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Malene amphibolites and related anorthosites from Akugdlerssuaq, inner Godthåbsfjord, with komatiite affinities

Allen P. Nutman

Mapping by helicopter reconnaissance in 1976 (Allaart *et al.* 1977) and subsequent more detailed mapping in 1981 (Nutman, 1982) showed that there are several units of anorthosite with associated amphibolite on Akugdlerssuaq, inner Godthåbsfjord. The anorthosite and amphibolite units are interspersed with units of strongly deformed Amîtsoq gneisses (identified by the presence of basic dyke remains and by enclaves of banded iron formation) sheeted by younger gneisses. Most of the contacts between anorthosite and amphibolite units and the Amîtsoq gneisses are clearly tectonic, whilst the remaining contacts could also be tectonic or are modified primary contacts (Nutman, 1982). The younger gneisses are of late Archaean age (Bridgwater & Nutman, unpublished Rb-Sr isotopic data).

The field characters of the anorthosites and amphibolites were described by Nutman (1982). The most important points are summarised below:

The amphibolites are banded and contain lenses and discontinuous horizons of garnet-biotite-quartz-feldspar rock, possibly paragneiss. The anorthosites range from medium-grained varieties with distinct layering to a more homogeneous type consisting of a gabbroic matrix crowded with plagioclase megacrysts. The amphibolites and anorthosites are not intimately interlayered, but units up to a couple of hundred metres wide are adjacent to each other. In the west of the area, in an augen of low deformation, the anorthosite is suggested as having intruded, and locally reacted with garnet-biotite gneiss. The age relations between the anorthosites and amphibolites and the gneisses which intrude both are the same as those found in the Fiskenæsset and Buksefjorden regions (Kalsbeek & Myers, 1973; Chadwick & Coe,

Table 3. Analyses of representative anorthosites and amphibolites, Akugdlerssuaq, inner Godthåbsfjord

Sample	292437	292462	292460	292427	292418	292428
Sio_2	46.89	48.18	42.12	48.38	4871	48.81
TiO_2	0.09	0.33	0.33	0.55	0.59	0.59
$A1_2O_3$	25.34	26.28	26.27	25.20	15.80	15.22
Fe_2O_3	2.17	0.81	3.33	2.36	2.34	2.42
FeO	3.36	3.43	6.76	8.58	8.70	8.77
MnO	0.08	0.05	0.16	0.19	0.18	0.18
MgO	3.74	2.95	4.23	8.53	8.17	7.96
CaO	10.02	13.04	7.51	10.92	10.67	10.58
Na_2O	3.01	1.44	0.46	2.17	1.81	1.79
K_2O	1.59	0.30	3.00	0.78	0.59	0.98
l.o.i.	3.32	1.22	4.46	1.87	2.28	2.37
P_2O_5	0.01	0.03	0.04	0.04	0.04	0.04
	99.62	98.06	98.67	99.57	99.88	99.71
Rb	75	7	168	17	36	52
Sr	250	134	235	70	54	104
Ba	317	40	648	86	51	148
Y	3.5	5	13	19	20	21
Zr	5.1	12	119	30	33	37
Ni	84	35	80	164	170	147
Cr	15	208	66	401	447	311

292437 & 292462 anorthosites, 292460 anorthosite contaminated by country rocks, 292427, 292418 and 292428 amphibolites.
l.o.i. loss on ignition.

1983), and the rocks are regarded as chronostratigraphically equivalent (see Table 1 of McGregor *et al.*, 1983, for the sequence of geological events in the region). The rocks of Akugdlerssuaq are in amphibolite facies, and there is no evidence to suggest that they have previously been affected by late Archaean granulite facies metamorphism.

Geochemistry

Twenty-three samples from the westernmost unit of anorthosite and amphibolite on Akugdlerssuaq (zone II *in* Nutman, 1982) were analysed for major elements at GGU and for selected trace elements by John Bailey, Petrological Institute, University of Copenhagen. Representative analyses are given in Table 3. Analytical methods, values for international standards and further analyses are available upon request. Samples used in this study were taken as far away as possible from shear zones and intrusive gneiss sheets.

Before consideration of the igneous evolution of the anorthosites and amphibolites on the basis of geochemical data, it is important to ascertain how much of the chemistry of the rocks is inherited from their igneous protoliths and how much is a reflection of metasomatism dur-

