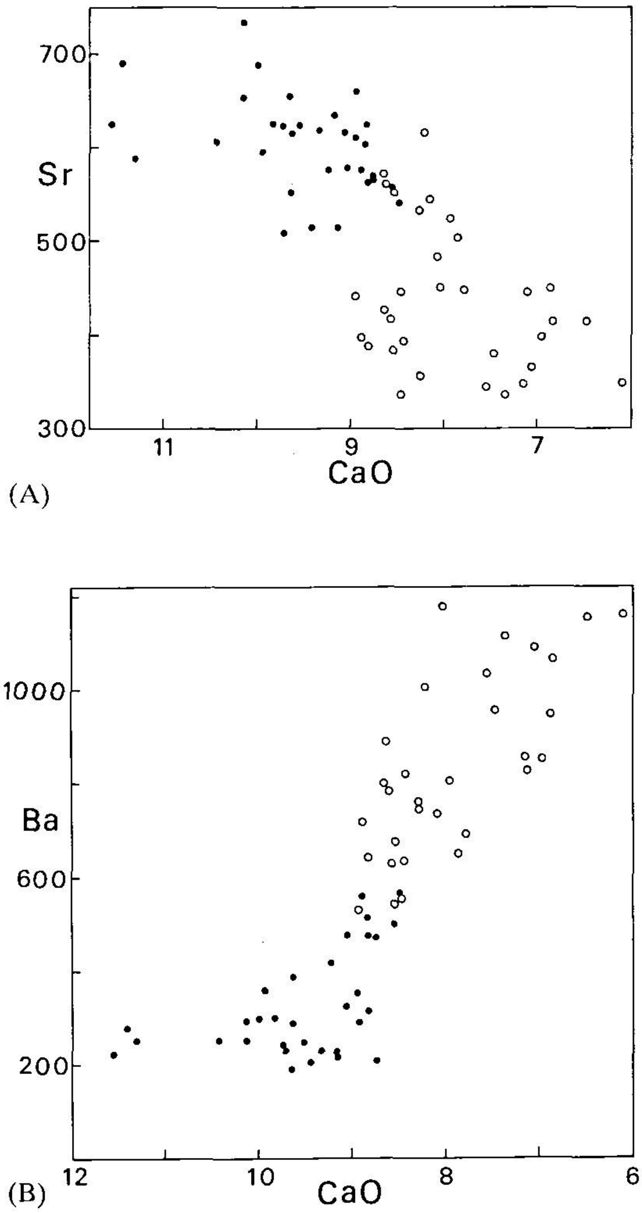


Fig. 5 A comparison of the compositions of anorthositic rocks (solid circles) and chilled dioritic pillows (open circles) associated with them. (A) CaO versus Sr. (B) CaO versus Ba. Compared with the anorthositic rocks, the associated chilled dioritic rocks are greatly depleted in Sr and enriched in Ba – consistent with the proposal that these chilled diorites represent residual liquids from the anorthosites.

Individual suites of chilled diorites often retain specific chemical characteristics or signatures of the anorthositic rocks with which they are associated. Two suites of anorthositic and related chilled dioritic rocks are plotted in Fig. 6. One suite consists of the Tigalak dioritic rocks and the anorthosites to which they grade along the eastern margin of the Tigalak body (T in Fig. 1). The other suite consists of chilled diorites from the Goodnews complex (G in Fig. 1) and

