The geochemistry of Lower Proterozoic mafic to felsic igneous rocks, Rombak Window, North Norway

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The supracrustal sequence of the Rombak Basement Window, consisting of volcanic rocks, pelitic sediments, greywackes with minor amounts of carbonate rocks and quartzites, was intruded by mafic dykes, mafic to intermediate plutons and a variety of granitoid batholiths c. 1.8-1.7 Ga ago. The region has experienced amphibolite-grade metamorphism, followed by retrogression to greenschist facies along Caledonian shear-zones.

On the basis of their petrographic and geochemical characteristics the volcanic rocks can be divided into 3 suites: (1) high-Mg basalts; (2) mafic to felsic volcanites with fairly high potassium contents and with calc-alkaline affinities; and (3) low-potassium, calc-alkaline felsic volcanites.

Based on major element geochemistry the evolution of the potassic volcanites is interpreted to have been controlled, in the case of mafic-intermediate varieties, by early fractionation of Fe, Mg-rich minerals, and by plagioclase crystallisation for the felsic varieties. Suites 2 and 3 are similar to associated granites and granodiorites in their chemical composition.

It is concluded that the volcano-sedimentary and intrusive rocks were formed in an Lower Proterozoic mature magmatic arc environment at the southern margin of a continent composed predominantly of Archaean tonalitic granitoid rocks and Lower Proterozoic greenstone terranes.

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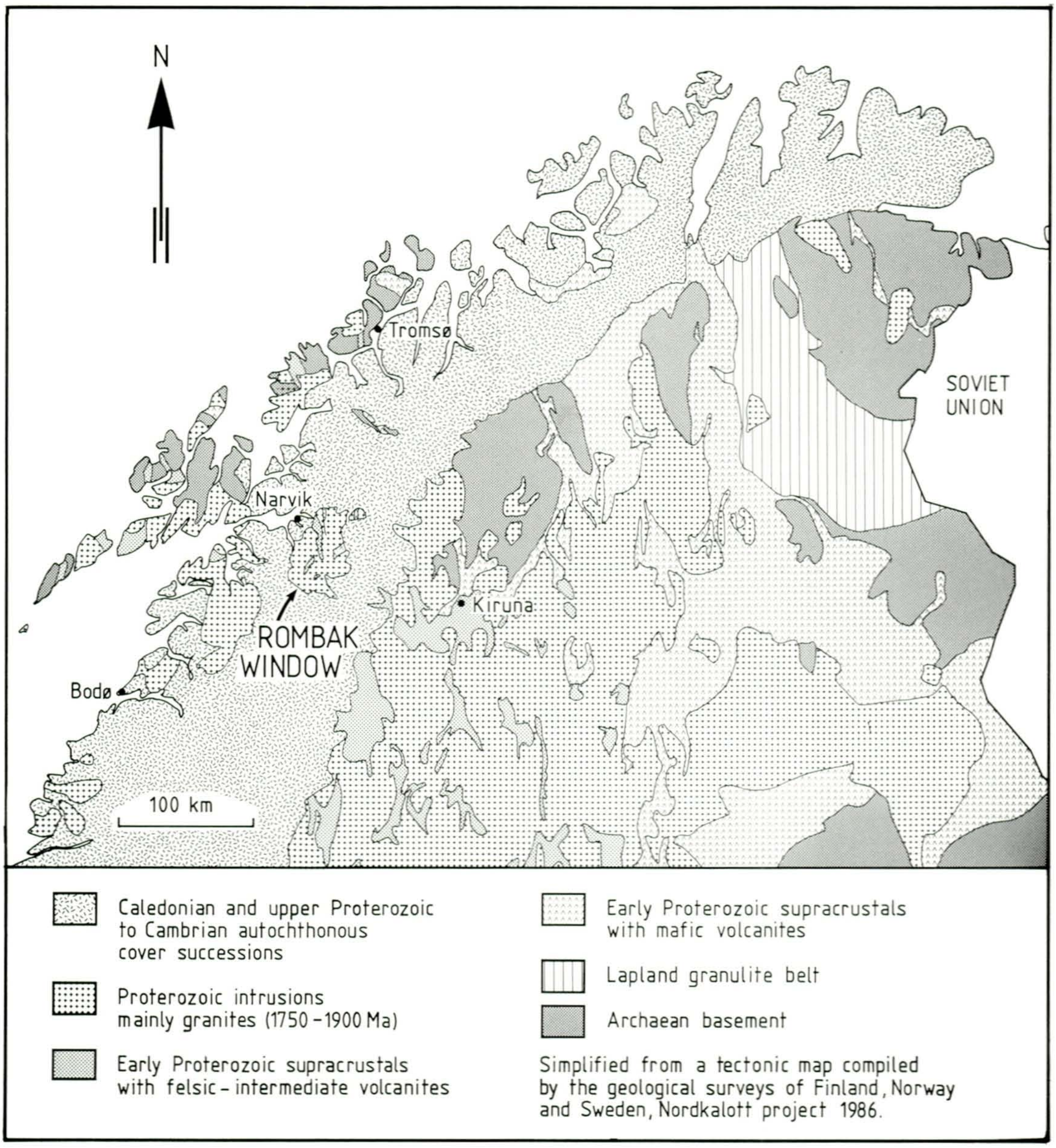
Introduction

The Rombak Basement Window is situated near the southern margin of the Archaean Domain (Pharaoh & Pearce 1984, Öhlander et al. 1987) of the Baltic Shield (Fig. 1). The window contains Lower Proterozoic supracrust al sequences consisting of turbidites and mafic to felsic volcanites that have been intruded by numerous, large, felsic to mafic plutons. The Proterozoic rocks of the window are surrounded by the allochthonous Caledonian nappe complexes (Gustavson 1974 a & b, Tull et al. 1985), and locally by a thin sequence of autochthonous sediments belonging to the Late Proterozoic to Cambrian Dividal Group (Vogt 1942, Gustavson 1974 a, Birkeland 1976).

On a regional scale, the Archaean of the Baltic Shield consists principally of felsic to intermediate, partly tonalitic gneisses with subordinate greenstone belts (Witschard 1984, Gaál & Gorbatschev 1987, Öhlander et al. 1987). In the earliest Proterozoic (c. 2.4 Ga) the Archaean craton was fragmented by episodes of rifting, and greenstone terranes formed by the submarine eruption of large volumes of basaltic (and some komatiitic) magma in these rifts (Gaal & Gorbatschev 1987). In northern Sweden, supracrustal sequences south of both the Lower Proterozoic greenstone terranes and the Archaean craton are dominated by volcanites that show a continuous compositional range from mafic to felsic types, and that have ages between 1.9 Ga and 1.8 Ga (Fritsch & Perdahl 1987).

The purpose of this paper is to describe the geochemistry of volcanic rocks that are part of the Lower Proterozoic supracrustal sequences exposed in the Rombak Window. The compositional characteristics of the volcanites, and of spatially associated plutonic rocks, are then discussed in the context of an evolving magmatic arc located above a subduction zone that is postulated to have existed in the region at some time between 1.9 and 1.7 Ga.



Simplified from a tectonic map compiled by the geological surveys of Finland, Norway and Sweden, Nordkalott project 1986.

Fig. 1. Major geological units of the northern part of the Baltic Shield in Norway, Sweden and Finland. Simplified from a tectonic map compiled by the geological surveys of Finland, Sweden and Norway, Nordkalott Project 1986.

Geologic setting of the Rombak Basement Window

Age relations

At present, very few rocks in the Rombak Window have been dated. Romer (this volume) has obtained an age of 2.3 Ga (Rb-Sr) for a suite of high-Mg, low-K_2O basalts in the Ruvssot-Sjangeli area. The relationship between the Ruvssot-Sjangeli supracrustal belt and the other belts in the western part of the window is not clear because the two regions are separated by a major, N-S-trending shear zone that is well exposed at Muohtaguobla

(Fig. 2). However, by analogy with volcanic rocks of similar composition and texture from dated supracrustal sequences of northern Sweden (Fritsch & Perdahl 1987, Widenfalk et al. 1987), supracrustal belts west of the Muohtaguobla Tectonic Zone probably have ages between 1.91 and 1.88 Ga. All the supracrustal sequences of the Rombak Basement Window have been extensively intruded by large plutons consisting predominantly of granite, but also including syenite, diorite and gabbro. Granites have been dated at 1.78 and 1.69 Ga (Rb-Sr) by Gunner (1981) and Heier & Compston (1969), respectively.

Lithology

A distinct feature of the Rombak Window is the pattern of N-S trending linear supracrustal belts (fig. 2) preserved between extensive regions of younger plutonic rocks (Vogt 1942, Gustavson 1974a & b, Birkeland 1976, Robyn et al. 1985, Korneliussen et al. 1986 a & b). Small rafts and inclusions of the supracrustal rocks are locally abundant in the plutons. All of the supracrustal rocks and the Early Proterozoic plutonic rocks of the Rombak Basement Window are metamorphosed at least under PT-conditions of the lower amphibolite facies.

The rocks within the window are variably deformed and show a generally N-S-trending, more-or-less vertical foliation. The contacts between the supracrustal belts and the surrounding granites are commonly sheared. Within the supracrustals, practically undeformed volcanic and sedimentary rocks with well-preserved primary textures are common.

