Marginal basin type metavolcanites of the Hersjø Formation, eastern Trondheim District, Central Norwegian Caledonides.

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The more than 300 km long greenstone belt of the eastern Trondheim district in the Caledonian Upper Allochthon displays considerable heterogeneity in lithology as well as metavolcanite geochemistry. A largely bimodal mafic-felsic volcanic assemblage comprises submarine flows, agglomerates, tuffs and tuffites. In many areas, especially in the south, these are intimately related to interlayered metapelitic units, graphitic phyllites, thin marbles and conglomerates. The metavolcanites in the investigated central area, in the Hersjø Formation, show a conspicuous tripartite subdivision in their geochemical traits: 1) A group of HFS element-poor metabasalts to subordinate andesites with LREE-depleted to slightly enriched patterns show differentiation trends and inter-element ratios characteristic of island arc tholeiites, although some have high Cr contents. 2) A group of metabasalts with compositions and trends comparable to somewhat fractionated MORB's, but with Th/Ta ratios suggesting a subduction zone affinity. 3) A LREE-enriched, bimodal metabasalt-rhyolite assemblage showing iron and titanium enrichment trends with inter-element ratios transitional between calc-alkaline and within-plate basalts. It is suggested that the early Tremadoc Hersjø Formation originated during the early stages of a marginal basin opening by rifting of a magmatic arc, with magma tapping from a heterogeneous mantle above an active, or previously active, west-dipping, subduction zone. Basin extension took place near a continental margin or a microcontinent, with contemporaneous deposition of sediments of platform affinity, probably on the Laurentian side of Iapetus. The marginal basin spreading migrated westwards in the early Tremadoc - Arenig interval, as reflected by the presence of predominantly MORB-type ophiolites in the western Trondheim District, before initial obduction of the marginal basin crust in approximately middle to late Arenig time.

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Introduction

In the eastern part of the Trondheim region a more or less continuous greenstone belt stretches from south of Dombås in the SSW to southeast of Snåsa in the NNE, a distance of more than 300 km. These metavolcanites have been variously termed the Musadal Group in the Dombås-Lesja area (Guezou 1978), the Fundsjø Group in the northern Meråker - Verdal area (Wolff 1967), and the Hersjø Formation in the central, Folldal-Røros district (Rui 1972). Generally these rocks have been correlated with the Støren Group greenstones of the western Trondheim district (Wolff 1967, 1979), although recent studies have cast some doubt on this correlation (Grenne & Lagerblad 1985).

The Eastern Trondheim District (ETD) greenstone belt contains a large number of synvolcanic, stratiform Zn-Cu-Fe sulphide deposits. More than 20 mines have been operating in the period from the middle of the seventeenth century until 1986. The majority of deposits were small, however, and only 5 orebodies exceeded 1 million metric tonnes (m.t.), with a maximum size of about 3 m.t. The biggest were found in the Folldal district, and at Killingdal (Rui 1973) and Hersjø north and west of Røros. The original shapes of the massive sulphide deposits are masked by the strong deformation; present morphologies range from thin plates to ruler-like bodies. Remnants of hydrothermal feeder-zones have been recognized adjacent to massive ore in only a few deposits. The ores are pyritic, with variable but generally minor contents of pyrrhotite. Although almost all were mined exclusively for chalcopyrite, a general feature of the ETD volcanite-hosted sulphide ores is a marked predominance of sphalerite over chalcopyrite. Zn values typically range from 3 to 15%, and Cu from less than 1% to 3% (Bjørlykke et al. 1980). This, together with a lead content of 0.2-0.4% in several deposits, distinguishes the ETD volcanogene sulphides from those of the Western Trondheim District ophiolites, which have very low Pb values and higher Cu/Zn ratios (Grenne et al. 1980, Grenne 1986).

The northern (Fundsjø) part of the greenstone belt is situated in the Meråker Nappe (Wolff 1979), a part of the Köli Nappe Complex in the Upper Allochthon of the Scandinavian Caledonides (Gee et al. 1985). In the Meråker-Verdal area, the Fundsjø Group is separated from the structurally overlying Gula Group or Complex to the WNW (Wolff & Roberts 1980) by a steeply dipping tectonic contact. The metavolcanites are stratigraphically overlain by grey and calcareous phyllites of the Sulåmo Group to the east, from which they are locally separated by a conglomerate composed of clasts derived from the volcanic complex (Chaloupsky 1967, Wolff 1967). The Sulåmo Group is overlain by a thick sequence of calcareous turbiditic greywackes belonging to the Kjølhaugen Group (Siedlecka 1967), and above these, black phyllites of the Slågan Group contain graptolites of Silurian (Llandovery) age (Getz 1890).

The Fundsjø Group has generally been correlated with the Hersjø Formation to the south, although Stephens & Gee (1985) suggest that the Fundsjø and Hersjø metavolcanic sequences are separated by a tectonic contact, the Hersjø situated in the easternmost part of the Gula Nappe. The predominantly metasedimentary Gula rocks have been interpreted to represent an epicontinental type of depositional environment (Guezou 1978); but the Gula *may* also include Precambrian elements (Wolff & Roberts 1980). A trondhjemite body (at Vakkerlien, Kvikne) within the sequence has given a U/Pb zircon age of 509+5/-4 Ma (Klingspor & Gee, referred in Stephens et al. 1985). The age of the ETD greenstone belt itself is not well established, although spatially the Hersjø part of it is very closely associated with Dictyonema-bearing black phyllites of early Tremadocian age (see below).

Recent investigations (Grenne & Lagerblad 1985) have shown that some dolerite dykes in the Fundsjø Group cut early isoclinal folds and metamorphic fabrics in the volcanites, indicating an early Caledonian deformation prior to uplift and erosion with deposition of the overlying successions. This is supported by the presence of predepositional metamorphic fabrics in clasts in the basal conglomerate of the Sulåmo Group (Roberts 1967). Furnes et al. (1980) suggested that the Fundsjø Group and the Gula Complex were tectonically juxtaposed in earliest Ordovician times and that both these units suffered a common, early Ordovician deformation and metamorphism. By early Ordovician time, also the Støren Group greenstones in the western Trondheim district were accreted to the Gula, and in this area the faunal assemblage in sediments lying unconformably above the Støren shows a mainly Laurentian affinity (Bruton & Bockelie 1980).

In the Tydal area (Fig.1) a large, synorogenic layered mafic intrusion (The Fongen-Hyllingen gabbro complex) was emplaced in the folded ETD greenstone belt (Hersjø Formation) and, according to Rui (1972) and Nilsen (1971), also partly in Gula rocks (see discussion below). Syenitic differentiates from this complex have yielded a zircon U/Pb age of 426 Ma (Wilson et al.1983).

