Geochemistry of Proterozoic supracrustal rocks in Finland
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GEOCHEMISTRY OF METASEDIMENTARY ROCKS OF THE PALEOPROTEROZOIC TAMPERE SCHIST BELT, SOUTHERN FINLAND

by
Yrjö Kähkönen and Jussi Leveinen

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This study is based on major and trace element analyses on 90 samples mainly from two profiles in the metaturbidite-dominated southern limb of the E-W trending major syncline of the ca. 1.9 Ga volcanic-sedimentary Tampere Schist Belt (TSB). The chemical compositions of the TSB graywackes resemble those of recent turbidite sands from "pooled active margins" (PAM), i.e., from continental arc basins, back-arc basins, strike-slip basins, continental collision basins and forearc basins of mature arcs.

The composition of the TSB metasedimentary rocks shows variation according to stratigraphic position. The stratigraphically lowermost graywackes have 60-68% SiO_2. The overlying graywackes are first fairly silicic (ca. 73-80% SiO_2), but upward in the succession the SiO_2 contents decrease until the uppermost graywackes (in part fluvial) of the study profiles have 53-60% SiO_2. The mudstones associated with the uppermost graywackes tend to have higher P_2O_5, CaO, Sr and LREE contents, and their chemical index of alteration (CIA) and K_2O/Na_2O ratios are lower than those typical in the lower mudstones. Mudstones with low CIA values also occur in the lowermost stratigraphic levels. The above features reflect variations in the character of provenance and in the activity of volcanism. Even the lowermost turbidites are derived from an evolved volcanic arc rather than from an immature arc. Upward in the succession, the proportion of volcanic material in the sedimentary rocks first decreases, but increases again higher in the succession. The increased volcanic activity resulted in steeper relief, rapid accumulation and limited chemical weathering.

In general, the TSB metasedimentary rocks have prominent LREE enrichments and they mostly do not display significant Eu depletions. The bulk of their Paleoproterozoic source rocks were fairly evolved, but intracrustally differentiated rocks were not important components in the source areas. Turbidites with these characteristic are possibly more common among post-Archean siliciclastic metasedimentary rocks than has been reported previously.

Key words (GeoRef Thesaurus, AGI): schist belts, metasedimentary rocks, turbidite, graywacke, mudstone, stratigraphy, geochemistry, rare earths, Proterozoic, Paleoproterozoic, Tampere, Finland

Yrjö Kähkönen and Jussi Leveinen, Department of Geology, P.O. Box 11 (Snellmaninkatu 3), FIN-00014 University of Helsinki, Finland

INTRODUCTION

The composition of sedimentary rocks is controlled by tectonism, provenance, weathering, transportation, sorting and diagenesis. Sorting is important since muds tend to show more severe weathering and are commonly higher in most trace elements than their associated sands (e.g. Sawyer 1986, McLennan et al. 1990). Evolution and progressive erosion of the source areas is visible in the upward variation of individual successions (Ojakangas 1968, van de Kamp & Leake 1985). Tectonism is a fundamental control of sedimentation and, accordingly, the compositions of modern graywackes are strongly influenced by the tectonic setting of depositional basin and provenance (Dickinson & Suczek 1979, Valloni & Maynard 1981, McLennan et al. 1990). Compositional characteristics can therefore be used to infer the tectonic setting and provenance of ancient sedimentary rocks (e.g. Bhatia 1983, Bhatia & Crook 1986, Roser & Korsch 1986) and they are also useful in constraining the evolution of continental crust through geological time.

The main purpose of this study is to present the compositional characteristics and variation of the predominantly turbiditic metasedimentary rocks of the Paleoproterozoic Tampere Schist Belt (TSB). In addition, we examine geochemical methods for discrimination of tectonic setting of young turbidite sands and sandstones, and apply them to the TSB graywackes. In our data, 72 samples are from two profiles: the Näsijärvi profile on the eastern shore of Lake Näsijärvi and the Pulesjärvi profile 10-15 km east of the former. In addition, 18 samples from dispersed localities in the TSB are compared with the data from these profiles.