The rock types present, and their relative proportions, vary considerably from one supracrustal belt to the next across the Rombak Window. The Sørdalen Supracrustal Belt in the southwestern part of the window (Fig. 2) is composed mainly of predominantly porphyritic, mafic, intermediate and felsic volcanites. Several units of mafic/intermediate amygdaloidal volcanites together with felsic volcanites have been identified (Fig. 3); locally, thin units of sediment separate distinct, mappable volcanic units. Debris flows are interbedded with the flows, particularly on the southern side of the belt. Clast size in the debris flows varies from under 1 dm to 0.5 m, and indicates a high-energy environment of deposition. The lowermost (eastern) felsic volcanite unit in the Sør-

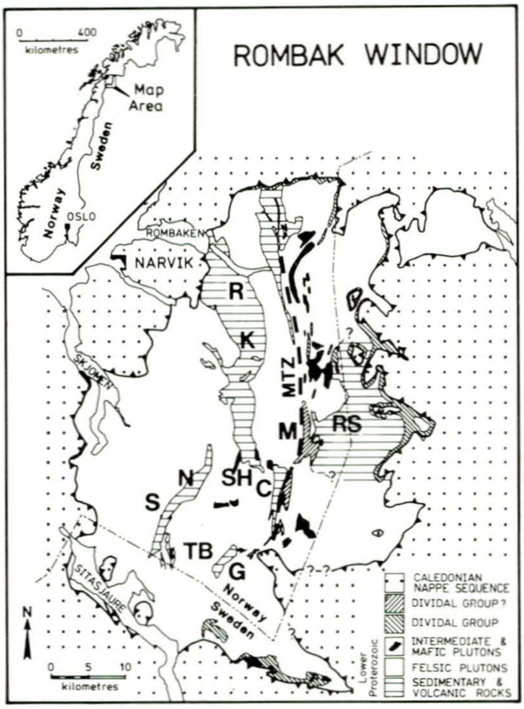


Fig. 2. Generalized geological map of the Rombak Window based on Sawyer & Korneliussen (this volume). Locations mentioned in the text: S — Sørdal, G — Gautelis, TB — tonalitic basement, N — Norddal, SH — Stasjonsholmen, M — Muohtaguobla, MTZ — Muotaguobla Tectonic Zone, RS — Ruvssot-Sjangeli, K — Klubbvatnet, R — Rombaksbotn, C — Cainhavarre.

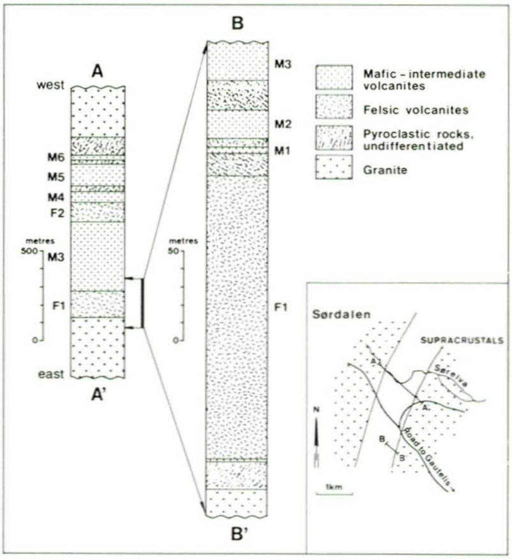


Fig. 3. Volcanic and sedimentary units of the Sørdalen Supracrustal Belt.

dalen Supracrustal Belt is K-feldspar-bearing and closely resembles volcanites at Cainhavarre.

The Stasjonsholmen-Rombak Supracrustal Belt contains a thick sequence of graded pelite-greywacke turbidites, with tuffitic layers in places. Amygdaloidal lavas with associated debris flows are developed at Klubbvatnet in the central to northern part of the Stasjonsholmen-Rombak Supracrustal Belt (Robyn et al. 1985).

In the Muohtaguobla area mafic and intermediate lavas (containing acicular plagioclase phenocrysts), felsic tuffs, pelites and graphitic schists, are complexly intermixed with cross-bedded quartzites and conglomerates belonging to the Dividal Group. The complexity of outcrop pattern in this area is of tectonic origin (Romer & Boundy 1988), since the region probably represents a Caledonian imbrication zone (terminology of Butler 1982) within the Rombak Window.

In the eastern part of the window the Ruvssot-Sjangeli supracrustal sequence contains mafic and ultramafic volcanites, fine-grained biotite schists, greywackes and silicate-banded carbonates (Romer 1988), and generally resembles a greenstone association. The mafic/ultramafic volcanic rocks occur as amphibolites (locally pillowed) and serpentinites, some of which contain up to 28% MgO.

At Gautelis (fig. 2) the supracrustal sequence is dominated by a turbidite sequence, but thin horizons of tuffitic mafic and felsic volcanites, conglomerates and debris flows are locally developed (Skonseng 1985). Pebbles in the scattered conglomeratic horizons consist of fine- to coarse-grained tonalite and granodiorite that resemble a nearby body of tonalite (called the Gautelis Tonalite Complex). The status of this complex is important, as it might represent older (perhaps Archaean) basement. It is overlain by a basal conglomerate containing clasts derived from the tonalite, and a dolomitic carbonate indicating platform sedimentation, followed by the turbidite sequence.

The individual volcanic units within the turbiditic pelites and greywackes in different parts of the window range in thickness from a few centimetres to approximately 10 m, and are in general tuffitic. In contrast, the thick volcanite (up to 1 km) successions are dominantly lava flows. This is clearly indicated by the presence of amygdules in some cases (Klubbvatnet and Sørdalen), and of delicate needle-shaped plagioclase phenocrysts (Muohtaguobla and Sørdalen) in others. Flow structures are preserved in some rhyolitic flows from the Stasjonsholmen area. Our interpretation is that the volcanites were erupted adjacent to a deep basin that was periodically receiving turbidite flows. Explosive volcanic eruptions formed ash which spread out over a large area. Where waterlain, the ash formed tuffitic horizons intercalated with the turbidites. A dominance of felsic over mafic volcanic pebbles in the debris flows in Sørdalen may indicate a larger volume of felsic volcanic material near to the volcanic centres.

The oldest intrusive rocks known in the Rombak Basement Window are those of the medium- to coarse-grained Gautelis Tonalite Complex. The Gautelis Tonalite Complex and the overlying conglomerate, dolomitic carbonate and turbidite sequence are intruded by a swarm of mafic dykes. These are in turn intruded by the numerous large plutons dated at about 1.78 Ga (Rb/Sr) by Gunner (1981). Minor mafic to felsic dykes cut the plutons and are of unknown age, although Gunner (1981) presents some evidence that they may be 1.3 Ga old (Rb/Sr).

Metamorphism

The Rombak window, at least in its central, western and southwestern parts, has been metamorphosed under amphibolite facies conditions (P 6kb, T 575°C; Sawyer 1986). Evidence for this is the widely preserved prograde mineral zonation patterns found in the intermediate and mafic volcanites. The age of this prograde metamorphism has not been clearly established, but is probably Lower Proterozoic. A greenschist-facies metamorphism has overprinted the rocks of the window to varying degrees; in most places its effects are minor, or even absent. However, in the Muohtaguobla area the greenschist-facies metamorphism has virtually obliterated all evidence of the earlier higher temperature event. The intensity of retrogression in the Muohtaguobla area is spatially related to the Caledonian deformation that has imbricated Lower Proterozoic and Dividal rocks (cf. Romer & Boundy 1988); hence the greenschist-facies metamorphism is likely to be of Caledonian age.

Geochemistry

Representative major and trace element analyses of extrusive and intrusive rocks from the Rombak Basement Window are given in Table 1. The major oxides were determined by XRF using fused glass beads. The trace elements V to Nb were determined by XRF using pressed powder pellets. The rare earths (REE), and Cs, Th, U, Ta and Hf were determined by instrumental neutron activation analysis. A complete list of all analysis is available from A. Korneliussen on request. For the element variation diagrams presented below, analyses are recalculated to an anhydrous basis.

Alteration processes involving relatively mobile elements such as Na_2O and K_2O, cannot be excluded. Analyses of rocks from shear zones in Sørdalen indicate some mobility of certain elements, but this appears to be relatively minor (these results are not included in this paper). There is a fairly good consistency between plots presented below involving elements which are generally accepted to be among the least mobile, i.e. Th, Hf, Ta, Nb, Y, Zr, Ti and the REE. This indicates an insignificant degree of element mobility during altera-

