Major element geochemistry of Neoproterozoic successions of Varanger Peninsula, North Norway, and Sredni and Rybachi Peninsulas, Northwest Kola, Russia: provenance patterns and basin evolution

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Major element analyses of 461 samples of Neoproterozoic sedimentary rocks were classified by using petrochemical plots and statistically treated in cluster analyses. In general, the studied siliciclastic rocks represent two major associations. The first contains arkoses to quartz arenites with predominantly illitic shales; it includes the majority of the studied formations and may be interpreted as a product of denudation of the continental crust. The second association comprises greywackes and lithic arenites associated with shales which contain some chlorite and Na-feldspars. The chemistry suggests that there was a contribution from a basic, Na-rich crust or volcanic source.
The geochemistry is in accord with interpretations of sedimentary environments and basin development based on other methods. It also indicates a temporarily cold and dry climate which is compatible with sedimentary facies analysis and the fact that there was no continental vegetation. Formations which are represented by interbedded variegated siliciclastic and carbonate rocks and exhibit traces of evaporites constitute another important climatic indicator.

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Introduction and scope

The Neoproterozoic (Upper Riphean and Vendian) successions of the Varanger, Rybachi and Sredni Peninsulas have been studied in the early nineties in a joint Norwegian-Russian project. Stratigraphic correlation, the nature and development of sedimentary basins and their subsequent deformation were the main objectives of the project and results of much of this research were published in a Geological Survey of Norway Special Publication (Roberts & Nordgulen, eds. 1995).

The Varanger Peninsula and the adjacent Rybachi-Sredni Peninsulas of NW Russia (Fig. 1) are important areas for understanding the Neoproterozoic geology of the northern Fennoscandian Shield for several reasons. These areas are interpreted as the northwesternmost part of the Timan - Kanin - Varanger Belt and are the best exposed, and perhaps the most thoroughly studied, segment of this elongate tectonic structure. A lithostratigraphy is well established and supported by a fairly well known time-stratigraphy based on various techniques (see e.g. Siedlecka 1995a). Correlation between the segments of the stratigraphic record has recently been outlined (Siedlecka et al 1995a, 1995b, Sochava 1995) (Fig. 2). Environments of deposition based on sedimentary facies analysis in the various formations are fairly well known. This is particularly true for the Varanger Peninsula. New research has also improved our understanding of the nature of the sedimentary environments in which the Neoproterozoic successions of Rybachi and Sredni were accumulated (Siedlecka 1995b). The geological history of this area may therefore provide a useful reference frame for the whole of the Timan - Varanger Belt, providing that also its bedrock geochemistry is studied to some extent.

While there are geochemical data available from the Rybachi and Sredni Peninsulas, relatively little attention has been paid to the importance of geochemistry of the Neoproterozoic rocks of the Varanger Peninsula, for an understanding of the palaeotectonic setting, nature of the provenance area(s) and the processes behind the formation of the stratigraphic successions. Some geochemical data from the Rybachi-Sredni areas have been published in Russian, with only two recent contributions in English (Siedlecka 1995a, Sochava 1995). On Varanger, with one exception (Siedlecka 1995a), geochemical data were non-existent. For this reason, the majority of the Neoproterozoic formations on Varanger Peninsula have now been sampled and so far analysed just for major elements. The results have been statistically treated along with the available analyses from the Rybachi-Sredni successions, and these are discussed jointly in this paper. The geology of the discussed areas is shown in Fig. 1, and lithostratigraphies and correlation in Fig. 2.

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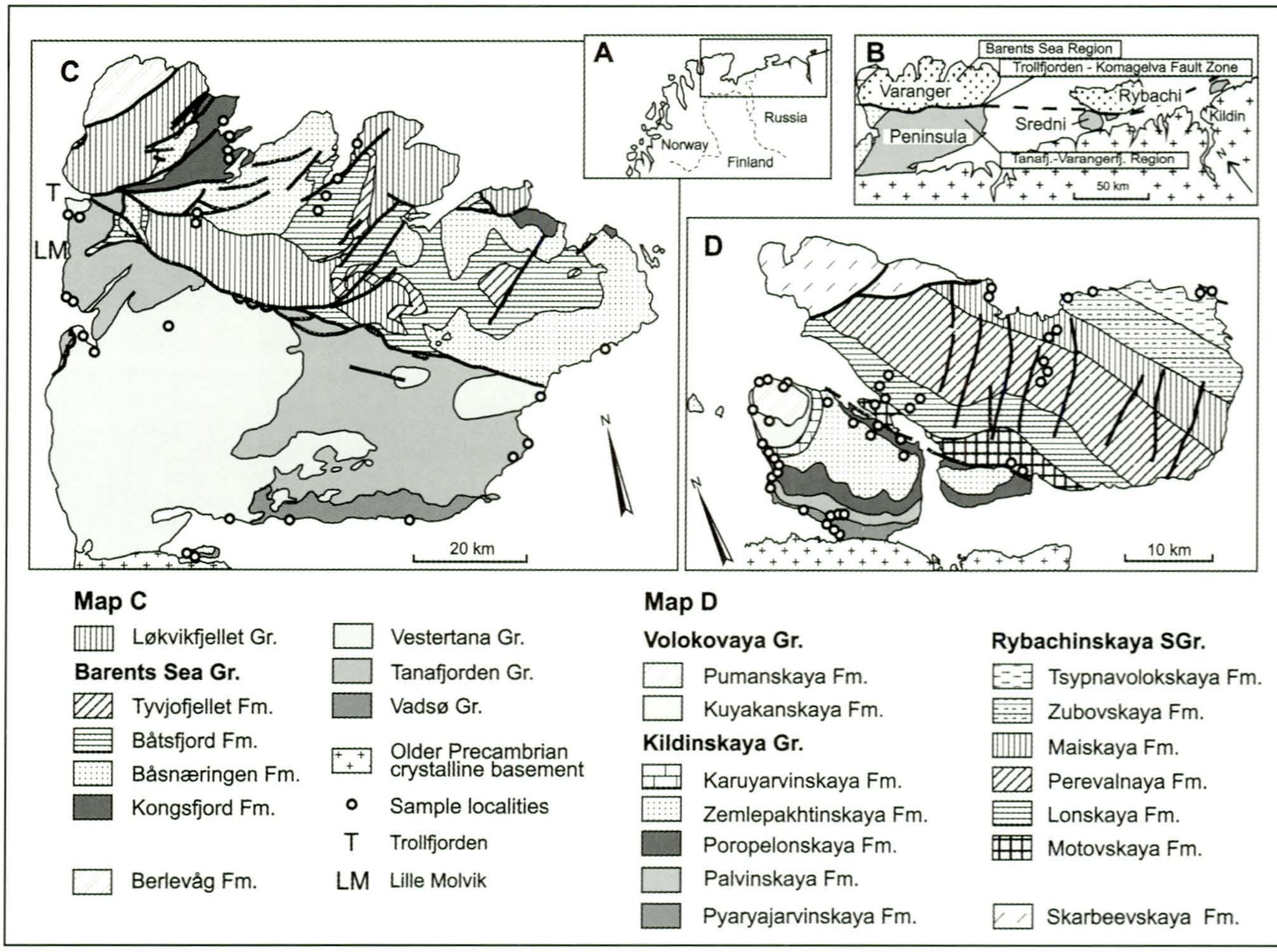

Fig. 1. Location map of the Varanger-Rybachi-Sredni area (A); main geological units in the Varanger-Rybachi-Sredni area (B); geological map of the Varanger (C), Rybachi and Sredni (D) Peninsulas (based on Siedlecka 1995a, 1995b, Negrutsa 1971, Roberts 1995).

Our objectives are as follows: (1) to present, for the first time, comprehensive major element analytical data on the Neoproterozoic successions of the Varanger Peninsula; (2) to compare these compositions with those of the Rybachi-Sredni area; (3) to evaluate the usefulness of major element composition for a better understanding of the nature of the provenance area and basin development; and (4) to provide a reference frame for further interpretation of the development of the Timan-Varanger Belt in Neoproterozoic time.

Geological framework

Neoproterozoic successions of the coastal areas of East Finnmark (Norway) and northern coastal Kola Peninsula (Russia) occur in five separate regions (Fig. 1B):

(1) Barents Sea Region (BSR), northeastern Varanger Peninsula;
(2) Tanafjorden -Varangerfjorden Region and Gaissa Nappe Complex (TVR), southwestern Varanger Peninsula;
(3) Rybachi Peninsula (RP);
(4) Sredni Peninsula (SP); and
(5) Kildin Island (KI), not included in this study, a correlative succession to that on Sredni.

The Neoproterozoic stratigraphic successions preserved in these areas are separated from each other either by fault lines, e.g. the Trollfjorden-Komagelva Fault Zone (TKFZ) and Sredni-Rybachi Fault Zone (SRFZ), or geographically (Fig. 1). Along strike they exhibit similarities in overall facies development and thicknesses while across the major faults, i.e. across regional depositional strike, they are totally different. A rift basin with a precursor fault to the TKFZ and SRFZ as the rift margin-forming structure has been suggested as the site of accumulation of these successions: *basinal* (also referred to as miogeoclinal or allochthonous) northeast of the fault, and *pericratonic* (autochthonous) southwest of the marginal escarpment (Siedlecka 1975, 1985, Siedlecka & Roberts 1995).

The Barents Sea Region comprises the most complete basinal succession, consisting of two groups separated from each other by a major angular unconformity and having a maximum thickness up to 15 km. The lower, Barents Sea

Group is a c.9000 m-thick continuous succession commencing with a submarine turbidite system and terminating with fluvial and coastal deposits. The upper, Løkvikfjellet Group is a c.6000 m-thick succession of predominantly shallow-marine sedimentary rocks (Levell 1978). The Rybachi segment of the basinal succession consists of the c.4000 m-thick Rybachinskaya Supergroup, which is comparable to and suggested to be stratigraphically correlative with the lowermost part of the Barents Sea Group in the BSR (the Kongsfjord Formation (Fig. 2) (Siedlecka et al. 1995a). Both units represent submarine turbidite systems. The substratum of the basinal successions is nowhere exposed and its nature may only be interpreted from the petrographical and geochemical composition of the Neoproterozoic sedimentary rocks.