TAMPERE SCHIST BELT

The Tampere Schist Belt (Fig. 1) is a Paleoproterozoic volcanic-sedimentary belt mainly composed of turbidite metasedimentary and mafic to felsic arc-type metavolcanic rocks (Ojakangas 1986,

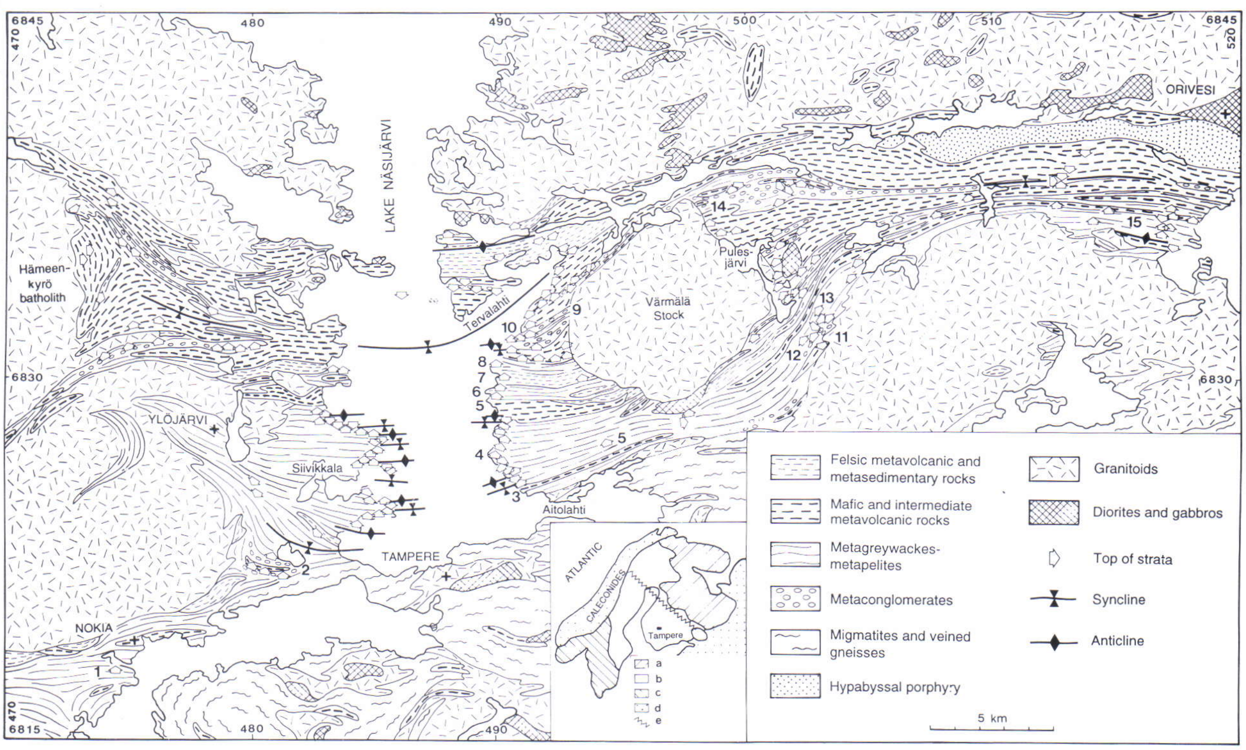

Fig. 1. Lithological map of the Tampere Schist Belt with top of strata observations and a simplified structural interpretation. Numbers 1-15 indicate important localities referred in the text: 1 = Vihola, 2 = Tohloppi, 3 = Kiviranta, 4 = Myllyniemi, 5 = Pirttiniemi, 6 = Tuuliniemi, 7 = Pylsynlahti, 8 = Tervakivi, 9 = Kolunkylä, 10 = Kisala, 11 = Viinaränninnotko, 12 = Ahvenlammi, 13 = Talvineva, Pynnölänkangas and Multivuori, 14 = Pohtola, 15 = Karppi. Puolamäki is situated ca. 1 km N of Multivuori. Slightly modified from Kähkönen (1989). The inset shows the location of the Tampere Schist Belt in the Svecofennian Domain: a = Archean, b = Svecokarelian, c = Post-Svecokarelian (Precambrian), d = Phanerozoic, e = boundary between the Svecofennian and Karelian Domains.

Kähkönen 1987, 1989). Metamorphism in the TSB culminated in low pressure conditions near the amphibolite-greenschist facies transition. (Since this study is concerned with the primary composition of supracrustal rocks, the names of the rock types are written from here on without the prefix meta-.) The volcanic rocks of the TSB have U-Pb zircon ages of 1.905-1.89 Ga (Kähkönen et al. 1989). The detrital zircons in the graywackes are mostly slightly older, ca. 1.91-2.0 Ga, and partly Archean (Huhma et al. 1991). Near Tampere, the TSB comprises a large F_1 syncline with an E-W trending subvertical axial plane and subhorizontal axis (Kähkönen 1989, Nironen 1989). According to Simonen (1953), the lowermost unit consists of more than 3 km of graywackes and mudstones. It is overlain by felsic volcanic and sedimentary rocks and then by intermediate to mafic volcanic rocks. Conglomerates characterize the next unit and are overlain by mafic volcanic rocks. In addition, the Osara turbidites at Viljakkala, 35 km NW of Tampere, are underlain by the pillow-basalt bearing Haveri Formation (Mäkelä 1980, Kähkönen & Nironen, this volume).