	Muohtag. (SN)		Cainhav. (SN)		Stasjonsh. (SN)		Gautelis (G)	
Sample	K301.3	K302.3	K254.3	K104.4	K101.4	K269.3	K101.5	K103.5
SiO2	63.60	61.78	69.59	68.48	77.87	76.35	75.70	72.72
Al2O3	18.41	18.54	14.23	13.93	11.19	11.65	13.01	13.87
Fe2O3	2.72	3.12	3.82	4.94	2.80	3.28	1.27	1.75
MnO	.06	.06	.06	.07	.02	.03	.02	.04
MgO	.58	.74	.37	.76	.15	.05	.29	1.44
CaO	2.05	2.08	1.57	1.46	.67	.35	1.36	1.92
Na2O	5.50	5.10	3.10	4.10	2.50	1.60	6.17	4.70
K2O	6.23	6.11	5.76	4.99	4.80	6.83	1.03	2.14
TiO2	.84	.79	.53	.56	.17	.23	.22	.26
P2O5	.25	.28	.12	.10	.01	.01	.03	.05
I.L.	1.29	.65	.63	.75	.45	.24	.53	.94
SUM	101.53	99.25	99.78	100.14	100.62	100.61	99.62	99.84
V	18	26	29	30	nd	nd	13	28
Sc	6	nd	6	8	nd	nd	4	8
Co	nd	nd	nd	8	nd	nd	10	3
Cr	nd	nd	13	13	nd	nd	nd	4
Ni	nd	nd	7	9	nd	nd	2	6
Cu	nd	nd	13	64	nd	nd	3	2
Zn	40	40	47	62	34	52	7	22
Pb	nd	13	20	23	26	38	12	11
Rb	107	71	226	228	259	300	25	69
Sr	206	380	186	116	176	74	290	333
Ba	1100	2300	896	822	94	46	886	1356
Zr	26	29	322	337	828	617	189	180
Y	9	9	45	51	79	83	17	19
Nb	7	nd	16	17	35	32	17	18
Cs	.76	-	-	3.10	4.77	-	.35	1.56
Th	.44	-	-	21.80	25.70	-	10.80	10.20
U	nd	-	-	7.74	7.30	-	4.90	2.19
Ta	nd	-	-	1.45	2.19	-	1.62	2.04
Hf	.64	-	-	8.60	17.50	-	5.05	4.44
La	21	20	63	61.20	86.00	135	42.60	34.90
Ce	38	38	98	132.00	191.00	220	78.50	68.50
Nd	17	18	46	52.50	73.30	92	25.90	23.40
Sm	3.70	3.30	10.70	8.84	14.30	18.30	4.04	3.49
Eu	2.80	3.20	1.20	1.10	.12	.29	.78	.78
Tb	.41	.39	1.20	1.20	1.84	2.10	.58	.42
Yb	.65	.66	4.50	4.19	6.63	7.60	2.25	1.63
Lu	.10	.11	.68	.71	1.04	1.18	.32	.23

nd = not detected; - = not determined

Table 1 (b). Major and trace element abundances in selected felsic volcanic rocks.

	Ruvssot (RS)		Sørdalen (SN)						
Sample	R1.3	R22.3	M1	M2	M3	M4	M5	M6	ARA
SiO2	48.57	45.55	49.57	54.26	58.83	57.94	54.99	49.99	54.26
Al2O3	9.88	7.49	11.92	14.10	16.18	16.38	17.80	17.91	15.72
Fe2O3	13.04	10.63	9.39	7.65	7.35	6.30	7.92	9.64	8.04
MnO	.09	.16	.18	.15	.13	.11	.08	.13	.13
MgO	7.75	20.56	11.19	6.19	3.20	1.94	1.74	3.75	4.67
CaO	6.86	8.85	9.47	6.18	5.35	5.06	4.48	7.83	6.40
Na2O	4.10	.50	2.63	4.05	3.59	4.60	4.90	3.97	3.96
K2O	.17	.03	2.69	3.91	3.12	3.78	4.36	2.84	3.45
TiO2	1.30	.25	.90	.89	.96	1.31	1.73	1.72	1.25
P2O5	.12	.02	.42	.38	.24	.40	.76	.68	.48
I.L.	6.86	4.28	1.41	.89	.86	.58	.38	.92	
SUM	98.74	98.32	99.77	98.65	99.81	98.42	99.14	99.38	
V	213	168	167	121	126	109	97	224	141
Sc	21	26	21	13	15	11	12	17	15
Co	36	89	54	31	21	17	18	36	30
Cr	277	2200	520	182	112	19	nd	58	149
Ni	90	1000	233	123	21	15	13	55	77
Cu	11	8	nd	nd	8	nd	5	9	5
Zn	38	98	174	151	166	122	71	100	131
Pb	nd	nd	nd	13	26	13	15	15	15
Rb	nd	nd	152	148	146	152	175	139	152
Sr	107	9	914	647	448	653	830	1423	829
Ba	56	25	1313	1550	721	1233	1567	1806	1365
Zr	93	25	112	236	190	415	419	197	262
Y	13	8	19	24	29	29	36	30	25
Nb	6	nd	12	19	11	24	27	15	18
Cs	-	nd	18.20	8.85	7.11	-	-	-	12.72
Th	-	.33	5.33	12.20	8.27	-	-	-	7.47
U	-	nd	.79	1.78	3.84	-	-	-	2.14
Ta	-	.07	.56	.93	.82	-	-	-	.64
Hf	-	.42	2.50	5.33	4.05	-	-	-	3.66
La	14	.66	48.00	66.80	35.03	91	105	104	74.52
Ce	25	nd	97.50	131.00	71.93	156	187	176	135.55
Nd	16	nd	33.30	39.50	27.20	68	88	84	55.89
Sm	3.40	.43	6.29	6.77	6.11	11.5	15.4	14.8	9.98
Eu	.97	.19	1.71	1.50	1.30	2.8	3.7	3.9	2.54
Tb	.27	.14	.79	.54	.83	.97	1.20	1.20	.92
Yb	1.40	1.12	1.70	2.28	2.62	2.60	2.60	3.3	2.47
Lu	.26	.14	.23	.35	.37	.45	.46	.67	.42

nd = not detected; - = not determined

Table 1 (a). Major and trace element abundances in selected mafic volcanic rocks.

	Mafic intrusions							Granites		Tonalites	
	Sørdal		Gautelis		Norddal			Sørdal		Gautelis	
Sample	KS11.3	K75.4	K133.4	K152.3	K273.3	K268.3	ARBI	KS5.3	KS36.3	K140.5	K143.5
SiO2	48.59	47.81	48.38	47.79	55.27	50.50	49.72	76.76	71.24	67.29	71.94
Al2O3	16.03	16.41	16.32	13.53	14.29	14.94	15.25	12.47	13.93	14.91	15.27
Fe2O3	12.63	12.12	12.36	14.71	10.83	12.19	12.47	1.36	3.54	4.47	1.31
MnO	.25	.18	.17	.20	.15	.18	.19	.02	.04	.05	.04
MgO	6.48	6.89	6.22	5.58	4.26	6.25	5.95	.08	.40	1.54	.42
CaO	8.47	7.93	9.67	9.21	6.15	8.88	8.39	.72	1.06	3.60	1.74
Na2O	3.20	3.40	2.30	2.70	2.70	2.50	2.80	3.30	2.50	4.50	6.59
K2O	2.07	2.39	1.20	1.37	3.04	1.45	1.92	5.06	6.45	2.12	1.52
TiO2	1.68	1.60	1.34	2.10	1.65	1.49	1.64	.10	.47	.54	.17
P2O5	.32	.29	.40	.83	.62	.35	.47	.01	.12	.13	.05
I.L.	.69	1.05	.90	.89	.86	1.31		.44	.40	.83	.78
SUM	100.41	100.08	99.26	98.91	99.82	100.04		100.33	100.15	99.98	99.83
V	197	214	247	326	169	208	227	nd	15	56	15
Sc	27	24	29	34	20	31	28	nd	5	8	4
Co	53	56	43	38	34	42	36	nd	nd	6	3
Cr	45	46	79	103	91	134	83	nd	nd	9	nd
Ni	48	46	77	55	24	31	47	nd	5	7	nd
Cu	5	77	66	23	13	15	33	6	11	11	4
Zn	129	93	133	120	131	142	125	33	59	36	17
Pb	12	nd	11	15	20	16	14	38	24	12	11
Rb	76	117	39	55	144	64	83	366	242	55	34
Sr	400	404	455	397	378	387	404	35	118	377	490
Ba	434	374	580	574	938	483	564	77	800	967	719
Zr	74	74	78	112	186	116	107	156	338	180	112
Y	23	19	21	34	40	26	27	88	48	16	11
Nb	nd	nd	5	nd	13	nd	5	14	17	12	9
Cs	-	18.70	2.10	-	-	2.00	7.60	-	-	1.40	.61
Th	-	.25	.93	-	-	2.00	1.06	-	-	7.58	11.60
U	-	.57	.32	-	-	.85	.58	-	-	1.48	1.84
Ta	-	.12	.22	-	-	.35	.23	-	-	1.13	.75
Hf	-	1.60	1.90	-	-	3.04	2.18	-	-	4.57	3.19
La	13	9.91	18.50	32	44	24.50	23.65	63	105	30.60	43.50
Ce	25	21.50	39.30	65	88	52.20	48.50	104	172	62.90	84.40
Nd	17	11.00	14.00	37	44	20.70	23.95	43	73	20.60	26.30
Sm	4.70	3.07	4.01	8.90	9.60	4.58	5.81	10.30	13.10	3.94	3.87
Eu	1.80	1.24	1.45	2.20	2.00	1.44	1.69	.17	1.40	.98	.64
Tb	.51	.68	.75	1.00	.72	.72	.73	1.80	1.50	.58	.40
Yb	1.70	1.76	2.12	2.50	3.30	2.44	2.30	7.40	3.70	1.44	1.00
Lu	.31	.31	.37	.50	.50	.32	.39	1.23	.61	.18	.13

nd = not detected; - = not determined

Table 1 (c). Major and trace element abundances in selected intrusive rocks.

tion as far as these elements are concerned. For the plots involving the more mobile elements Na_2O and K_2O some scatter caused by alteration is likely to occur, though it is assumed that the igneous trend in these plots is real since the interpretation of the major and trace element plots is relatively consistent.

