Notes – *Notiser*

Rare earth element patterns from the Ordovician volcanites of Smøla, Nordmøre, west-central Norway

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Data on REE chemistry of the Ordovician basaltic volcanites of Smøla show marked LREE enrichment and patterns which correspond with those known from Pleistocene and Recent calc-alkaline lavas of intra-oceanic setting. This confirms earlier work suggesting that eruption of the Smøla volcanic rocks occurred in a mature, evolved, island arc environment. Comparison with data from the broadly coeval, calc-alkaline, lower part of the Snåsavatn volcanites 250 km to the northeast suggests that the latter were erupted closer to the palaeo-continental margin than was the case for the Smøla rocks.

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The geology of the island of Smøla, ca. 100 km west of Trondheim, is perhaps best known for its fossiliferous limestone, which contains a varied fauna considered by Bruton & Bockelie (1979) to be of late Arenig- early Llanvirn age. Associated with the limestone, and locally interdigitating with it, is an assemblage of low greenschist facies rocks of basic to acidic character (Fediuk & Siedlecki 1977). A closer study of these volcanites has revealed an association ranging from high-alumina basalt, through basaltic andesites, andesites and dacites to sporadic rhyolites, with a major and common trace element chemistry denoting clear calc-alkaline affinities (Roberts 1980a). The volcanites, with slightly later plutonic associates, mainly quartz-hornblende diorites and granodiorites, are indicative of effusion in a mature island arc milieu genetically related to a destructive plate margin. A proposed paleogeographical setting for the magmatic rocks, involving a marginal basin situated to the east of the arc, is outlined in the 1980 a paper.

The purpose of this note is to report on the rare earth element (REE) patterns displayed by representative samples of the Smøla basalts. Following the main geochemical study, six basalt samples were chosen from different parts of the volcanite sequence for REE and Sc, Hf, Ta, Th and U determination; these were samples with fairly average major and common trace element concentrations and low Fe_2O_3/FeO ratios.

The REE patterns

The rare earth element and supplementary trace element analyses were carried out by Dr. Jan Hertogen at the Department of Physico-Chemical Geology, University of Leuven, Belgium, using instrumental neutron activation. The samples were irradiated at the University of Ghent nuclear reactor. Element concentrations are presented in Table 1.

In Fig. 1 the element contents for the different samples are normalised to a chondritic average, for graphic representation of their chemical patterns. A striking feature is the apparent consistency of the profiles from sample to sample, with the partial exception of samples SM 4 and SM 10; all are markedly LREE-enriched and show a high degree of fractionation. La, for example, falls in the range c. 50–80 times chondritic abundances. The patterns show log-linear or slightly convex-upward decreases from the high LREE levels, with a gradual flattening or downward convexity within the HREE towards c. 7–9 times chondrite contents for Yb and Lu in four of the samples. In the case of SM 4 and SM 10 these are more HREE-enriched than other samples, with slightly sharper convex-downward profile and with lu at 12-16 times chondritic concentrations. Despite these slight differences, the type of profile portrayed is characteristic for calc-alkaline basalts from modern island arc settings (Jakes & White 1972, Nicholls et al. 1980) (Fig. 1), and would thus confirm the conclusions reached from the earlier geochemical study concerning the nature of these Ordovician volcanites.

A point to note is that the greatest spread, in terms of pattern, is in the HREE. This could possibly relate to garnet-control, during either partial melting or fractionation. The downward