Bimodal metavolcanites in the Eastern Trondheim District

The ETD greenstone belt displays considerable lithological variations, both across and along strike. In the north, where the tectonic thickness of the *Fundsjø* part of the greenstone belt reaches some 9 km, it comprises amphibolites and quartz keratophyres, usually finely interlayered (Wolff 1973), with subordinate layers of coarse tuffs. The proportion of felsic metavolcanites can be estimated to 15-20% of the volcanic complex (Grenne & Lagerblad 1985). In addition to the effusive felsic rocks there are large amounts of trondhjemitic and dioritic intrusive rocks (Wolff 1973) whose genetic relationship to the metavolcanites is uncertain. Between the Gula Group proper and the rocks typical of the Fundsjø Group, there is a thin unit, the Gudå Group, which has been variously included in the Fundsjø Group (Wolff 1973) or the Gula (Wolff 1967,1979). The eas-

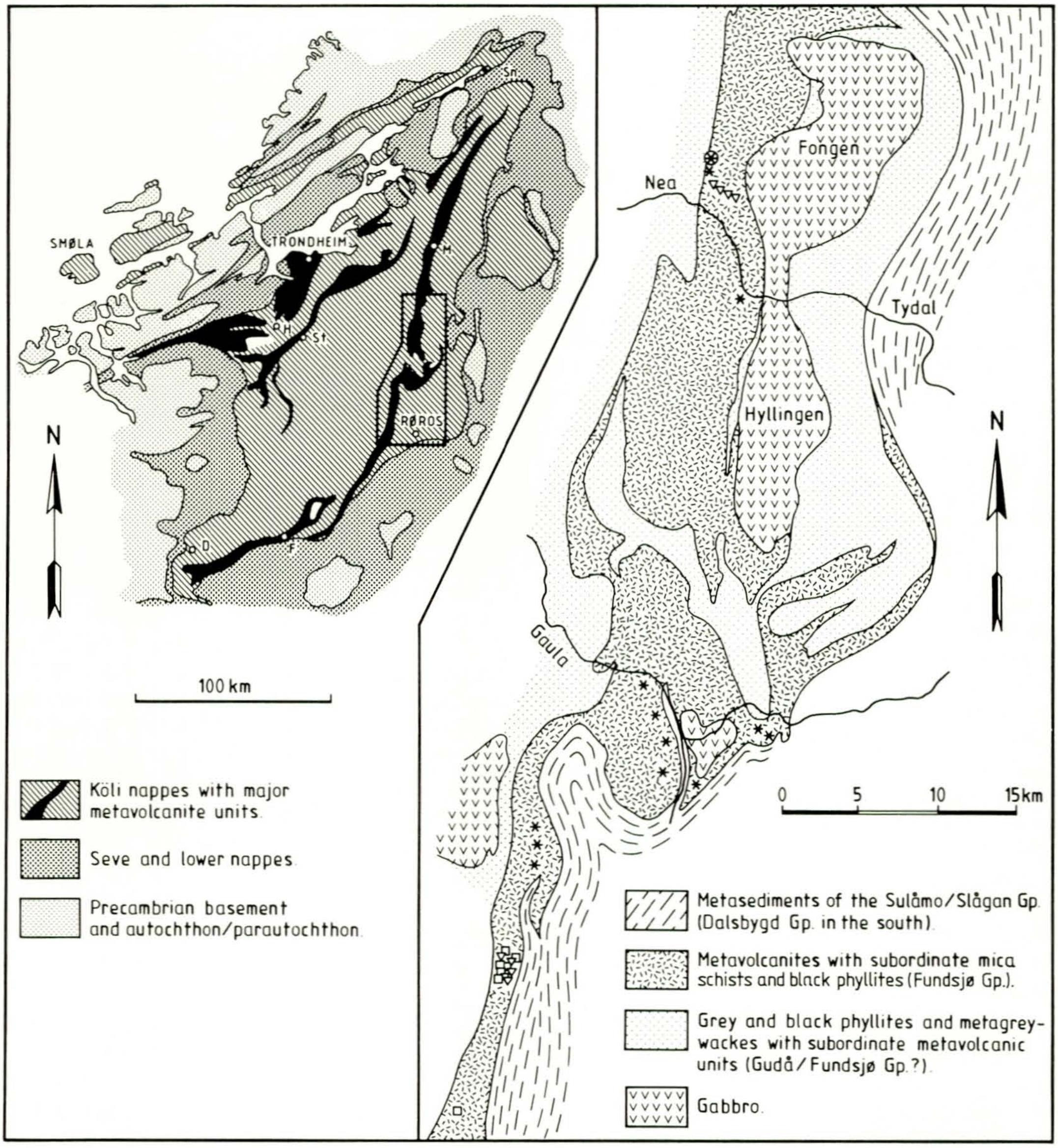


Fig. 1 Geological map of the Røros-Tydal area. *Sample localities: squares* - type A; *triangles* - type B; *asterisks* - type C. *D* - Dombås; *F* - Folldal; *H* - Hølonda; *St* - Støren; *M* - Meråker; *Sn* - Snåsa.

tern part of the Gudå Group is transitional to the Fundsjø Group and consists of tuffaceous units interlayered with massive metabasalts (Grenne & Lagerblad 1985). Further west, increasing amounts of pelitic and carbonaceous material occurs together with the metavolcanites, locally also with horizons of marble and graphite schist.

In the southern, Dombås area, the *Musadal* part of the ETD greenstone belt contains a considerably larger proportion of metasediments, intercalated with metabasalts (partly pillowed) and quartz keratophyres. The metasediments include impure quartzites, metapelites of tuffaceous origin, calcareous schists with thin marble layers and common units of graphitic schists, possibly indicating a shallow-water volcanic environment (Guezou 1978).

Table 1. Major and trace element composition of Hersjø Formation metavolcanites. Trace elements in ppm.

