Contrib Mineral Petrol (1990) 105:1–10

Contributions to Mineralogy and Petrology

Pillow lavas as protoliths for eclogites: evidence from a late Precambrian-Cambrian continental margin, Seve Nappes, Scandinavian Caledonides

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Received May 16, 1989 / Accepted March 6, 1990

Abstract. Pillow lavas containing an eclogitic mineral assemblage, locally with glaucophane/crossite, are described from the Tsäkkok Lens within the Seve Nappes, north-central Scandinavian Caledonides. Critical primary relationships to the host metasedimentary rocks which are dominated by marble and quartz-garnet-phengite schist are preserved. It is argued that these clastic rocks, and the ongoing igneous activity in the Tsäkkok Lens, are late Precambrian to Cambrian in age and that these rocks were deposited/emplaced along the outermost part of a continental margin related to the continent Baltica.

Variations in the whole-rock chemistry of the eclogitic rocks within the Tsäkkok Lens suggest that most elements were mobile during post-extrusive/intrusive evolution. Only Ti, P and Y show significant magmatic trends in element vs Zr plots. Discriminant diagrams employing the elements Ti, P, Zr, Y, Nb and Cr suggest a tholeiitic protolith with a tendency towards enriched mid-ocean ridge basalt (E-MORB) affinity characterized by a relatively low Zr/Nb ratio. A similarity to metabasic rocks occurring in other Seve thrust sheets but lacking evidence for high-P metamorphism is apparent. A common origin for all these rocks is inferred. The Tsäkkok eclogites formed by 'in situ' high-P metamorphism and provide further evidence for subduction of continental crustal material down to mantle depths. This subduction event has been related to collision of Baltica with an outboard arc system during the late Cambrian to early Ordovician.

Introduction

The structure of the Scandinavian Caledonides is dominated by an assembly of thrust sheets conveniently divided into four major complexes, the Lower, Middle, Upper and Uppermost Allochthons (Gee et al. 1985). One of the critical elements for modelling the tectonic stacking of these allochthons has proven to be the abundant development of high-pressure (high-P) metamorphic rocks which are dominated by eclogites.

Most of these high-P rocks and by far the most well-known occurrences are preserved in the window of Proterozoic gneisses in southwestern Norway, referred to as the Western Gneiss Region (Griffin 1987 and references therein). Eclogites are also present in some of the tectonostratigraphically higher thrust sheets belonging to the Middle Allochthon (Griffin 1972, Austrheim and Griffin 1985) and the Seve Nappes of the Upper Allochthon (van Roermund and Bakker 1984, van Roermund 1985, Andréasson et al. 1985, Stephens and van Roermund 1984, Nicholson 1984, Santallier 1988). All these units represent the tectonically shortened Baltoscandian margin of the early Palaeozoic continent Baltica (Gee 1975, Stephens and Gee 1989). Ongoing work has even demonstrated the occurrence of eclogites in the exotic terrane(s) situated within the Uppermost Allochthon (Gustavson 1979, Krogh et al., in press).

Attention is focused here on eclogites occurring in the Seve Nappes of the Upper Allochthon in southern Norrbotten, Sweden (Fig. 1a). The principal aims are to document the volcanic origin of at least some of these eclogites and their primary relationship to the host metasedimentary rocks. Furthermore, it will be shown that their chemical signature is similar to that of metabasic rocks occurring elsewhere in the Seve Nappes which lack evidence for high-P metamorphism.

Geological setting

Regional geology

The Seve Nappes are characterized by an assemblage of predominantly medium- and high-grade metasedimentary and metabasic rocks extending almost continuously along the Caledonian mountain chain in Scandinavia (Zachrisson 1973 and Fig. 1a). They are thought to have been derived from the transition zone between the continent Baltica and the ocean Iapetus (Gee 1975). The Seve