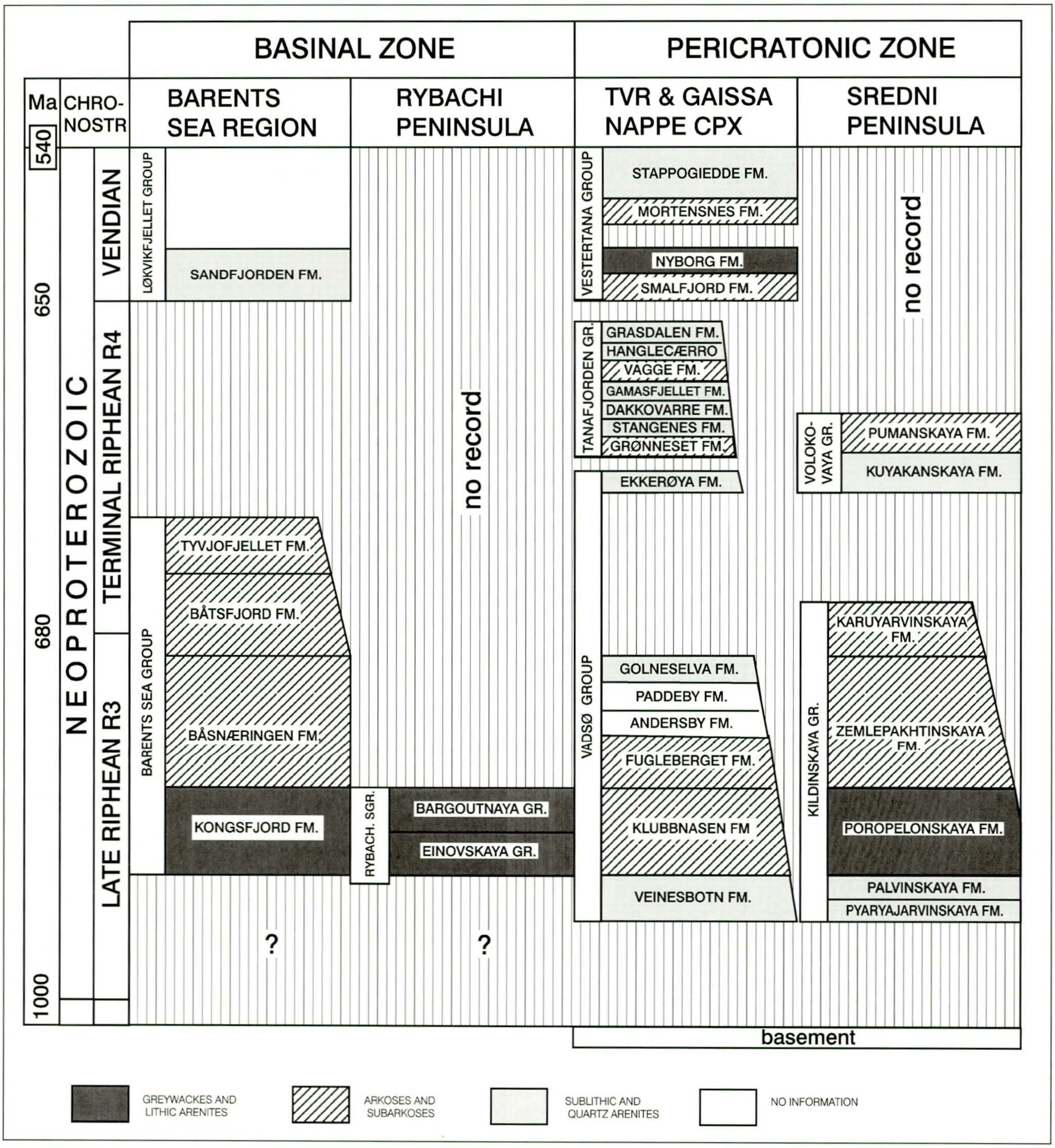

Fig. 2. Stratigraphic correlation of the Neoproterozoic successions of the Varanger, Rybachi and Sredni Peninsulas (based on Siedlecka 1995a with modifications) and sandstone types according to the major element plot (cf. Fig.3). The Skarbeevskaya and Berlevåg Formations are not included because their stratigraphic positions are uncertain.

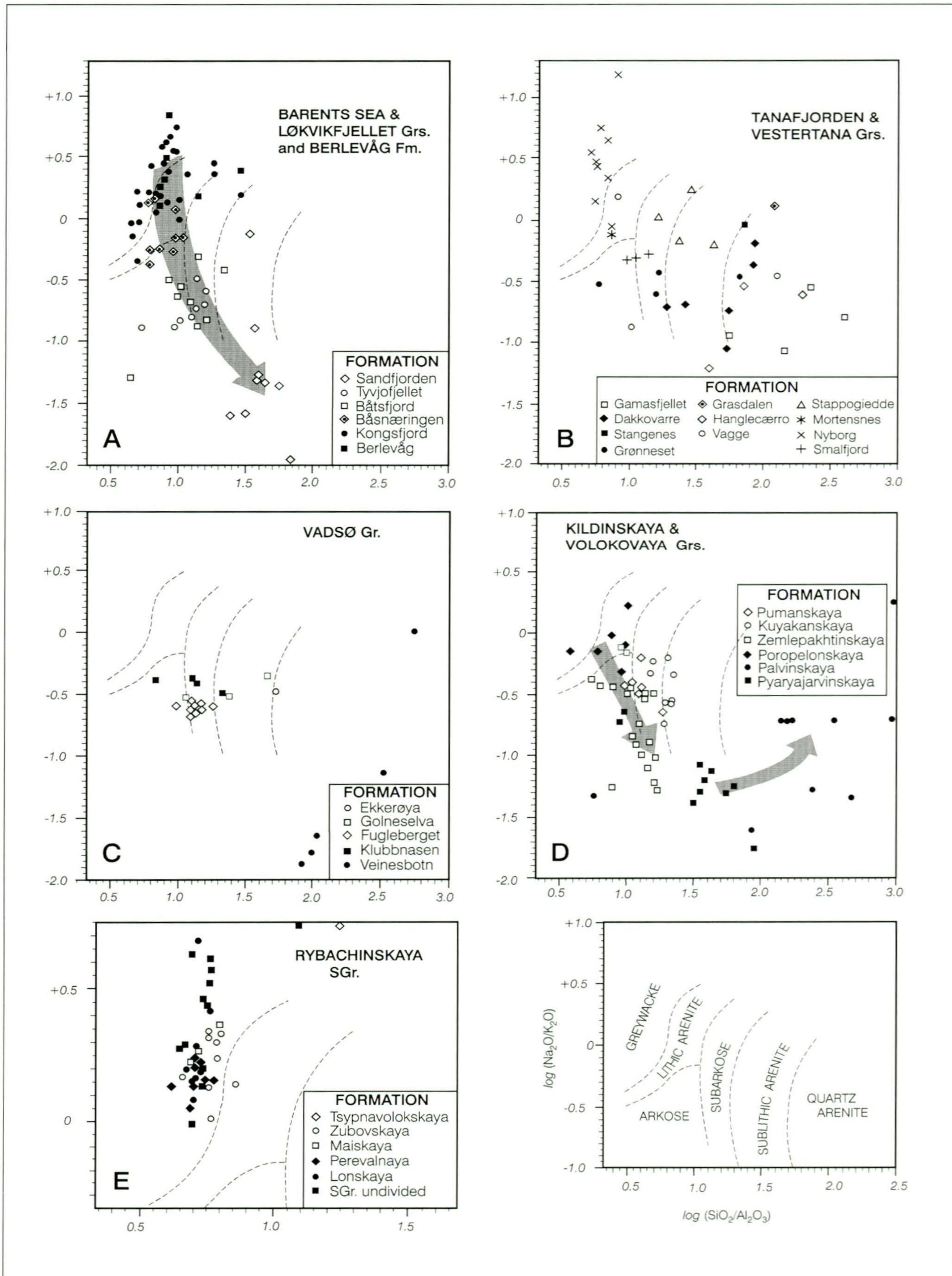

Fig. 3. Neoproterozoic sandstones of the Varanger, Rybachi and Sredni Peninsulas on the diagrams log SiO_2/Al_2O_3 vs. log Na_2O/K_2O (Pettijohn et al. 1987).

By contrast, the pericratonic successions rest unconformably on the older Precambrian crystalline substratum, parts of which constituted the obvious provenance area or areas (Siedlecka 1995a). They consist mainly of fluvial, coastal, shallow-marine and deltaic deposits which, on Varanger Peninsula and further to the west, include the Varangerian glacial record. The pericratonic successions are characterised by several unconformities; the most pronounced of these are the pre-Ekkerøya and pre-Smalfjord unconformities on Varanger, and the pre-Volokovaya unconformity on the Sredni Peninsula (Fig. 2). In spite of the geographical proximity between the TVR and the SP (and Kildin Island), a straightforward lithostratigraphic correlation is not possible. Stratigraphic correlation along strike and across the marginal fault zone is therefore based on the integration of a variety of features and methods, primarily microfossils, stromatolites, radiometric ages and field evidence (see Siedlecka 1995 for references). The importance of unconformities cannot be assessed too lightly, particularly the 'missing link' pre-Ekkerøya unconformity in the Lille Molvik-Trollfjorden area (Rice 1994) (Fig.1C).

Material and analytical methods

Major element compositions of 461 samples of the Upper Proterozoic sandstones, siltstones, clayey shales and carbonate rocks from the Varanger (231 samples) and Rybachi and Sredni (230 samples) Peninsulas are included in this study. From Varanger, sandstones are represented by 129 samples, siltstones by 40, clayey shales by 46 and carbonate rocks by 16 samples. The following collections of samples were used:

Varanger Peninsula: (1) 188 samples collected by A.Sochava under the guidance of A.Siedlecka, analysed by using conventional wet chemical analyses; (2) 34 samples from the Kongsfjord and Berlevåg Formations; and 9 samples from the Nyborg and Golneselva Formations, all collected by A.Siedlecka and analysed by the XRF method.

Rybachi-Sredni Peninsulas: 216 samples collected by A.Sochava and 14 by A.Siedlecka on Rybachi-Sredni, all analysed by the XRF technique.

The analyses of the 188 samples collected on the Varanger Peninsula constitute the core of this contribution. The analytical data have been listed in an unpublished report (Siedlecka 1996). Results of analyses of the samples collected previously by A. Siedlecka have been reported in Siedlecka (1995a). The average major element compositions of the main rock-types from the formations on Rybachi and Sredni have been presented in Sochava (1995). The individual analyses from these areas have not been published.

The mean compositions of the samples from various formations on Varanger Peninsula are shown in Tables 1 and 2, and of all samples used in the cluster diagrams in Table 3.

Major element geochemistry: classification plots and cluster dendrograms

Sandstones were categorised by adopting the chemical classification diagram of Pettijohn et al. (1987). This classification has the advantage of defining the petrographic names of different types of sandstone. We use these names later in this paper while describing and discussing the chemical characteristics of the analysed rocks.

The distribution pattern which emerges from the plots (Fig. 3) shows that the sandstones range in chemical (i.e. mineralogical) maturity from greywackes or arkoses to quartz arenites. The sandstones of the Barents Sea Group (plot A) seem to show a trend of increasing maturity upwards in the stratigraphic section and, at the same time, a distinct decrease in relative sodium content. Sandstones of the Sandfjorden Formation of the Løkvikfjellet Group exhibit the highest maturity in the BSR, while the Berlevåg Formation, which is thrusted upon the Løkvikfjellet Group, is comparable in chemical signature to the Kongsfjord Formation. The Tanafjorden Group comprises sandstones of moderate to high maturity, while the Vestertana Group in its lower part is dominated by immature sandstones, especially the greywackes of the Nyborg Formation (plot B). Sandstones of the Vadsø Group show a clear bimodality in maturity with a predominance of subarkoses (plot C), while the Sredni succession contains sandstones which exhibit a considerable scatter (plot D). There is, however, a distinct trend in the lower Kildinskaya Group, from arkoses in the Pyaryajarvinskaya to quartz arenites in the Palvinskaya Formation. There is also a second different trend from the lithic arenites of the Poropelonskaya to the K-enriched arkoses of the Zemlepakhtinskaya Formation. Plot E shows the immature nature of sandstones of the Rybachinskaya Supergroup, comparable to that of the Berlevåg, Kongsfjord and Nyborg Formations (plot A). Interpretations of these distribution patterns are presented later, along with a geochemical subdivision of the rocks as indicated by cluster dendrograms.