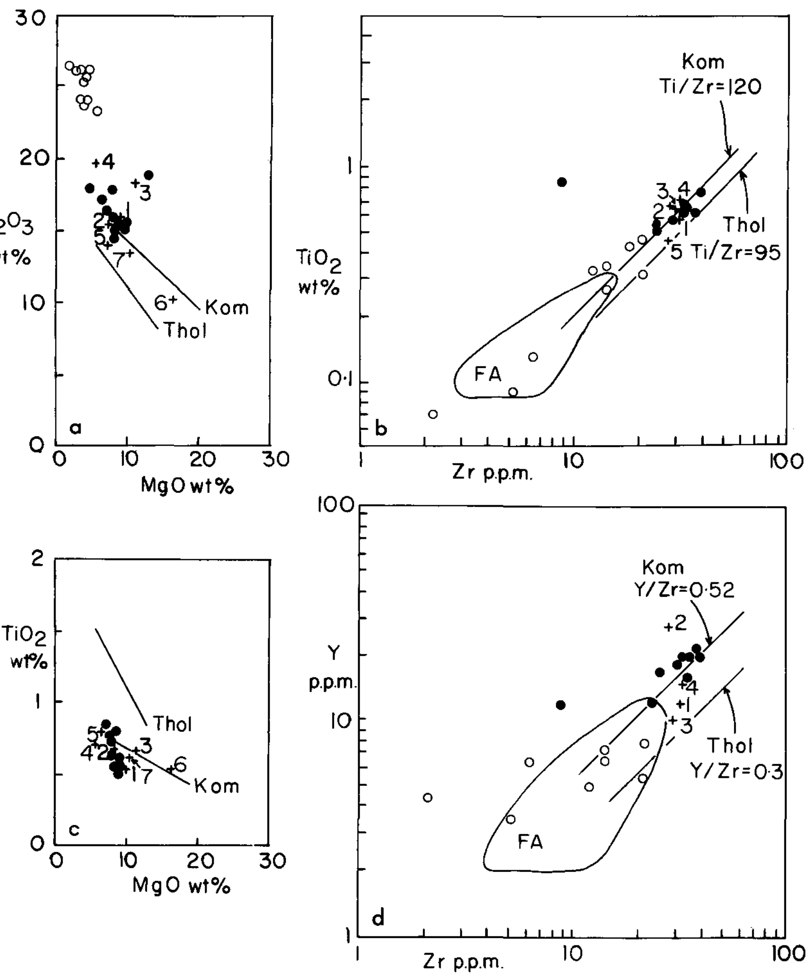

Fig. 18. TiO_2, Al_2O_3, MgO, Y and Zr variation of Akugdlerssuaq amphibolites, anorthosites and comparative rocks. ● Akugdlerssuaq amphibolite and ○ anorthosite. Field FA is for Fiskenæsset anorthosites (Weaver *et al.*, 1981) and 1 is average of 10 low-Zr amphibolites from Fiskenæsset (Weaver *et al.*, 1981). Numbers 1 to 5 are averages of Malene amphibolite lithotypes (Chadwick, 1981), and 6 and 7 averages of Malene high-Mg and low-Mg amphibolites respectively (Hall, 1980). Thol and Kom are liquid trends for Abitibi picrite-tholeiite and komatiite units (Arndt *et al.*, 1977).

ing regional metamorphism and intrusion of younger gneisses. In the anorthosites and amphibolites there is an irregular variation between LREE (light rare earth element), Rb, Ba, Pb, Th and K_2O versus MgO content. Thus it is evident that the geochemistry of these rocks cannot be solely accounted for by igneous fractionation processes that gave rise to their protoliths. Studies of the adjacent Amîtsoq gneisses suggest that LREE, Rb, Ba, Pb, Th and K_2O were mobile on a regional scale during late Archaean high-grade metamorphism and intrusion of gneiss sheets (Nutman & Bridgwater, unpublished data). Nesbitt & Sun (1976) concluded that TiO_2, Zr and Y are relatively immobile during regional metamorphism and alteration, whilst MgO and Al_2O_3 are also considered relatively immobile during high-grade metamorphism (e.g. Wells, 1979). For the anorthosites and amphibolites of Akugdlerssuaq these components when plotted form fairly well defined trends against each other (fig. 18); these trends resemble those found in less recrystallised suites of igneous rocks (e.g. data *in* Nesbitt & Sun, 1976), and are regarded as a first approximation of the igneous variation in the protoliths of the amphibolites and the anorthosites.

MgO-Al_2O_3 (fig. 18). The anorthosites form a cluster at high Al_2O_3 and low MgO content, reflecting their high cumulate plagioclase content. The amphibolites form a cluster around *c.* 8 wt% MgO, 16 wt% Al_2O_3, with a linear scatter of a few samples that have higher Al_2O_3 and lower MgO content.

TiO_2-Zr (fig. 18). The anorthosites and the amphibolites form a linear scatter of Ti/Zr value of *c.* 120. There is no overlap in the scatter between the amphibolites (higher TiO_2 and Zr content) and the anorthosites.

MgO-TiO_2 (fig. 18). The amphibolites have a low TiO_2 content for a given MgO.

Y-Zr (fig. 18). The amphibolites scatter close to a Y/Zr = 0.5 line. The anorthosites show greater scatter on the plot than the amphibolites (which have higher Y contents). Increasing scatter with low Y content could be due to lower precision in determining Y when present in low abundance. There is perhaps a tendency for Y/Zr to increase with decreasing Zr content. This is to be expected in a mixture of plagioclase cumulate and intercumulus basic liquid, because Y is admitted into plagioclase crystals.