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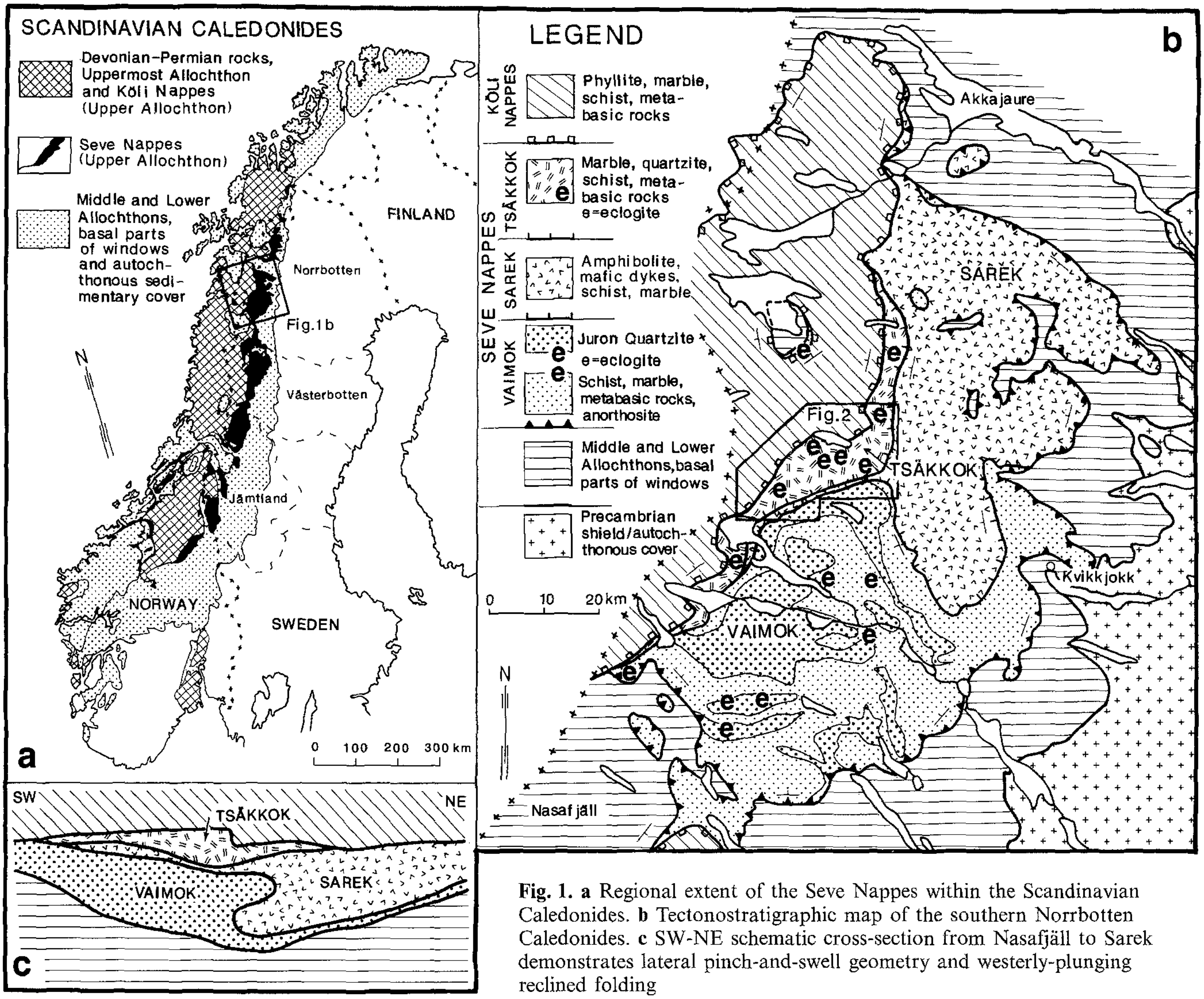

Fig. 1. a Regional extent of the Seve Nappes within the Scandinavian Caledonides. **b** Tectonostratigraphic map of the southern Norrbotten Caledonides. **c** SW-NE schematic cross-section from Nasafjäll to Sarek demonstrates lateral pinch-and-swell geometry and westerly-plunging reclined folding

Nappes are built up of several internal tectonic units, demonstrated or inferred to be thrust sheets (Trouw 1973, Zachrisson and Stephens 1984). In southern Norrbotten, three such units have been recognized. These show a pronounced mega-lens geometry and are, in part, complexly interfolded (Zachrisson and Stephens 1984, and Fig. 1b and c).

Eclogite and, more commonly, amphibolite are hosted by feldspathic quartzite and psammitic schist in the lowermost Seve unit (Vaimok Lens) in southern Norrbotten (Andréasson et al. 1983, Santallier 1988). Eclogite crystallization occurred at 503 ± 14 Ma (Sm-Nd, Mørk et al. 1988). This was followed by uplift through temperatures necessary for intracrystalline retention of Ar in hornblende (c. 500° C) at 491 ± 8 Ma and in phengite (c. 400° C) at c. 440 Ma ($^{40}Ar/^{39}Ar$, Dallmeyer and Gee 1986). The tectonostratigraphically overlying unit (Sarek Lens) is dominated by mafic rocks which show no evidence of high-P metamorphism. In the central parts of this unit, mafic bodies occur as a more or less pristine sheeted intrusive complex with occasional screens of metasedimentary rocks (Andréasson 1986). The eclogites forming the focus of the present study occur in the uppermost Seve unit (Tsäkkok Lens).

Tsäkkok Lens

The Tsäkkok Lens can be divided lithostratigraphically into two units (Kullerud 1987, Snilsberg 1987 and Fig. 2). The contact between these units is transitional and is based on proportions of metasedimentary rocks and the nature of the mesoscopic structures. The lower unit is dominated by homogeneous and strongly foliated quartzo-feldspathic schist with subordinate amounts of coarse-grained garnet-mica schist, calcareous schist and marble. The upper unit is principally composed of marble, quartzite and quartz-garnet-phengite schist, complexly folded on both a meso- and macroscopic scale.

Metabasic rocks occur as lenses or layers and are more abundant within the upper unit (Fig. 2). They often show a mineralogical zoning with an eclogite paragenesis in the massive cores and a retrogressive amphibolite to greenschist paragenesis in the foliated outer rims.

The metamorphic evolution has been described in terms of a six-stage, clockwise P, T and t (time) path, from an early-amphibolite stage, via high-P blueschist and eclogite stages, to initial post-eclogite, late-amphibolite and greenschist stages (Kullerud 1987 and Table 1). Garnet-clinopyroxene geothermobarometry (Ellis and Green 1979, Holland 1980) suggests temperatures and minimum pressures of 500–630° C and 12–14.5 kb (c. 40–50 km) during the high-P stages (Stephens and van Roermund 1984, Nicholson 1984, Kullerud 1987). The foliation in the retrogressed parts of the mafic bodies lies parallel to, and has been correlated with, the principal grain-shape fabric in the host metasedimentary rocks (Kullerud 1987). Although high-P assemblages have not been observed in the metasedimentary rocks, foliation microlithons, porphyroblasts enclosed in the principal grain-shape fabric and inclu-