Extrusive rocks

Major elements: A plot of (Na_2O + K_2O) versus SiO_2 (Fig. 4) for the volcanites of the Rombak supracrustal belts shows that the 2.3 Ga Ruvssot-Sjangeli volcanites are more mafic and contain less alkalis than volcanites from west of the Muohtaguobla Tectonic Zone. Three of the Ruvssot-Sjangeli samples clearly represent liquid compositions (2 samples with >28% MgO are probably cumulates) and are subalkaline. In contrast, the mafic and intermediate volcanites from the Sørdalen, Muohtaguobla and Rombak areas plot across the boundary between the alkaline and subalkaline fields. For rocks with >66 % SiO_2 the (Na_2O + K_2O) versus SiO_2 plot is not a useful means of distinguishing between alkaline and subalkaline series. However, Fig. 4 shows that the volcanites from west of the Muohtaguobla Tectonic Zone, i.e. the Sørdalen mafic-intermediate and felsic volcanites and the Stasjonsholmen, Cainhavarre and Muohtaguobla felsic volcanites in the Norddal area, form a continuous range in SiO_2 contents from 50 to 78 %, with a preponderance of andesitic compositions.

The Na_2O versus K_2O plot (Fig. 5) illustrates three important compositional differences within the Rombak volcanites: (a) The Ruvssot-Sjangeli extrusives are K_2O-deficient and have variable, but low, Na_2O contents; (b) the Gautelis felsic volcanites from within the Gautelis Tonalite Complex have a higher Na_2O/K_2O ratios than the other volcanites from west of the Muohtaguobla Tectonic Zone; and (c) within the Sørdalen, Stasjonsholmen, Muohtaguobla and Rombak volcanites the mafic members

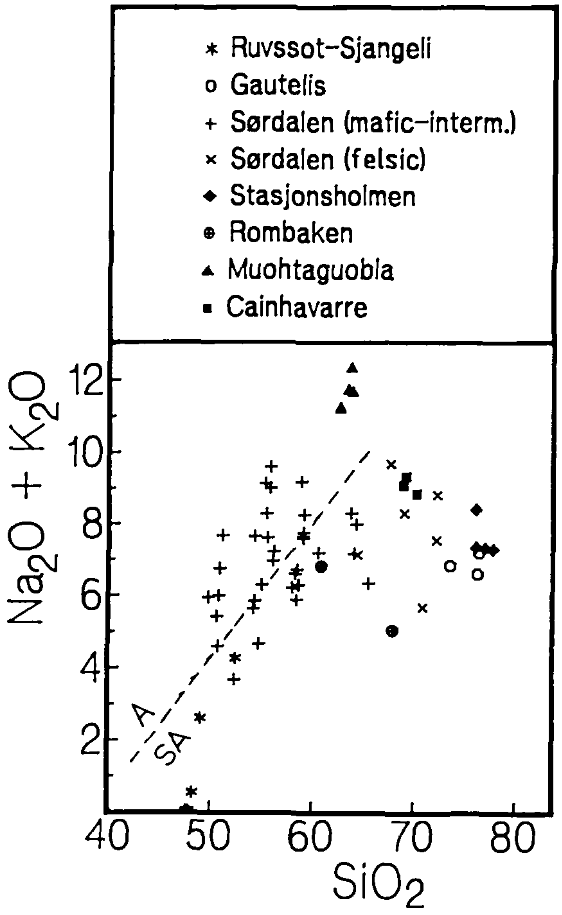


Fig. 4. (Na_2O+K_2O) versus SiO_2 plot for the Rombak Window volcanites. A - alkaline, SA - subalkaline.

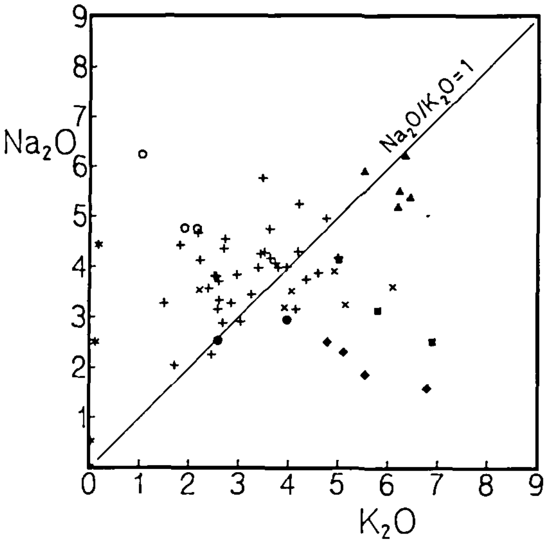


Fig. 5. Na_2O versus K_2O plot for the Rombak Window volcanites. Symbols as in Fig. 4.

have higher Na_2O/K_2O ratios than the associated felsic volcanites.

On the basis of Figs. 4 and 5 the volcanites of the Rombak Window supracrustal sequences are divided into three principal types: (1) The RS (Ruvssot-Sjangeli)-type; low-K_2O mafic to ultramafic subalkaline extrusives from the 2.3 Ga supracrustal belt in the Ruvssot-Sjangeli area. (2) The G (Gautelis)-type; low-K_2O, high-Na_2O rhyodacitic to rhyolitic volcanites within the Gautelis Tonalite Complex. (3) The SN (Sørdal-Norddal)-type; a suite of mafic to felsic, generally K_2O-rich extrusives that are characteristic of the Sørdalen-Norddalen area, but occur widely in the supracrustal belts west of the Muohtaguobla Tectonic Zone.

The three types of volcanites are shown on a (Na_2O+K_2O)-FeO_{tot}-MgO plot (Fig. 6). Some of the SN-type volcanites were clearly classified as alkaline on Fig. 4, and Fig. 6 confirms that the SN volcanites cannot be part of a tholeiitic trend, but belong to either the alkaline suite or the calc-alkaline suite defined by Irvine & Baragar (1971). Thus, on the basis of major elements alone the largest group of volcanic rocks in the Rombak Window (the SN-type) cannot be classified with certainty, but the predominance of andesitic compositions favours a calc-alkaline affinity. In contrast, the G-type rocks (three samples) are classified directly as belonging to the calc-alkaline suite and the RS-rocks as tholeiitic (see below), though the mafic member of the RS-type plot near to the tholeiitic/calc-alkaline boundary.

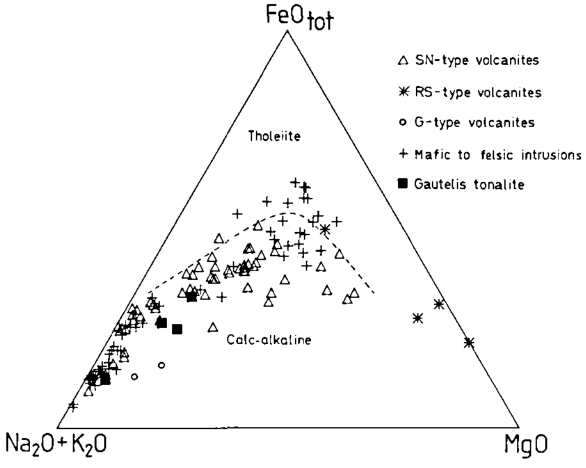


Fig. 6. The Rombak Window suite of volcanic and intrusive rocks plotted in an AFM diagram.

Trace elements: Chondrite-normalised REE patterns for the Rombak volcanites are shown in Fig. 7. All the samples, except those from the ultramafic rocks of the RS group (Fig. 7a), have similar REE patterns that are enriched in the light rare earths (LREE), but have essentially unfractionated heavy rare earths (HREE). The mafic RS-type volcanite (Fig. 7a) differs somewhat from either the SN- or the G-type volcanites (compare Figs. 7a, b, and c) in its lower La/Sm_N ratio. Nevertheless, the LREE-enriched patterns of the SN-, G- and mafic RS-type volcanites resembles the REE patterns of calc-alkaline mafic and andesitic magmas (e.g. McBirney et al. 1987, Meen & Eggler 1987, Gill 1981), but contrasts with the smooth REE patterns characteristic of alkali basalts and andesites (e.g. Eiche et al. 1987, Lanphere & Frey 1987, Frey 1981, Gill 1981). Thus, the REE patterns suggest that the Rombak mafic to felsic volcanites belong to the calc-alkaline suite.

In general, the felsic rocks have higher total REE contents than the more mafic rocks. The change in REE abundance is accompanied by a change in the Eu anomaly present, as is demonstrated by the felsic members of the SN-type volcanites (Fig. 7b). The samples with the highest total REE contents have large negative Eu anomalies, whereas the samples with low total REE contents have positive Eu anomalies. This feature is here ascribed to low-pressure fractionation of feldspar (probably plagioclase) in the parental magma.

The REE pattern for the ultramafic extrusives of the RS-type (lowermost curve on Fig. 7a) is LREE-depleted, and ranges from 1 to 4 times chondritic values. This type of pattern is interpreted as indicating that these rocks were derived from a LREE-depleted mantle. The REE pattern and low Zr content of these ultramafic rocks resembles Type I (also known as aluminium undepleted) komatiites (Sun & Nesbitt 1978, Jahn et al. 1982), but because the Ruvssot-Sjangeli samples are Ti-depleted they also have some affinities with boninitic magmas. Boninite series volcanites, however, range from 52 to 68 % SiO_2 (Bloomer & Hawkins 1987).