Clayey shales were classified in ternary plots devised by Golovenok (1977) (Fig. 4). The plots show that the shales fall mainly within or close to the illite field. Some fairly clear departures from this pattern were revealed in the Båtsfjord and Tyvjofjellet Formations in the upper Barents Sea Group, in the Tsypnavolokskaya Formation on Rybachi and in the Karujarvinskaya on Sredni (Fig. 4). These deviations are analysed later along with sandstones, with the cluster dendrograms, and discussed in a wider stratigraphic context.

The above classifications of sandstones and shales are based on the use of ratios of only three or four elements. This means that the majority of the analytical data and information provided by about 10 major elements are not included. In order to fill this gap we treated our data by applying a statistical cluster programme. Cluster analysis applied to geochemical data is based on complete major element information and provides a tool for grouping together closely associated rocks as reflected by their chemical composition.

The analysed rocks cluster together into several distinct groups on the basis of their relatively close similarity in composition (Figs. 5 - 7). A decreasing degree of similarity is shown by the stepwise higher level within group distance shown by the dendrograms.

Several characteristics of the studied rocks emerge from an analysis of the cluster dendrograms (Figs. 5 - 7). The most conspicuous is the clustering of sandstones (Fig. 5). Therefore, our analysis of the clustering patterns starts with

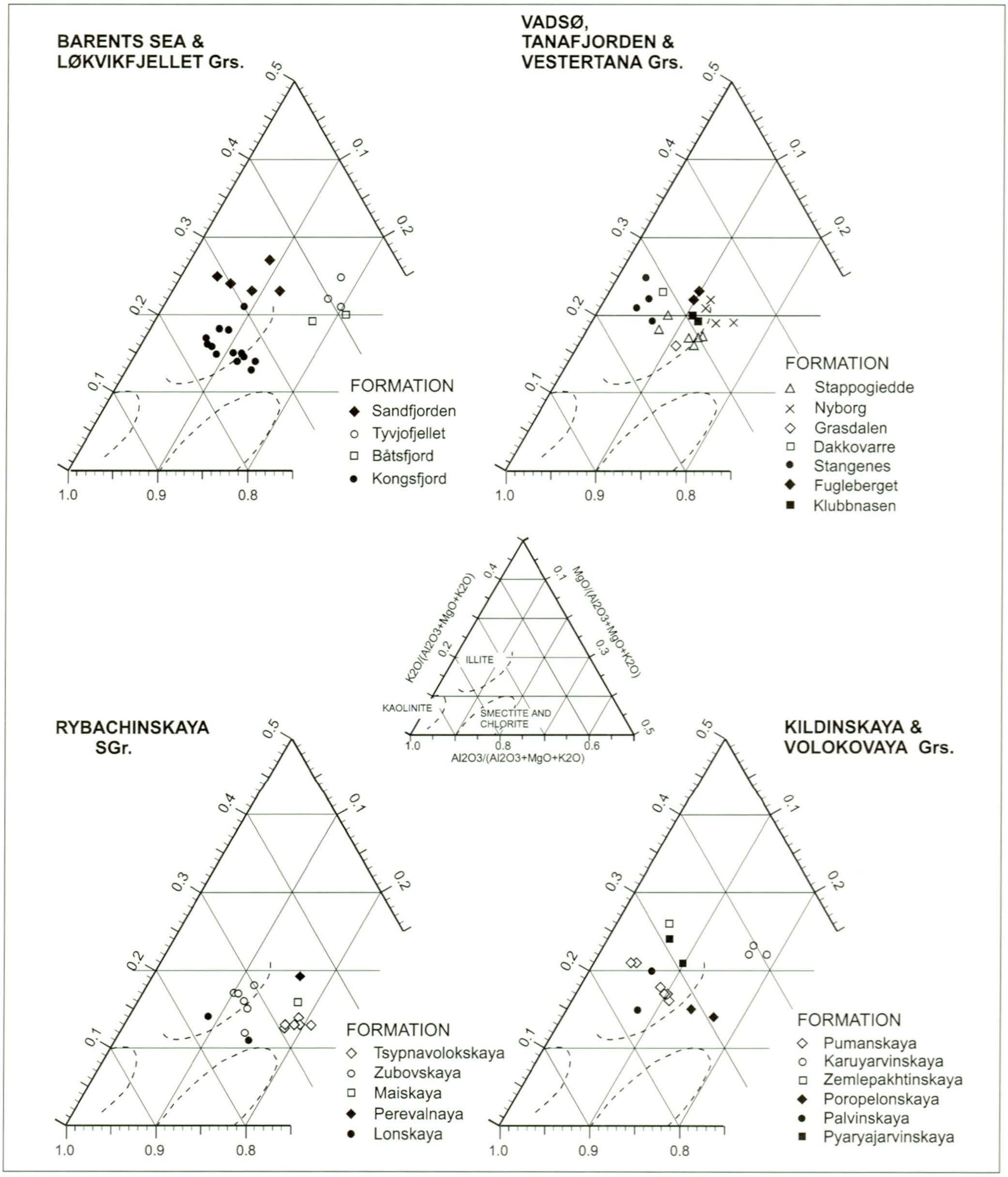

Fig. 4. Neoproterozoic clayey shales of the Varanger, Rybachi and Sredni Peninsulas on the diagrams $Al_2O_3/(Al_2O_3+MgO+K_2)$ vs. $K_2O(Al_2O_3+MgO+K_2O)$ (Golovenok 1977).

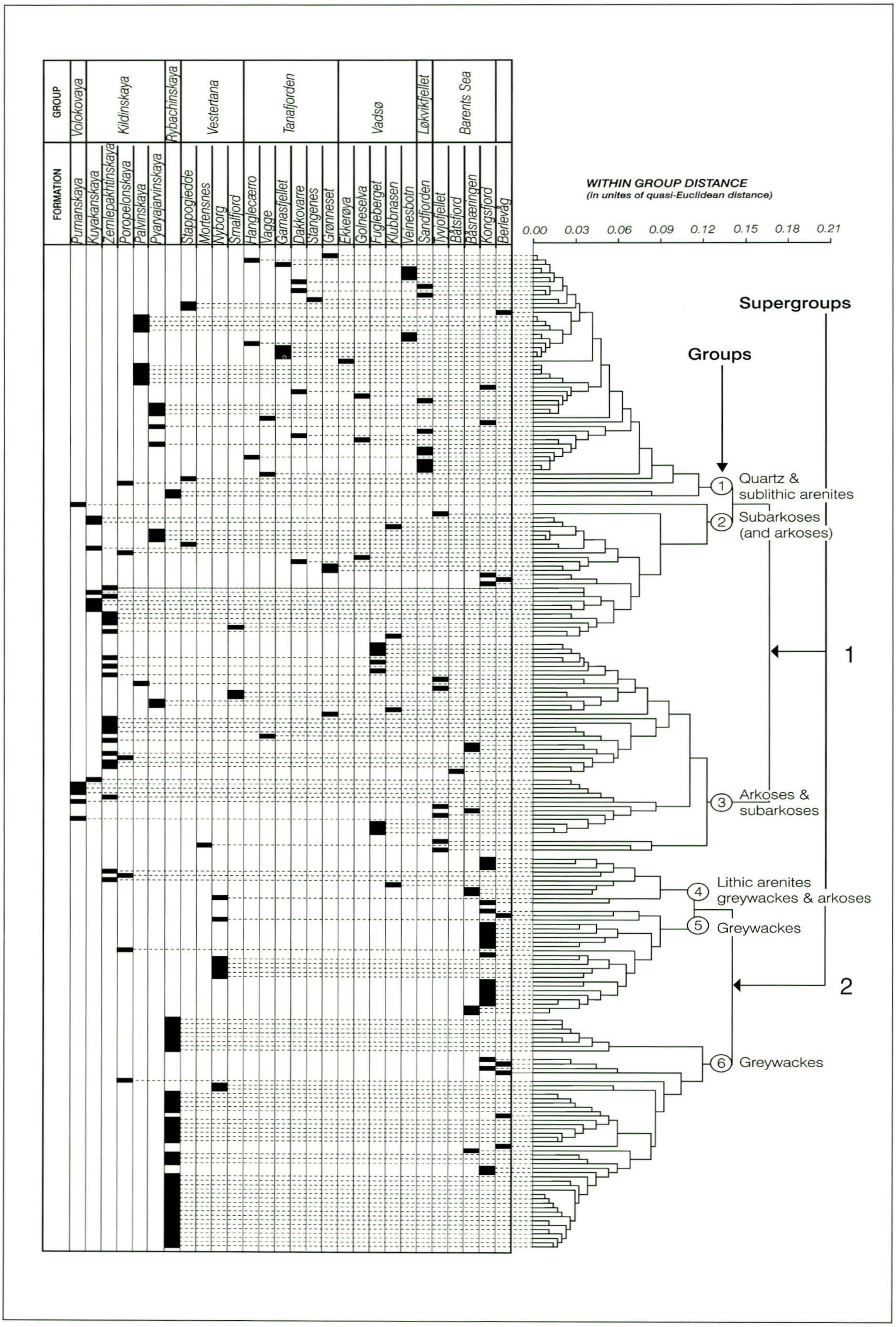

Fig. 5. Cluster dendrogram for sandstones.

that of the sandstones and is supplemented with the clustering patterns of associated siltstones and clayey shales.

The majority of sandstones of the analysed formations fall into the supergroup 1, groups 1 - 3 (Fig. 5.). They represent sandstones ranging from quartz arenites to arkoses, are characterised by usually high SiO_2, predominance of K_2O over Na_2O, Fe_2O_3 over FeO, fairly high TiO_2 and mostly low MgO. The second supergroup, groups 4 - 6, has compared with the first supergroup, a significantly lower SiO2 content, higher Na_2O, Al_2O_3T and MgO. It consists primarily of greywackes. The patterns for siltstones and clayey shales exhibit more scatter and are clustering into eleven and seven groups, respectively. Interestingly, a combined approach to the sandstones, siltstones and clayey shales as they occur in the stratigraphic successions shows both some striking similarities as well as some anomalies where similarities could normally be expected. The latter deserve special attention. This is particularly true for the sandstone groups 2 and 3. Although there is an overale pattern of clustering of the formations from the basinal realm separately from those of the pericratonic realm, there are also several examples of both realms being represented in one cluster group. For convenience, in the analysis which follows they are labelled (b) and (p), respectively.