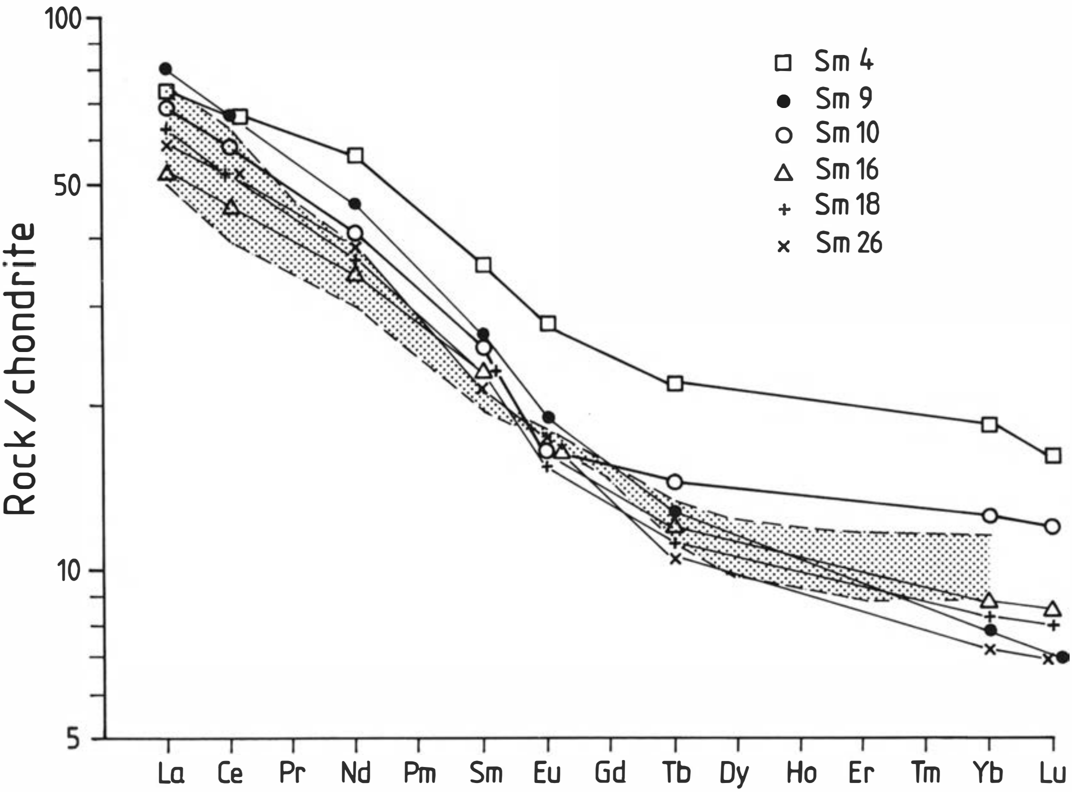

Fig. 1. REE patterns for the Smøla basaltic volcanites. The different symbols refer to original sample numbers SM 4–SM 26. Element normalisation values derive from chondrite data culled from papers by Masuda et al. 1973, Nakamura 1974 and Evensen et al. 1978. The shaded area represents the range of average REE patterns from the calc-alkaline to high-K calc-alkaline basaltic lavas from the Quaternary Sunda island arc, Indonesia (Whitford et al. 1979, Nicholls et al. 1980).

Table 1. Rare earth element and Sc, Hf, Ta, Th and U contents (ppm), and selected ratios, from representative samples of the Ordovician metabasalts from Smøla, west-central Norway.

Sample no.	SM. 4	SM. 9	SM. 10	SM. 16	SM. 18	SM. 26
La	25.2	27.5	23.5	17.8	21.5	20.2
Ce	59.2	60.0	52.0	40.7	47.5	46.7
Nd	36.9	30.0	26.6	22.3	24.0	25.0
Sm	7.50	5.61	5.22	4.80	4.72	4.61
Eu	2.25	1.51	1.31	1.34	1.26	1.37
Tb	1.14	0.64	0.74	0.63	0.58	0.55
Yb	3.70	1.56	2.47	1.70	1.67	1.44
Lu	0.55	0.24	0.42	0.29	0.29	0.24
Sc	25.7	25.9	25.2	32.7	26.4	25.9
Hf	4.40	3.40	4.15	2.29	2.74	2.22
Ta	0.34	0.37	0.52	0.28	0.36	0.44
Th	3.52	6.03	5.57	3.37	4.74	4.31
U	1.35	1.69	1.98	0.56	1.54	1.23
$(La/Yb)_N$	3.89	12.29	5.75	6.12	8.00	9.23
$(La/Sm)_N$	2.00	3.19	2.76	2.26	2.78	2.73

convexity in the REE profiles from Nd through to Yb, however, compares well with REE patterns calculated for up to 15 % fractional melting of an amphibole-bearing lherozolite (using partition coefficients for temperatures of 1000–1100°C) and has little in common with the HREE-depleted profiles determined for liquids from garnet-bearing sources (Nicholls & Harris 1980).

In Fig. 2 the samples are grouped within the field for magma types generated along destructive plate boundaries. Interestingly, their position within this diagram is similar to that for samples from a unit of calc-alkaline volcanics from the Snåsavatn basaltic greenstones of Nord-Trøndelag (Roberts 1981, and in prep.). In this case, however, there are geochemical indications that these particular lavas were erupted closer to a continental margin than was the case for the Smøla rocks. The Snåsavatn greenstones lie in strike continuation from the Smøla volcanites, exhibit a comparable magnetite – pyrite – chalcopyrite mineralisation (Carstens 1956, Fediuk & Siedlecki 1977), and occur in close association with the Snåsa Limestone which itself carries fossils of similar type (Roberts 1980b) and age to those occurring in the Skjølberg Limestone of Smøla (Bruton & Bockelie 1979). This would suggest that products of the mature Middle Ordovician arc can be traced over some 250 km of strike in this part of the central Norwegian Caledonides, from an intra-oceanic setting in the southwest to one nearer to the palaeo-continental margin towards the northeast.

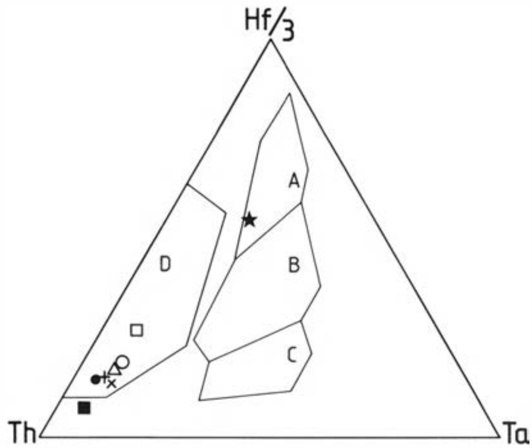

Fig. 2. The Smøla analyses on a Th-Hf-Ta diagram (after Wood et al. 1979). Symbols as in Fig. 1. The Snåsavatn greenstone CAB group average (2 samples) is indicated by a filled square; for comparison, the Snåsavatn OFB group average (4 samples) is marked by an asterisk. Field A – N-type (normal) MORB. Field B – E-type (largely hygromagmatophile element enriched) MORB. Field C – within-plate basalts. Field D – basalts formed at destructive plate boundaries (both island arc and Andean type).

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