In order to examine the compositional variations of a number of trace elements simultaneously, normalised element plots ('spidergrams') are used (Fig. 8). In Fig. 8 the trace elements with a strong affinity for the silicate melt — the hygromagmatophile elements (HYG)

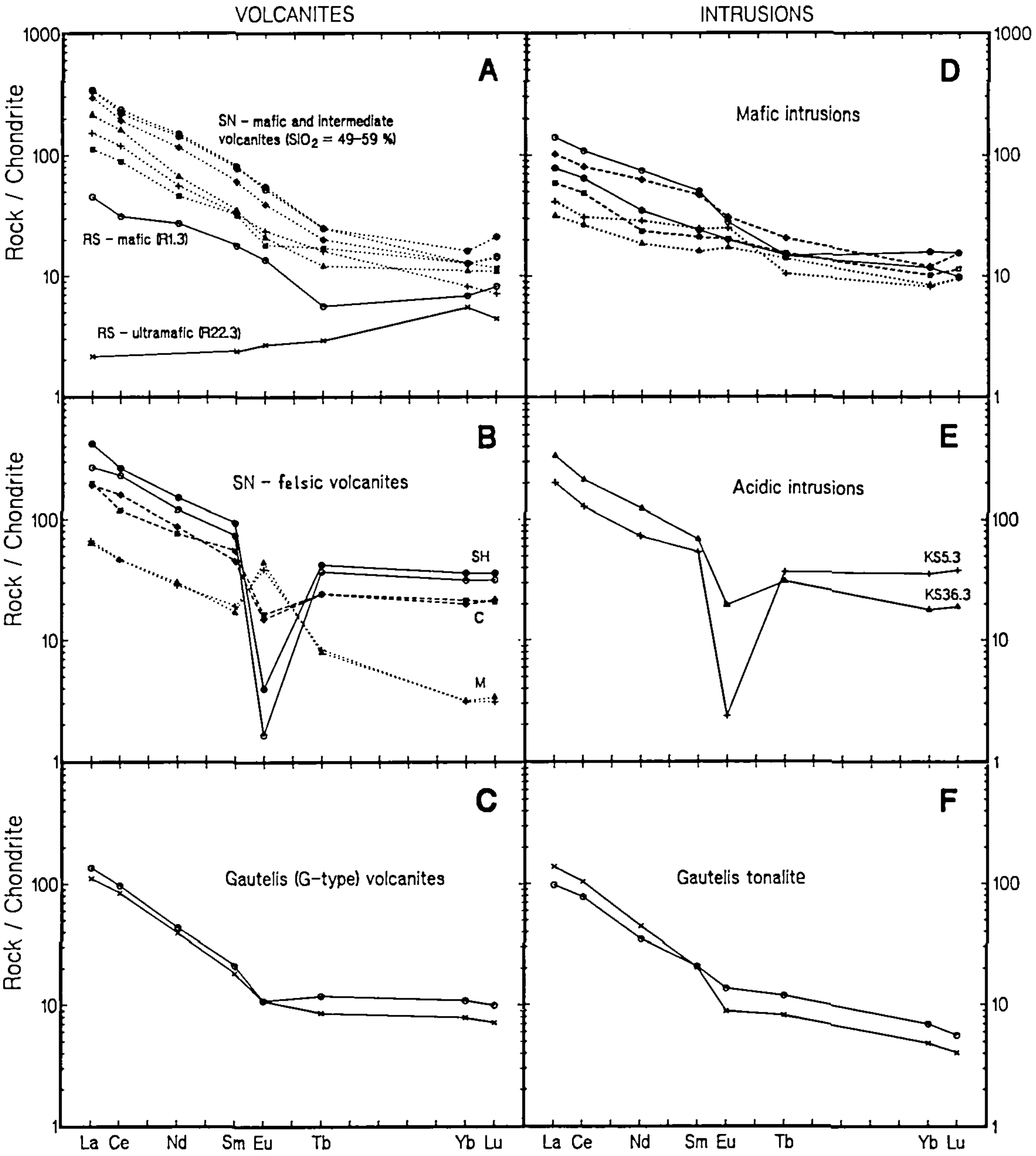


Fig. 7. Chondrite-normalised REE patterns for Rombak volcanites and intrusive rocks (normalising factors from Taylor & Gorton, 1977). (A) RS-type mafic and ultramafic extrusives and SN-type mafic and intermediate volcanites. (B) SN-type felsic volcanites. SH — Stasjonsholmen, C — Cainhavarre, M — Muohtaguobla. (C) G-type volcanites. (D) Mafic dykes from Sørdal (dashed) and Gautelis (stippled) and small mafic plutons from Norddal (solid lines). (E) Two granitic batholites from Sørdal (solid lines); one from the western side of the Sørdal supracrustal belt (KS5.3) and the other from the eastern side (KS36.3). (F) Tonalitic rocks from the Gautelis tonalite complex. Note that the Gautelis tonalite complex exhibits HREE fractionation and has a nearly smooth REE pattern compared with the G-type volcanites, suggesting that they may not be related.

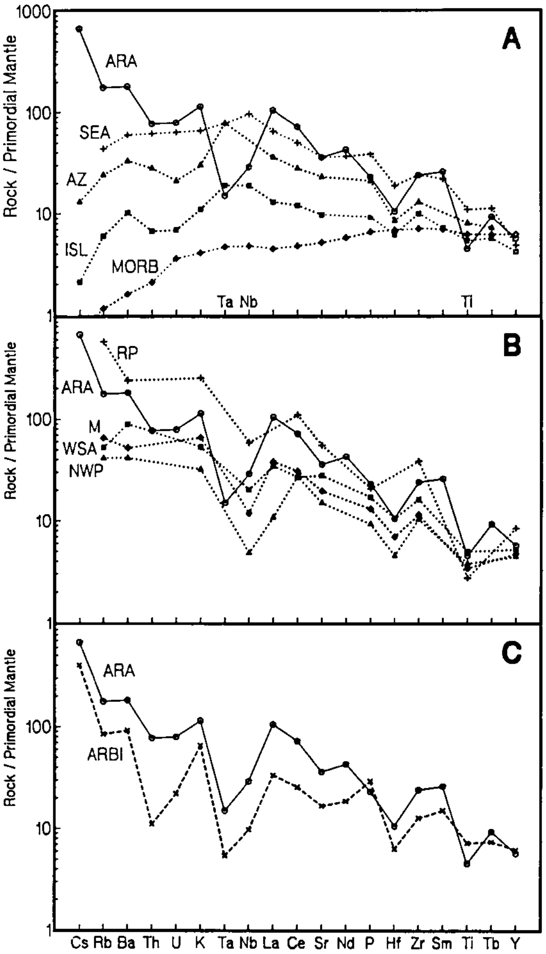


Fig. 8. The composition of some Rombak Window rocks normalised to the primordial mantle. The elements have been arranged after the scheme of Wood (1979) in the order of increasing calculated bulk partition coefficient for mantle mineralogies, i.e. the more 'incompatible' elements to the left in the diagram.

(a) Comparison of average Rombak Basement Window basaltic andesite (ARA) with selected mafic lavas from anorogenic tectonic environments. ARA is the average of the six mafic-intermediate units M1 to M6 from the Sørdal profile (Fig. 3). SEA — a basanite from Victoria, SE Australia; AZ — Azores basalt; ISL — an Icelandic basalt, MORB — normal mid ocean ridge basalt. Data after Wood et al. 1979.

(b) Rombak Window andesite (ARA) compared to orogenic andesites (52–56 % SiO_2). The apparent similarity suggests that the Rombak Window andesites are of orogenic type, i.e. subduction-related. RP — K-rich Series of Volcanic Roman Province, Mediterranean; M — Mediterranean (excluded K-rich Series of Roman Province); WSA — Western (Andean) South America; NWP — North-Western Pacific. Andesite data after Ewart (1982).

(c) Comparison of Rombak Window mafic dykes and minor mafic plutons represented by the average of 6 analysed samples from Sørdal, Gautelis and Stasjonsholmen (ARBI; see REE-plots of the individual samples in Fig. 7d) and ARA.

of Frey & Gordon (1974) — are arranged in order of increasing D values (mineral/liquid partition coefficients) for partial melting under mantle conditions of low P_{H_2O} and P_{O_2}. The abundance of HYG-elements in the Rombak samples is then normalised to the values found in primordial mantle (i.e. undepleted mantle) using the mantle values of Wood (1979). Compared to anororogenic basalts (Wood 1979) the Rombak basaltic andesites (represented by the average Rombak Window basaltic andesite — ARA) are characteristically enriched in the more HYG-elements and display a distinct negative Ta-Nb anomaly (Fig. 8a). Thus, it is inferred that the Rombak Window basaltic andesites are not of a anorogenic type. In contrast, when compared to orogenic (or subduction-related) andesites (Fig. 8b) a strong similarity in HYG-element contents is observed, suggesting a similar origin. The relative enrichment of the large ionic lithopile (LIL) elements such as Cs, Rb, K and Ba in subduction-related rocks is considered to be the result of the dehydration, or incipient melting, of subducted lithosphere enriching the overlying mantle wedge (Hanson 1977, Best 1975, Hawkesworth et al. 1977). The depletion of Ta, Nb and Ti in the subduction-related igneous rocks is attributed to the retention of a Ta-Nb-rich refractory titanium oxide phase at high P_{H_2O} and P_{O_2} conditions in the overlying mantle wedge (Best 1975, Hawkesworth et al. 1977, Sun 1979).

