Geochemical evidence for a rift-related origin of metadolerites within the Senja Nappe, Troms, North Norwegian Caledonides

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Metadolerites transecting platform-related to miogeoclinal metasedimentary rocks of the Senja Nappe in Troms, North Norwegian Caledonides, are little altered and reflect primary magmatic characteristics. They show the geochemical signature of a tholeiitic spreading ridge (MORB) basalt, which is transitional between 'within plate' and 'plate margin' basalt, based on major and trace element concentrations. The geochemistry, nature of the host rocks, and structural position in the nappe pile suggest a correlation of the Senja Nappe metadolerites with metadolerites of the late Ordovician/Silurian Balsfjord Group of the Lyngen Nappe (Upper Allochthon), generated during an episode of post-Finnmarkian crustal extension.

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The Scandinavian Caledonides are characterized by a sequence of large-scale nappes which were transported eastward across autochthonous rocks of the Baltic Platform during Early to Middle Paleozoic closure of the Iapetus ocean (Gee 1975; Sturt 1984; Stephens & Gee 1985). The nappes are grouped into four main nappe complexes named the Lower, Middle, Upper and Uppermost Allochthon respectively (Gee & Zachrisson 1979; Gee 1982; Roberts & Gee 1985). Although the various allochthons in general thin westward, they may in some areas be traced more or less continuously across the entire orogen. The metamorphic grade increases from east to west within each nappe complex, a feature which together with a westward increase in regional strain, makes correlation across the orogen in certain areas difficult.

The Lower and Middle allochthons consist of tectonically imbricated sequences of sedimentary rocks with slices of Precambrian crystalline rocks, most probably representing the depositional basement for the sediments. The metasedimentary units involved in the Lower Allochthon are readily correlated with the autochthonous/parauthochthonous Upper Proterozoic platformal sequence. Relatively thick monotonous psammites, not easily correlated with the platformal sequence, dominate the metasedimentary rocks of the Middle Allochthon. Based on data from south and central Scandinavia, Kumpulainen (1980) and Nystuen (1980) interpreted these sequences as being deposited during initial Late Proterozoic rifting of the Laurentia-Baltic Craton. Dolerite dikes and mafic volcanites of the Middle Allochthon are most likely a manifestation of the initial igneous activity which preceded formation of the Iapetus oceanic crust (Andreasson et al. 1979; Solyom et al. 1979; Kumpulainen 1980; Furnes et al. 1980).

The Upper Allochthon is an extremely heterogeneous, composite nappe complex dominated by typical eugeoclinal rocks, but includes also penetratively deformed and metamorphosed Precambrian crystalline rocks (Seve) in the lower portions. Island arc and back arc sequences as well as ophiolite fragments are recognized within the Upper Allochthon (Stephens & Gee 1985). Most of these rocks are not readily correlated with the Upper Proterozoic to Silurian metasediments within the Lower and Middle Allochthons, and should be considered 'suspect terranes' (Coney et al. 1981; Schermer et al. 1984). The metamorphic grade and structural development vary considerably within the Upper Allochthon. An unconformity of apparently regional extent is present within some of the tectonic units within the Upper Allochthon (Sturt 1984). The rocks below the unconformity, which appear to be of pre-Ashgill age, are polymetamorphic and have undergone complex deformation. This deformation is interpreted to be associated with the Late Cambrian/Early Ordovician Finnmarkian Orogeny (Sturt 1984). Dallmayer & Gee (1986) have suggested that the Finnmarkian orogeny represents the initial closure of the Iapetus Ocean. During this event, most of the ophiolites present in the Scandinavian Caledonides were obducted onto a deforming continent (Sturt et al. 1983; Stephens & Gee 1985). The deformation and metamorphism seen in the post-Finnmarkian Upper Ordovician and younger rocks are associated with the Scandian Orogeny. In a late phase of this orogenic event, the entire nappe pile was translated across the continental margin to its present position.

Also the Uppermost Allochthon is an extremely heterogeneous nappe complex. It is dominated by schists, feldspathic gneisses, amphibolites and marbles. A klippe of the Uppermost Allochthon in Troms contains eclogites (Andresen et al. 1985; Krogh et al., in prep.). There is a possibility that the Uppermost Allochthon may represent ensialic thrust sheets derived from a westerly suspect continental terrane. This terrane shows an active continental margin (Cordilleran) history during the Early–Middle Paleozoic.

The tectonostratigraphy described above was first recognized in the central Scandinavian Caledonides (Gee & Zachrisson 1979) but has since been applied successfully both northward and southward along the eastern part of the orogen (Roberts & Gee 1985). To the west and north, on the Norwegian side of the international border, a subdivision into a Lower, Middle, Upper, and Uppermost is sometimes difficult to recognize due to increasing metamorphism and strain combined with facies variations. This problem is particularly pronounced in northern Nordland and Troms, where mapping of individual thrust units is complicated by dissecting fjords partly controlled by post-Caledonian high angle brittle faults (Andresen et al., in prep.). In an attempt to decipher the tectonostratigraphy in this region and to see how it fits with the established tectonostratigraphy further east and south, we have started a systematic geochemical investigation of the mafic igneous rocks in two traverses across the orogen. It is hoped that the geochemical data together with the associated metasedimentary sequences should differentiate between tectonic units or terranes derived from: (1) the Iapetus rift prism of the Baltic Shield, (2) island arcs, back-arc basins or ophiolite fragments formed within the Iapetus Ocean of the Upper Allochthon, (3) some continental-related terrane from the other side of the Iapetus Ocean, or (4) some microcontinent of unknown origin. This paper presents geochemical data on metadolerites from the Senja Nappe, in its type area on Senja (Fig. 1).