Sample No:	A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
SiO_2	46.91	50.50	57.30	50.10	46.80	45.90	44.74	53.04	49.15	50.80	51.06	49.32	50.98	49.27	50.05	47.30	52.44	48.20	47.90
Al_2O_3	14.48	15.10	14.40	14.60	17.98	18.22	17.46	15.13	14.70	14.00	14.90	14.26	13.62	14.76	14.53	15.00	12.54	14.00	14.60
Fe_2O_3	8.90	14.40	13.50	10.90	7.42	7.65	7.78	13.00	11.76	14.40	14.79	13.15	13.14	13.24	12.10	18.30	14.06	15.30	15.00
TiO_2	.19	.80	.69	.85	.67	.69	.68	1.08	1.10	1.72	1.79	1.52	1.60	1.58	1.73	2.05	1.78	1.90	1.76
MgO	7.26	6.30	4.10	5.80	8.85	8.89	9.28	6.00	7.11	8.00	4.71	7.56	7.34	7.00	6.60	6.40	6.80	7.80	11.80
CaO	10.98	5.90	4.00	8.10	10.40	10.97	11.04	5.59	10.22	7.30	7.45	9.73	8.98	9.56	8.62	6.20	8.50	6.20	5.00
Na_2O	3.80	5.30	5.56	5.36	2.69	2.57	2.36	4.20	3.20	4.00	4.59	3.03	2.83	3.23	3.75	4.91	3.44	3.71	2.53
K_2O	.05	.18	.18	.12	.10	.13	.08	.17	.11	.17	.12	.18	.17	.23	.12	.12	.12	.11	.12
MnO	.22	.25	.15	.13	.11	.12	.12	.17	.19	.24	.18	.25	.17	.28	.19	.24	.20	.22	.23
P_2O_5	.04	.05	.08	.06	.07	.08	.08	.13	.10	.12	.15	.13	.14	.13	.14	.19	.14	.15	.14
L.O.I.	5.26	2.65	1.25	2.88	2.80	3.28	4.24	1.20	1.52	1.89	.27	.30	.35	.34	1.63	1.17	.13	4.30	4.16
Total	98.09	101.43	101.21	98.90	97.89	98.50	97.86	99.71	99.16	102.64	100.01	99.43	99.32	99.62	99.46	101.88	100.17	101.89	103.24
Zr	15	22	23	32	41	41	43	48	50	75	91	92	96	97	100	106	109	110	116
Y	9	16	10	18	19	18	19	23	28	28	43	37	41	36	37	46	44	41	45
Sr	104	138	88	75	202	239	219	103	154	294	112	231	175	232	149	56	89	77	56
Rb	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	6	<5	<5	<5	<5	<5
Ni	87	6	5	84	210	216	227	18	37	35	13	48	46	53	49	11	49	22	39
Cr	477	29	37	250	590	584	600	67	69	88	5	116	110	140	107	42	70	46	97
Ba	14	21	48	5	<10	<10	<10	<10	18	27	18	35	34	69	21	27	30	<10	<10
V	219				166	162	166	400	316		618	364	369	354	364		371		

Sample No:	B11	B12	B13	B14	B15	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
SiO_2	49.09	53.00	49.10	50.60	50.42	51.40	51.40	46.09	50.30	49.08	47.60	52.18	50.20	50.35	51.40	50.10	52.30	78.75
Al_2O_3	15.47	13.40	14.50	13.60	14.05	15.20	16.60	14.07	15.20	14.10	17.10	15.20	16.00	15.57	15.80	15.70	15.50	10.98
Fe_2O_3	14.31	14.40	14.70	16.00	13.23	9.70	9.50	10.81	8.60	10.44	10.60	10.39	10.30	10.13	12.40	10.70	11.40	1.08
TiO_2	1.76	1.82	1.65	1.94	2.08	1.35	1.51	1.81	1.47	1.74	1.53	1.83	1.78	1.78	2.10	2.26	2.38	.14
MgO	7.84	6.20	7.00	7.20	6.28	7.00	8.70	6.13	7.20	6.60	7.50	6.09	6.00	5.53	4.80	5.40	4.30	.05
CaO	6.85	6.80	6.00	6.40	7.86	10.20	8.70	8.39	9.30	10.13	8.30	7.22	11.00	9.42	9.00	9.60	9.80	.32
Na_2O	3.97	4.77	4.60	4.29	4.00	3.61	4.32	2.27	4.93	2.46	4.32	3.76	4.03	4.00	4.21	5.16	3.96	2.34
K_2O	.14	.14	.21	.24	.11	1.06	.28	1.12	2.19	1.25	.19	.86	.44	1.03	.35	.23	.11	5.51
MnO	.19	.30	.18	.16	.26	.17	.14	.17	.15	.19	.15	.22	.18	.16	.23	.17	.16	.05
P_2O_5	.17	.16	.15	.35	.21	.24	.27	.26	.26	.23	.24	.35	.32	.29	.38	.42	.45	.02
L.O.I.	2.03	.68	1.54	1.30	1.02	2.17	1.22		1.51		2.58		.82		.55	2.15	.47	
Total	101.82	101.67	99.63	102.08	99.52	102.10	102.64		101.11		101.13		101.07		101.22	101.89	100.83	
Zr	119	127	127	129	146	126	133	134	137	140	144	152	172	173	214	253	271	148
Y	48	38	42	41	49	29	27	35	29	38	27	36	30	38	31	36	42	62
Sr	87	142	123	137	152	217	289	221	210	315	315	202	473	279	424	373	657	24
Rb	<5	<5	<5	<5	<5	44	<5	31	130	48	<5	17	7	17	<5	<5	<5	265
Ni	43	24	46	32	35	50	81	34	61	36	93	20	32	21	16	27	11	3
Cr	85	39	138	68	44	220	309	222	288	166	161	110	76	174	32	114	20	42
Ba	24	<10	12	64	16	96	78	376	336	529	13	199	190	166	106	21	37	29
V	390				403			339		305		293		287				<10

The Hersjø Formation

The metavolcanites analysed in the present study were sampled in the central, Hersjø part of the ETD greenstone belt, in the Røros-Tydal area (Fig.1). Here, pillowed basic effusives predominate in certain areas, while in other places felsic metavolcanites alternate with metabasites (Kisch 1962, Olesen et al.1973). Evidence of felsic volcanism is particularly common to the north, where also mafic and felsic tuffs, agglomerates and graphitic or calcareous metapelites are prominent rock

Table 2. INAA analyses (ppm) of REE, Th, Ta, Hf, and Sc. Nb (ppm) by mass spectrometry.