The Kongsfjord(b), Berlevåg(b) and Nyborg(p) Formations, and the Rybachinskaya Group(b)

The Kongsfjord greywackes occur mostly in group 5 while those in the Berlevåg Formation and the Rybachinskaya Group distinguish themselves by having maximum values

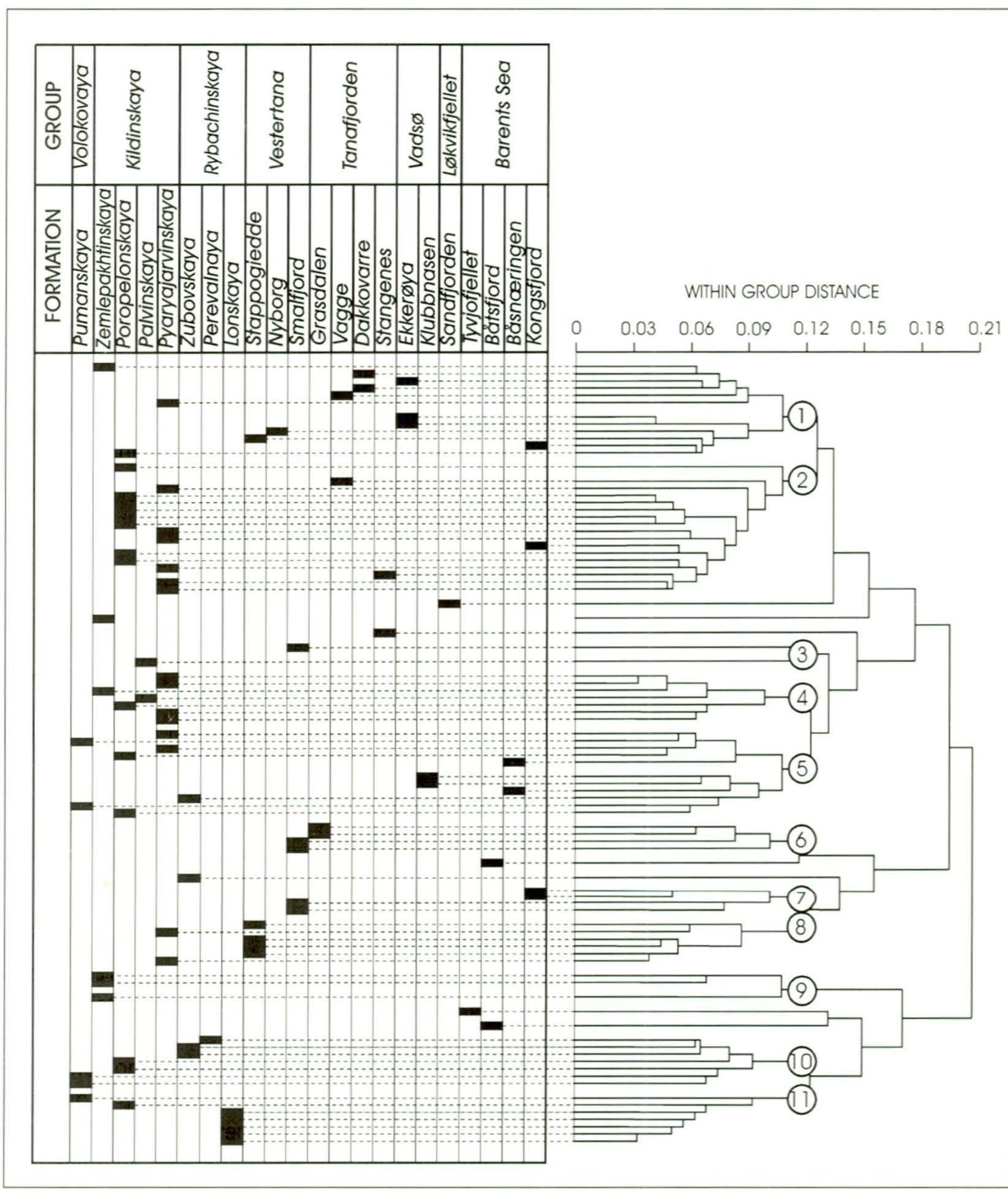

Fig. 6. Cluster dendrogram for siltstones.

for Na_2O, CaO and Al_2O_3 and cluster together into group 6 (Fig. 5). Siltstones associated with greywackes (Fig. 6, parts of groups 10 and 11) exhibit very high Al_2O_3 contents. The majority of the clayey shales cluster in group 1 (Fig. 7) and are characterised by maximum contents of Na_2O and MgO, high FeO and CaO, low K_2O and a significant predominance of FeO over Fe_2O_3. These characteristics do not deviate much from those of the greywackes with which the shales are associated. However, in the Kongsfjord Formation a bimodality in the shale composition is registered (Fig. 7). In fact, the majority of Kongsfjord shales cluster in group 7 comprising illitic shales with high Al_2O_3, FeO and K_2O contents. A similar bimodal distribution may be traced for the shales of the Nyborg Formation (Fig. 7, groups 2 and 4). The shales of group 4 have a composition contrasting with the remainder of the formation by having minimal contents of Al_2O_3 and Na_2O, maximal MgO content and relatively high K_2O. These characteristics are not discernible on the classification diagramme, Fig 3. In addition, shales of the Nyborg Formation are usually red and show a predominance of Fe_2O_3 over FeO. They can be interpreted as illitic with some chlorite admixture, and are similar to the shales of the Karujarvinskaya, Tyvjofjellet and Båtsfjord Formations in terms of their high MgO content. Shales with a high admixture of dolomitic cement and dolomites are also present in the Nyborg Formation (Table 1).

The Sandfjorden Formation(b), the Tanafjorden Group(p), and the Veinesbotn(p), Ekkerøya(p), Stappogiedde(p), Pyrayarjarvinskaya(p) and Palvinskaya(p) Formations

Sandstones of these units are characterised by the highest contents of SiO_2, low contents of all other elements and a predominance of K_2O over Na_2O (Fig. 5, group 1).

The Vagge Formation differs from the remaining formations of the Tanafjorden Group by both the presence of arkoses with a high content of K_2O and of lithic arenite with a predominance of Na_2O over K_2O (Fig. 3B, Table 1). On the

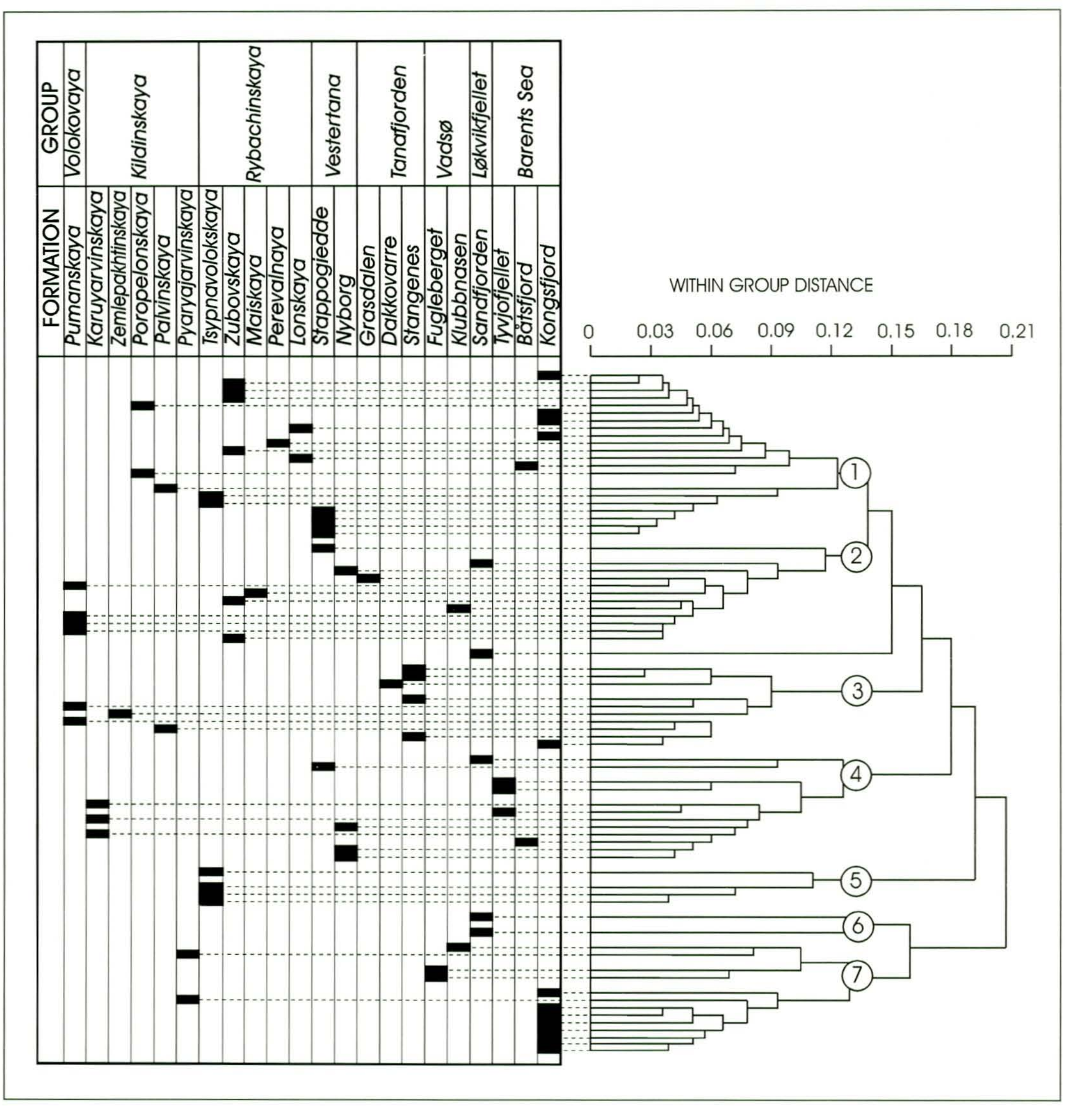

Fig. 7. Cluster dendrogram for clayey shales.

Sandstones

Formation	Berlevåg		Kongsfjord		Båsnæringen		Batsfjord		Tyvjofjellet		Sandfjorden		Veinesbotn		Klubbnasen		Fugleberget	
Numb. of samples.	7		26		8		1		7		9		5		4		8	
SiO_2	79.14	7.13	76.10	6.53	74.67	3.45	80.84		77.37	5.07	93.95	1.63	97.38	1.37	82.82	7.13	82.82	2.13
TiO_2	0.59	0.50	0.80	0.29	0.82	0.26	0.54		0.64	0.21	0.16	0.18	0.03	0.00	0.49	0.15	0.99	0.14
$Al2O_3$	8.25	2.66	9.71	3.00	10.14	1.87	6.64		7.26	2.47	2.45	0.67	0.70	0.44	7.01	2.73	6.00	0.57
$Fe2O_3$	2.79*	1.05	5.04*	1.66	1.05	0.66	1.03		2.12	1.20	0.12	0.16	0.31	0.27	0.21	0.23	0.87	0.54
FeO					3.24	0.68	3.05		0.52	0.24	0.45	0.28	0.07	0.13	2.68	1.55	1.82	0.32
MnO	0.07	0.04	0.06	0.02	0.06	0.02	0.01		0.03	0.03	0.01	0.00	0.01	0.00	0.01	0.00	0.03	0.03
MgO	0.79	0.23	1.65	0.60	1.65	0.28	1.91		1.86	0.59	0.27	0.15	0.03	0.02	0.88	0.62	0.80	0.27
CaO	1.89	1.40	1.05	0.68	0.67	0.35	0.27		2.01	1.30	0.35	0.08	0.10	0.10	0.30	0.03	0.84	0.53
Na_2O	2.52	1.09	2.06	0.60	2.00	0.62	0.53		0.61	0.19	0.09	0.11	0.01	0.00	1.05	0.37	0.72	0.08
K_2O	1.12	0.64	1.37	0.79	2.71	0.68	2.52		3.49	1.03	1.08	0.46	0.39	0.31	2.65	0.71	2.84	0.30
P_2O_5	0.07	0.05	0.13	0.04	0.12	0.03	0.11		0.10	0.04	0.02	0.01	0.03	0.00	0.12	0.04	0.13	0.02
LOI	2.06	1.16	2.02	0.66	2.79	0.50	2.25		3.50	1.08	0.75	0.20	0.23	0.06	1.47	0.84	1.75	0.80
Total	99.29		99.99		99.92		99.70		99.51		99.70		99.29		99.69		99.61	