Geological setting of the Senja Nappe

The Caledonian allochthons in Central Troms occur in a NE-SW trending depression in the underlying Precambrian basement (Fig. 1). Andresen et al. (1985) recognized seven major Caledonian lithotectonic units in this area (Fig. 1). These are, in ascending order: the Dividal group (autochthonous), Målselv Nappe, Senja Nappe, Dyrøy Nappe/Nordmannvik Nappe, Lyngen Nappe, and Tromsø Nappe Complex. Based on lithologic similarities together with its tectonic position in the nappe pile (Andresen et al. 1985), the psammite-dominated Målselv Nappe was correlated with the Kalak Nappe Complex of the Middle Allochthon (Roberts & Gee 1985). The Lyngen Nappe – including the Lyngen Gabbro, a possible ophiolite fragment (Sturt et al. 1983), and the low to intermediate grade metamorphic rocks of the Balsfjord Group – is clearly a suspect terrane of the Upper Allochthon. Tectonically on top of the Lyngen Nappe are kyanite-mica schists, garnet-amphibolites, anorthosites, calc-silicates, high-pressure granulites and ecologites of the Tromsø Nappe Complex, now considered a klippe of the Uppermost Allochthon. The high grade, strongly mylonitized rocks below the Lyngen Nappe were named the Nordmannvik Nappe by Zwaan & Roberts (1978). Andresen et al. (1985), following Fareth (1981), correlated this unit with the high grade metamorphic rocks on Dyrøy and eastern Senja. Fareth (1981) and Andresen et al. (1985) named the rocks above the Precambrian basement, but below the Dyrøy Nappe on Senja, the Senja Nappe. The dominant lithologies within the Senja Nappe in its type area are marbles, garnet-mica schists and minor metapsammites and amphibolites. The amphibolites occur as lenses and layers with slightly discordant contacts to the compositional layering in the host rock, a

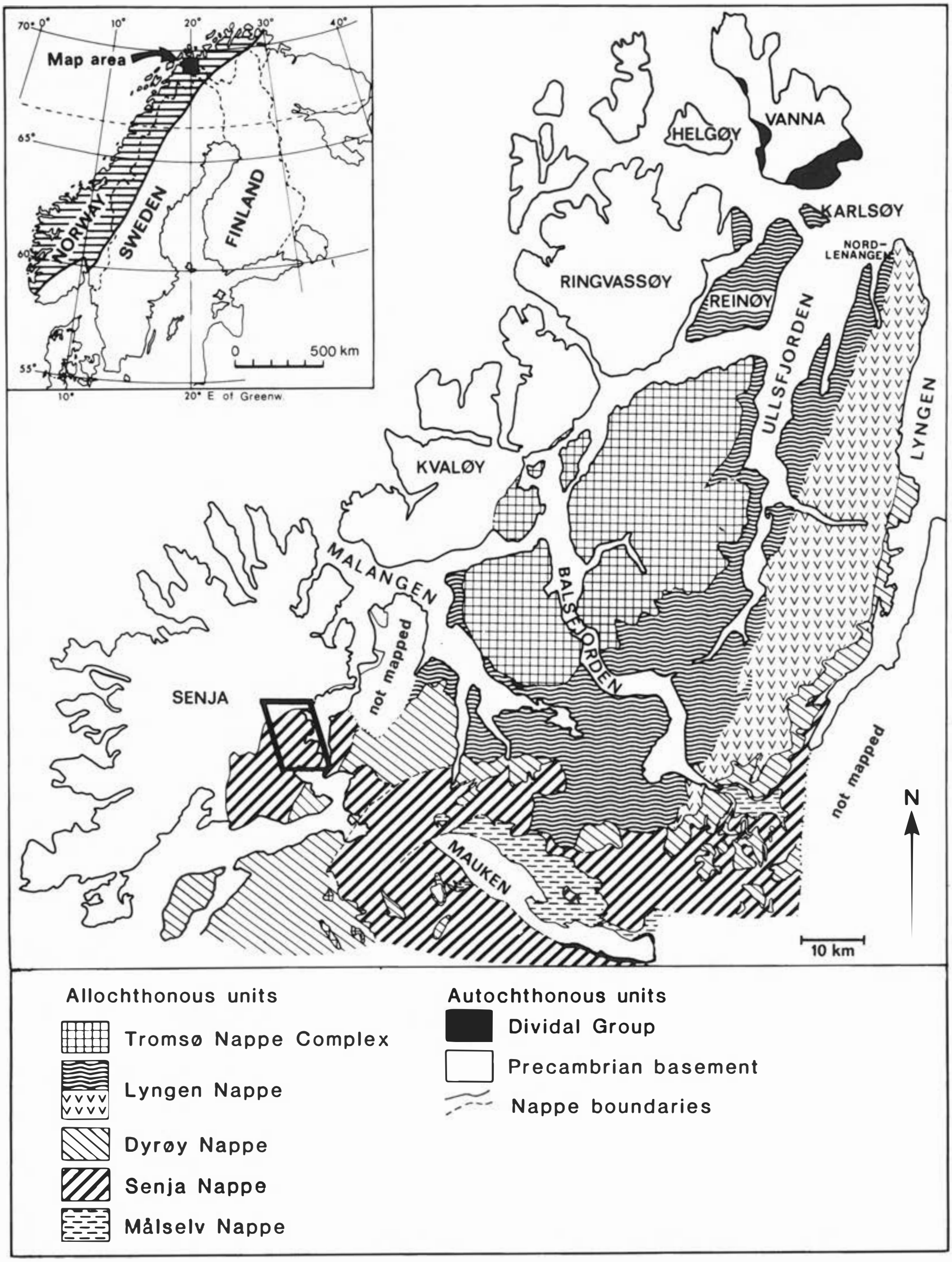


Fig. 1. Geological map showing the distribution of the main Caledonian tectonic units in western Troms (Andresen et al. 1985). The sampling area is indicated by the box.

feature taken in support of an intrusive origin. The Senja Nappe was correlated with a sequence of metapelites, metapsammites, marbles, amphibolites and granitoid rocks on the mainland, rocks which Zwaan & Roberts (1978) had subdivided into the Vaddas and Kåfjord Nappes east of Lyngen. It should be kept in mind, however, that this correlation is questionable (Andresen et al. 1985). Accordingly the data and conclusions presented in this study have validity only for the Senja Nappe in its type area.

The structural position together with the occurrence of numerous dolerite dikes would normally favour a correlation of the Senja Nappe with the Lower/Middle Allochthon. On the other hand, the relatively large percentage of carbonates present in the Senja Nappe favours a correlation with terranes typical of the Upper Allochthon, unless a dramatic facies change exists within the Middle Allochthon. One objective of this study was thus to see if the geochemistry of the metadolerites would give any clue as to the geotectonic origin of the Senja Nappe, and consequently whether it should be considered part of Middle or Upper Allochthon.