FeO^{tot}/MgO varies from *c.* 1 to 1.5 in the amphibolites and anorthosites. Higher FeO^{tot}/MgO can in some cases in the anorthosites be correlated with higher Ba and K_2O content; some of this type of sample were regarded in the field as anorthosite contaminated by assimilation of biotite-garnet gneiss (e.g. sample 292460, Table 3).

The variation of Al_2O_3, MgO, TiO_2, Zr and Y in the anorthosites and amphibolites from Akugdlerssuaq resembles that of the anorthosites and low-Zr amphibolites in the Fiskenæsset region (Weaver *et al.,* 1981). Using partition coefficients derived by Pearce & Norry (1979), Weaver *et al.* (1981) argued that the TiO_2, Y and Zr variations for the amphibolites and anorthosites from the Fiskenæsset region show that they are consanguineous and that plagioclase was the only significant accumulated phase in most stratigraphic levels of the anorthosite units. Weaver *et al.* (1981) also pointed out the high Al_2O_3 for a given MgO content and the low abundance of Zr, Y and TiO_2 in the parental magma of the Fiskenæsset anorthosites, and the low-Zr amphibolites with which they were considered to be related. The same observations and deductions can be made about the rocks from Akugdlerssuaq; namely that they are consanguineous and were derived from a parental magma of high Al_2O_3 for given MgO content. Chronostratigraphically equivalent Malene amphibolites described by Chadwick (1981) and Hall (1980) include varieties with similar chemistry to the Akugdlerssuaq amphibolites (fig. 18), as well as groups of iron-rich tholeiitic composition.

The amphibolites from Akugdlerssuaq are not cumulate-rich rocks, and may approximate to liquid compositions. Along with other Malene amphibolites and amphibolites from Fiskenæsset, they are compared here with well-documented liquid compositions of iron-rich tholeiite and komatiite affinity from the mid-Archaean Abitibi volcanosedimentary belt of Ontario (Arndt *et al.*, 1977; Sun & Nesbitt, 1978) (fig. 18). The Akugdlerssuaq amphibolites, then low-Zr amphibolites from Fiskenæsset (Weaver *et al.*, 1981) and some Malene amphibolites of Chadwick (1981) have compositions resembling Abitibi basaltic komatiites; in addition Hall (1980) described groups of amphibolites resembling pyroxenitic and basaltic komatiites in composition (fig. 18). There are also some Malene amphibolites of iron-rich tholeiite affinity (Chadwick, 1981, and fig. 18).

Hall & Friend (1979) suggest that the 'oceanic' affinities of Malene amphibolites is evidence that they were part of ensimatic crust. However, Gill & Bridgwater (1979) showed that the mid-Archaean Ameralik dykes that cut early Archaean continental crust have compositional characters of 'oceanic' basalts. It is also interesting to note that some sets of Ameralik dykes also have high Al_2O_3 for a given MgO content and low Zr and TiO_2 abundances compared with iron-rich tholeiites (e.g. samples 173277, 173278, 171754 and 158440 *in* Gill & Bridgwater, 1979). It is possible that at least some of the Ameralik dykes could have been feeders to Malene volcanism (Chadwick, 1981; Nutman & Bridgwater, 1983). Furthermore, komatiites and compositionally similar Phanerozoic rocks such as boninites and some ophiolites are argued by some workers not to be representative of typical oceanic crust, but can be formed in intra-sialic rifts or fore-arc basins (Cameron & Nisbet, 1981; Nisbet, 1981).

Therefore the 'oceanic' chemistry of Malene amphibolites is not evidence against proposals that some Malene rocks were erupted onto, and adjacent to continental crust, represented by the early Archaean Amîtsoq gneisses (Chadwick & Nutman, 1979; Chadwick, 1981; Nutman & Bridgwater, 1983).

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Geological mapping and mineral exploration in the Motzfeldt Centre of the Igaliko nepheline syenite complex, South Greenland

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The mineral occurrences of the Motzfeldt Centre, discovered by the South Greenland regional uranium exploration programme (Armour-Brown *et al.*, 1984, Tukiainen *et al.*, 1984), are now being explored for their Nb and Ta potential under a project financed by the EEC's Resources and Raw Materials Programme and The Geological Survey of Greenland. Accompanying the mineral exploration several other investigations are being carried out, and there is a close co-operation between the various groups working in the area.

The 1984 field activities comprised geological mapping, geochemical and geophysical investigations, and mineral exploration. The field activities were supported by GGU's facilities at Narssarssuaq where Jørgen Lau acted as base camp manager. A Jet Ranger helicopter, chartered on an *ad hoc* basis from the Ice Reconnaissance Centre at Narssarssuaq, was used for camp moves, geological reconnaissance and servicing of the field teams. De-