Intrusive rocks

Some workers (e.g. McCarthy & Groves 1979, Tindle & Pearce 1981) have pointed out that many granitic plutons are predominantly accumulations of crystals, and do not necessarily represent melt compositions; thus comparison with volcanic rocks is not straightforward. For the purposes of this study our primary point in documenting the compositional characteristics of the Rombak Window plutonics is to show their close compositional similarity with the SN-volcanites.

Major elements: On the (Na_2O+K_2O)-FeO_{tot}-MgO plot (Fig. 6) the intrusive rocks generally plot along a calc-alkaline trend similar to the SN-type volcanites. Many mafic dykes and minor mafic plutons are, however, iron enriched compared with the mafic SN-type volcanites, and they plot on the tholeiite side of the tholeiitic-/calc-alkaline boundary. A corresponding phosphorus and titanium enrichment for these rocks (ARBI) is shown in Fig. 8c.

Trace elements: Figs. 7 d-f show the chondrite-normalized REE patterns of mafic dykes and minor plutons and felsic plutonic rocks from the Rombak Window. The Rombak Window intrusive rocks have REE patterns of similar shape, specifically LREE-enriched and without significant fractionation of the HREE. The REE patterns therefore resemble those of the calk-alkaline rocks in the area. In general, the Rombak intrusive rocks have REE pattern of similar shape and level as the SN-type volcanites which they intrude.

On the mantle-normalised hygromagmatophile element diagram, Fig. 8c, the Rombak Window mafic dykes and minor plutons are enriched in the LIL elements in a manner similar to the SN-type extrusive rocks. Furthermore, they also have prominent negative Ta-Nb and Ti anomalies, indicative of subduction-related magmas.

Discussion

Several Lower Proterozoic volcanic terranes in North America and on the Baltic Shield bear a striking resemblance to modern arc systems in lithological and geochemical characteristics (Condie 1987, Vivallo & Claesson 1987, among others). A common problem is the bimodality in the volcanic successions, with a rarity of andesites; in proper arcs the volcanic suites show a continuous evolution from mafic to felsic including large volumes of andesite. A bimodality, however, can be explained by a rifting of the volcanic arc (Condie 1987, Vivallo & Claesson 1987) and is not at all contradictory to a hypothesis that modern-style plate tectonics were active in the Lower Proterozoic. It is particularly interesting to observe that a convincing ophiolite complex has been described from northeast Finland (Kontinen 1987), giving the best evidence so far that modern plate-tectonic processes were active in the Lower Proterozoic. Thus, an interpretation of the rocks in the Rombak Window in the context of modern plate tectonics is relevant.

On the basis of major and trace elements and REE data the ultramafic rocks of the Ruvssot-Sjangeli area are shown to be comparable to komatiites, and the SN-, G- and mafic RS-type volcanites all belong to the calc-alkaline suite. Potassic andesite is the most common rock type within the most extensive volcanites: the SN-type. Various discrimination diagrams have been proposed to classify the tectonic settings of volcanic and plutonic rocks by means of their geochemistry, and these have been applied to the Rombak Window volcanites. The Th-Hf-Ta concentrations of mafic to felsic volcanic and intrusive rocks from the Rombak Window are plotted in the diagram (Fig. 9) of Wood et al. (1979), which has the advantage of being able to distinguish the tectonic settings of both mafic and felsic magma types. The Rombak igenous rocks plot well within the field D in Fig. 9, which is the field for magma suites formed along destructive plate margins, i.e. subduction-related magmas. On the TiO_2 versus Zr plot of Pearce et al. (1981) the indicated tectonic setting of the Rombak volcanites and intrusives with SiO_2 contents ‹56 % is transitional from 'arc' to 'within-plate' (Fig. 10); the MORB possibility is excluded for lithological reasons. The same transitional character is shown on the Rb versus (Y+Nb) plot (Fig. 11) for the SN-type volcanites and the Rombak granites. However, the Rb-poor Gautelis Tonalite Complex and G-type volcanites plot well within the 'volcanic arc' field.

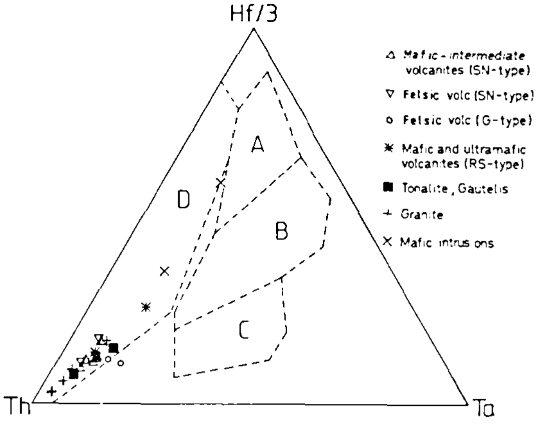


Fig. 9. Mafic and felsic volcanic and intrusive rocks plotted in the Th-Hf-Ta discrimination diagram after Wood et al. (1979) and Wood (1980). Field A — N-type MORB; field B — E-type MORB; field C — within-plate basalts: field D — magma series at destructive plate margins.

From Table 1 and Figs. 5 and 7 it can be seen that many of the SN-type volcanites are high-K calc-alkaline andesites. Recently, Gill (1981) and Meen (1987) have discussed the

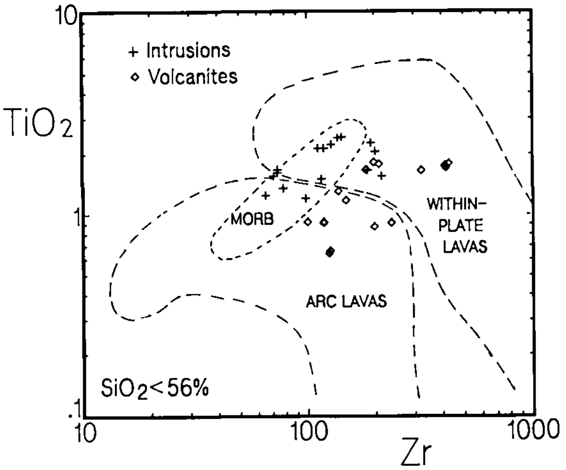


Fig. 10. Volcanites and mafic dykes and minor plutons (SiO_2 ‹56%) plotted on the TiO_2-Zr diagram after Pearce (1980).

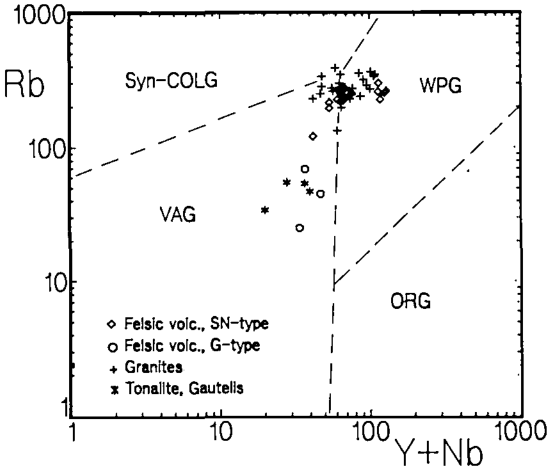


Fig. 11. Volcanic and intrusive rocks (SiO_2 › 56%) plotted in the Rb-(Y+Nb) discrimination diagram of Pearce et al. (1984). Syn-COLG — syn-collisional granites, WPG — within plate granites, ORG — ocean ridge granites, VAG — volcanic arc granites.

origin of such rocks and noted that they often have a definite spatial and temporal association with low-K calc-alkaline andesites and high-potassium andesites of alkaline affinity (shoshonites). Meen (1987) has proposed that the observed transition from low-K calc-alkaline to high-K calc-alkaline to shoshonitic andesites away from the trench is related to the depth at which fractional crystallization takes place in a magmatic arc: the more potassic rocks originating beneath the thickest crust. Thus, the SN-type volcanic rocks of the Rombak Window could represent magmas extruded through a thick crust, and on the log (CaO/(Na_2O + K_2O)) versus SiO_2 diagram of Brown (1982) they do indeed plot on the «increasing arc maturity» side of normal calc-alkaline andesites.

A major problem in the interpretation of the earliest Proterozoic evolution of this region is the paucity of precise age-determinations. The conglomerate which overlies the Gautelis Tonalite Complex (with the G-type volcanites) is itself overlain by a dolomitic carbonate that is in turn overlain by the greywacke sequence. The nature of the carbonate-greywacke contact is not yet known. The Gautelis Tonalite complex represents the local basement and could be of either Archaean or Lower Proterozoic age. In either case the conglomerate indicates an erosional period that was followed by platform carbonate sedimentation. The Gautelis greywacke-tuffite sequence indicates the later formation of sedimentary basins that received sediment derived in part from calc-alkaline volcanic rocks (SN-type). The tectonic setting of the sedimentary basin was near to either a volcanic island or a magmatic arc sited on continental crust, since thick piles of volcanic rocks indicate a position proximal to the volcanic centres; a more distal position for the greywackes and pelites is indicated by the thin interbedded tuffs.