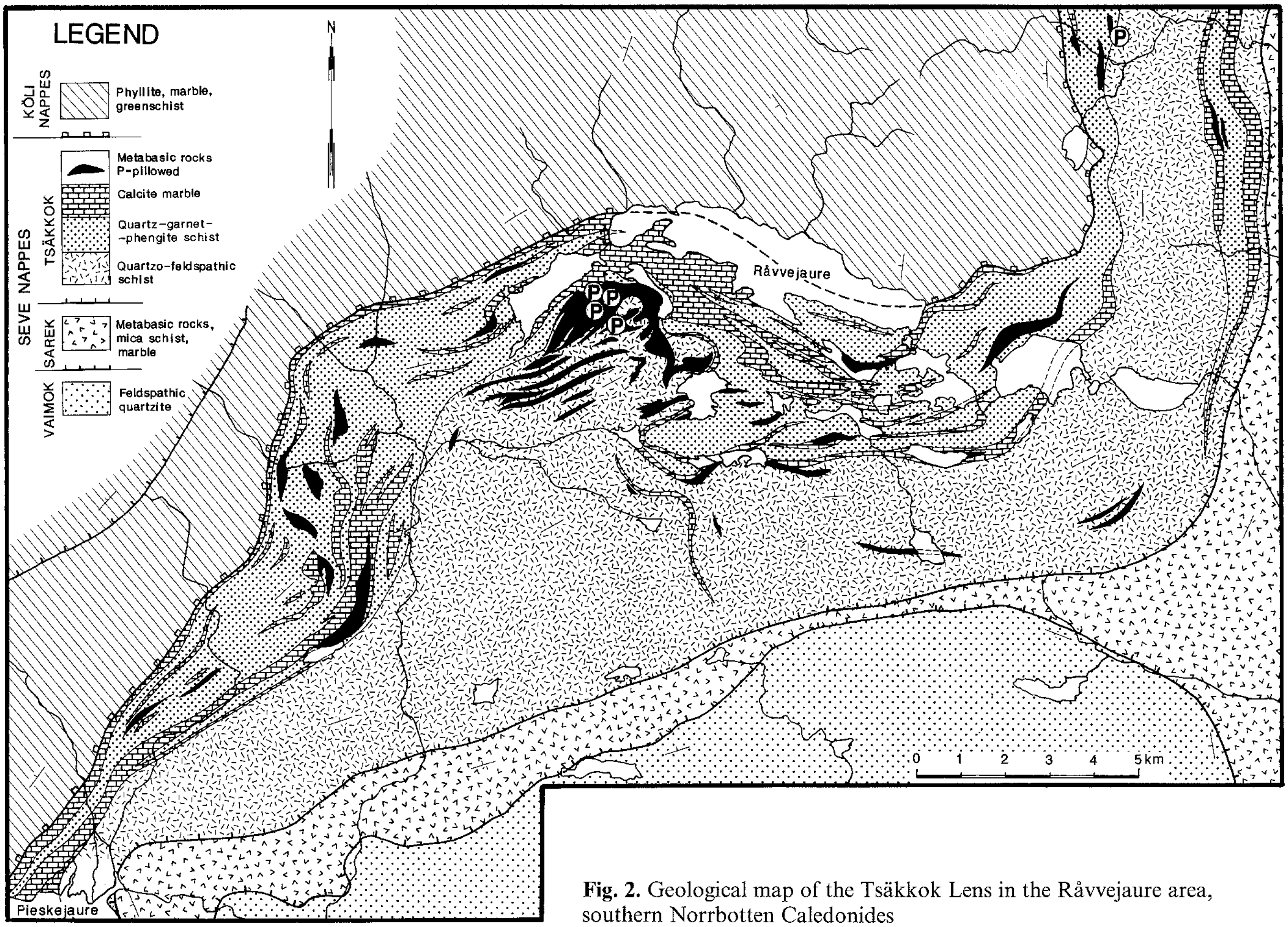

Fig. 2. Geological map of the Tsäkkok Lens in the Råvvejaure area, southern Norrbotten Caledonides

Table 1. Mineral assemblages in the pillowed samples

Sample (BFKK)	Early-amphibolite stage	High-pressure stages	Initial post-eclogite stage	Late-amphibolite and greenschist stages
84082 Pillow		Gar (Omph)	Pg	Ab, Hbl, Ep, Bi, Chl
84082 Interstitial material	Clz, Pa	Gl, Gar, Clz, Pa	Pg, Ph	Ab, Hbl, Ep
84085 Pillow	Clz, Pa	Gar, Pa, Clz	Ph	Ab, Hbl, Ep, Bi
84125 Pillow	Clz	Gar, Clz	Ph, Pg	Ab, Hbl, Ep, Chl
84127 Pillow	Clz, Pa, Pg	Clz, Pa, Gl, Na-Aug, Omph, Gar		
84128 Pillow	Clz, Pa, Pg	Clz, Pa, Gar, (Omph, Gl)		Ab, Hbl, Chl
84129 Pillow			Barr	Ab, Hbl, Chl, Ep
84130 Pillow		(Gar, Gl)	Ph	Ab, Hbl, Ep, Bi
84130 Interstitial material		Gar, Gl, Clz	Pg	Ab, Hbl

Mineral abbreviations: Ab = albite, Barr = barroisite, Bi = biotite, Chl = chlorite, Clz = clinozoisite, Ep = epidote, Gar = garnet, Gl = glaucophane/crossite, Hbl = actinolite/hornblende, Na-Aug = sodic augite, Omph = omphacite, Pa = paragonite, Pg = pargasite, Ph = phengite. In addition to the phases listed in the table, quartz, calcite and a Ti-phase are always present. Rutile is the stable Ti-phase until the late-amphibolite stage when rutile breaks down to titanite. The metamorphic stages are according to Stephens and van Roermund (1984) and Kullerud (1987) based on textural relationships in the Tsäkkok metabasic rocks sions within the porphyroblasts provide evidence for a deformational and metamorphic history older than formation of the grain-shape fabric (Snilsberg 1987).