STRATIGRAPHY OF THE NÄSIJÄRVI AND PULESJÄRVI PROFILES

A tentative stratigraphic division of the Näsijärvi and Pulesjärvi profiles is given in Table 1. Deformation and faults make the interpretation in places problematic. The pronounced deformation at Kiviranta, Pylsynlahti, Multivuori and Rukojylhännotko (a valley southeast of Multivuori) are attributable to faults and shear zones, and they cause breaks in the succession. In the southernmost part of the Näsijärvi profile, the stratigraphic position of the Kiviranta succession is problematic (see Kähkönen, this volume). The structure is complex in the southern part of the Pulesjärvi profile but a minor anticline is present near Viinaränninnotko. Since the lithologies of the southern and northern limbs of this anticline are contrasting, faults in the hinge zone are implied. South-dipping subvertical reverse faults are suggested by Kähkönen (this volume). This would mean that the Viinaränninnotko volcanic and sedimentary rocks in the southern limb of the minor anticline are stratigraphically below the Ahvenlammi member of the Myllyniemi formation in the northern limb. The exact boundary between the Viinaränninnotko succession and the Ahvenlammi member is obscure.

The deformation also makes the estimation of the unit thickness difficult in certain locations. This concerns particularly the Kupinniemi and Pynnölänkangas members and the Tuuliniemi formation (Table 1) which are dominated by mudstones. However, the 2-2.5 km estimated thicknesses for the Pulesjärvi and Kolunkylä successions are not complicated by deformation. The total thickness of the succession in the Näsijärvi profile is approximated to be close to 7 km (see also Simonen 1953). Pronounced deformation and intrusions make the succession considerably thinner in the Pulesjärvi profile.

Most of the sediment-dominated southern part of the Pulesjärvi profile is included into the Myllyniemi formation. The successions at Tervakivi and Puolamäki are similar since they, at both localities, comprise the lower volcanic member with feldsparphyric high-K rhyolite and the upper, graywacke-dominated sedimentary member in which the graywackes become more mafic upward (Appendix). Therefore, the strata at Puolamäki are included in the Tervakivi formation. The lower parts of the Pulesjärvi volcanic and sedimentary rocks are probably lateral equivalents of the lower parts of the Kolunkylä volcanic and sedimentary rocks but the upper parts of these successions are more difficult to correlate at the moment.

Table 1. Tentative stratigraphic division of the Näsijärvi and Pulesjärvi profiles. Based on Seitsaari (1951), Simonen and Kouvo (1951), Ojakangas (1986), Rautio (1987), Leveinen (1990), and data of Y. Kähkönen. The predominating rock types are given for each unit. The Kiviranta succession, south of Myllyniemi, is not included because of the problems discussed in Kähkönen (this volume).

NÄSIJÄRVI PROFILE	**PULESJÄRVI PROFILE**
	Pohtola volcanic and sedimentary rocks (mostly gentle dips) - volcanic rocks, conglomerates, graywackes and mudstones
	--- profile continues ca. 2 km west, at Pohtola
Kolunkylä sedimentary and volcanic rocks (2 - 2.5 km) - conglomerates, graywackes, mudstones and various volcanic rocks	**Pulesjärvi** volcanic and sedimentary rocks (2 - 2.5 km) - mafic to intermediate Pl±Ur-phyric volcanic rocks separated by five 10 - 70 m thick sedimentary units of graywackes and conglomerates
Tervakivi formation (ca. 300 m) - thinly to medium bedded graded graywackes (ca. 250 m) - volcanics with a feldspar-phyric high-K rhyolite (ca. 20 m)	**Tervakivi** formation at Puolamäki (ca. 0.5 km) - thinly to medium bedded graded graywackes (ca. 400 m) - feldspar-phyric high-K rhyolite (50 m)
Pylsynlahti schists (ca. 800 m, pronounced deformation)	--- 200 - 300 m with poor exposure
Tuuliniemi formation (400 - 700 m, folding) - mudstones	**Multivuori** schists (ca. 400 m, noncoherent) - mudstones and intermediate volcanic rocks, divided into two parts by felsic schists and mylonite
Pirttiniemi formation (ca. 400 m) - intermediate volcanic rocks	--- fault at Rukojylhännotko
Myllyniemi formation (1.5 - 2 km) - **Kupinniemi** member (0.5 - 1 km, folding) mudstones, few thinly to medium bedded graywackes rare volcanic rocks - **Jukonniemi** member (500 - 600 m) medium to thickly bedded graywackes, and mudstones - **Alasenlahti** member (ca. 200 m) medium to thickly bedded graywackes, and mudstones - **Vaarinniemi** member (ca. 150 m) mudstones and thinly to medium bedded graywackes	**Myllyniemi** formation in the Pulesjärvi profile (ca. 1 km, folding, tops mostly to the northwest) - **Pynnölänkangas** member (0.5 - 0.7 km, folding) mudstones and fine-grained graywackes - **Talvineva** member (ca. 200 m) very thickly to medium bedded graywackes - **Ahvenlammi** member (ca. 100 m) non-stratified or graded clast-supported pebbly gravels --- break due to folding and faulting
--- pronounced deformation	**Viinaränninnotko** volcanic and sedimentary rocks (200 - 300 m, top of strata to the south) - mudstones - mafic volcanic rocks (ca. 35 m) - very thickly bedded pyroclastic rocks (ca. 35 m) - mudstones and thinly bedded graywackes, in part tuffaceous