Sample No:	A4	A6	B8	B9	C2	C8	C9	C10	C13
La	3.60	1.30	4.50	3.20	10.20	21.50	20.40	35.20	50.90
Ce	7.90	2.90	8.30	10.40	19.20	37.60	35.70	59.90	110.00
Sm	1.90	1.50	4.10	3.70	3.00	4.50	5.30	5.80	10.10
Eu	.55	.55	.92	1.15	.85	1.29	1.46	1.65	.15
Tb	.35	.30	.83	.75	.63	.73	.85	.88	2.54
Yb	1.50	1.50	4.50	3.90	2.40	2.40	3.70	2.80	7.30
Lu	.23	.24	.58	.57	.34	.38	.55	.46	1.11
Th	.58	.07	.15	.30	2.50	3.00	3.60	5.20	23.10
Ta	.04	.02	.07	.06	.56	.80	.72	1.13	2.40
Nb	.36	.29	.92	.93	11.00	17.00	12.00	24.00	92.00
Hf	1.30	.90	3.30	2.60	3.70	4.10	5.30	4.40	7.80
Sc	39.00	33.60	47.10	39.80	35.00	37.50	34.90	31.10	2.90

types. Volcanic flow units commonly wedge laterally into tuffs and pelitic material, a feature interpreted by Olesen et al. (1973) to be of primary origin. Pelitic and semipelitic metasediments with intercalations of mafic tuffs are the main rock types of the eastern part of the Hersjø Formation in the Tydal area. Along strike, just south of these pelite-tuff dominated parts, Rui (1972) distinguished between the more pelitic units which he preferred to include in the Gula Group (or Complex), and a transitional, 'heterogeneous rock sequence' comprising pelitic to semipelitic schists interlayered with basic tuffs, conglomerate and marble. Graptolite-bearing (Dictyonema) black phyllites of early Tremadocian age (Vogt 1940) are interlayered with the metavolcanites (Nilsen 1971), although Nilsen considered the black phyllites to be Gula rocks infolded into the Hersjø. Gee (1981), on the other hand, included the Dictyonema-bearing phyllites in the Hersjø, pointing to their intimate relationships with pillow lavas and a cross-cutting metadolerite dyke swarm.

Geochemistry

Thirty-six samples of pillowed and massive basic flows, and one felsic effusive, have been analysed in the present study. All these samples are from indisputable Hersjø rocks. Major and trace elements (Table 1) were determined by XRF on fused glass beads and pressed powder pellets, respectively, except for Na_2O which was analysed by flame photometry. Rare earth elements (REE), Th, Ta, Hf and Sc were analysed by INAA and Nb by mass spectrometry (Table 2).

The majority of samples are basaltic in composition (Table 1). Only one can be characterized as intermediate (andesitic) with a SiO_2 value of 57.3%, while the abundant felsic flows in the area are represented by one rhyolitic sample. In differentiation diagrams for TiO_2, using FeO(tot)/MgO and Zr as differentiation index (Figs. 2 and 3), there appears to be a tripartite subdivision of the basic-intermediate rocks. This is confirmed by other diagrams (see below), and in all diagrams the three separate metavolcanite types have been distinguished by different symbols. Sample localities for the three types are given in Fig.1.

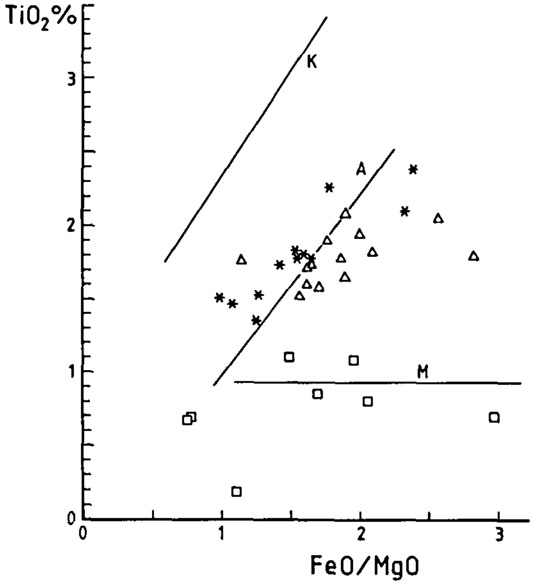


Fig. 2 TiO_2 vs. FeO(tot)/MgO plot of Fundsjø Group metavolcanites. *Trend lines*: *A* - abyssal tholeiites; *K* - Kilauea, Hawaii; *M* - Macauley Island, Kermadec arc. *Squares* - type A; *triangles* - type B; *asterisks* - type C.

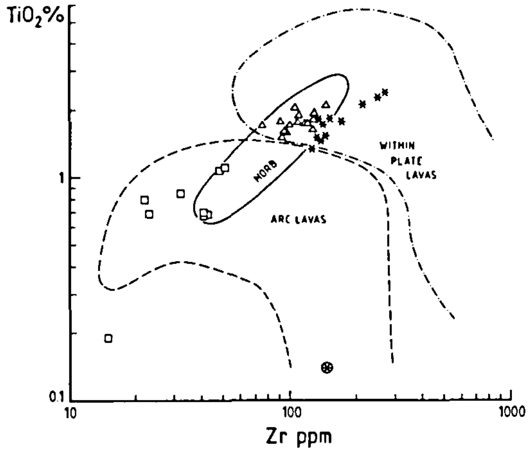


Fig. 3 TiO_2 vs. Zr plot of Fundsjø Group metavolcanites. Symbols as in Fig. 2. Andesite (type A) is marked by a filled square, and rhyolite (type C) by an asterisk enclosed by circle.

In the TiO_2 vs. FeO(tot)/MgO diagram (Fig.2), type A (which includes the one andesitic sample), apparently defines a flat differentiation trend, with little or no enrichment of TiO_2, a feature which according to Miyashiro (1975) is characteristic of island arc magma series. These samples are clearly separated from the other two types, which both have considerably higher titanium values and show moderate enrichment trends.

The TiO_2 vs. Zr diagram (Fig.3) suggests that types B and C are not comagmatic. For comparable Zr contents, type C metabasalts have significantly less titanium, although the most fractionated of these rocks have TiO_2 values up to 2.38% (at c.270 ppm Zr - cf. Table 1). Type A and type B are clustered into a low-Zr (<50 ppm) and a higher-Zr (>75 ppm) type, respectively. The apparent 'Zr discontinuity' between the types, together with the disparate trends in Fig. 2, suggests that the basalts of type B are not the products of simple fractionation of type A basaltic melts. The latter fall exclusively in the discrimination field for arc lavas (Pearce & Norry 1979), and outside or peripheral to the MORB field.