Sm-Nd isotope studies on eclogites within the upper part of the Tsäkkok Lens provide an age of 505±18 Ma for the high-P metamorphism (Mørk et al. 1988). This is consistent with the radiometric age-dating results for the retrogressed eclogites in the structurally deeper Vaimok Lens. These data demonstrate a late Cambrian to early Ordovician, high-P metamorphic event in the outer part of the Baltoscandian margin. This has been related to a collision between the continent Baltica and an outboard arc system (Dallmeyer and Gee 1986). According to Ernst (1988), the low P/T ratio during eclogite retrogression in the Tsäkkok Lens is consistent with a collisional régime. Development of the principal grain-shape fabric in the metasedimentary rocks has been linked (Snilsberg 1987) to the younger, Silurian-Devonian continent-continent collisional event in the Scandinavian Caledonides (Gee 1975, Griffin and Brueckner 1980).

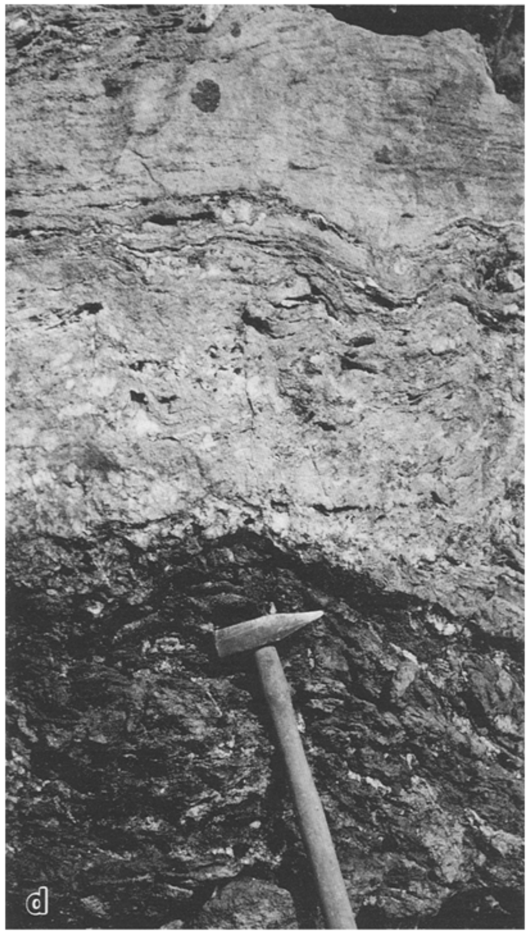

Fig. 3. a. Pillow-structured eclogite with dark rims and interstitial fillings. A radial fracture pattern, inferred to be related to initial cooling of the lava flow, is still preserved in the lowermost pillow. The dark spots are composed of garnet. Diameter of camera top = 7 cm. **b.** Similar pillow-lava structure in eclogite. Length of hammer approximately 50 cm. **c.** Angular mafic fragments in a calcareous matrix. This rock is inferred to represent the top of a lava flow or possibly even pyroclastic material. **d.** Upper (?), fragmental part of a mafic lava flow overlain by pebbly and eventually layered marble. The fragmental structure in both volcanic and carbonate clastic material is inferred to be primary in character

Protolith signature

In general, no traces of primary features remain in the Tsäkkok metabasites and the contact rocks are strongly foliated and retrogressed. However, at a few critical places within an area of approximately 1 km^2, southwest of Råvvejaure (Fig. 2), the metabasic rocks show, in general, remarkably little strain and well-preserved pillow lavas have been observed (Fig. 3a and b). Primary depositional contacts are also locally present between the metabasic and enclosing/intercalated metasedimentary rocks. Pillows were also identified at one other locality approximately 12 km further northeast.

A compilation of mineral assemblages observed in samples of pillow lava is presented in Table 1. Apart from a higher frequency of alkali amphibole (crossite to glaucophane), the pillow lavas do not differ mineralogically from the other metabasic rocks in the Tsäkkok Lens. Although omphacite is still preserved in several samples, most are dominated by garnet and a fine-grained symplectite of albite and actinolitic amphibole. The symplectite is interpreted to represent the recrystallization product after the eclogitic or possibly even the initial post-eclogitic stage mineralogy. Apart from a slight modal increase in garnet and glaucophane towards the pillow rims in some samples, there is no pronounced mineralogical or textural difference between cores and rims of pillows. The interstitial fillings and the 1–10 mm thick zones between the pillows consist mainly of carbonate, are often rich in garnet and frequently contain alkali amphibole.

Pillows or fragments of pillows vary in size from <10 up to 100 cm in diameter. Where primary depositional relationships are preserved, the contact zone is marked by volcanic breccia (Fig. 3c), sometimes in juxtaposition with pebbly metasandstone or marble (Fig. 3d). The mafic material in the volcanic breccia is interpreted to have been derived from the top of a pillowed flow or may even represent a pyroclastic input. Deposition of calcareous clastic material and mafic volcanic flows in a subaqueous fan environment is suggested.