SEDIMENTARY ENVIRONMENTS

According to Ojakangas (1986), the TSB sedimentary rocks are mostly mid-fan turbidites of a submarine fan deposited in a forearc basin. Paleocurrent data suggest that the dominant sources were located to the east and southeast (Ojakangas 1986, Rautio 1987, Leveinen 1990). The conglomerate-dominated strata of the Ahvenlammi member are submarine channel or canyon deposits (Leveinen 1990). They represent more proximal environments than the other parts of the Myllyniemi formation.

Rautio (1987) interpreted the Kolunkylä sedimentary rocks as submarine mid-fan, upper fan and channel deposits. Since the Pulesjärvi sedimentary rocks are characterized by well-rounded, clast-supported, strongly channelized conglomerates and cross-bedded graywackes they probably resulted from tractional processes (Leveinen 1990). This Pulesjärvi succession, 2-2.5 km thick, contains a possible welded ignimbrite but no pillow lavas. The depositional environment of the Pulesjärvi sedimentary rocks was probably fluvial. Together, the volcanic-rich uppermost parts of the study profiles represent a change from submarine to partly subaerial environments on the slopes of a volcanic apron. Considering the interpreted fluvial (at Pulesjärvi) vs. submarine (at Kolunkylä) environments and the observed paleocurrent trends, it is evident that the succession at Pulesjärvi was deposited higher on the apron than the succession at Kolunkylä.

We also present data from the Mauri arkose, 25-40 km west of Tampere. Matisto (1968) suggested a fluvial-deltaic environment for this unit, but its stratigraphic position is not well known.

ANALYTICAL METHODS

Most of the analyses were carried out on pressed rock powder briquettes with a Philips PW 1400/AHP XRF instrument at the Research Centre of Rautaruukki Company (Ala-Vainio 1986). Two samples were analyzed with a Philips 1480 XRF instrument at the Geological Survey of Finland. For five samples the determinations, including La, were made by Dr. Antti Vuorinen with a Jobin Yvon 70+ ICP-AES instrument at the Department of Geology, University of Helsinki. Three samples were checked by Dr. Tim Brewer with a XRF instrument at the University of Nottingham. Rare earth elements, Ta, Hf and Th were determined by the instrumental neutron activation method at the Technical Research Centre of Finland (Rosenberg et al. 1982). The results are given in Tables 2 and 3.

RESULTS

The TSB sedimentary rocks vary widely in their chemical composition. This is in part attributed to sorting and grain-size effects, but there is also significant variation according to the stratigraphic position. This variation reflects differences in the character of source areas.

The SiO_2 contents of the TSB graywackes vary from 53% to 80% (Fig. 2, Table 2). The CIA values (chemical index of alteration, Nesbitt & Young 1982) range between 33 and 61, mostly between 50 and 60. Note that the lowest CIA values are not due to carbonate but come from mafic graywackes rich in pseudomorphs after clinopyroxene clasts. The conglomerate samples (526a-YK/89, 21-22-Ahv/85) are largely similar to their associated graywackes. In general, the mudstones are lower in SiO_2 and Na_2O than the graywackes (the mafic graywackes excluded), and their Al_2O_3, TiO_2, FeO, K_2O, Ni and Zn contents and CIA values are mostly higher. When compared with rocks with similar SiO_2 contents, the mudstones tend to have higher Al_2O_3, K_2O and CIA, and lower MnO, CaO, P_2O_5, Sr and Zr than the graywackes. The effects of grain size and sorting are also shown by the siltstones and mudstone-graywacke mixtures; these rocks are intermediate between the clayey mudstones and high-Si graywackes. On the other hand, the graywackes with ca. 60-68% SiO_2 tend to comprise a group between the mafic graywackes and high-Si graywackes.