Material and methods

Petrography

The metadolerites of the Senja Nappe are homogeneous, massive to weakly foliated, and display a completely recrystallized, lepidoblastic fabric. Relict phenocrysts and/or primary igneous mineral phases have not been observed. Some of the samples contain aligned feldspar and quartz grains, together with lepidoblastic hornblende, defining a weak foliation. Grain size is 0.3 to 0.5 mm, but increases in the foliated samples. The characteristic mineral assemblage is: hornblende + plagioclase (albite) + quartz (minor) + magnetite (minor) + chlorite + epidote ± biotite/white mica ± carbonate (accessory), indicating growth under medium to upper greenschist/lower amphibolite facies P-T conditions (Winkler 1976) for the entire suite of rocks. The common occurrence of garnet mica-schist country rocks confirms this interpretation.

Sampling and analytical procedure

The samples analyzed in this study were collected in a 20 km long traverse along the east coast of Senja (Fig. 1). A total of 15 samples were taken from mafic lenses and sheets, within quartzites, garnet micaschists and calcareous schists/marbles. In sampling we tried to avoid sheared parts of the amphibolite bodies. The samples were analysed for major oxides and five trace elements, using an automatic X-ray fluorescence (Philips) spectrometer at the University of Tromsø. The major elements were determined on fused glass pills employing the method of Padfield & Gray (1971). The trace elements Rb, Sr, Y, Zr and Nb were analysed on pressed powder tablets. The obtained values were calibrated against the international standards AN-G, BM, DR-N, and UB-N, using recommended values of Abbey (1980).

Geochemical results

The geochemical data from the analysed samples are given in Table 1. The data suggest that the Senja Nappe metadolerites represent a suite of rocks with little chemical variation (Table 1). The texture and mineralogy of the metadolerites are not affected by metasomatic alteration. However,

Table 1. Major and trace element composition of the Senja Nappe metadolerites. FeO^T means total iron recalculated as FeO (Irvine & Baragar 1971).

	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
SiO2	45.36	47.32	48.97	49.90	49.53	48.97	49.25	49.75	50.03	48.70	49.57	49.51	49.37	49.30	51.14
TiO2	2.30	1.64	2.13	2.50	2.78	2.50	2.23	2.49	2.37	2.70	2.89	2.11	2.49	2.02	2.43
Al2O3	15.31	15.69	14.86	13.65	13.59	13.60	14.24	14.18	14.09	14.03	13.60	14.21	13.94	14.28	13.50
Fe2O3	13.27	10.92	12.48	13.42	13.83	13.33	12.97	13.43	13.67	13.62	14.40	12.37	8.04	12.10	12.94
MnO	0.23	0.13	0.19	0.24	0.22	0.23	0.20	0.25	0.28	0.22	0.21	0.17	0.18	0.21	0.21
MgO	7.14	8.00	6.47	5.90	5.94	6.46	6.60	6.55	6.37	6.12	5.84	6.24	6.32	6.50	5.52
CaO	10.88	10.84	10.27	9.68	9.87	10.10	9.49	9.98	10.09	9.47	8.65	10.68	15.42	10.82	9.55
Na2O	2.60	3.11	3.13	2.54	2.19	2.19	2.26	2.30	1.64	3.24	3.09	3.10	2.75	2.88	3.38
K2O	0.42	0.55	0.37	0.71	0.69	0.69	0.96	0.56	0.51	0.35	0.30	0.57	0.35	0.84	0.97
P2O5	0.33	0.16	0.28	0.28	0.33	0.28	0.24	0.28	0.25	0.28	0.33	0.23	0.28	0.22	0.32
Tot.	97.84	98.36	99.15	98.82	98.97	98.35	98.44	99.77	99.30	98.73	98.88	99.19	99.14	99.17	99.96
Rb	0.00	17.00	7.10	2.40	12.00	16.00	26.00	11.80	4.30	7.70	3.30	9.90	6.60	12.00	38.00
Sr	207.00	508.00	206.00	129.00	138.00	143.00	149.00	193.00	134.00	259.00	358.00	342.00	304.00	165.00	220.00
Y	48.00	34.00	42.00	63.00	62.00	58.00	50.00	56.00	51.00	59.00	61.00	51.00	52.00	48.00	69.00
Zr	235.00	131.00	157.00	235.00	242.00	197.00	176.00	203.00	184.00	213.00	244.00	181.00	180.00	159.00	258.00
Nb	17.20	4.80	5.00	6.50	9.20	8.30	6.30	6.30	6.50	8.60	6.90	6.30	5.60	5.00	8.00
FeOT/MgO	1.67	1.23	1.74	2.40	2.10	1.86	1.77	1.85	1.93	2.00	2.22	1.78	1.99	1.98	2.11

since primary magmatic textures are not preserved, it is not possible to evaluate early stage (syn-intrusive) alteration effects on petrographical background. Hydrothermal alteration, e.g. spilitization, may have mobilized the alkalies (Stephens 1980). Similarly, carbonatization of the metadolerites may have occurred due to extraction of Ca from the calcareous metasedimentary rocks found in the Senja Nappe. However, the amount of potassium and calcium-rich secondary minerals such as biotite, chlorite and calcite appears to be very low in the metadolerites.

Some control on the question of chemical mobility is provided by the plot of selected elements/oxides against FeO^T/MgO as a differentiation index (Fig. 2). We chose the FeO^T/MgO-ratio as a differentiation index since this ratio normally increases in a basaltic magma evolving from basic into acid composition by different fractional crystallization processes (Pearce & Norry 1979). From Fig. 2 striking linear trends exist between all elements and the FeO^T/MgO-ratio, except for Na_2O, K_2O, Rb and Sr. Of particular interest are the positive correlation trends for P_2O_5, TiO_2, Zr and Y versus differentiation index, and the negative correlation of MgO and CaO, indicating that the first mentioned elements were enriched and the latter removed as differentiation proceeded. Similar changes appear when basic magmas undergo fractional crystallization (Le Maitre 1962). The elements Na, K, Ca, Rb, and Sr all show a spread on Fig. 2, indicating mobility of these elements, perhaps due to spilitization (Stephens 1980). Hence, it is concluded that the chemical variability seen in the geochemical data from the Senja Nappe metadolerites reflect a combination of inherited magmatic fractionation trends and post-magmatic mobility of certain elements, particularly Na, K, Ca, Rb, and Sr (Pearce & Norry 1979; Sun et al. 1979; Winchester & Floyd 1984).