In the Ti-Zr-Y discriminant diagram (Fig. 4) of Pearce & Cann (1973) the three types are again relatively well separated. Type B basalts are found in the middle of the field which includes MORB, while type A metavolcanites are only partly overlapping the latter and stretch

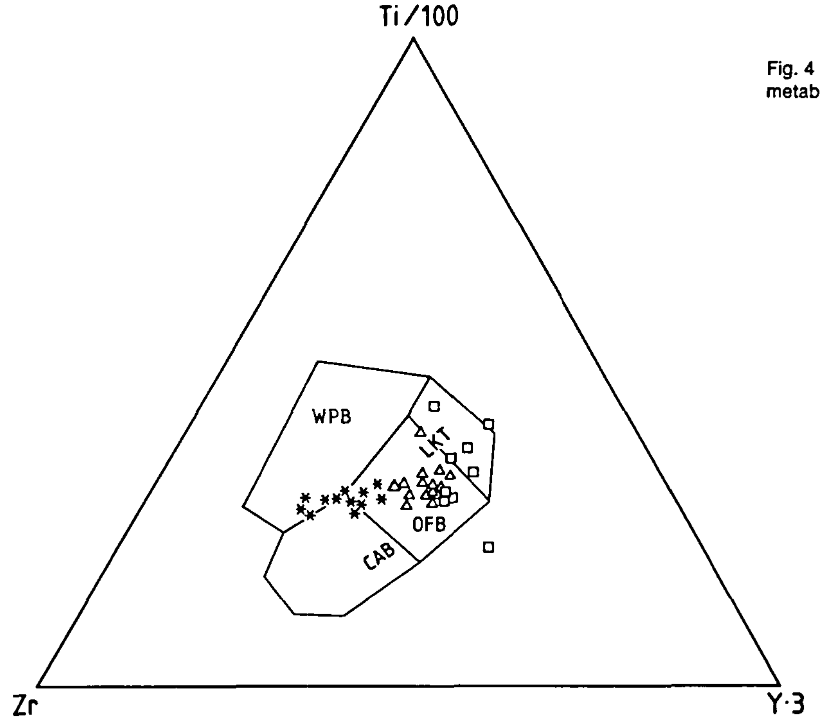


Fig. 4 Ti-Zr-Y plot of Fundsjø Group metabasalts. Symbols as in Fig. 2.

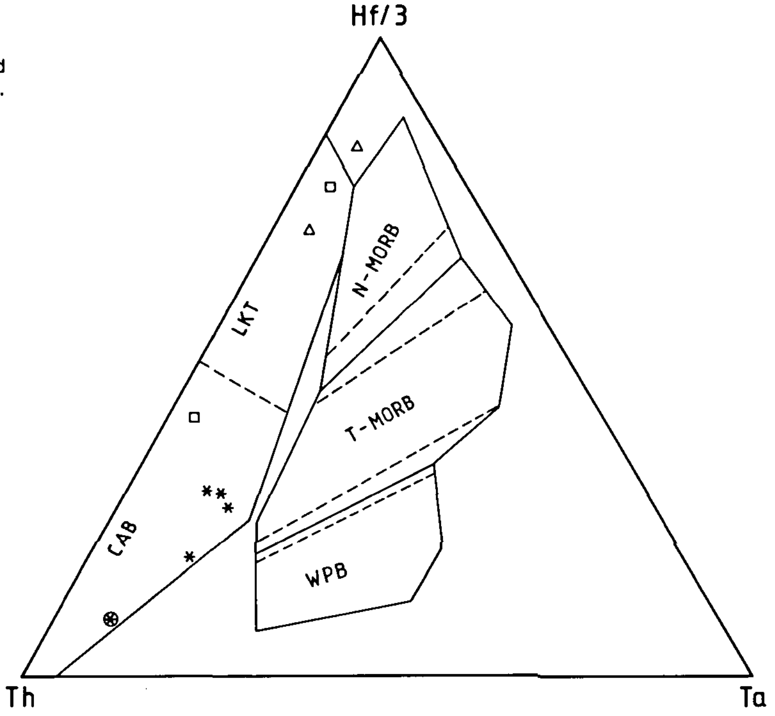


Fig. 5 Th-Hf-Ta plot of selected Fundsjø Group metavolcanites. Symbols as in Figs. 2 and 3.

well into the field for island arc tholeiites. Separated from these two types, the type C metabasalts plot along a trend which lies on the discrimination boundary between the fields for calc-alkaline basalts/ ocean-floor basalts and within-plate tholeiites. The most differentiated of the samples are those displaced furthest towards the Zr apex, a feature obviously reflecting the more moderate enrichment of titanium and yttrium than of zirconium during magmatic differentiation of the type C basaltic magma.

Inter-element ratios between Hf, Ta and Th are only moderately affected by crystal fractionation processes even in felsic melts (Wood et al. 1979), and in the Hf-Ta-Th diagram (Wood 1980) the Hersjø metarhyolite sample has been plotted together with eight selected metabasalts (Fig.5). A remarkable feature of these plots is that none of the samples fall in the discrimination fields for mid-ocean ridge or within-plate volcanites, despite a similarity to non-arc magmas (for some of the samples) in other diagrams (cf. Fig.3). The type B samples plot close to the border of the arc tholeiite field and are 'least different' from normal MORB, which is to be expected also from the previous diagrams and their whole-rock composition (Table 1). The metabasalts of type A are comparable to arc tholeiites; a marked difference between the two analysed samples may indicate that the flows assigned to this type were not necessarily comagmatic. The type C metavolcanites, including the rhyolitic sample, fall wholly within the field designated to calc-alkaline rocks. The relative displacement of the metarhyolite towards the Th apex is compatible with this rock being related to the type C metabasalts (cf. Wood et al. 1979), the relative enrichment of Th was apparently caused by the less incompatible nature of Hf and Ta in the felsic melt. All type C samples are fairly close to the outer boundary of the calc-alkali field. This is in accordance with the transitional calc-alkali/ within-plate affinity of the same rocks in the Ti-Zr-Y diagram (Fig. 4).

Rare earth element (REE) patterns confirm the difference between the type C flows and types A and B. The former (Fig.6A) display a marked light REE (LREE) enrichment, with $(La/Yb)_N$ ratios between 3 in the least fractionated and 8 in the most fractionated of the analysed metabasalts. The pattern of the metarhyolite seems to confirm its genetic relationship to the type C basic flows. A strong negative Eu anomaly denotes that plagioclase was an important fractionating mineral during formation of the felsic melt. No increase in Eu