Sandstones

Formation	Golneselva		Ekkerøya		Gronneset		Stangenes		Dakkovarre		Gamasfjellet		Vagge		Hanglecærro		Smalfjord**	
Numb. of samples.	3		1		4		1		5		4		3		3		3	
SiO_2	90.44	5.74	92.65		87.81	8.28	95.18		93.58	3.36	97.58	0.20	80.43	9.86	95.97	2.13	82.26	2.20
TiO_2	0.15	0.08	0.03		0.22	0.20	0.04		0.07	0.06	0.03	0.00	0.34	0.10	0.05	0.05	0.42	0.06
$Al2O_3$	4.38	2.70	1.75		6.37	4.73	1.35		2.49	1.61	0.79	0.67	5.82	4.55	1.46	0.99	7.30	1.17
$Fe2O_3$	1.13*	0.23	1.04		0.31	0.35	0.94		0.35	0.30	0.01	0.00	5.66	5.12	0.01	0.00	0.78	0.16
FeO			0.80		0.23	0.17	0.10		0.35	0.40	0.10	0.00	1.49	1.04	0.10	0.00	1.79	0.21
MnO	0.02	0.00	0.09		0.01	0.00	0.03		0.02	0.00	0.01	0.00	0.07	0.07	0.01	0.00	0.02	0.00
MgO	0.21	0.09	0.49		0.20	0.19	0.05		0.17	0.13	0.04	0.00	0.47	0.25	0.08	0.07	0.98	0.11
CaO	0.03	0.03	0.97		0.16	0.03	0.05		0.16	0.09	0.14	0.00	0.14	0.00	0.14	0.12	0.32	0.08
Na_2O	0.60	0.28	0.10		0.83	0.60	0.39		0.32	0.13	0.02	0.00	0.41	0.35	0.09	0.07	1.26	0.17
K_2O	1.87	1.10	0.30		2.67	1.99	0.42		1.28	0.71	0.16	0.10	1.23	1.58	0.60	0.49	2.51	0.47
P_2O_5	0.04	0.03	0.02		0.02	0.02	0.02		0.04	0.05	0.01	0.00	0.05	0.00	0.03	0.00	0.09	0.00
LOI	0.44	0.48	1.32		1.14	0.62	0.85		0.85	0.38	0.54	0.16	2.10	0.61	0.55	0.20	2.09	0.24
Total	98.19		99.56		99.97		99.42		99.68		99.43		98.21		99.09		99.82	

Sandstones

Formation	Nyborg		Mortensnes**		Stappogedde	
Numb. of samples.	9		1		4	
SiO_2	72.02	3.04	71.22		89.08	6.61
TiO_2	0.80	0.09	0.48		0.18	0.12
$Al2O_3$	11.47	1.32	9.78		3.60	1.33
Fe_2O_3	5.24*	0.75	0.95		0.46	0.58
FeO			2.27		0.39	0.26
MnO	0.08	0.01	0.07		0.03	0.00
MgO	2.17	0.42	2.42		0.69	0.90
CaO	0.57	0.25	2.22		1.01	1.74
Na_2O	3.24	0.79	2.00		1.01	0.52
K_2O	1.16	0.60	2.46		0.99	0.42
P_2O_5	0.09	0.21	0.09		0.03	0.02
LOI	2.66	1.40	5.77		2.34	2.47
Total	99.50		99.73		99.81	

Carbonate-bearing sandstones

Formation	Båsnæringen	Båtsfjord		Tyvjofjellet	Fugleberget	Dakkovarre	Grasdalen
Numb. of samples.	1	8		1	1	1	1
SiO_2	63.95	66.55	10.61	78.00	64.52	77.21	59.17
TiO_2	1.23	0.41	0.14	0.51	0.99	0.06	0.02
$Al2O_3$	6.75	6.11	2.18	4.82	6.73	1.43	0.49
Fe_2O_3	0.61	0.64	0.50	0.59	1.99	2.61	0.01
FeO	3.35	1.72	1.27	0.90	1.91	6.76	0.10
MnO	0.43	0.09	0.04	0.09	0.25	0.58	0.01
MgO	5.14	3.82	2.55	2.89	3.72	1.99	9.19
CaO	5.70	7.35	3.15	3.80	5.91	0.42	11.68
Na_2O	1.40	0.60	0.26	0.60	0.82	0.13	0.18
K_2O	1.17	2.58	0.72	2.34	3.15	0.70	0.14
P_2O_5	0.48	0.07	0.02	0.06	0.20	0.11	0.01
LOI	9.78	10.06	3.74	5.80	9.79	7.27	18.78
Total	99.99	100.00		100.40	99.98	99.27	99.78

** Fe total as Fe2O3 *** diamictites

Siltstones

Formation	Kongsfjord		Båsnæringen	Båtsfjord		Tyvjofjellet	Sandfjorden	Klubbnasen		Ekkerøya		Stangenes	Dakkovarre
Numb. of samples.	4		2	3		1	1	3		3		2	2
SiO_2	71.27	2.03	67.18	59.77	9.33	59.89	77.20	63.38	4.67	73.99	2.07	68.09	70.07
TiO_2	0.79	0.07	1.04	0.67	0.15	0.81	1.33	0.82	0.14	0.49	0.20	0.64	0.69
Al_2O_3	12.51	2.43	14.33	11.53	2.40	13.69	8.37	12.65	2.00	12.39	1.64	12.38	14.58
Fe_2O_3	0.78	0.31	0.47	3.24	1.62	4.49	0.76	0.84	0.48	1.91	0.38	2.97	1.05
FeO	3.59	0.61	5.85	1.77	0.68	1.90	5.02	5.78	0.60	1.86	0.36	3.89	2.33
MnO	0.05	0.03	0.09	0.06	0.05	0.04	0.04	0.16	0.24	0.06	0.04	0.11	0.02
MgO	1.77	0.29	2.43	5.49	2.81	5.23	1.27	3.08	0.89	1.19	0.13	1.50	1.17
CaO	1.40	0.75	0.55	4.20	4.17	2.22	0.28	1.93	2.60	0.22	0.17	0.35	0.21
Na_2O	2.43	0.65	1.69	0.35	0.16	1.08	0.06	1.91	0.08	1.22	0.27	2.19	1.83
K_2O	2.08	1.07	2.94	4.27	1.01	5.38	3.08	3.41	0.49	3.73	0.45	3.34	4.72
P_2O_5	0.09	0.07	0.18	0.16	0.04	0.16	0.08	0.21	0.03	0.08	0.03	0.07	0.07
LOI	3.48	0.23	2.63	8.63	6.77	5.80	2.88	5.69	3.65	2.63	0.21	4.53	3.06
Total	100.24		99.38	100.14		100.69	100.37	99.86		99.77		100.06	99.80

Siltstones

Formation	Vagge	Grasdalen	Smalfjord**		Nyborg	Stappogiedde	
Numb. of samples.	2	2	5		1	5	
SiO_2	73.33	64.43	68.86	4.71	75.58	68.59	2.06
TiO_2	0.52	0.67	0.55	0.11	0.49	0.67	0.05
Al_2O_3	13.06	13.48	11.97	2.00	9.39	12.87	0.63
Fe_2O_3	1.67	1.17	1.29	0.31	0.48	1.75	0.37
FeO	1.68	2.82	2.58	1.64	2.87	3.33	0.30
MnO	0.02	0.01	0.04	0.00	0.05	0.11	0.03
MgO	0.69	5.72	2.58	0.57	1.49	1.67	0.56
CaO	0.21	1.25	1.47	0.42	0.70	1.14	0.45
Na_2O	1.24	2.10	1.70	0.68	1.80	2.51	0.34
K_2O	4.35	2.84	3.18	1.47	3.08	2.68	0.55
P_2O_5	0.06	0.11	0.12	0.00	0.10	0.12	0.00
LOI	2.55	5.23	5.08	0.78	2.98	4.43	0.60
Total	99.38	99.83	99.42		99.01	99.87	

Carbonate-bearing siltstones

Formation	Tyvjofjellet	Grasdalen	Smalfjord**
Numb. of samples.	2	1	1
SiO_2	50.92	55.10	65.86
TiO_2	0.54	0.67	0.54
Al_2O_3	7.91	12.86	10.59
Fe_2O_3	2.00	1.37	1.03
FeO	1.51	1.67	2.39
MnO	0.14	0.06	0.06
MgO	8.18	5.60	3.07
CaO	9.34	5.84	3.20
Na_2O	0.39	1.60	1.60
K_2O	3.11	3.87	4.00
P_2O_5	0.09	0.17	0.13
LOI	15.70	11.18	7.40
Total	99.83	99.99	99.87

Table 1. Mean composition of Upper Proterozoic sandstones and siltstones of the Varanger Peninsula (left values -averages; right values - standard deviations) (162 samples)

cluster dendrogram, the lithic arenite is similar to the sandstones of the Zemlepakhtinskaya and Båsnæringen Formations (Fig. 5).

Siltstones show similar characteristics to the sandstones; they are SiO_2 - rich, and low in Al_2O_3 and Na_2O, and there is some variability in MgO content. The majority of the clayey shales associated with these sandstones and siltstones are illitic in composition and exhibit high, or the very highest registered K_2O contents and high Al_2O_3. On the dendrogram (Fig. 7) they cluster mainly in groups 3 and 6, primarily because of the differences in the contents of CaO and MnO (low in group 3) and of TiO_2, Fe_2O_3 (high in group 6), SiO_2 and CaO (minimal in group 6). Shales of the Sandfjorden Formation have the highest mean content of K_2O and lowest Na_2O in the studied set and plot in the field of illitic shales (Table 1, Fig. 4). On the cluster dendrogram, two shales of this formation form a separate group 6 characterised by high Al_2O_3, TiO_2, Fe_2O_3 and especially K_2O (Fig. 8, Table 5). These shales have the highest mean contents of LOI and show a tendency to swelling similar to that seen in K-bentonitic clays.

The single sample of siltstone, as with the shales, has high TiO_2 and has the lowest mean content of Na_2O in the studied set (Table 1).

The Stappogiedde Formation has a complex major element geochemistry. The sandstones range from fine-grained to coarse-grained subarkoses and sublithic arenites (Fig. 3). The sandstones have approximately the same mean contents of Na_2O and K_2O with a predominance of the former in one of the samples, and they resemble some of the samples from the Stangenes and Kuyakanskaya Formations. Siltstones are distinguished by the highest Na_2O mean content in the set and show a similarity to some (the most polymictic) of the siltstones in the Pyaryajarvinskaya Formation (Table 1, Fig. 7). Shales have relatively low Al_2O_3 and K_2O contents and are included in group 1 on the cluster diagram (Fig. 8). They are compositionally similar to shales of the Tsypnavolokskaya Formation and there is also some similarity to shales of the Rybachinskaya Supergroup and the Poropelonskaya and Kongsfjord Formations. The presence of red beds in the Stappogiedde Formation is reflected in the predominance of Fe_2O_3 over FeO in the compositions of sandstones and shales (Table 1).