If fractional crystallization occurred during ascent of the basic magma, the increase in TiO_2 and FeO^T and decrease in MgO (Fig. 2) were probably related to enrichment of ilmenite/magnetite as crystallized phases in the melt rather than to removal of crystallized olivine-pyroxene, as in normal basalt fractionation (Fig. 3; Moorhouse & Moorhouse 1979). Strong iron enrichment trend is confirmed by the AFM-plot (Fig. 4d) and the general high content of magnetite in the mineral mode. The positive correlation between P_2O_5 and Zr relative to the differentiation index (Fig. 2) may indicate that fractionation of apatite and zircon from the melt had not started, producing a drop in the pattern of these elements versus differentiation index (Cox et al. 1979). Since such drops usually occur at a later stage in the magma differentiation history, it is suggested that the linear spread of many elements of the studied metadolerites (Fig. 2) is related to an early (?) stage of fractionation of a relatively primitive basaltic magma. This suggestion is supported by constant ratio between Zr and P_2O_5 with differentiation (Fig. 2), and a notable variation in Zr and Zr/Y-ratio shown below.

On the other hand, secondary mobility of Na, K, Rb and Sr, and to a lesser extent Ca, is shown by an irregular scatter of these elements in the differentiation index plot (Fig. 2). This element mobility may have been caused either by diagenetic spilitization, or hydrothermal alteration related to the Caledonian regional metamorphism. The slight covariant decrease of Sr and Ca with differentiation index may indicate breakdown of Ca-rich minerals (Ca-plagioclase and clinopyroxene), producing rocks enriched in, or with variable CaO and Na_2O-contents. The high and variable amounts of K_2O and Rb suggest covariant mobility, perhaps as an effect of biotitization (potassium-metasomatism). The mobility of the alkalies was, however, not comprehensive enough to move the rock compositions out of the igneous spectrum field in Hughes' (1973) diagram (Fig. 4a). In the ACF-diagram, too (Fig. 4b), all samples, except one, plot well inside the igneous basalt field of Coombs (1963). Bearing this in mind, the application of various discrimination plots to the Senja Nappe metabasic intrusions for classification and geotectonic setting interpretation may be valid for, at least, the presumably immobile elements Ti, Zr, Y, Nb and P.

The Senja Nappe metadolerites have a consistent subalkaline tholeiitic to weak andesite basalt affinity, when applying the immobile elements outlined above (Fig. 4f). The same character is indicated by the alkali-silica diagram, and on an AFM triangle (Figs. 4c, d), despite the fact of presumed alkali mobility. The samples plotting close to the alkali-basalt dividing lines on these diagrams may have been derived from a magma transitional between subalkaline and alkaline basalt, or alternatively, their composition is a result of secondary alteration. Hence, care

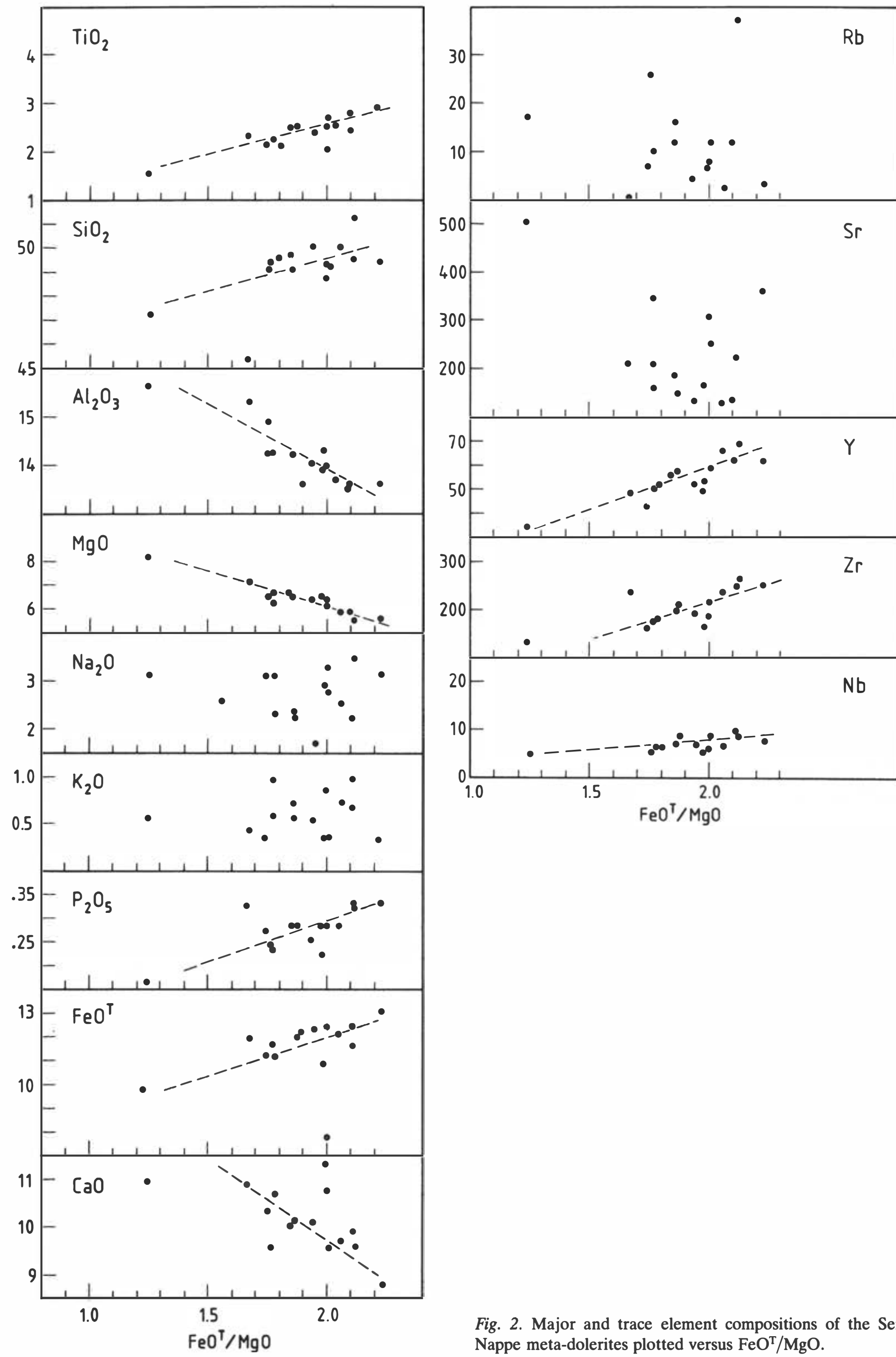


Fig. 2. Major and trace element compositions of the Senja Nappe meta-dolerites plotted versus FeO^T/MgO.