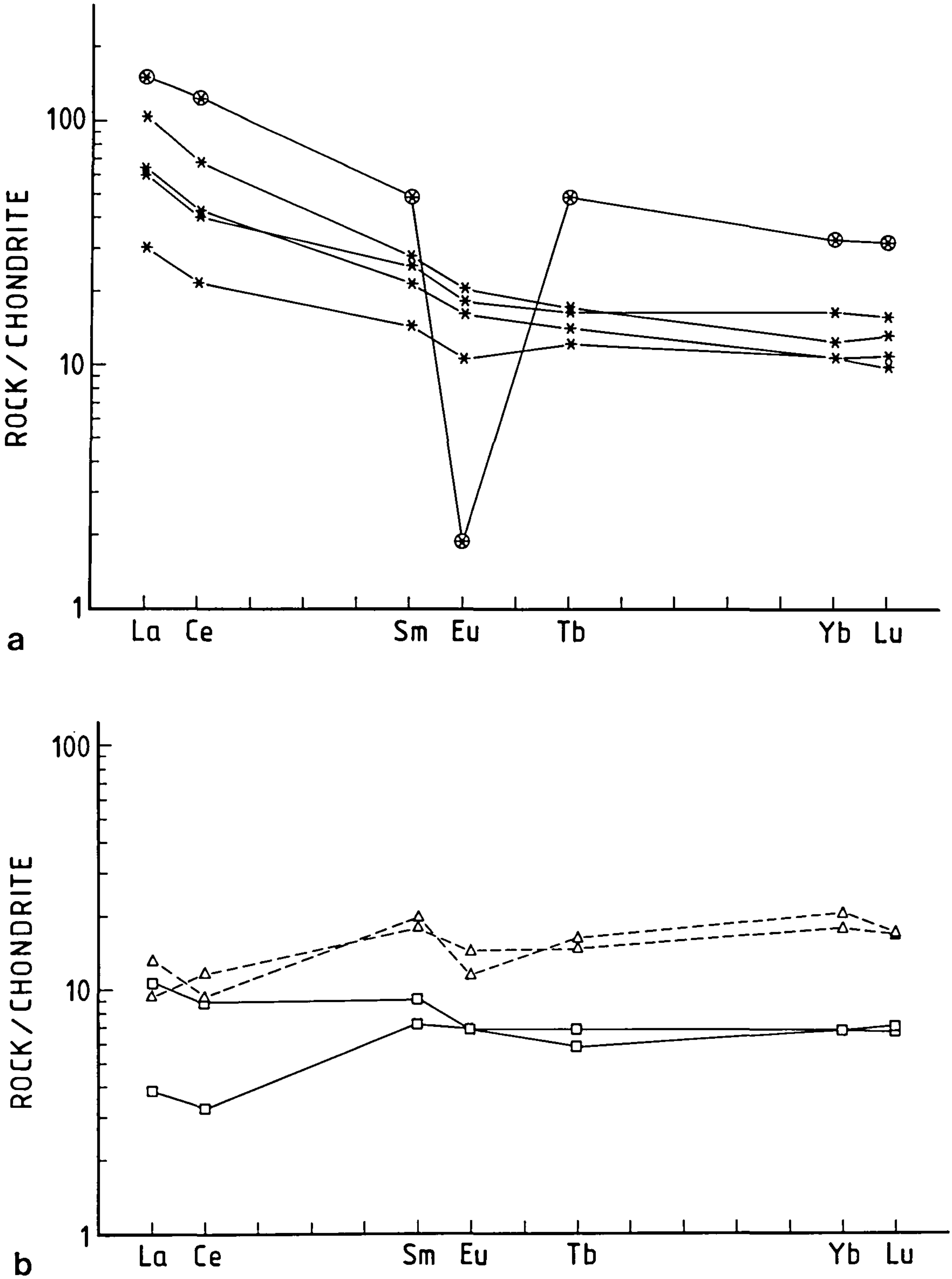
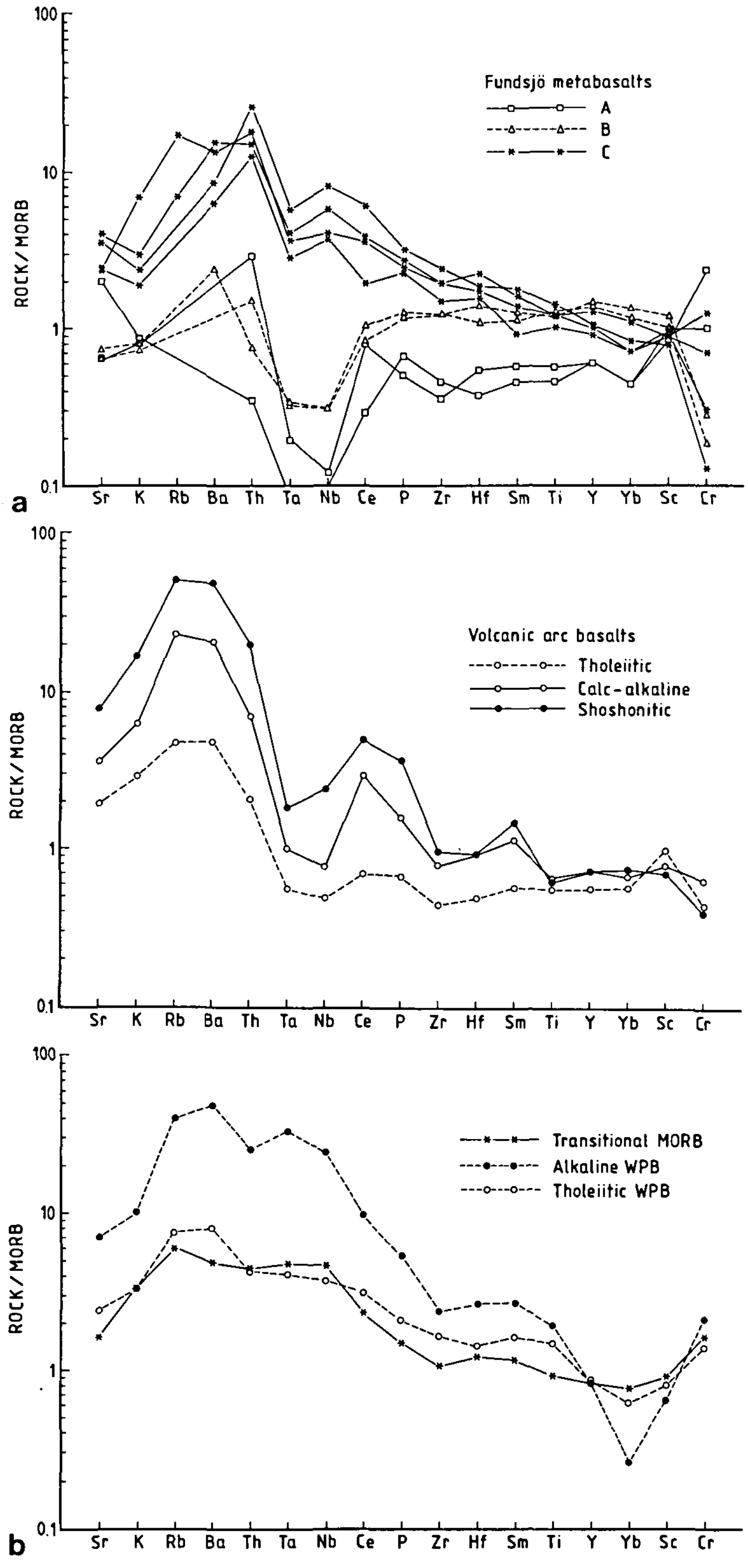


Fig. 6 Chondrite-normalised REE patterns of Fundsjø Group metavolcanites. A) type C; B) types A and B. Symbols as in Figs. 2 and 3.