The Båsnæringen(b), Båtsfjord(b) and Tyvjofjellet(b) Formations, the bulk of the Vadsø Group(p), the Vagge(p), Smalfjord(p) and Mortensnes(p) Formations and the Poropelonskaya(p), Zemlepakhtinskaya(p), Karuyarvinskaya(p) and Kuyakanskaya(p) Formations

Groups 2 and 3 on the cluster dendrogram for sandstones embrace subarkoses to arkoses, subordinate sublithic arenites, and have a transitional position between group 1 on one side and groups 4 to 6 on the other (Fig. 5). The sandstones clustering in groups 2 and 3 are from parts of the stratigraphic sections in both basinal and pericratonic realms. When analysing groups 2 and 3 of the sandstone dendrogram in combination with the stratigraphic position of the samples, it appears that they reflect, at least partly, a distinct geochemical change (1) upwards in the Båsnæringen Formation, (2) from the Klubbnasen to the Fugleberget Formation and (3) from the Poropelonskaya to the Zemlepakhtinskaya Formation. The sandstones of the lower Båsnæringen Formation, for example, represent greywackes similar to those of the Kongsfjord Formation. Higher up, however, the Båsnæringen sandstones are geochemically different: they have higher K_2O and SiO_2 contents and also higher MgO, Fe_2O_3 T and TiO_2. The more K- Fe- and Ca-rich varieties show an affinity with the sandstones of the overlying Båtsfjord and Tyvjofjellet Formations, and this same feature applies to the siltstones and clayey shales. On the other hand, the greywacke-akin sandstones of the Båsnæringen Formation may be geochemically loosely compared to those of the Klubbnasen Formation, and those with $K_2O>Na_2O$ and $Fe_2O_3>FeO$ to the Fugleberget Formation. The sandstones of the latter have the highest TiO_2 content in the studied set, presumably caused by a concentration of heavy minerals - probably titanomagnetite, ilmenite and leucoxene. Siltstones of this formation also have high TiO_2 contents (Table 1), and there is also some similarity to sandstones of the Tyvjofjellet and Pumanskaya Formations. Shales of the Fugleberget Formation, on the other hand, are distinguished by the highest mean contents of Al_2O_3, TiO_2, Fe_2O_3 and P_2O_5 and one of the highest K_2O contents in the studied set (Table 2). The notable predominance of Fe_2O_3 over FeO distinguishes these shales from those in the underlying Klubbnasen Formation.

The Poropelonskaya sandstones show a very scattered pattern of the major element compositions, while shales are illitic with a Na-feldspar admixture comparable to the Group 1 shales of the Kongsfjord Formation (Fig. 7). The Båsnæringen subarkoses show an affinity with both the Zemlepakhtinskaya and the Kuyakanskaya Formations (Figs. 3 and 5, groups 2 and 3). Shales of the overlying Zemlepakhtinskaya, on the other hand, are akin to those of the Båtsfjord-Tyvjofjellet Formations in terms of $K_2O>Na_2O$ and $Fe_2O_3>FeO$. In addition, the Klubbnasen sandstones, are similar to both the Båsnæringen and the Zemlepakhtinskaya (and the Smalfjord) Formations with a distinct predominance of FeO over Fe_2O_3. On the cluster dendrogram they appear in groups 2 to 4, ranging from arkoses to greywackes (Figs. 3 and 5). Another feature of interest is the fairly high contents of P_2O_5 in shales of the Fugleberget Formation and in the siltstones of the Zemlepakhtinskaya, which are also comparable on other geochemical and sedimentological grounds (cf. Sochava 1995, Siedlecka et al. 1995a).

Dolomite-cemented sandstone with intraformational clasts of sandstone from the lower part of the Båsnæringen Formation have relatively high contents of TiO_2, MnO and

P_2O_5 (Table 1). Phosphate-bearing sandstones have been described from this stratigraphic unit (Negrutsa et al. 1995). A high TiO_2 content in siltstones of the Båsnæringen Formation may reflect a concentration of heavy minerals. Sandstones and siltstones with high contents of TiO_2 are known also from the Zemlepakhtinskaya Formation of the Sredni Peninsula (Negrutsa 1971).

Arkoses and lithic arenites of the Båtsfjord and Tyvjofjellet Formations cluster in group 4. Those which have a considerable amount of carbonate cement are excluded from the cluster dendrogram. The predominance of Fe_2O_3 in the sandstones, siltstones and shales reflect the presence of red beds. Shales and siltstones usually contain an admixture of carbonate (high MgO and CaO) and are comparable to those of the Karuyarvinskaya Formation (Fig. 7, group 4). Carbonate rocks (Båtsfjord Formation: 3 samples of dolomite, one limestone and one dolomitic limestone) are usually represented by interbedded thin layers of fine-grained carbonate and siltstone and have a relatively high admixture of silica (Table 1).

Geological significance of the major element geochemistry: source areas, tectonics and palaeogeography

The cluster dendrograms, and particularly the one for sandstones (Fig. 5), will again be a starting point in the discussion which follows. The two supergroups emerging on this dendrogram reflect (along with the statistical data on dendrograms for siltstones and shales) the presence of two major associations of rocks.

The first association may be interpreted as a product of denudation of the continental crust. It is mostly represented by sediments occurring in the successions of the pericratonic areas of the rift basin (TVR and SP). The second association has a different geochemical signature, characteristic for the basinal successions (parts of the BSR and RP). Rocks of some formations, however, plot both in the first and in the second association, and obviously groups 3 and 4 of the sandstones represent an intermediate or 'transitional' major element geochemistry, which appears to have some stratigraphic importance. Therefore, further on, we use the term transitional because it reflects better the stratigraphic contexts and is explained by changes of environments of deposition and provenance areas with time. The arkosic Båsnæringen Formation, for example, is a large progradational slope-prodelta-delta plain succession (Siedlecka & Edwards 1980, Siedlecka et al 1989) with a swich from a retrogradational Kongsfjord - lowermost Båsnæringen development to a progradational trend higher up. Therefore, depending from which part of the Båsnæringen Formation, lower or upper, the samples were taken, they will show similarities either to the Klubbnasen, considered to represent a prodelta, as the lower Båsnæringen does, or e.g. to the Zemlepakhtinskaya and Fugleberget Formations, both of which are interpreted as delta front and braided fluvial plain sediments (Banks et al. 1971, Siedlecka et al. 1995a) as with the upper Båsnæringen Formation.

The geochemical changes also suggest the possibility of a change in composition of the provenance area, which might have resulted either from a deeper level of erosion, a change of direction of palaeocurrents, i.e. direction of material supply, which might have been caused by a tectonic event and development of an unconformity. Interestingly, the units with the transitional major element geochemistry within separate successions (Poropelonskaya - Zemlepakhtinskaya, Klubbnasen - Fugleberget, the Båsnæringen Formation and the uppermost Bargoutnaya Group (comparable to the lower Båsnæringen Formation)) appear to have a similar stratigraphic position (see Fig. 2). This in turn suggests that perhaps there was just one particular tectonic event in the hinterland that led to changes in palaeogeography and, consequently, influenced the distribution of the activated source areas and intensified the sediment supply.

Quartz arenites, abundant in the first association (group 1 in Fig. 5), may reflect both a deep weathering of source areas and degradation of the landscape, and the important role of aeolian or wave breaker processes in reworking the clastic material prior to the Neoproterozoic sedimentation. The quartz arenite-rich formations, i.e. the Hanglecærro, Gamasfjellet, and parts of Grønneset and Veinesbotn, were accumulated either as coastal sands and shelf blanket or as fluvial mature sands and reflect, in general terms, a tectonic stability, peneplained landscape and a long-lasting reworking of the sediment.

Interpretation of the major element geochemistry of the Ekkerøya Formation remains uncertain. The single sample of fine-grained sandstone with quartz overgrowth cement plots on the boundary between quartz arenites and sublithic arenites (Fig. 3). Siltstones have relatively high SiO_2 contents and are similar to the siltstones of the Dakkovarre, Vagge and Nyborg Formations (Table 1, Fig. 7). Mapping and sedimentological and biostratigraphic research have shown that the formation changes laterally in thickness and lithology, that it accumulated in several different environments and that it is separated from the subjacent and overlying formations by unconformities (Johnson 1978, Vidal 1981) (Fig. 2). It may therefore be assumed that some relief rejuvenation and a period of both intensified and diverse sedimentation took place before a major regression and prior to accumulation of the Tanafjorden Group.

Quartz arenites and arkoses are associated with unusually K_2O-rich clayey shales (the mean composition in several formations is >6 % with a maximum of c.7.4 % in the Fugleberget Formation, see Table 2). A possible explanation for this specific feature is the absence of vascular vegetation on the Precambrian continents. This was the main reason for the difference in weathering in the Precambrian, compared to younger periods, particularly the substantially lower mobility of potassium in the weathering crusts which promoted

Clayey shales

Formation	Kongsfjord		Båtsfjord		Tyvjofjellet		Sandfjorden		Klubbnasen		Fugleberget		Stangenes	
Numb. of samples	13		2		3		5		2		2		4	
SiO_2	56.65	3.63	58.37		55.39	1.89	54.84	5.31	56.78		48.29		61.85	3.09
TiO_2	0.96	0.07	0.85		0.95	0.04	1.56	0.34	1.05		1.31		1.13	0.23
Al_2O_3	19.84	2.23	16.26		15.82	0.45	20.82	3.35	19.25		22.26		19.79	2.20
Fe_2O_3	2.20	0.70	2.92		6.35	1.00	4.93	1.96	2.08		6.64		1.74	0.31
FeO	5.17	1.20	3.26		1.54	0.22	1.36	1.04	4.61		3.03		1.66	1.44
MnO	0.06	0.01	0.04		0.02	0.00	0.03	0.00	0.03		0.03		0.02	0.00
MgO	2.81	0.48	5.07		5.07	0.04	2.38	0.68	3.17		3.39		1.25	0.30
CaO	0.84	0.35	1.25		1.53	0.28	0.64	0.56	0.31		0.51		0.32	0.10
Na_2O	1.79	0.45	1.17		0.80	0.11	0.18	0.11	1.28		0.51		1.78	0.26
K_2O	4.35	1.14	5.25		6.15	0.57	7.53	1.25	5.41		7.38		5.87	1.19
P_2O_5	0.10	0.05	0.12		0.17	0.04	0.21	0.13	0.19		0.22		0.11	0.04
LOI	5.06	0.84	5.54		5.72	0.75	6.30	2.42	5.59		6.23		4.37	0.69
Total	99.83		100.10		99.51		100.78		99.75		99.80		99.89	