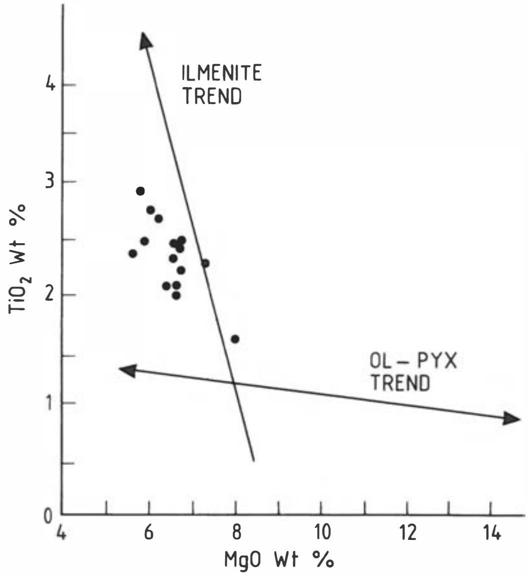


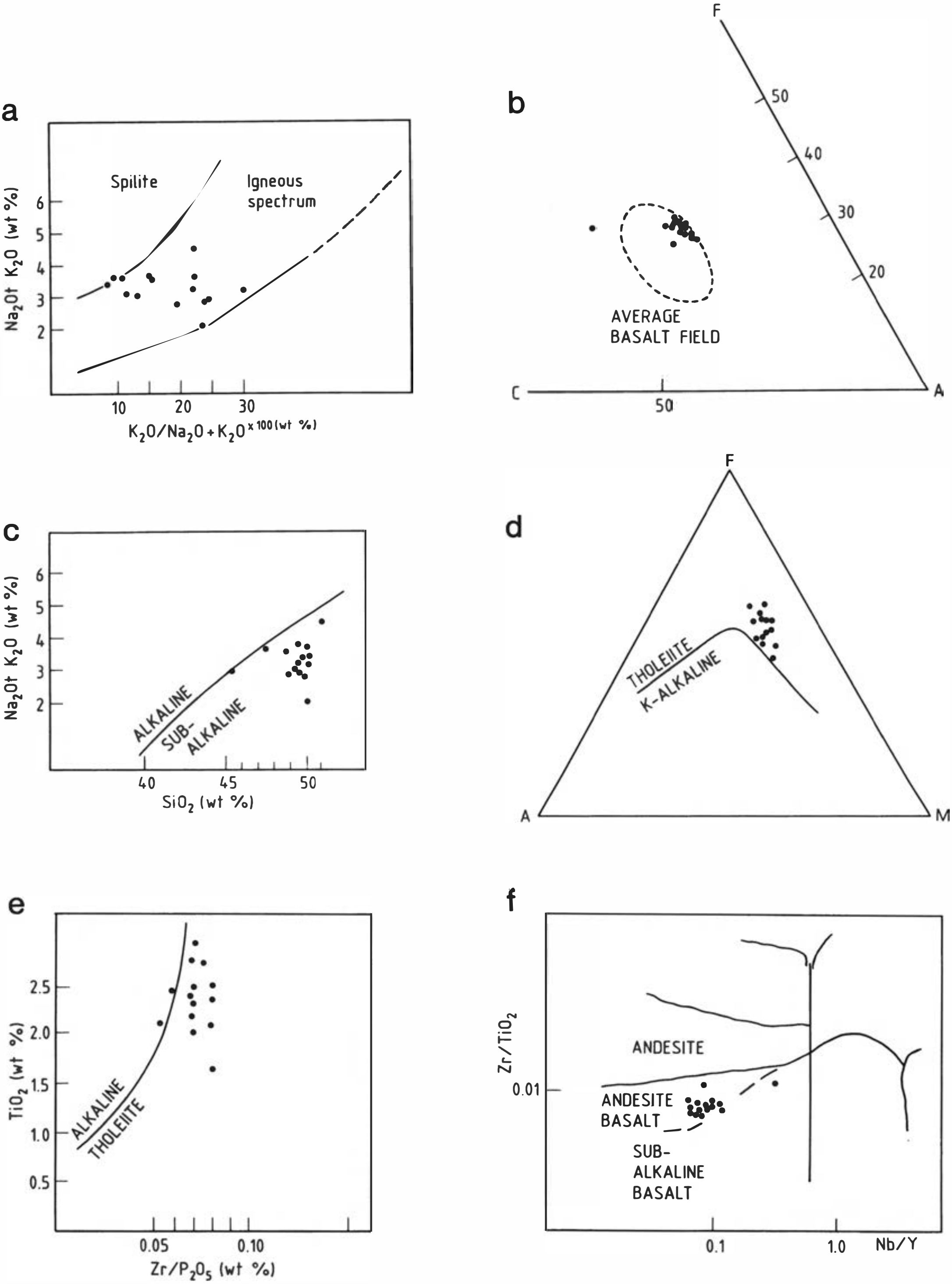
Fig. 3. TiO_2 plotted against MgO, attempting to distinguish possible olivine–pyroxene fractionation trends from ilmenite fractionation trends (Moorhouse & Moorhouse 1979) for the Senja Nappe metadolerites.

should be taken considering the validity of plots including the alkalies. A tholeiitic, instead of calc-alkaline evolution line, is supported by the positive correlations of TiO_2, FeO^T, and SiO_2 versus FeO^T/MgO (Fig. 2), according to Miyashiro (1975). Based on their distribution on various trace element classification plots, such as the TiO_2 versus Zr/P_2O_5 diagram (Fig. 4e; Winchester & Floyd (1976), and the Zr/TiO_2 versus Nb/Y-diagram (Fig. 4f; Winchester & Floyd 1977), the compositions are clearly tholeiitic.