Fig. 7 A) MORB-normalised trace element patterns of selected Fundsjø Group metabasalts. Symbols as in Fig. 2. B) MORB-normalised trace element patterns of recent volcanic rocks from various tectonic settings. Data from Pearce (1982).



anomaly can be detected from the least to the most fractionated of these metabasalts, although many are plagioclase-phyric indicating that feldspar may have been a fractionating phase.

Contrary to the above, the type B metabasalts (Fig.6B) have LREE-depleted patterns comparable to normal MORB, with a negative Eu anomaly for one sample. Their $(La/Yb)_N$ ratios are 0.5-0.6. A similar ratio is seen in one of the two analysed type A lavas (Fig. 6B), while the other one shows slight LREE enrichment with a $(La/Yb)_N$ ratio of 1.4. This difference is in accordance with the more 'enriched' character of the latter sample in the Hf-Ta-Th diagram (Fig.5).

A rock/MORB normalizing diagram (Fig.7A) again demonstrates the ambiguous geochemical affinity of these metavolcanites. Type A and B rocks all have low large-ionic lithophile (LIL) element contents, strong depletion of Ta and Nb and fairly high Th/Ta ratios, comparable to arc tholeiites (Fig.7B). Type B, however, shows values of high field strength (HFS) elements (except Ta and Nb) that definitely are higher than those found in arc tholeiites. Type A is compatible with an arc tholeiite composition as far as the HFS elements are concerned, but many of these samples are considerably more Cr-rich (cf. Table 1) than normal for tholeiitic arc magmas (cf. Pearce 1984), although such basalts do occur locally in the Izu-Bonin arc (Shiraki et al. 1978).

The type C metabasalts (Fig.7A) are significantly enriched in the LIL elements Sr,K, Rb, Ba and Th (see also Table 1). With the exception of Th, these elements are susceptible to changes during processes like sea-floor weathering and metamorphism (Saunders & Tarney 1984). However, in the present samples there is a clear consistency between the enrichment of the mobile LIL elements and the more stable thorium, and the most incompatible of the stable HFS elements (Ta-P). A similar consistency, but with low values of the same elements, is seen in the type A and B samples (Fig.7A), indicating that primary variations in the LIL element contents are not completely masked by secondary changes. The LIL element enrichment, in particular Th, makes the type C metabasalts in many respects comparable to certain types of 'enriched' arc magmas such as high-K calc-alkaline and shoshonitic basalts (Fig.7B). However, significantly different from evolved arc lavas are the much higher levels of HFS elements in the Hersjø type C rocks, as well as their smooth patterns from Nb towards Sc which is more reminiscent of within-plate or transitional MORB magmas (Fig.7B). Additionally, the type C metavolcanites display iron-enrichment (not shown) and TiO_2-enrichment differentiation trends (Figs.2 and 3), completely different from those found in the calc-alkaline volcanite series. The mafic-felsic bimodality is also atypical of such series. On the other hand, the increased Th/Ta ratios in type C obviously rule out a normal mid-ocean ridge or within-plate volcanic setting (cf. Fig.7B).

Discussion

Geochemical data on metabasites from the Fundsjø part of the eastern Trondheim District greenstone belt, in the Meråker-Verdal area (Fig.1), have been presented by Grenne & Lagerblad (1985). There, tholeiitic amphibolites comparable to both types A and B (or transitional between the two) predominate, and were interpreted as having formed in a Tremadocian to late Cambrian immature, ensimatic island arc setting. The 'MORB-type' amphibolites (similar to the type B) were ascribed to incipient arc rifting.

Sequences comparable to the Fundsjø part of the ETD greenstone belt occur north of the Grong-Olden basement culmination, in the Gjersvik (Grenne & Reinsbakken 1981) and Stekenjokk areas (Stephens & Gee 1985). As with the Fundsjø Group, both these areas comprise bimodal mafic-felsic metavolcanic sequences with the geochemical signature of arc tholeiites and MORB (Stephens 1982, Reinsbakken 1986), interpreted to represent immature arc and arc-rifting volcanism, respectively. The Stekenjokk area also contains rift-related magmatic rocks (Stephens 1982) which have some similarities with the transitional calc-alkaline/WPB (Type C) metavolcanites in the Hersjø part of the ETD greenstone belt. Moreover, the Stekenjokk metavolcanites are intimately associated with U-rich black shales (Sundblad & Gee 1985) comparable to the Dictyonema-bearing phyllites which are associated with the ETD metavolcanites.

The present major and trace element geochemistry on less deformed, clearly effusive rocks from the Hersjø Formation is generally in accordance with the interpretation from the

Fundsjø Group further north. However, it is not clear from these more complete geochemical data, if *any* of the analysed metavolcanites represent true island arc type magmas, or if they *all* formed in an arc-related marginal basin. The type A samples are definitely those most akin to normal arc tholeiites, having a flat TiO_2 differentiation trend and characteristically very low HFS element contents. On the other hand, many of these samples have Cr contents that are considerably higher than those which are *typical* for arc tholeiites.

The type B metabasalts show geochemical traits that are in most respects similar to somewhat fractionated, normal MORB magmas with *clear iron - titanium enrichment trends* and a depleted LREE pattern. A slight increase in their Th/Ta ratios is here the only signature of subduction zone magma affinity.

The conspicuous geochemistry of the Hersjø type C metavolcanites is transitional between calc-alkaline, within-plate and mid-ocean ridge magmas, although the high Th/Ta ratios clearly denote their genetic relationship to subduction processes.

It has been demonstrated by Saunders & Tarney (1984) that back-arc marginal basins are commonly floored by volcanites transitional between normal MORB and arc tholeiites or calc-alkaline magmas. Basalts with MORB or calc-alkaline characteristics are often erupted in close spatial proximity, as in the Mariana Trough. A calc-alkaline component in such transitional rocks is found particularly in narrow ensialic basins, where marginal basin spreading is related to mature, continent-based arcs. The transitional character of back-arc magmas can be explained by LIL (and H_2O) enrichment of their mantle source by fluids derived from the dehydrating subducted slab (Saunders & Tarney 1984). This enrichment may be more localized than in a normal magmatic arc setting. Magmatism locally taps the variably LIL element-enriched sources and may thus produce a spectrum of basalt types.