Clayey shales

Formation	Dakkovarre		Grasdalen		Nyborg		Stappogiedde	
Numb. of samples	1		1		4		6	
SiO_2	60.29		62.52		59.01	1.00	60.86	2.14
TiO_2	1.25		0.82		0.90	0.03	0.88	0.02
Al_2O_3	20.22		17.74		16.56	0.74	16.78	0.71
Fe_2O_3	2.16		1.90		4.97	0.81	4.37	1.84
FeO	2.03		3.41		2.41	0.42	2.92	2.01
MnO	0.01		0.02		0.05	0.00	0.09	0.05
MgO	1.72		2.68		3.44	0.53	2.67	0.57
CaO	0.14		0.56		0.94	0.52	0.59	0.18
Na_2O	2.00		1.00		1.93	0.15	1.58	0.66
K_2O	6.67		4.00		5.06	0.33	4.12	0.37
P_2O_5	0.13		0.18		0.16	0.00	0.14	0.04
LOI	4.06		4.38		4.63	0.73	4.94	0.67
Total	100.68		99.21		100.06		99.94	

Carbonate-bearing clayey shales

	Båtsfjord	Nyborg
Numb. of samples	1	2
SiO_2	49.65	48.59
TiO_2	0.68	0.77
Al_2O_3	14.06	13.28
Fe_2O_3	5.11	1.40
FeO	2.57	4.37
MnO	0.05	0.09
MgO	7.00	6.90
CaO	4.31	6.19
Na_2O	0.35	1.82
K_2O	6.00	2.73
P_2O_5	0.15	0.15
LOI	10.68	12.95
Total	100.61	99.24

Carbonate rocks

Formation	Batsfjord		Grasdalen		Nyborg
Numb. of samples	6		8		2
SiO_2	31.41	8.20	9.30	12.42	14.82
TiO_2	0.35	0.13	0.09	0.14	0.22
Al_2O_3	6.08	2.46	1.75	3.13	2.95
Fe_2O_3	0.98	0.42	0.13	0.24	0.53
FeO	2.10	0.71	0.79	1.29	1.83
MnO	0.11	0.04	0.05	0.04	0.35
MgO	9.30	5.03	19.39	3.50	16.60
CaO	20.41	2.80	26.14	6.09	23.42
Na_2O	0.73	0.64	0.31	0.37	0.27
K_2O	1.83	0.91	0.71	0.86	1.05
P_2O_5	0.08	0.03	0.02	0.02	0.06
LOI	26.32	5.75	41.10	8.31	37.81
Total	99.70	99.78	99.91		

Table 2. Mean composition of Upper Proterozoic shales and carbonate rocks of the Varanger Peninsula

the accumulation of potassium-rich pelites of predominantly illitic composition. The absence of vegetation on land was at the same time the main reason for an extensive aeolian reworking of clastic material. The overall effect of these processes was the accumulation of widespread blankets of quartz arenites accompanied by siltstones and pelites enriched in fine-grained potassic feldspars and micas (Sochava et al. 1994). This applies specifically to the Tanafjorden Group. Another commonly suggested explanation for a high K_2O content in clayey shales is metasomatic enrichment of clays in K_2O during diagenetic processes (Sochava et al. 1994 and references therein). This explanation appears to be the most probable for the origin of the K-rich bentonitic clays in the Sandfjorden Formation.

The second association, comprising greywackes and lithic arenites is represented by the Rybachinskaya Supergroup and Kongsfjord, Berlevåg, Nyborg and Poropelonskaya Formations (cf. the dendrograms, particularly Fig. 5). The remarkable predominance of Na_2O over K_2O, the high content of MgO in sandstones and the overall geochemistry of the shales are the geochemical signatures of this association. The known facts that in the upper continental crust the contents of K_2O and Na_2O are approximately equal, and that during weathering and transport of the siliciclastic material the relative amount of sodium can only decrease, suggest that sodium-rich, basic or intermediate rocks might have constituted the source material. Uplift and denudation of sodium- and magnesium-rich rocks, such as e.g. those of the Lower Archaean Kolskaya Group of the Murmansk Block in northern Kola Peninsula (Rundkvist & Mitrofanov 1988), may offer a possible explanation. In addition, or alternatively, intermediate to basic volcanic activity may have contributed. In either case, the explanation invokes tectonic activity in the hinterland.

The similarities between the greywacke-rich lithostratigraphic units, as shown by the cluster dendrograms, has been previously explained by the presence of a considerable volume of turbidites, i.e. by a similarity of sedimentation mechanism which produced texturally and mineralogically immature turbiditic sediments. The turbidites of the Kongsfjord Formation and the bulk of the Rybachinskaya Group accumulated on submarine fans at the foot of an

Sandstones (Fig.6)

No. group	1		2		3		4		5		6	
Numb. of samples.	55		30		46		11		24		51	
SiO2	94.10	3.87	87.29	2.45	80.32	3.34	70.35	2.71	74.03	3.50	71.71	2.97
TiO2	0.08	0.09	0.30	0.21	0.68	0.35	0.99	0.19	0.90	0.25	0.49	0.15
Al2O3	1.81	1.38	5.24	1.31	7.05	1.36	12.47	1.36	10.37	1.81	12.56	1.77
Fe2O3*	1.13	0.99	2.14	0.77	3.06	0.97	5.69	1.08	5.46	0.98	3.90	1.09
MnO	0.02	0.02	0.02	0.02	0.04	0.03	0.05	0.03	0.07	0.02	0.05	0.02
MgO	0.25	0.26	0.53	0.33	1.07	0.56	2.12	0.30	1.86	0.58	1.53	0.46
CaO	0.37	0.53	0.31	0.18	0.88	0.81	0.59	0.46	0.97	0.57	1.84	0.78
Na2O	0.23	0.37	0.78	0.52	0.87	0.45	1.91	0.59	2.58	0.57	3.54	0.67
K2O	0.62	0.50	2.01	0.67	2.88	0.57	3.02	0.52	1.30	0.45	1.93	0.76
P2O5	0.04	0.03	0.08	0.06	0.10	0.04	0.16	0.03	0.13	0.03	0.12	0.03
LOI	0.72	0.66	0.81	0.65	1.89	1.07	2.69	1.03	2.14	0.38	1.76	0.71
Total	99.37		99.51		98.84		100.04		99.81		99.43	

Siltstones (Fig.7)

No. group	1		2		3		4		5		6	
Numb. of samples.	12		17		2		7		11		5	
SiO2	72.13	3.33	71.88	3.97	66.28		61.97	3.08	64.04	3.22	65.59	2.62
TiO2	0.62	0.24	0.78	0.11	0.68		0.98	0.18	0.92	0.12	0.68	0.10
Al2O3	12.56	2.01	12.45	1.97	13.84		16.29	1.49	15.24	1.64	13.64	0.71
Fe2O3	1.52	0.70	1.46	0.45	1.59		2.54	0.61	1.63	0.77	1.47	0.57
FeO	2.66	0.63	3.19	0.98	4.70		5.17	0.80	5.64	0.66	2.30	0.54
MnO	0.04	0.03	0.03	0.02	0.03		0.03	0.00	0.06	0.03	0.02	0.00
MgO	1.41	0.34	2.03	0.67	1.81		3.01	0.54	2.62	0.63	4.37	1.44
CaO	0.37	0.28	0.36	0.10	0.55		0.27	0.09	0.70	0.40	1.50	0.36
Na2O	1.43	0.40	2.39	0.42	0.56		1.56	0.53	2.03	0.40	1.51	0.67
K2O	3.86	0.58	3.03	0.74	4.28		4.64	0.61	3.46	0.46	3.54	0.84
P2O5	0.08	0.03	0.10	0.05	0.10		0.10	0.04	0.16	0.07	0.13	0.05
LOI	2.89	0.77	1.84	0.80	4.62		2.97	0.44	3.11	0.40	5.07	0.78
Total	99.57		99.54		99.04		99.53		99.61		99.82	

No. group	7		8		9		10		11	
Numb. of samples.	4		6		3		7		7	
SiO2	73.11	1.01	69.06	2.55	58.66	2.55	61.09	2.35	60.30	1.31
TiO2	0.63	0.23	0.72	0.08	1.15	0.06	1.03	0.28	0.94	0.25
Al2O3	10.20	0.47	12.42	1.04	16.72	0.36	16.78	1.27	18.17	1.85
Fe2O3	0.91	0.38	1.65	0.43	6.48	1.67	2.61	0.80	4.08	0.77
FeO	3.00	1.26	3.26	0.35	2.85	1.54	4.85	0.45	3.10	0.34
MnO	0.06	0.02	0.12	0.03	0.04	0.00	0.05	0.00	0.05	0.02
MgO	2.10	0.53	1.81	0.64	3.12	0.59	3.01	0.59	2.85	0.72
CaO	1.74	0.40	1.36	0.46	0.24	0.00	1.03	0.57	1.05	0.49
Na2O	2.54	0.41	2.68	0.13	0.22	0.08	2.39	0.29	2.05	0.31
K2O	1.48	0.53	2.74	0.53	5.93	0.63	3.44	0.38	4.25	0.84
P2O5	0.13	0.02	0.11	0.03	0.24	0.09	0.22	0.05	0.14	0.02
LOI	4.04	0.71	3.97	0.99	3.83	0.31	3.00	0.40	2.95	0.71
Total	99.94	99.90	99.48	99.50	99.93					

Clayey shales (fig 8)

No. group	1		2		3		4		5		6		7	
Numb. of samples.	21		12		10		12		4		2		13	
SiO2	58.70	1.78	61.40	1.72	61.65	2.26	58.38	2.31	58.93	1.34	49.06		53.22	3.16
TiO2	0.85	0.10	0.91	0.17	1.09	0.16	0.89	0.18	0.75	0.03	1.88		1.09	0.16
Al2O3	17.68	1.01	17.32	1.01	19.43	1.72	16.38	0.87	16.61	1.12	24.29		21.45	1.54
Fe2O3	2.63	0.95	2.81	1.18	2.10	0.82	5.57	1.41	2.17	0.20	5.84		3.28	1.59
FeO	4.87	0.84	3.56	1.66	2.44	1.15	2.19	0.81	5.76	0.63	0.63		4.49	1.32
MnO	0.09	0.03	0.04	0.01	0.02	0.02	0.04	0.01	0.34	0.03	0.03		0.04	0.01
MgO	3.36	0.62	2.66	0.39	1.45	0.37	4.13	1.10	3.25	0.34	1.77		3.02	0.49
CaO	1.08	0.53	0.81	0.40	0.29	0.13	0.84	0.51	2.00	0.85	0.28		0.61	0.31
Na2O	1.89	0.48	1.67	0.66	1.57	0.59	1.02	0.59	1.67	0.03	0.16		1.34	0.51
K2O	3.81	0.66	4.39	0.75	5.72	1.03	5.62	0.61	3.01	0.22	8.38		5.55	1.41
P2O5	0.14	0.04	0.16	0.05	0.08	0.05	0.14	0.03	0.14	0.04	0.15		0.11	0.06
LOI	4.41	1.17	3.84	0.85	3.96	0.65	4.77	0.85	4.89	0.32	8.78		5.58	0.73
Total	99.51		99.57		99.80		99.97		99.52		101.25		99.78	

Table 3. Mean composition of sandstones, siltstones and shales included in cluster groups (379 samples)

active faulted escarpment at approximately the same time (Siedlecka et al. 1995). This means that the basin and its surroundings were tectonically active and that the activity caused relief rejuvenation. Additionally, the geochemistry, particularly the high Na - K ratio (as compared with the first association) may not only reflect erosion of a sodium-rich, older Precambrian, uplifted continental crust but also of a volcanite-dominated mountain belt as e.g. the Karelian Polmak-Pasvik-Pechenga Greenstone Belt (Siedlecka et al. 1995a). Moreover, it cannot be excluded that some penecontemporaneous basic volcanism may have contributed material to these formations; and some of the older dolerite dykes present in the lower Barents Sea Group may have been emplaced even before before the sedimentation of the Neoproterozoic successions was completed (e.g. Holtedahl 1918, Roberts 1975, Rice & Reiz 1994).