Interpretation of paleotectonic settings for basic volcanic sequences – including mid-ocean ridge basalt (MORB), island-arc/volcanic arc tholeiite (IAT/VAB), calc-alkaline basalt (CAB), and within-plate basalt (WPB) – was started by Pearce & Cann (1973), utilizing the elements Ti, Zr, Y, Nb, and Cr. We attempt to evaluate the geotectonic setting of the Caledonian metadolerites of the Senja Nappe by employing the presumably least mobile elements. On the Ti–Zr–Y, and Ti–Zr–Sr diagrams (Fig. 5a, b; Pearce & Cann 1973), the metadolerites plot in the ambiguous 'MORB + LKT + CAB' field. The cluster within the MORB field in the Ti–Zr–Sr diagram is surprising, since Sr appears to have been mobile during metamorphism (Fig. 2). In this diagram only one sample (sample 44) shows the effect of secondary Sr-enrichment, by plotting close to the Sr-edge (Fig. 5b). The rocks show an affinity to both WPB and MORB on the Ti–Zr diagram (Fig. 6a) of Pearce (1980).

In discriminating between continental and oceanic basalt magmas the ratio Y/Nb can be further used. According to Pearce & Cann (1973) and Floyd & Winchester (1975), the Y/Nb-ratio of continental tholeiites usually ranges between 1 and 4.5 (alkali basalts < 2), increasing to an average of between 8 and 10 for tholeiites with oceanic character. The plot utilizing TiO_2 as ordinate (Fig. 6b) shows that, except for one sample (43), metadolerites of the Senja Nappe display unambiguous oceanic character despite the fact that the TiO_2-content is somewhat higher than usual compared with normal oceanic basalts (Pearce 1980). The oceanic affinity is also seen in the ternary diagrams TiO_2–K_2O–P_2O_5 (Fig. 7a; Pearce et al. 1975), and MgO–FeO^T–Al_2O_3 (Fig. 7b; Pearce et al. 1977). In the latter diagram the samples plot close to the boundary between oceanic and continental tholeiite. An oceanic affiliation is also indicated by the incompatible Zr/Y and Ti/Y-ratios, and Nb (Pearce & Gale 1977). 'Within plate basalts' have usually a higher concentration of elements such as Ti, Nb, and Zr, relative to Y, than 'oceanic' and 'plate margin' types (Pearce & Gale 1977). The ratios Zr/Y and Ti/Y should therefore effectively distinguish between these two magma types (Pearce 1980). In a plot of the Zr/Y versus Ti/Y-ratios (Fig. 8a), the metadolerites cluster unambiguously in the 'plate margin' field, whereas there is an overlap between the MORB and WPB fields in the Zr/Y versus Zr diagram (Fig. 8b; Pearce & Norry 1979), although the data distribution still appears to be dominantly in the MORB-field.

The geochemical pattern of a basic rock suite normalized to an average MORB-composition may give additional clues as to the geotectonic setting (Gale & Pearce 1982). In Fig. 9 we compare the normalized patterns for selected elements in samples 45, 50, 53 and 57 with patterns for typical MORB, WPB and IAT magma types. The elements Ti, Nb, P, Zr, and Y, which are all presumably immobile, have been slightly enriched in the Senja Nappe metadolerites relative to the MORB-composition. The enrichment of Rb, Sr, and K, except in sample 53, may be due to secondary alteration, a feature which has probably obscured the original chemical pattern. Despite these reservations, the metadolerites


a
Spilite
Igneous spectrum
$Na_2O + K_2O$ (wt %)
6
5
4
3
2
10
20
30
$K_2O/Na_2O+K_2O \times 100$ (wt %)
b
F
50
40
30
20
AVERAGE BASALT FIELD
C
50
A
c
$Na_2O + K_2O$ (wt %)
6
5
4
3
2
ALKALINE
SUB-ALKALINE
40
45
50
SiO_2 (wt %)
d
F
THOLEIITE
K-ALKALINE
A
M
e
TiO_2 (wt %)
2.5
2.0
1.5
1.0
0.5
ALKALINE
THOLEIITE
0.05
0.10
Zr/P_2O_5 (wt %)
f
Zr/TiO_2
0.01
ANDESITE
ANDESITE BASALT
SUB-ALKALINE BASALT
0.1
1.0
Nb/Y

readily match the flat immobile element patterns characteristic of tholeiitic MORB and in part WPB-patterns (Fig. 9; Hawaii tholeiite), thus confirming the results obtained from other discriminant diagrams. The WPB-pattern (Fig. 9) emerges from the immobile element Nb, rather than from the high and variable K and Rb contents.

In summary, the clustering of data points in most discriminant plots suggests that the metadolerites were derived from the same parental magma, intruding the sedimentary rocks of the Senja Nappe. It appears from the foregoing discussion that the metadolerites were most likely formed as melts derived exclusively from a MORB-tholeiitic magma. The 'transitional basalt-andesite' affinity of some of the metadolerites, indicated by slightly higher-than-normal Ti, Zr, Y, and Nb-contents (Wood et al. 1979) relative to Pearce's (1980) standard MORB, may be due to more advanced fractionation. This explanation is confirmed by the relatively high FeO^T/MgO-ratio in these samples. Alternatively, the transitional character may reflect contamination of the dolerites with host rock continental material, for example along a plate boundary. Similar magmas have been described by Easton (1983) as being generated during continental rifting. The observed chemical characteristics of the Senja Nappe metadolerites may then adhere to magma intrusions accompanying lithosphere thinning, preceding the formation of a passive continental margin. A process of crustal extension is indicated by the cross-cutting relationships between the metadolerites and the country rock.

Fig. 4. Plot of the Senja Nappe metadolerites in various discrimination diagrams for classification.

a. Alkali-ratio diagram to distinguish spilites (Hughes 1973).

b. ACF-diagram with the average basalt field of Coombs (1963). $A = Al_2O_3 - (Na_2O + K_2O)$, $C = CaO$, $F = FeO^T + MgO + MnO$.

c. Alkali-silica variation diagram distinguishing between alkaline and subalkaline basalts.

d. AFM-diagram distinguishing tholeiitic and calc-alkaline basalt trends.

e. TiO_2–Zr/P_2O_5 plot of Winchester & Floyd (1976) showing tholeiitic to weak alkaline character of the study metadolerites.

f. Zr/TiO_2 versus Nb/Y diagram (Winchester & Floyd 1977) illustrating the subalkaline, andesite-basalt nature of the metadolerites.