In view of their transitional character and geochemical complexity, it is reasonable to assume that the Hersjø Formation metavolcanites *originated* in a marginal basin setting by tapping of magma from a heterogeneous source above a subduction zone. Tectonic deformation has obliterated indications of the primary stratigraphic relationships between the three metavolcanite types described above, so it is not clear if the 'LKT-type' (type A) rocks are the oldest, as would be expected in the arc rifting model suggested by Grenne & Lagerblad (1985) for the Fundsjø part of the ETD greenstone belt, and previously for the Stekenjokk sequence by Stephens (1982). Furthermore, rifting of a *primitive*, ensimatic arc is somewhat contradictory to the 'evolved' nature of the transitional, marginal basin-type (C) lavas. In view of the model proposed by Saunders & Tarney (1984), a marginal basin setting for the *entire* Hersjø Formation, above a relatively mature subduction zone, appears to be a more favourable model, although one cannot rule out the possibility that parts of the sequence (type A) represent remnants of the *disrupted arc*. This does not necessarily imply that subduction was contemporaneous with the marginal basin spreading (cf. Saunders & Tarney 1984); the localized LIL enrichment processes may well have been related to earlier (10-20 Ma?) subduction episodes.

It is likely that the marginal basin extension took place close to a continental margin. This is indicated by the quartzitic or quartzo-feldspathic composition of metagreywackes intimately related to the volcanic and tuffaceous rocks (Rui 1972, Guezou 1978) and by the platform affinity of the associated, graptolite-bearing black phyllites (Gee 1981). Lead isotope data on syn-volcanic, massive stratiform sulphides from the area indicate a lead isotope source with a considerable proportion of lead derived from a shield area, mixed with mantle-derived lead (Birkeland & Bjørlykke 1986). This is also in accordance with the 'epicontinental' depositional environment (Guezou 1978) assumed for the metasediments of the closely related Gula Group. It is not clear from these data, however, whether the basin developed adjacent to the Baltoscandian or the Laurentian platform, or a microcontinent with in the Iapetus ocean. Black U-rich shales of the type found in the Hersjø were widespread in Cambrian-early Ordovician times on the Baltic Shield, but also occur in North America. The Dictyonema species in Hersjø was also of worldwide distribution in the early Tremadoc (D.L.Bruton, pers.comm.1987). Hence, neither Laurentian/Baltoscandian province affinity nor subduction polarity can be determined conclusively by these relationships.

The only metavolcanite sequences with clear, mature arc signature in the Upper Allochthon of the central Scandinavian Caledonides are found on the island of Smøla, west of the

Trondheim district, and near Snåsa (Fig.1). On Smøla, a wide spectrum of calc-alkaline metavolcanites, ranging from basaltic through to rhyolitic (Roberts 1980), are spatially related to limestones of Arenig to Llanvirn age (Bruton & Bockelie 1979). Evolved calc-alkaline basalts to andesites of a continental margin affinity (Roberts et al. 1984) are penecontemporaneous with limestones of similar age in the Hølonda area (Bruton & Bockelie 1980). These were tentatively interpreted by Roberts et al. (1984) to have formed adjacent to a microcontinent within the Iapetus ocean. In both these areas the early Ordovician fauna show a well-defined Laurentian affinity, although the global tectonic significance of faunal provincialism in this region has been disputed (Roberts et al. 1984).

In the Hølonda area, the calc-alkaline metavolcanites, of early Llanvirn age, are stratigraphically underlain by ophiolite complexes (Vassfjellet, Løkken, Grefstadfjellet, Resfjellet - Grenne et al.1980, Roberts et al. 1984, Grenne 1986, Heim et al.1987) and the supposed correlatable Støren Group greenstones. U/Pb zircon dating of comagmatic plagiogranites at Løkken and Vassfjellet give early to mid Arenig ages for these ophiolites (Dunning & Grenne, in prep). N-type MORB geochemical affinities predominate, but subduction-related volcanites occur at high levels in the Løkken ophiolite (Grenne, in prep), denoting probably a marginal basin setting. There is evidence of some deformation of these ophiolites prior to deposition of overlying conglomerates and other sediments and the calc-alkaline volcanites (Vogt 1945, Bruton & Bockelie 1980, Grenne 1986). This event, the 'Trondheim Disturbance' (Holtedahl 1920), may thus be broadly coeval with, but probably less penetrative than, the early Ordovician deformation of the ETD greenstone belt and the Gula Group.

Based on geochemical variations in the calc-alkaline Smøla and Hølonda volcanic suites, an east-dipping subduction zone beneath a mature arc/marginal basin couple has been inferred for the late Arenig-early Llanvirn in this region (Roberts 1980, Roberts et al. 1984). The very evolved character of the Hølonda calc-alkaline rocks, contrasting strongly with the underlying tholeiitic greenstones of the ophiolites, seems to imply that the oceanic crust of a probably fairly wide marginal basin was accreted on to a considerably thickened lithosphere in approximately late Arenig times, prior to the calc-alkaline volcanism. An early Ordovician obduction of the Støren Group *sensu stricto* on the western part of Gula was suggested by Gale & Roberts (1974), and it is reasonable to assume that this applies also to the other ophiolites in the western Trondheim district. This indicates a possible palaeogeographic link between the western ophiolites and the ETD greenstone belt; the intervening Gula Group possibly representing seaward-migrated fragments of a rifted continental margin within the marginal basin. The early development of this basin may be seen in the early Tremadoc, markedly subduction-influenced, ETD metavolcanites. The evolved character of some of these rocks, as well as lead isotope compositions and the epicontinental type sediments, are explicable in terms of proximity to a continental margin. The wide distribution of ophiolites in the western Trondheim district suggests that, within a time span of 10-20 Ma (early Tremadoc - mid Arenig), the marginal basin spreading migrated westwards, leaving intra-basinal continental edge fragments upon which the western ophiolites were obducted during the late Arenig. Such an evolution, in view of the faunal provincialism in the west, is most compatible with marginal basin spreading on the western side of Iapetus, along the Laurentian plate margin. It also indicates the possibility that the subduction zone to which the basin was related, may have been west-dipping. However, it is possible that active subduction along this zone ceased in the Tremadoc or somewhat earlier; this can also be inferred from a general lack of true arc-related volcanism throughout the Caledonian-Appalachian orogen in the Tremadoc to mid Arenig interval (Dunning & Pedersen, 1988; Pedersen et al., in prep), in sequences relatable to the western side of Iapetus. The appearance of arc volcanism in late Arenig-early Llanvirn times in the western Trondheim district may signify a re-activation of subduction in this marginal basin/inactive arc system, coupled possibly with a shift in subduction polarity and displacement of the subduction zone towards the west, accompanied also by tectonic shortening and oceanic crust obduction within the basin.

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