Geochemistry

Analytical techniques

Whole-rock analyses of major and minor elements in 27 metabasic rocks from the Tsäkkok Lens are included in this study. Most of the samples come from localities displaying no primary features; two samples (BFKK 84128 and BFKK 84129) are from the metamorphosed pillow lavas. A Philips PW 1410 XRF was employed for 24 analyses at the Department of Geology, University of Oslo. Fused pellets containing rock powder and a $Li_2B_4O_7$ flux mixed

Table 2. Selected whole-rock analyses for the Tsäkkok eclogites and retro-eclogites

	1	2	3	4	5	6	7	8	9	10
						Pillowed	Pillowed			
	BFKK 84080	BFMS 80103	BFKK 84162	BFKK 83089	BFKK 83039	BFKK 84128	BFKK 84129	BFKK 83054	BFKK 83021	BFKK 83131
Wt %										
SiO_2	48.61	47.20	50.23	49.29	50.35	51.46	49.25	48.62	49.65	48.49
TiO_2	1.44	1.11	1.45	1.45	1.74	1.47	1.47	1.13	1.30	1.80
Al_2O_3	15.04	17.10	14.55	14.59	9.35	13.70	13.54	14.93	14.54	14.04
Fe_2O_3*	12.22	10.30	11.12	11.13	12.89	11.25	11.34	9.92	11.24	12.21
MnO	0.20	0.18	0.19	0.21	0.21	0.14	0.16	0.16	0.18	0.25
MgO	9.31	8.30	7.26	7.20	10.48	8.44	7.96	8.54	7.23	7.24
CaO	9.03	11.90	9.58	9.84	11.35	7.36	11.31	10.35	10.76	8.72
Na_2O	2.15	1.80	3.73	3.30	1.99	4.30	2.49	2.83	3.75	3.43
K_2O	0.65	0.30	0.02	0.40	0.27	0.04	0.07	0.19	0.00	0.36
P_2O_5	0.14	0.08	0.15	0.16	0.20	0.12	0.14	0.12	0.12	0.13
LOI	0.54	2.90	0.48	0.74	0.74	0.83	1.60	2.71	0.50	2.00
	99.33	101.17	98.76	98.31	99.57	99.11	99.33	99.50	99.27	98.67
ppm										
Rb	16	nd	<1	13	6	1	<1	4	<1	8
Sr	132	nd	257	196	77	262	462	487	165	278
Zr	84	66	88	94	110	99	92	72	86	114
Nb	8	nd	8	8	14	7	8	9	8	9
Y	28	16	30	32	34	29	32	26	28	40
Cr	284	319	276	261	328	433	261	449	322	397
Ni	217	120	86	87	84	93	76	142	99	108
Y/Nb	3.5	–	3.8	4.0	2.4	4.1	4.0	2.9	3.5	4.4

Fe_2O_3* = total Fe as Fe_2O_3; nd = not determined

Analyses 1–4 are from the central parts of eclogite bodies where omphacite is well preserved. Analysis 5 comes from the retrogressed margin of an eclogite body where there is a strong grain-shape fabric (omphacite absent). Analyses 6–10 represent intermediate rock types containing an albite-amphibole symplectite + omphacite and a grain-shape fabric