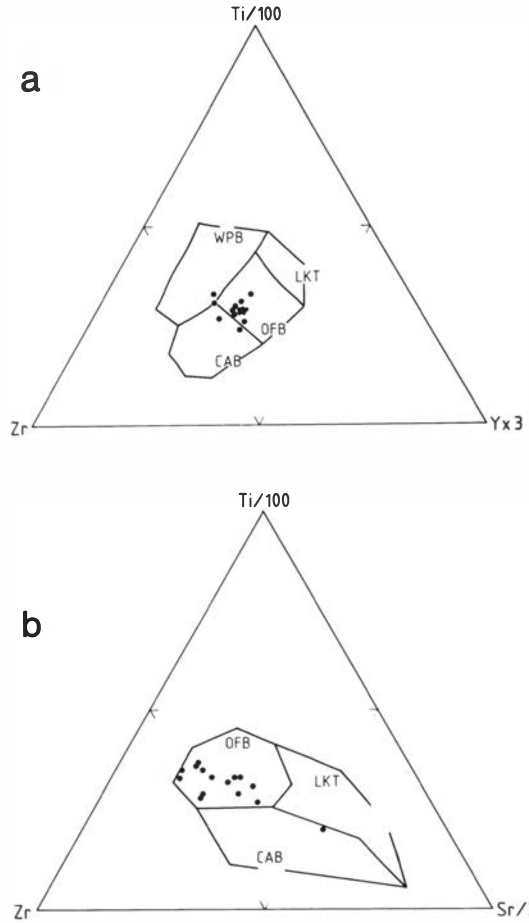


Fig. 5.

a. Triangular plot of Ti–Zr–Y (Pearce & Cann 1973) discriminating ocean floor/ocean ridge (OFB-MORB), continental basalts (WPB), low-potassium tholeiites (LKT), and calc-alkali basalts (CAB).

b. Discrimination diagram using Ti, Zr, and Sr, to show the distinct OFB-affinity of the Senja Nappe metadolerites. Subdivision as in a.

Geological implications

The geochemical signature of the tholeiitic metadolerites of the Senja Nappe, transitional between within plate/plate margin and spreading ridge basalts, combined with the platformal to miogeoclinal nature of the country rocks, indicates that the Senja Nappe represents a slice of a dolerite intruded, partly rifted sedimentary basin. The structural position of the Senja Nappe on Senja as well as the occurrence of mafic dikes favour a correlation with the Middle Allochthon. The extensive carbonate build-ups so typical of the

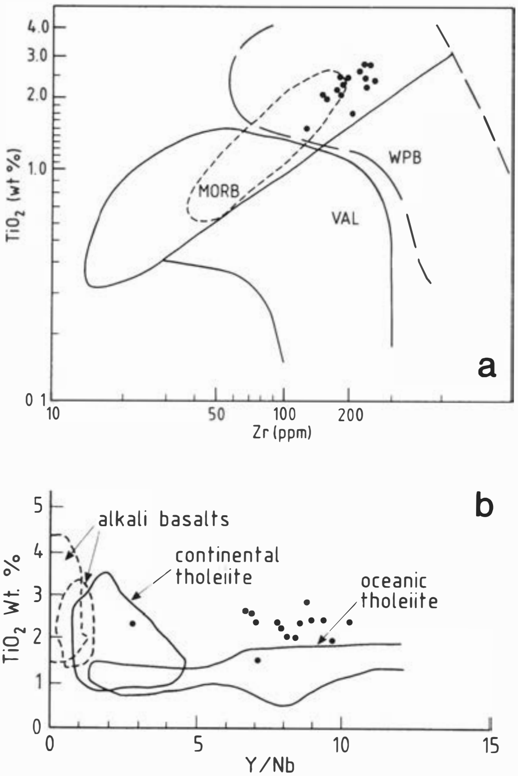


Fig. 6.
a. Plots of the Senja Nappe metadolerites in the TiO_2–Zr plot (Pearce 1980).
b. TiO_2 plotted against Y/Nb separating tholeiites from alkaline basalts, and continental from oceanic tholeiites (Floyd & Winchester 1975).

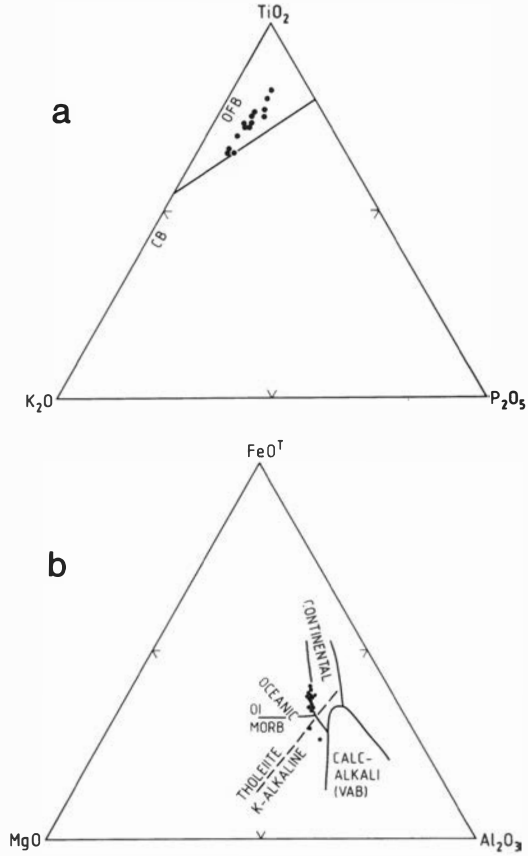


Fig. 7.
a. TiO_2–K_2O–P_2O_5 diagram distinguishing basalts of oceanic (OFB) and continental (CB) environments (Pearce et al. 1975).
b. MgO–FeO^T–Al_2O_3 diagram (Pearce et al. 1977) showing fields of calc-alkaline (VAB) and tholeiitic basalt (continental, oceanic, oceanic islands; OI, and MORB basalt).

Senja nappe are, however, not characteristic of the Middle Allochthon (Kalak Nappe Complex) further east. A dramatic facies change is thus invoked if the Senja Nappe on the basis of rift-related metadolerites should be incorporated in this allochthon.