Sawyer & Korneliussen (this volume) have shown that the tectonic setting in which the greywackes (turbidites) formed can be inferred from their composition by determining the possible source-rock types. The turbidites from Rombaksbotn and Gautelis formed in an active marginal basin setting adjacent to a mature volcanic arc that was, in the case of Gautelis, probably located on a tonalitic crust of Lower Proterozoic or Archaean age. An Andean-type setting is proposed. From a consideration of the geochemistry of the SN-type volcanites it is possible to elaborate on the history of that magmatic arc.

The high MgO content in some of the SN-type volcanites indicates that the parental magma originated by the partial melting of a mantle source. As indicated by the REE patterns (Fig. 7b) of the felsic SN-volcanites, fractional crystallization has been a major factor in the evolution of the calc-alkaline volcanites. A negative Ta-Nb anomaly (Fig. 8b) and the

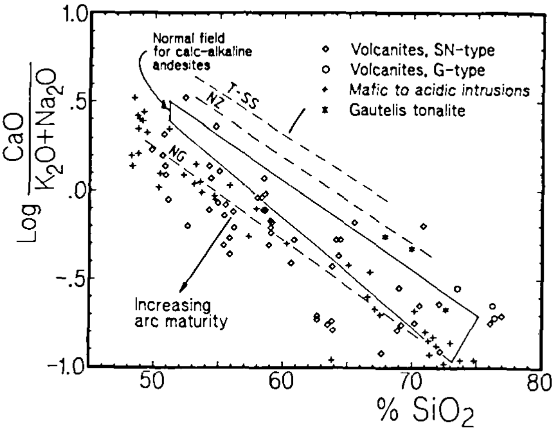


Fig. 12. Plot of log ($CaO/(Na_2O+K_2O)$) against SiO_2 for volcanic and intrusive rocks in the Rombak Window (RS-type excluded). The trends for volcanic suites from modern magmatic arcs and the field indicating the range for normal calc-alkaline andesites are from Brown (1982). T-SS - Tonga-S.Sandwich; NZ - New Zealand; NG - New Guinea.

enrichment of the LIL-elements in the basaltic andesites indicates a subduction-related magma origin. Thus three stages are envisioned: (1) The parental magma may have originated in the mantle wedge above the related subduction zone, followed by (2) crystal fractionation by Fe-Mg silicates to generate fractionated, gradually more siliceous, intermediate magmas; and finally (3) a late stage of magma evolution in which the felsic magmas were formed, and which was, to a large extent, controlled by the fractional crystallization of plagioclase, presumably at shallow crustal levels. During this process significant interaction with crustal rocks is likely to have occurred. In modern geological settings magmatic rocks similar to those of the Rombak Window potassic calc-alkaline suite are believed to have originated beneath a thickened crust. Thickening may result from magma injection into, or magma extrusion onto the crust; in either case potassic calc-alkaline volcanites represent a late-stage mature or 'continentised' stage of magmatic arc development (Fig. 12). Since no rocks with distinct alkaline REE pattern were found in the Rombak Window there is no reason to suppose that the magmatic arc reached the stage of rifting.

The Ruvssot turbidites are more mafic than those from Gautelis or Rombaksbotn, and appear to contain neither continent-derived, nor fractionated volcanic material; thus, Sawyer & Korneliussen (this volume) proposed an intraoceanic setting. Furthermore, they were able to determine that the Ruvssot turbidites contain material that could have been derived from RS-type volcanites. The komatiitic affinity of the ultramafic members of the RS-type volcanites and their associated low-K mafic calc-alkaline pillow basalts that show only slight LREE-enrichment is consistent with a primitive, intra-oceanic island arc setting for the volcanic rocks of eastern Rombak Basement Window.

Thus, the eastern part of the Rombak Basement Window contains the remnants of the early stages of an intra-oceanic arc volcanism which occurred at about 2.3 Ga. In contrast, the western part of the window contains the remains of a younger, but pre-1.78 Ga, mature volcanic arc located on continental crust perhaps of Archaean, but probably of Proterozoic age. The present close spatial relationship of these two terranes may be due to either Lower Proterozoic collision, or crustal shortening of the Lower Proterozoic crust during the Caldonian orogeny.

It is interesting to note that in northern Sweden, the supracrustal rocks south of the Archaean Domain (Fig. 1) are dominated by a continuous series of mafic to felsic volcanites of continental affinity (Fritsch & Perdahl 1987). Their age is 1.9 Ga based on U-Pb dating of zircons (Skiöld 1988). In the Skellefte district (300 km south of Kiruna) this province gives way southwards to a somewhat older, predominantly felsic volcanic province of marine affinity (Claesson 1985, Wilson et al. 1987). It has been suggested that the Skellefte province could be related to the northward-directed subduction of oceanic crust under a Lower Proterozoic continent (e.g. Hietanen 1975, Wilson et al. 1987), and that the continental province north of the Skellefte district represents a continent-based magmatic arc which developed after the marine magmatic arc (Wiedenfalk et al. 1987).

In contrast to the Skellefte calc-alkaline/tholeiitic volcanic suite which shows a bimodality with a scarity of andesitic rocks (Vivallo 1987), the dominant type of volcanic rock in the Rombak Window (the SN-type) shows a continuous evolution from calc-alkaline basalt to rhyolite with a large proportion of andesite. The bimodal character of the Skellefte volcanic suite led Vivallo (1987) to suggest that the Skellefte volcanic arc was dominated by extensional forces during long periods, probably producing incipient rifting. There is no reason to suppose that the Rombak Window magmatic arc reached the stage of rifting. It is possible to make a tentative correlation that could be tested by precise age determinations, that the Gautelis Tonalite Complex in the Rombak Basement Window is equivalent to the Jörn tonalitic complex (Claesson 1985) and its associated felsic volcanic rocks in the Skellefte district of Sweden. The younger greywacke-volcanite sequence (SN-type) may then have formed in the Rombak equivalent of the continent-based magmatic arc of northern Sweden. If such a correlation is correct, then the Gautelis Tonalite Complex has an age of approximately 1.9 Ga, and the greywackes and calc-alkaline SN-type potassic volcanism are somewhat younger.

Conclusions

The 2.3 Ga Ruvssot-Sjangeli intra-oceanic volcanic arc rocks and associated turbidite sequence are the oldest rocks found in the eastern part of the Rombak Window, whereas in the south rocks of the Gautelis Tonalite Complex (unknown age) are the oldest. The Gautelis Tonalite Complex is overlain by a basal conglomerate and a sequence of dolomitic carbonates indicating platform sedimentation. After carbonate deposition a sequence of turbidites and potassic arc-related volcanites (the SN-type) developed, presumably at about 1.9 Ga. The composition of these calc-alkaline volcanic rocks ranges from that of basalt to rhyolite, but is predominantly andesitic, and is consistent with the arc being of a mature, continentised-type resting upon tonalitic continental crust. At present it is not known whether the Ruvssot-Sjangeli and Gautelis rocks formed a continuous basement to the carbonates, or whether the sequence was assembled during a Lower Proterozoic collision event prior to 1.9 Ga.

The similarities in major element and trace element composition between the potassic arc-related volcanites and the 1.78 Ga intrusive rocks (Figs. 6, 7, 8 & 12) indicate a related source. Thus, the abundant plutonic rocks in the Rombak Window could, perhaps, represent a later and deeper stage of mantle activity as the volcanic arc thickened.

Acknowledgements

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References

Best, M.G. 1975: Migration of hydrous fluids in the upper mantle and potassium variation in calc-alcalic rocks. *Geology 3,* 429–432.

Birkeland, T. 1976: Skjomen, berggrunnsgeologisk kart N10 - M 1:100000. *Nor. geol. unders.*

Bloomer, S.H. & Hawkins, J.W. 1987: Petrology and geochemistry of boninitic series volcanic rocks from the Marianas Trench. *Contr. Mineral. Petrol. 97,* 361–377.

Brown, G.C. 1982: Calc-alkaline intrusive rocks: their diversity, evolution, and relation to volcanic arcs. *In* Thorpe, R.S. (ed.) *Orogenic andesites and related rocks.* John Wiley, London, 437–61.

Butler, R.W.H. 1982: The terminology of structures in thrust belts. *J. Struct. Geol. 4,* 239–246.

Condie, K.C. 1987: Early Proterozoic volcanic regimes in southwestern North America. *In* Pharaoh, T.C., Beckinsale, R.D. & Rickard, D. (eds.) *Geochemistry and Mineralization of Proterozoic Volcanic Suites.* Geol. Soc. Spec. Publ. 33, 211–218.

Claesson, L.Å. 1985: The geochemistry of Early Proterozoic metavolcanic rocks hosting massive sulphide deposits in the Skellefte district, northern Sweden. *J. Geol. Soc. London 142,* 899–909.

Eiche, G.E., Francis, D.M. & Ludden, J.N. 1987: Primary alkaline magmas associated with the Quarternary Alligator Lake volcanic complex, Yukon Territory Canada. *Contr. Mineral. Petrol. 95,* 191–201.

Frey, F.A. 1981: Application of neutron activation analysis in mineralogy and petrology. *In* Muecke, G.H. (ed) *Neutron Activation Analysis in the Geosciences.* Min. Assoc. Canada Short Course 5, 167–210.

Frietsch, R. & Perdahl, J.-A. 1987: On the nature of lower Proterozoic volcanic rocks in southern Norrbotten, northern Sweden. *Proterozoic Geochemistry (symp.), IGCP 217, Lund,* (abstr.) p. 35.