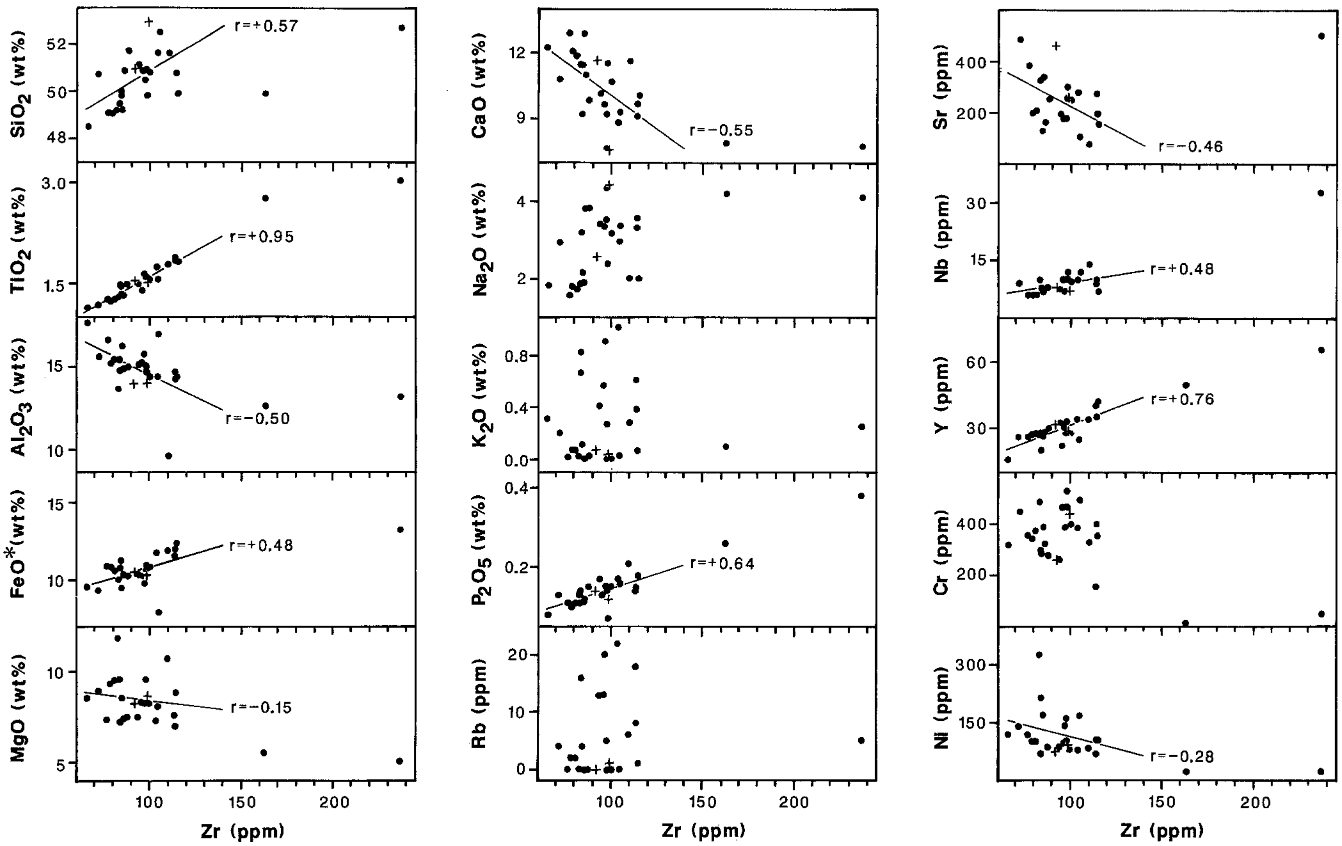

Fig. 4. Element-Zr plots for eclogites and retro-eclogites in the Tsäkkok Lens. Before plotting on this and the following figures, the whole-rock analyses have been recalculated to 100% after subtracting loss of ignition (LOI). ● = sample lacking protolith signature, + = metamorphosed pillow lava, r = correlation coefficient based on all analyses except the two with high Zr contents. FeO* = total Fe content calculated as FeO

in the ratio 1:9 were used. Trace element (Rb, Sr, Zr, Nb, Y, Cr and Ni) analyses of these samples were carried out on a similar apparatus at the Geological Museum, Tøyen, Oslo, using pressed powder pellets. Three analyses were carried out at the Geological Survey of Sweden, Uppsala, following the procedure described by Stephens (1982). Selected whole-rock analytical data are provided in Table 2.

Post-magmatic element mobility

In order to gain some control on the post-magmatic element mobility in the metabasic rocks, the analytical data have been plotted on an element vs Zr diagram (Fig. 4). Zr has been used since it is both a moderately incompatible element and apparently shows restricted mobility in a variety of post-magmatic alteration processes (Cann 1970; Pearce and Norry 1979, Sheraton 1984). A good correlation between Zr and a particular element can be expected if the samples belong to a single magmatic series and if the element under consideration suffered negligible mobility during post-magmatic processes. By contrast, lack of correlation suggests mobility of the element

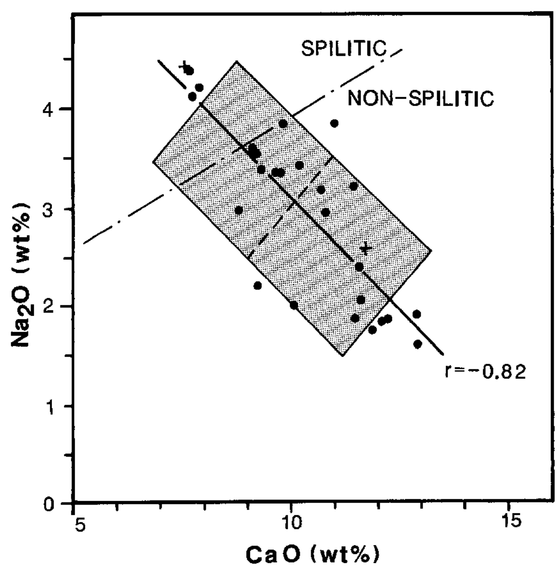

Fig. 5. Na_2O-CaO plot. Symbols as in Fig. 4. The *shaded field* contains mean values of unaltered basalts and is based on Stephens (1982); alkaline and calc-alkaline basalts plot to the *NW* and tholeiitic basalts to the *SE* of the *dashed line* in this field. The line separating spilites and non-spilites is based on Graham (1976)