Rift-related metadolerites are, however, not unique to the Riphean/Vendian rocks involved in the Middle Allochthon. Also the Upper Ordovician/Silurian Balsfjord Group, unconformably overlying the Lyngen Gabbro, is intruded by numerous metadolerite dikes (Munday 1970, 1974; Minsaas 1981; Velvin 1984; Andresen et al. 1985). The dominance of metapelites, marbles and psammites in the Balsfjord Group (Andresen & Bergh 1985; Bergh & Andresen 1985) strengthens this correlation, although Fareth (1981) and Andresen et al. (1985) interpreted the Balsfjord Group as representing a higher structural level than the Senja Nappe. This latter interpretation was, however, based on a correlation between the Senja Nappe proper and a sequence of psammites, pelites and marbles structurally below the Nordmannvik/Dyrøy Nappe on the mainland, a correlation which recent fieldwork does not support (K. B. Zwaan written communication; own observations). The lithologic similarities, including the presence of metadolerites, between the Balsfjord Group and the Senja Nappe in its type area suggest a genetic link between the two units. Published geochemical data on metadolerites from the Middle Allochton (Kalak Nappe Complex) show, however, considerable scatter in most variation diagrams (Gayer et al. 1985), most probably due

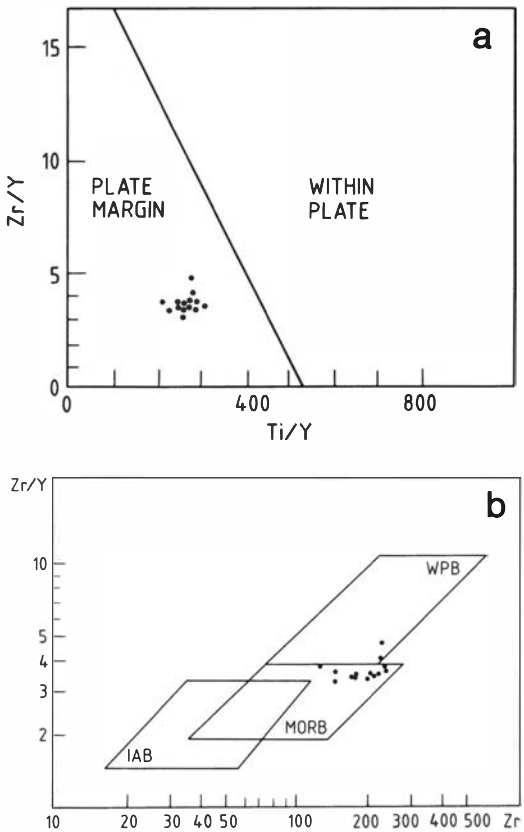


Fig. 8.
a. Zr/Y versus Ti/Y to distinguish 'within plate' basalt from 'plate margin' basalts (Pearce & Gale 1977). Note the tight cluster of the Senja Nappe metadolerites in the 'plate margin' field.
b. Zr/Y versus Zr plot, separating mid-ocean ridge basalt (MORB), island arc basalt (IAB), and within plate basalt (WPB) fields (Pearce & Norry 1979).

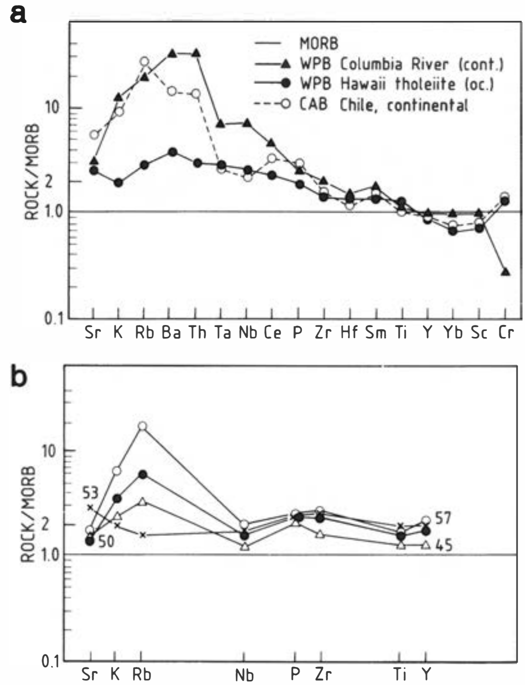


Fig. 9.
a. Geochemical trace element patterns for some typical present-day basalts normalized to an average MORB (Pearce 1980).
b. Plot of four representative samples (Samples 45, 50, 53, and 57) of the Senja Nappe metadolerites, normalized to average MORB-composition (Pearce 1980).

to post-magmatic alteration. These data are thus unreliable for comparison with the Senja Nappe metadolerites and in identifying geotectonic setting. The geochemical data from the metadolerites in the Balsfjord Group, however, do show a tholeiitic trend (Gayer et al. 1985).

The explanation favoured here is that the Senja Nappe represents a westerly extension of the Balsfjord Group or is derived from the same sedimentary basin as the Balsfjord Group. It probably occurs at the same structural level as the Lyngen Nappe, but it could also be at a lower structural position due to large scale folding or reverse faulting. The above correlation implies a Late Ordovician to Silurian depositional age for the Senja Nappe on Senja. If the structural position of the Senja Nappe is the same as for the Lyngen Nappe, it further implies that the high grade rocks on eastern Senja, structurally on top of the Senja Nappe, should be correlated with the Tromsø Nappe Complex and not the Nordmannvik Nappe as proposed by Andresen et al. (1985).

Conclusions

Despite intense deformation combined with upper greenschist facies metamorphism, geochemical data on metadolerites from marble, micashists and quartzites within the Senja Nappe appear to reflect primary magmatic characteristics. The metadolerites are subalkaline thoeliitic in composition and show only minor compositional variation. Most of the compositional variation is probably due to ilmenite fractionation. A comparison with basaltic rocks of known plate tectonic setting indicates that the Senja Nappe metadolerites are transitional between within plate and plate margin basalts, with the signature of spreading ridge basalt (MORB). Based on the nature of the country rocks, an origin at an oceanic spreading ridge seems unlikely, and an origin below a rifted sedimentary basin is suggested. The nature of the country rocks suggests a correlation with the Late Ordovician/Silurian Balsfjord Group of the Lyngen Nappe, rather than the dolerite intruded psammites of the Middle Allochthon (Kalak Nappe Complex).

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