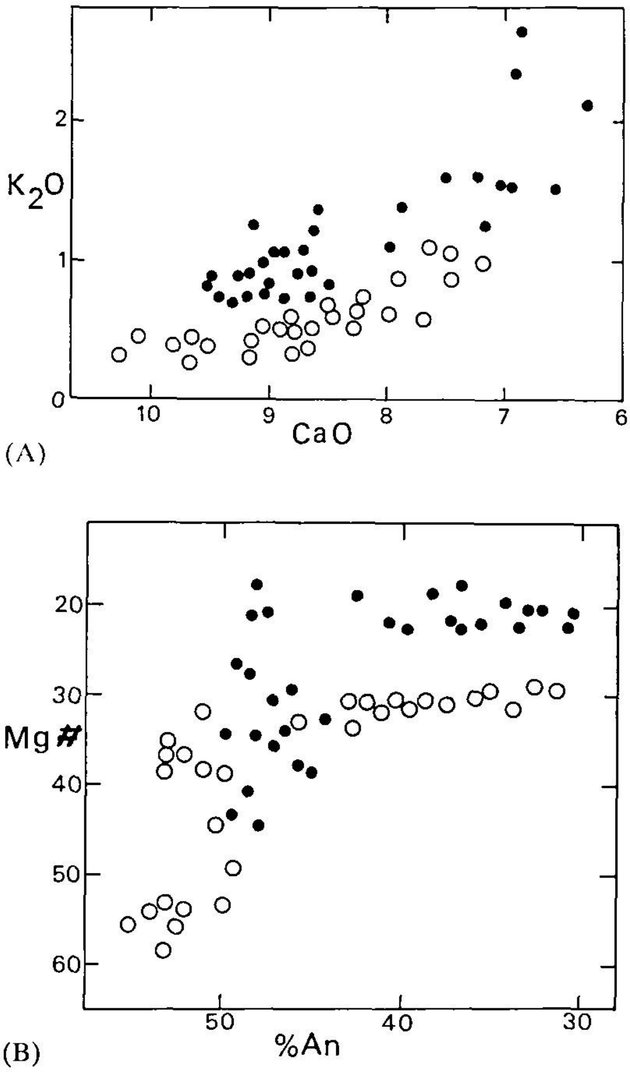


Fig. 6 A comparison of the compositions of anorthosites and associated chilled diorites from two different intrusive complexes. Solid circles represent diorites from the Goodnews complex and adjacent anorthosites (G in Fig. 1); open circles represent diorites from the Tigalak layered intrusion and adjacent anorthosites. (A) CaO versus K_2O. (B) Weight percent An of normative plagioclase versus cation Mg# (= 100 Mg / Mg + Fe_T). Anorthosites show little variation in An while Mg# varies to minimum values comparable to those of their associated diorites. This wide range in Mg# is in part due to the difficulty of obtaining samples large enough to be fully representative of the widely scattered areas of interstitial pyroxenes and oxides. Diorites show little variation in Mg# (due to cotectic crystallization of mafic silicates and oxides) while An varies to very low values. Note that each suite of related anorthosites and diorites has a distinctive chemical character.

their associated anorthosites. The Goodnews diorites and anorthosites have distinctly higher K_2O than the Tigalak rocks (Fig. 6A); they are also slightly more sodic (in terms of normative An) and trend to lower Mg# than the Tigalak rocks. The fact that such characteristics carry over from anorthosite to diorite provides strong support for deriving the diorites locally from the same magmas that produced the anorthosites. The dioritic portions of both suites trend to low An at nearly constant Mg#; this nearly constant Mg# reflects the cotectic crystallization of mafic silicates and oxides (ilmenite and magnetite).

Initial Sr and Nd isotopic compositions are highly variable in both the anorthositic and dioritic rocks of the Nain complex, and this variability suggests that crustal contamination was a significant factor in their formation (SIMMONS et al., 1985). The more primitive isotopic compositions of early-formed minerals (plagioclase, high-Al orthopyroxene megacrysts) separated from the anorthosites suggest that these phases were less affected by crustal contamination than later-crystallizing interstitial phases. Because of this relationship ASHWAL and WIEBE (1989) have suggested that crustal contamination occurred gradually as crystal-laden anorthositic magmas were emplaced into the upper levels of the crust. If this model is correct for the Nain complex, it will be difficult to use the isotopic compositions of closely associated diorites and anorthosites to demonstrate or preclude a comagmatic relationship. Instead, it will be necessary to rely on field relations, petrography, and selected aspects of the geochemistry.

Discussion

The bulk of the evidence from the Nain complex suggests that many of the Fe-rich dioritic rocks have formed near the final level of emplacement from residual liquids related to magmas that produced the anorthosites. This does not preclude the possibility that similar diorites may have been generated from anorthosite-related magmas undergoing crystallization at depth as suggested by EMSLIE (1978). There is overwhelming evidence to indicate that the dioritic rocks are not comagmatic with the associated granitic rocks. In this respect evidence in the Nain complex contrasts greatly with the model of linkage by fractional crystallization proposed for the Norwegian Rogaland complex (DUCHESNE and WILMART, 1989).

Acknowledgements

This research has been supported by NSF Grants EAR-7514423 and EAR-8318671 .

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Manuscript received December 12, 1989; accepted February 15, 1990.