The possibility that a volcanic source rock may have contributed clastic material to this association is supported by a comparison of the REE and Sc distribution in the greywacke association with that in the quartz arenite - arkose association (Fig. 8). The siliciclastic rocks of the Rybachinskaya Supergroup and the Kongsfjord Formation are characteri-

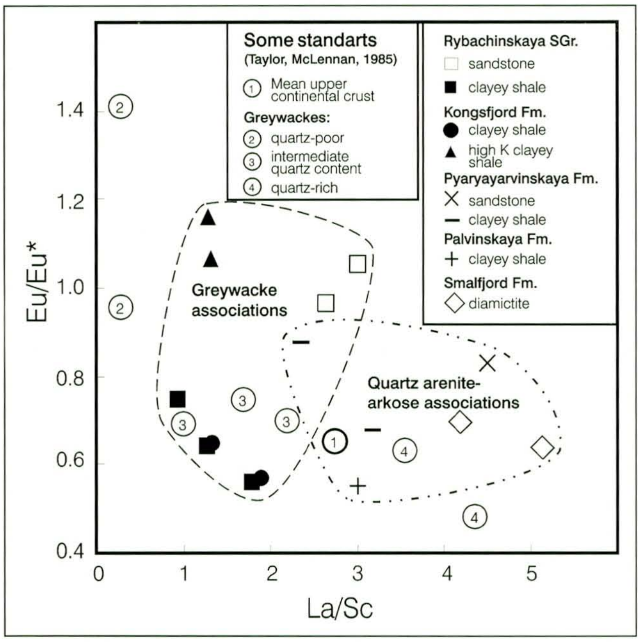

Fig .8. Distribution of REE and Sc in the quartz arenite - arkose association as compared with their distribution in the greywacke association.

zed by a lower La/Sc ratio and the presence of rocks in which, in some cases, there is a slight positive Eu anomaly (c.1.0 - 1.2). This supports the previously reported geochemical similarity of the discussed greywackes with those accumulated at an 'active' continental margin (perhaps an active spreading zone and not necessarily a converging plate scenario). The absence of a negative Eu anomaly is a characteristc feature of Archaean rocks and post-Archaean mantle volcanic rocks (Taylor & McLennan 1985).

CIA (Chemical Index of Alteration) values of clayey shales in the two discussed sandstone-siltstone-shale associations are mostly between 60 and 70, with an average value of 66 (Fig. 9). This is below the average composition of shales from the four Meso- and Neoproterozoic stratigraphic intervals in Russia (68-71, Sochava et al. 1994) and especially of average shale (70 -75, Nesbitt & Young 1982). The lack of vegetation on Precambrian land promoted the mechanical reworking of clasts, rather than chemical alteration, in a desert-like landscape. The Varangerian tillites provide evidence of a cold climate during the deposition of at least the lower part of the Vestertana Group, and the average CIA value is 63. The evidence of evaporitic conditions in the Båtsfjord Formation (correlative to the evaporitic Karuyarvinskaya Formation on Sredni, see Fig. 2) and in the correlative to the Grasdalen Formation, the lower Porsanger Dolomite (Siedlecka 1975, Tucker 1975), suggests a dry climate in at least parts of pre-Varangerian time. The CIA values for the Båtsfjord rocks, however, are inconclusive.

The material which was redeposited by turbidity currents obviously derived from an area where a dry or cold climate suppressed chemical weathering. Only in the Rybachinskaya Group is there a trend of increasing CIA values stratigraphically upwards, suggesting a gradual climatic change (Fig. 9). For other turbiditic units, e.g. Kongsfjord or Nyborg, our data are probably insufficient. In summary, it can be stated that attempts to decipher the degree of weathering by CIA alone are not entirely satisfactory.

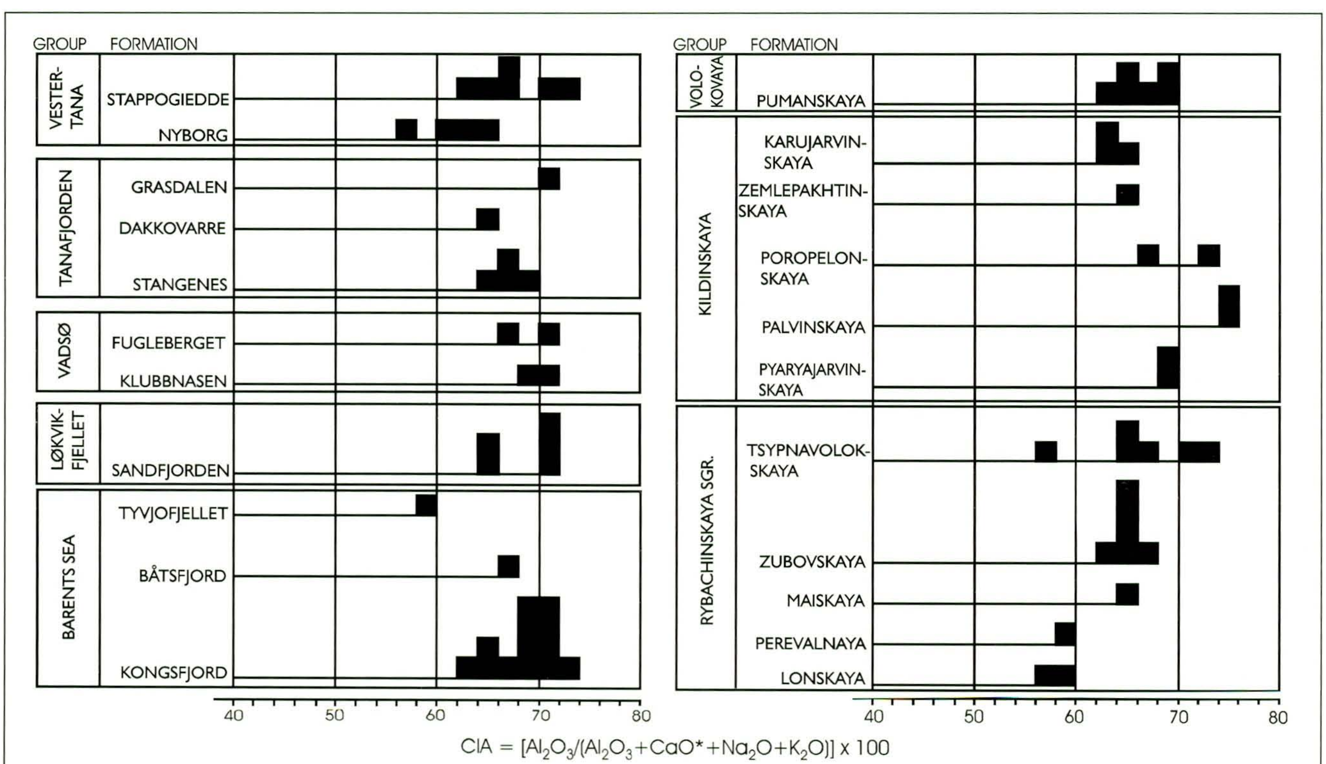

Fig.9. Chemical Index of Alteration (CIA) of the clayey shales of the studied successions.

The two types of shale in the Kongsfjord Formation which are quite different in geochemical composition and the presence of oligomictic sandstones among the greywackes might be considered as suggestive of the existence of two different sources for the siliciclastic material. The oligomictic sandstones may, however, represent submarine channel-fill sands transported by traction currents and would therefore differ from the adjacent turbidite beds in their higher textural and chemical maturity. In the Rybachinskaya Supergroup, oligomictic sandstones (Tsypnavolokskaya Formation) are also present which were deposited on a slope upon the Rybachinskaya submarine turbidite system, i.e. in a different environmental setting where traction currents, rather than turbidity currents, were operating. Therefore, only the contrasting chemical compositions of the shales may be used to suggest a contribution of material from different sources.

Turbidites of the Nyborg Formation are similar to the other turbidites in their major element composition. This formation, however, has a well-documented younger age than the Kongsfjord Formation (e.g. Vidal 1981, Rice 1994, Siedlecka 1995a). It therefore reflects a younger, Early Vendian episode of tectonic activity and relief rejuvenation, perhaps related to the early stages of the Baikalian orogenic event which was responsible for the folding and low-grade metamorphism of the Rybachinskaya Supergroup (Negrutsa 1971, Roberts 1995) and even parts of the Barents Sea Group in NE Varanger peninsula (Roberts 1996).

The compositions of sandstones and siltstones of the Stappogiedde Formation differ from those in the other formations of the TVR and suggest that different provenance areas were involved. Sedimentological research has shown that current directions in the Vestertana Group were quite variable, and both westerly and southeasterly provenance areas have been suggested (Banks et al. 1971, Banks 1973) for the middle, Innerelv Member of the Stappogiedde Formation, while the source area for the lower, Lillevatn Member was located to the south. A northeasterly source area was reported for the upper, Mandrapselva Member, as well as for the overlying Breivik Formation (Banks et al. 1971). It has been suggested that this particular source area could have been the rising topographic welt associated with the Baikalian deformation front (Roberts 1996).

Conclusions

The Neoproterozoic sedimentary successions of the Varanger, Sredni and Rybachi Peninsulas are represented by associations of rocks which differ from each other in origin, including the composition of the provenance areas, mechanisms of transport and environments of accumulation, and these factors are reflected in their chemical compositions. Major element geochemistry may therefore be used as an additional tool for tectonic and palaeogeographic reconstructions. The principal results of this work on geochemistry are as follows:

1. There is a difference in composition of the sediments in the two major tectonic realms: (1) Southwest of the Trollfjorden-Komagelva and Sredni-Rybachi Fault Zones, in the pericratonic realm, the basin fill is represented predominantly by siliciclastic sediments of the arkose - quartz arenite composition, whereas (2) the basinal domain northeast of these fault zones is characterised by an abundance of greywackes and lithic arenites.

2. There is a transitional signature in portions of the stratigraphic successions suggesting a change in the sedimentary environments, probably reflecting relief rejuvenation in the hinterland and also changes in the composition of the source area.

3. Two geochemically different types of shale in the Kongsfjord Formation are also suggestive of changes in the areas from which the clastic material was derived.

4. One particular shale in the Sandfjorden Formation has a bentonite-like composition which may indicate an influx of volcanic ash or, alternatively, a metasomatic alteration during diagenesis.

5. The compositions of Stappogiedde Formation sandstones and siltstones are different from those of the other formations of the TVR and, along with the palaeocurrent patterns, are suggestive of changing provenance areas with different locations.

6. The anomalously high contents of K_2O in some shales and the usual association of K_2O-rich shales with quartz arenites are explained by a low mobility of potassium due to the lack of vegetation and a cold and dry climate. These features, along with the widespread occurrence of quartz arenites, represent important differences between these Neoproterozoic sediments and those from the Phanerozoic siliciclastic successions.

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