Gaál, G. & Gorbatschev, R. 1987: An outline of the Precambrian evolution of the Baltic Shield. *Precamb. Res. 35,* 15–52.

Gill, T. 1981: *Orogenic Andesites and Plate Tectonics.* Springer Verlag, 390 pp.

Gunner, J.D. 1981: A reconnaissance Rb-Sr study of Precambrian rocks from the Sjangeli-Rombak Window and the pattern of initital ^{87}Sr/^{86}Sr ratios from northern Scandinavia. *Nor. Geol. Tidsskr. 61,* 281–290.

Gustavson, M. 1974 a: Narvik. Beskrivelse til det berggrunnsgeologiske gradteigskart N9 - 1:100000. *Nor. geol. unders. 308,* 34 pp.

Gustavson, M. 1974 b: Geologisk kart over Norge, berggrunnskart Narvik 1:250000. *Nor. geol. unders.*

Hanson, G.N. 1977: Evolution of the sub-oceanic mantle. *J. Geol. Soc. London 134,* 235–253.

Hawkesworth, C.J., O'Nions, R.K., Pankhurst, R.J., Hamilton, P.J. & Evensen, N.M. 1977: A geochemical study of island-arc and back-arc tholeiites from the Scotia sea. *Earth Planet. Sci. Lett. 36,* 253–262.

Heier, K. & Compston, W. 1969: Interpretation of Rb-Sr age pattern in high-grade metamorphic rocks, North Norway. *Nor. Geol. Tidsskr. 49,* 257–283.

Jahn, B.-M., Gruru, G. & Glikson, A.Y. 1982: Komatiites of the Onverwacht Group S.Africa. REE geochemistry, Sm/Nd age and mantle evolution. *Contr. Mineral. Petrol. 80,* 25–40.

Kontinen, A. 1987: An Early Proterozoic ophiolite — the Jormua mafic-ultramafic complex, northeastern Finland. *Precamb. Res.,* 313–341.

Korneliussen, A. & Sawyer, E. 1986: Berggrunns-og malmgeologi med særlig vekt på muligheter for gull, sydlige deler av Rombakvinduet, Nordland. *Nor. geol. unders. Unpubl. report 86.167,* 70 pp.

Korneliussen, A., Tollefsrud, J.I., Flood, B. & Sawyer, E. 1986: Precambrian volcano-sedimentary sequences and related ore deposits, with special reference to the Gautelisfjell carbonate-hosted gold deposit, Rombak basement window, Northern Norway. *Nor. geol. unders. Unpubl. report 86.193,* 46 pp.

Lanphere, M.A. & Frey, F.A. 1987: Geochemical evolution of Kohala Volcano, Hawaii. *Contr. Mineral. Petrol. 95,* 100–113.

McBirney, A.R., Taylor, H.P. & Armstrong, R.L. 1987: Paricutin re-examined: a classic example of crustal assimilation in calc-alkaline magmas. *Contr. Mineral. Petrol. 95,* 4–20.

McCarthy, T.S. & Groves, D. I. 1979: The Blue Tier batholite, northeastern Tasmania. *Contr. Mineral. Petrol. 71,* 193–209.

Meen, J.K. 1987: Formation of shoshonite from calc-alkaline basalt magmas: geochemical and experimental constraints from the type locality. *Contr. Mineral. Petrol. 97,* 333–351.

Meen, J.K. & Eggler, D.H. 1987: Petrology and geochemistry of the Cretaceous Independence volcanic suite, Absaroka Mountains, Montana: Clues to the composition of the Archaean sub-Montana mantle. *Bull. Geol. Soc. Am. 98,* 238–247.

Öhlander, B., Skiöld, T., Hamilton, P.J. & Claesson, L.Å. 1987: The western border of the Archaean province of the Baltic Shield: evidence from northern Sweden. *Contr. Mineral. Petrol. 95,* 437–450.

Pearce, J.A. 1980: Geochemical evidence for the genesis and eruptive setting of lavas from Tethyan ophiolites. *In* Panayiotou, A. (ed.) *Ophiolites* Proceedings, International Ophiolite Symposium, Nicosia. Cypros Geol. Surv., 261–272.

Pearce, J.A., Alabaster, T., Shelton, A.W. and Searle, M.P. 1981: The Oman ophiolite as a Cretaceous arc-basin complex: evidence and implications. *Phil. Trans. R. Soc. A 300,* 299–317.

Pearce, J.A., Harris, N.B.W. & Tindle, A.G. 1984: Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *Journ. Petrol. 25,* 956–983.

Pharaoh, T.C. & Pearce, J.A. 1984: Geochemical evidence for the geotectonic setting of Early Proterozoic metavolcanic sequences in Lapland. *Precamb. Res. 10,* 283–309.

Robyn, T.L., Flood, B., & Thomassen, B. 1985: A comparison of geophysical data and geological mapping, Rombak Precambrian window, northern Norway. *47 th. E.A.E.G. meeting in Budapest,* 26 pp.

Romer, R.L. 1988: *Disturbance of Pb, Sr and Nd isotope systems related to medium and low grade metamorphism illustrated with data from the polymetamorphic Early Proterozoic (Rombak)-Sjangeli basement window of the Caledonides of Northern Sweden.* Doctoral Thesis, Luleå Univ. of Technology, 1988:65 D, 124 pp.

Romer, R.L. & Boundy, T.M. 1988: Lithologic and tectonic profile across the Muohtaguobla area, Rombak basement window, Northern Norway. *Nor. geol. unders. Unpubl. report 88.116,* 11 pp.

Sawyer, E, 1986: Metamorphic assemblages and conditions in the Rombak basement window. *Nor. geol. unders. Unpubl. report 86.168,* 25 pp.

Skiöld, T. 1988: Implications of new U-Pb zircon chronology to Early Proterozoic crustal accretion in northern Sweden. *Precamb. Res. 38,* 147—164.

Skonseng, E. 1985: Berggrunnsgeologisk kartlegging i Gautelisområdet, Skjomen, Nordland. Feltrapport. *Nor. geol. unders. Unpubl. report 85.214,* 16 pp.

Sun, S.S. 1980: Lead isotope study of young volcanic rocks from mid-ocean ridges, ocean islands and island arcs. *Phil. Trans. R. Soc. London, Ser. A. 297,* 409—445.

Sun, S.S. & Nesbitt, R. 1978: Petrogenesis of Archaean ultrabasic and basic volcanics: Evidence from rare earth elements. *Contrib. Mineral. Petrol. 65*, 301—325.

Taylor, S.R. & Gorton, M.P. 1977: Geochemical application of spark source mass spectrography — III. Element sensitivity, precision and accuracy. *Geochem. Cosmoch. Acta 41,* 1375—1380.

Tindle, A.G. & Pearce, J.A. 1981: Petrogenetic modelling of in situ fractional crystallization in the zoned Loch Doon pluton, Scotland. *Contrib. Miner. Petrol. 78,* 196—207.

Tull, J.F., Bartley, J.M. Hodges, K.V., Andresen, A., Steltenpohl, M.G. & White, J.M. 1985: The Caledonides in the Ofoten Region (68—69 N), North Norway: key aspects of tectonic evolution. *In* D.G. Gee & B.S. Sturt (eds.) *The Caledonide Orogen — Scandinavia and Related Areas.* John Wiley & Sons, Chichester, 553—568.

Vivallo, W. 1987: Early Proterozoic bimodal volcanism, hydrothermal activity, and massive sulfide deposition in the Boliden-Långdal area, Skellefte district, Sweden. *Econ. Geol. 82,* 440—456.

Vivallo, W. & Claesson, L.-Å. 1987: Intra-rifting and massive sulphide mineralization in an Early Proterozoic volcanic arc, Skellefte district, northern Sweden. *In* Pharaoh, T.C., Beckinsale, R.D. & Rikard, D. (eds.) *Geochemistry and mineralization of Proterozoic volcanic suites.* Geol. Soc. Spec. Publ. 33, 69—79.

Vogt, T. 1942: Trekk av Narvik-Ofoten traktens geologi. *Nor. Geol. Tidsskr. 21,* 198—213.

Widenfalk, L., Claesson, L.-Å. & Skiöld, 1987: Rocks associated with uplift of a Proterozoic continental margin, N. Sweden. *Proterozoic Geochemistry (symp.), IGCP 217, Lund, (abstr.),* p. 92.

Wilson, M.R., Claesson, L.Å., Sehlstedt, S., Smellie, J.A.T., Aftalion, M., Hamilton, P.J. & Fallic, A.E. 1987: Jörn: an early Svecokarelian granitoid complex from northern Sweden. *Precamb. Res. 36,* 201—225.

Witschard, F. 1984: The geological and tectonic evolution of the Precambrian of northern Sweden — a case for basement reactivation? Precamb. Res. 23, 275—315.

Wood, D.A. 1979: A variably veined suboceanic upper mantle - Genetic significance for mid-ocean ridge basalts from geochemical evidence. *Geology 7,* 499—503.

Wood, D.A., Joron, J.-L. & Treuil, M. 1979: A re-appraisal of the use of trace elements to classify and discriminate between magma series erupted in different tectonic settings. *Earth Planet. Sci. Lett. 45,* 326—336.

Wood, D.A. 1980: The application of the Th-Hf-Ta diagram to problems of tectonomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the British tertiary volcanic province. *Earth Planet. Sci. Lett. 50,* 11—30.