Metasomatic alteration of dolerite in the Proterozoic sediments of north-eastern Disko Bugt

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Alteration of a dolerite sheet along quartz-carbonate veins resulted in profound changes in its chemical composition. Per 1000 kg of the original dolerite 135 kg of volatiles, 38 kg of Na_2O and 23 kg of CaO were added, and 76 kg of FeO* (total iron expressed as FeO) and 8 kg of K_2O were removed. Large proportions of the original Rb, Ba, Sr, Zn, Cu and Ni were carried away during the alteration.

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The Precambrian basement of the Atâ Sund region in north-eastern Disko Bugt contains a unit of Proterozoic supracrustal rocks, the Anap nunâ group, that overlies Archaean supracrustals (see Kalsbeek, 1989, and references cited therein, Fig. 1). The Anap nunâ group con-

Fig. 1. Geological sketch of the Atâ Sund region with the location of the dolerite outcrop on Qeqertakavsak (Q). Stippled: Archaean gneisses; crosses: Archaean granitoids; horizontal ruling: Archaean supracrustal rocks; cross-hatched: Proterozoic sediments (the Anap nunâ group).

sists mainly of siltstones with large outcrops of albite-rich rocks believed to have been formed by large scale albitisation of siltstones. Alteration of the sediments is often related to joint systems associated with (quartz-) carbonate veins that may range up to a metre in width. The sediments contain local sheets of dolerite which may also be strongly altered along quartz-carbonate veins. The profound metasomatic changes accompanying the alteration of such a dolerite are here described for a locality on the south coast of Qeqertakavsak, an island in the fjord Torssukátak (Fig. 1). Although the alteration of this dolerite is only a local phenomenon, it is of interest because it gives an indication of the kind of chemical changes that may be expected during alteration of the sediments.

Field setting and lithology

The dolerite in question is surrounded by superficial deposits, and its relation to its sedimentary host is not clear. It is cut by quartz-carbonate veins, up to about 10 cm wide, and along these veins the dolerite is bleached in 10–50 cm wide zones (Fig. 2). The altered rock is red-brown on the weathered surface, but 'fresh' samples consist of white, fine grained, compact rock. The more well-preserved dolerite is dark grey in hand specimen, and relatively fine grained. It retains a doleritic texture, although thin section study shows that the igneous mineral paragenesis is largely replaced by actinolite, epidote and albite, with only local remnants of clinopyroxene and igneous plagioclase. The altered white rock is mainly composed of albite, quartz and carbonate with subordinate fine grained micaceous matter.
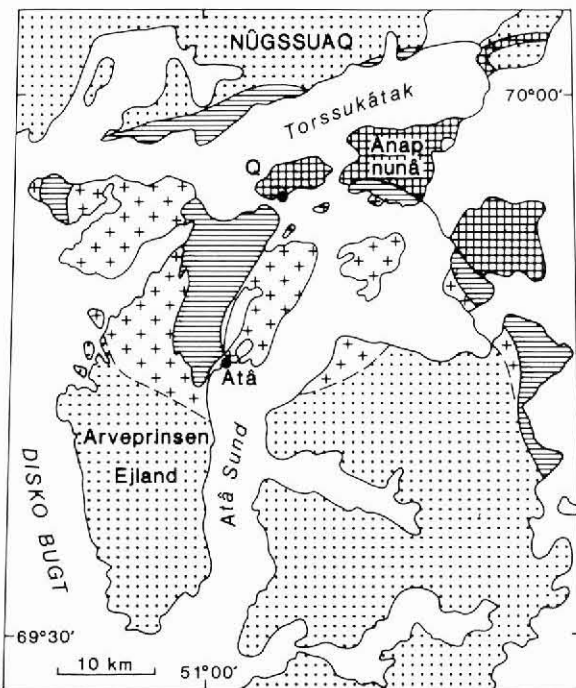
Fig. 2. Dolerite (1) with alteration zones (2) along a quartz-carbonate vein (3). The boundary between the altered rock and the dolerite has been accentuated for clarity; in the field the difference between the two rocks is marked by a strong colour contrast.

Table 1. Chemical compositions of a dolerite and its alteration product, Qeqertakavsak, northeastern Disko Bugt

	A	B
SiO$_2$ (wt %)	52.18	46.74
TiO$_2$	0.78	0.92
Al$_2$O$_3$	14.83	13.34
Fe$_2$O$_3$	1.64	0.12
FeO	8.97	2.41
MnO	0.10	0.06
MgO	5.66	5.14
CaO	7.97	9.19
Na$_2$O	3.03	6.10
K$_2$O	1.92	0.99
P$_2$O$_5$	0.10	0.10
volat.	2.39	14.31
	99.59	99.32
Rb (ppm)	85	24
Ba	250	173
Pb	2	<2
Sr	237	66
Y	21	15
Th	6	5
Zr	88	91
Nb	5.2	5.0
Zn	38	7
Cu	78	16
Ni	76	31
Ga	18	16

A: GGU 355023, dolerite; B: GGU 355024, altered dolerite. Volat. is the total of volatiles determined from the loss on ignition. Major elements were analysed by X-ray fluorescence spectrometry (Na by atomic absorption spectrometry) at the GGU laboratories, and trace elements by XRF at the Institute of Petrology, University of Copenhagen.