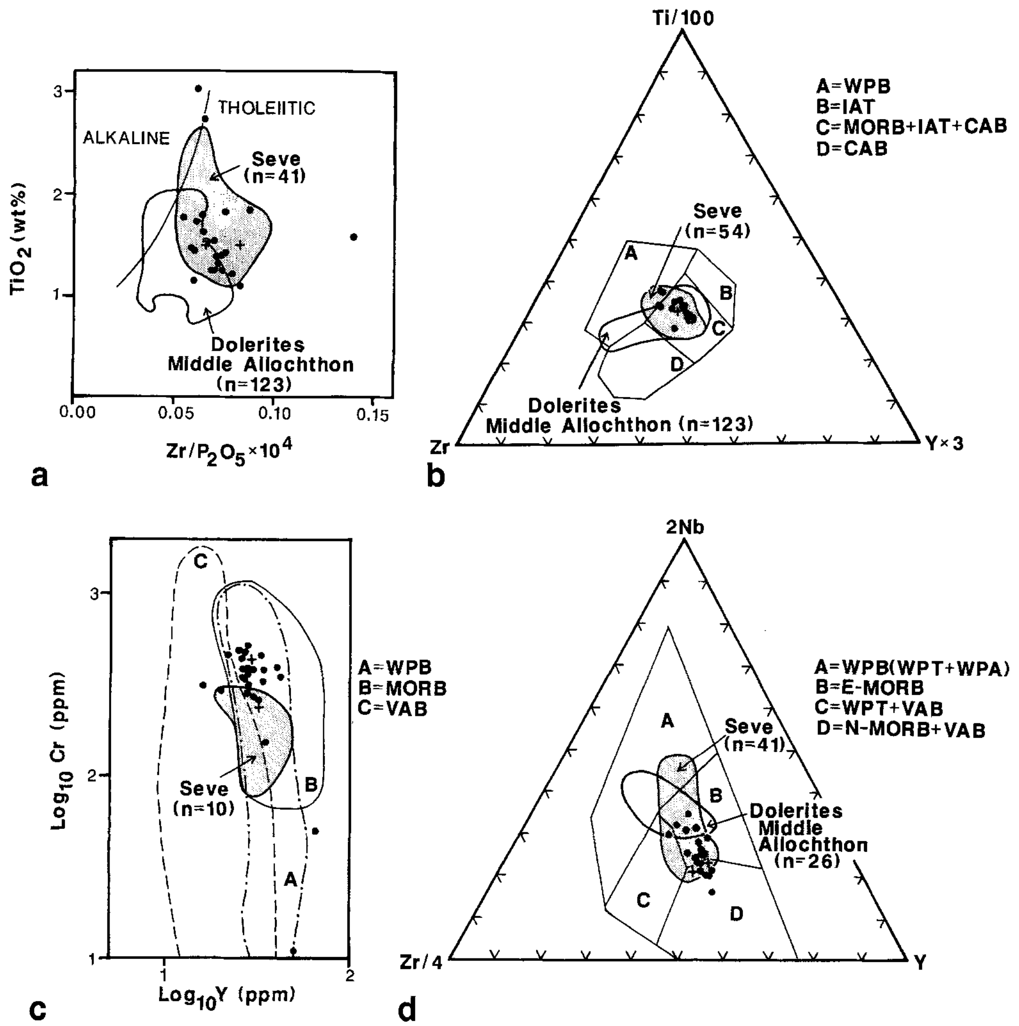

Fig. 6a–d. Discriminant diagram plots for Tsäkkok eclogites and retro-eclogites marked with symbols as in Fig. 4. For comparison, fields are shown for dolerites in the Middle Allochthon (Solyom et al. 1979a) and Seve metabasic rocks (*shaded area*) lacking evidence for high-P metamorphism (Solyom et al. 1979b, Hill 1980, P.G. Andréasson and Z. Solyom, personal communication 1989). **a** TiO_2-Zr/P_2O_5 after Winchester and Floyd (1976). **b** Ti-Zr-Y after Pearce and Cann (1973). **c** $\log_{10}$Cr-$\log_{10}$Y after Pearce (1982). **d** Zr-Nb-Y after Meschede (1986). WPB = Within-plate basalt (WPT = Tholeiitic, WPA = Alkaline), MORB = Mid-ocean ridge basalt (N-MORB = Normal, E-MORB = Enriched in incompatible elements), VAB = Volcanic arc basalt (IAT = Tholeiitic, CAB = Calc-alkaline)

under consideration and/or absence of a comagmatic series.

Two samples differ from the main group of analyses by their distinctly higher Zr contents (Fig. 4) and have been excluded when the various correlation coefficients have been calculated. Nevertheless, these samples often lie close to the extension of the best-fit lines and are enriched in less compatible (TiO_2 and Y) and depleted in more compatible (MgO, Cr and Ni) elements. Thus, they probably represent more evolved compositions. It is important to note also that the two metamorphosed pillow lava samples do not deviate from the main group of analyses.

Apart from TiO_2 ($r = +0.95$), Y ($r = +0.76$) and to a less extent P_2O_5 ($r = +0.64$), the element vs Zr plots show scattered patterns and, thereby, low correlation coefficients. Since the elements Ti, Y and P, like Zr, are relatively immobile during post-magmatic processes in mafic rocks (Pearce and Norry 1979, Sheraton 1984), their patterns on the element vs Zr plots suggest that the samples analyzed here belong to the same magmatic series. This is supported by the weakly positive correlation coefficients for SiO_2, FeO* (total Fe expressed as FeO) and Nb, and the weakly negative correlation coefficients for Al_2O_3, CaO and Sr. Significant element mobility during post-magmatic processes is considered to be the more important factor controlling the common scattered pattern on the element vs Zr plots. The distinctive negative correlation on a Na_2O vs CaO plot (Fig. 5) suggests that early pre-deformational processes related to sub-seafloor spilitization may explain the alteration signature established here.

Protolith magma type and tectonic affinity

The metabasic rocks from the Tsäkkok Lens show relatively high Y/Nb ratios (2–6) indicative of a tholeiitic basalt protolith (Winchester and Floyd 1976). This is supported by the relatively low TiO_2 contents at respective Zr/P_2O_5 ratios (Fig. 6a). In a Ti-Zr-Y triangle (Fig. 6b), the metabasites plot in a tight cluster in, or very close to, the field which includes both mid-ocean ridge basalts (MORB) and volcanic arc basalts. Although care is required in use of the more mobile element Cr, the Tsäkkok metabasic rocks show relatively high Y values at respective Cr concentrations (Fig. 6c). This feature strengthens the interpretation that these metabasic rocks do indeed display an affinity to MORB. The relatively low Zr/Nb ratios and the distribution of the analyses on a Nb-Zr-Y triangle (Fig. 6d) suggest that the protolith basalts show a tendency towards enriched mid-ocean ridge basalt (E-MORB) affinity.

Discussion and concluding remarks

The only unambiguous example of pillow lavas as protoliths for eclogites has been described from the Western Alps, especially in the Zermatt-Saas Fee area (Bearth 1959, 1970, 1973, Oberhänsli 1982, Barnicoat and Fry 1986, Barnicoat 1988). At Rimpfischhorn, for example, an approximately 500 m thick sequence containing eclogitized pillow lava overlies serpentinite and is interpreted as part of an ophiolite complex. Pillow lavas metamorphosed under blueschist conditions are much more common and have been reported, for example, from the Franciscan Complex, western USA (Coleman and Lee 1963, Brown and Bradshaw 1979, MacPherson 1983) and from southeastern Anglesey, U.K. (Barber et al. 1981, Dallmeyer and Gibbons 1987). Apart from the Anglesey example, where the high-P metamorphism affects late Precambrian-Cambrian rocks and is probably Cambrian in age, the protolith age of all high-P metamorphosed pillow lavas known to us is Mesozoic or younger and the high-P metamorphism of these rocks Cretaceous or younger. Thus, the Tsäkkok example reported here represents one of the oldest pillow lava sequences affected by high-P metamorphism and perhaps the oldest when it concerns transformation to eclogite. This is independent evidence that subduction processes were in operation and convergent plate settings in existence at least at the end of the Cambrian.