Geochemistry

Chemical analyses of the dark dolerite and the totally altered rock are presented in Table 1. With respect to the major elements the most obvious differences are the strongly increased proportions of volatiles and sodium in the altered rock, and the strong depletion in iron. To quantify the transfer of chemical components during alteration use has been made of the Gresens (1967) equation:

$$X_n (\%) \underset{A \to B}{=} f_v \cdot g_B/g_A \cdot C_n^B - C_n^A$$

where X_n is the weight of component n added to or removed from rock A to yield rock B, expressed as per cent of the weight of rock A. f_v, the 'volume factor', is the ratio between the volumes of B and A. g_B and g_A are the specific gravities of B and A. These have been measured, and are 2.954 for the dolerite (A) and 2.745 for the altered rock (B). C_n^B and C_n^A are the concentrations of n in B and A.

The Gresens equation cannot be solved directly because it contains two unknowns (f_v and X_n), but it gener-ates a set of straight lines in an X_n v. f_v diagram, one for each analysed component, that depict the combinations of f_v and X_n which satisfy the equation (Fig. 3).

Aluminium is often among the more immobile elements during metasomatic processes, and, assuming $X_{Al_2O_3} = 0$, the Gresens equation yields $f_v = 1.20$ (i.e. a volume increase of 20% during alteration). Also for $X_{SiO_2} = 0$ and $X_{MgO} = 0$ f_v values of c. 1.20 are obtained and an increase in volume of c. 20% is therefore thought to be plausible.

At $f_v = 1.20$ the following transfer of components can be computed (or read off from the diagram of Fig. 3).

About 135 kg of volatiles, 38 kg of Na$_2$O, and 23 kg of CaO have been added per 1000 kg of the original rock, and 76 kg of FeO* (total iron expressed as FeO) and 8 kg of K$_2$O have been removed. In all c. 200 kg of foreign components have been added and c. 80 kg have been
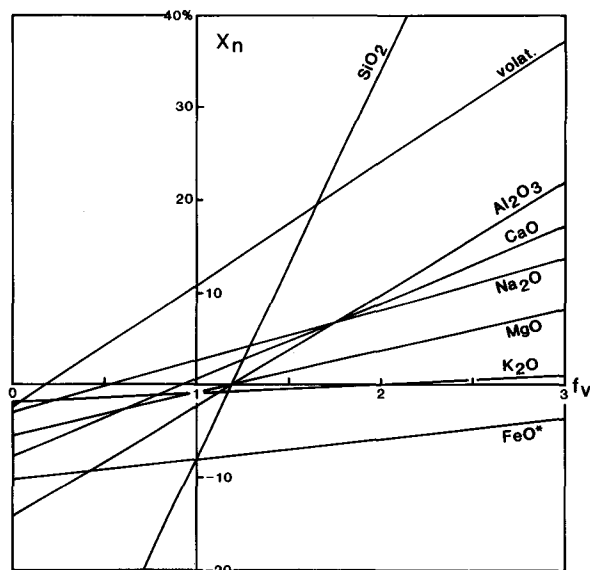
Fig. 3. Diagram showing the combinations of X_n and f_v values that satisfy the Gresens equations for element transfer during alteration of the dolerite. X_n values represent the weights of the different oxides n added to or removed from the dolerite during alteration, expressed in per cent of the original rock. f_v is the ratio of the rock volumes after and before alteration. The vertical axis is drawn at $f_v = 1$ (corresponding to zero change in volume); to the left of this ($f_v < 1$) the rock volume is diminished, and to the right ($f_v = > 1$) it is increased during alteration. For further explanation see the text. Volat.: total volatiles; FeO*: total iron expressed as FeO.

removed per 1000 kg dolerite. During the process the volume of the rock was increased by some 20%, considerably more than the increase in weight, and as a consequence the altered rock has a lower specific gravity than the original dolerite.

Discussion

Calculations of this kind can only give correct results if the protolith of the altered rock was indeed equivalent to the fresh rock analysed. This assumption cannot be verified, but in the present case the two analysed samples were collected at a very close distance (about a metre), and since the dolerite at this locality is fairly homogeneous, the assumption of chemical equivalence is reasonably justified, at least for the major elements. For minor and trace elements this is less certain, and the transfer of such elements can therefore only be quantified if large sample collections are studied (see Zeck *et al.*, 1988, 1989). From the available data (Table 1), however, the impression is gained that TiO_2, P_2O_5, Zr, Nb, and Ga were relatively immobile, but that the al-

tered rock is strongly depleted, among other elements, in Mn, Rb, Ba, Sr, Zn, Cu and Ni.

The increase in volume of the rock of 20% deduced above is much more than generally believed to be realistic (for a discussion of this topic see Zeck *et al.*, 1988). However, the metasomatic changes described here probably took place at a shallow level in the crust. The Proterozoic sediments on Qeqertakavsak are almost unmetamorphosed, and the style of folding suggests near-surface deformation associated with brittle fracturing (local brecciation of the rocks and the formation of numerous joints). Under such conditions a considerable but local increase in volume of rocks that form only a minor part of the total rock mass would not seem impossible. Alternatively, if the volume increase was considerably less than 20%, massive depletion in SiO_2 must have taken place to satisfy the Gresens equation (at $f_v = 0$, for example, 80 kg of SiO_2 per 1000 kg dolerite must have left the system, see Fig. 3).

The metasomatic alteration of the sediments on Qeqertakavsak is probably of the same nature as that of the dolerites, but less extreme. The geochemistry of these transformations is being studied at present, and the available evidence indicates that also here introduction of volatiles and sodium and leaching of iron were important. Altered sediments contain local lenses of hematite which were probably formed from iron that was leached from sediments elsewhere. It is likely that the local occurrence of sulphide mineralisation in the sediments is the result of the same process. The ultimate cause of these transformations is not known, but it is possible that the intrusion of the dolerites themselves provided the heat source necessary to set up convection of hot ground water that caused the metasomatism.

References

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