'In situ' vs 'exotic' model for eclogite formation?

Even though the presence of pillow lavas demonstrates the volcanic origin of at least some of the eclogites in the Tsäkkok Lens, it is the relationship along the contacts to the host metasedimentary rocks which are also critical in evaluating models for eclogite formation. Clearly most contact relationships do not eliminate the possibility that there has been considerable movement along the boundaries between the eclogites and the host metasedimentary rocks. Nevertheless, at some of the critical pillow lava localities, the contacts between the well-preserved eclogitized pillow lavas and the host metasedimentary rocks are primary, supporting the case for 'in situ' high-P metamorphism.

A second approach to the metamorphic problem involves the regional geochemical signature of the metabasic rocks in the Seve Nappes and dolerites in the structurally underlying Middle Allochthon. The present study has shown that the protolith of the eclogites and retroeclogites in the Tsäkkok Lens was a tholeiitic basalt with a tendency towards E-MORB affinity characterized by a relatively low Zr/Nb ratio. Tholeiitic dolerites (Ottfjället Dolerites) intruding feldspathic sandstones in the uppermost tectonic unit of the Middle Allochthon (Solyom et al. 1979b) and, more conspicuously, metabasic rocks occurring in some other Seve thrust sheets along the mountain belt (Solyom et al. 1979a, Hill 1980, P.G. Andréasson and Z. Solyom, personal communication, 1989), all characterized by the lack of evidence for high-P metamorphism, share the same geochemical signature. Comparison is based on the discriminant diagrams which utilize the less mobile elements Ti, Zr, Y, P and Nb (Fig. 6). This regional geochemical similarity, irrespective of the pressure of metamorphism, is considered to provide support to an 'in situ' model.

Protolith age and tectonic setting

The quartzo-feldspathic metasedimentary and metabasic rocks which dominate the Seve Nappes have been related to the feldspathic sandstones and dolerites in the structurally highest thrust sheet of the underlying Middle Allochthon (Strömberg 1969). This correlation is critical since the highest unit in the Middle Allochthon contains a glaciogenic marker horizon (Kumpulainen 1980) intruded by dolerites yielding a whole-rock K-Ar age on samples free of excess Ar of 665 ± 10 Ma (Claesson 1976, Claesson and Roddick 1983). If the above correlation is correct, then a late Precambrian to Cambrian age for the eclogite protoliths and their host rocks in the Tsäkkok Lens can be inferred.

Support for such an age is obtained from recent Sm-Nd isotope data for a dolerite from the Seve Nappes in Västerbotten where a clinopyroxene-plagioclase-whole-rock isochron is interpreted to reflect a crystallization age of 666 ± 22 Ma (E.W. Mearns, personal communication, 1989). A late Precambrian to Cambrian protolith age is also consistent with the Sm-Nd isotope data for eclogite minerals and whole-rock samples in southern Norrbotten which apparently date the peak of high-P metamorphism to 505 ± 18 Ma (Mørk et al. 1988) and the $^{40}Ar/^{39}Ar$ hornblende age of 491 ± 8 Ma which dates part of the subsequent uplift history (Dallmeyer and Gee 1986). Since the time required to establish eclogite conditions in the subducted slab has been suggested to be of the order of 20 Ma (Dallmeyer and Gee 1986), a protolith age older than approximately 525 Ma is inferred.

The lithology of the Seve host rocks, the geochemical signature of the eclogites and the various dating results record a complex geotectonic evolution at the edge of the continent Baltica from late Precambrian into Ordovician time. This evolution has been related to the opening of the ocean Iapetus and later collision of the outer margin of the continent Baltica with an outboard arc complex (Gee 1975, Dallmeyer and Gee 1986). It is probable that each successively higher tectonic unit within the Seve Nappes represents a more oceanward, pre-deformational segment of the old continental margin.

Most of the metasedimentary rocks in the Tsäkkok Lens are quartzitic or quartzo-feldspathic in character. However, they also contain a substantial carbonate component as well as lithologies intermediate between the quartz- and carbonate-rich varieties. Mafic igneous rocks, including pillow lavas, with tholeiitic basalt composition and a tendency towards E-MORB affinity occur in this sequence. The sedimentary rocks are suggested to represent the outermost part of a clastic wedge deposited during late Precambrian to Cambrian time on the thinned edge of the continent Baltica or even on the newly-formed ocean floor. Source areas were of continental character and probably included a carbonate platform. Subduction of the outermost part of the continental margin to depths >40–50 km occurred during the late Cambrian to early Ordovician in the continent – outboard arc collisional régime. The Tsäkkok case history provides further evidence for the subduction of continental crustal material down to mantle depths (Schreyer 1988).

Acknowledgements. This work was completed in the context of the Inter-Nordic Nordkalott Project, an interdisciplinary mapping programme north of latitude 66° N carried out by the Geological Surveys of Finland, Norway and Sweden. We wish to thank P.G. Andréasson for providing us with unpublished chemical analyses for the Seve metabasic rocks in the Sarek area. P.G. Andréasson, J.G. Liou and M.B.E. Mørk kindly read and revised an early version of the manuscript. Comments by two anonymous referees are also appreciated.

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Editorial responsibility: W. Schreyer