Pronounced recrystallization in the Pulesjärvi profile makes it difficult to petrographically distinguish between clayey and silty mudstones, but the clayey mudstones proper from the Näsijärvi profile have SiO_2 of ca. 60-64% (volatile-free basis), Al_2O_3 of 17 to 21%, K_2O:Na_2O ratios of 1.5 to 5, and CIA values of 59 to 69. Among the mudstones, the sensitivity of CIA indices, of K_2O/Na_2O ratios and of SiO_2 contents, to grain size is shown by the Jukonniemi and Tuuliniemi siltstones. These siltstones tend to have lower Al_2O_3, CIA and K_2O/Na_2O, and higher SiO_2 than the associated clayey mudstones (Table 2).

Some of the rocks studied which are mudstones in grain size are tuffs rather than epiclastic rocks. In the Näsijärvi profile, sample 532-YK/89 (poor in micas, contains possible shards and a few oversized Pl-clasts) is a good example. It is higher in silica (73% SiO_2) and has a CIA value of 52, lower than the distinctly epiclastic mudstones which typically have ca. 60% SiO_2 and CIA values of ca. 56-68. In the Pulesjärvi profile, the fine-grained felsic sample Tre 85 is also considered tuff rather than epiclastic according to its petrography, high silica contents and low CIA value (Table 2).

The chondrite-normalized REE patterns of the TSB sedimentary rocks show enrichments of LREE over HREE (La_N:Yb_N mostly 8-14) and the HREE patterns are flat or gently sloping (Tb_N:Yb_N mostly 1.1-1.5; Fig. 3; Table 3). The Eu/Eu^* values range

Table 2. Major and trace element data for the sedimentary rocks of the Tampere Schist Belt. Rock types: cgl = conglomerate, cgr = coarse-grained graywacke, gr = graywacke, fgr = fine-grained graywacke, am-gr = amphibole-bearing graywacke, sm = silty mudstone, m = mudstone, cm = clayed mudstone, ftm = felsic tuffaceous mudstone. Oxides in weight%, trace elements in ppm. Total Fe as FeO. XRF analyses mostly by Rautaruukki, (GSF) by Geological Survey of Finland, (Br) by Tim Brewer. (UH) indicates analyses made by ICP-AES at the Department of Geology, University of Helsinki. In the Näsijärvi and Pulesjärvi profiles, the samples are arranged according the stratigraphic position from the bottom to the top.

NÄSIJÄRVI PROFILE

MYLLYNIEMI FORMATION

	Vaarinniemi				Alasenlahti							
	1-B-YK/91	1-Bm-YK/91	4-YK/91	46-RWO/82	10-YK/91	11-YK/91	1-YKÄ/84	1-YKÄ/84	525-YK/89	2-YKÄ/84	501-YKÄ/88	501-YKÄ/88
rock type	gr (UH)	sm (UH)	gr (UH)	gr	gr (UH)	gr (UH)	gr	gr	cm (GSF)	gr	gr	gr (Br)
SiO_2	60.81	65.43	61.65	63.90	75.17	73.96	74.76	76.37	58.89	79.16	76.90	76.46
TiO_2	0.71	0.63	0.80	0.57	0.56	0.46	0.43	0.35	0.77	0.24	0.32	0.42
Al_2O_3	20.39	15.61	15.15	14.20	11.28	12.30	12.68	11.56	18.54	9.93	10.30	11.10
FeO	3.94	5.76	8.04	5.05	4.51	3.69	3.06	2.44	6.73	2.23	2.23	3.46
MnO	0.07	0.08	0.10	0.06	0.04	0.03	0.04	0.03	0.05	0.03	0.03	0.03
MgO	1.59	2.30	3.09	2.05	1.40	1.40	1.32	1.05	2.65	0.94	0.84	1.41
CaO	4.21	1.47	2.00	1.68	1.42	0.77	0.72	0.81	0.70	0.93	0.96	0.71
Na_2O	5.18	2.29	2.82	3.40	2.95	2.45	2.32	2.73	1.62	2.66	2.88	2.42
K_2O	1.69	3.17	3.38	2.51	1.58	2.74	2.76	2.27	5.34	1.62	1.63	2.44
P_2O_5	0.24	0.10	0.17	0.20	0.01	0.11	0.14	0.12	0.15	0.09	0.14	0.07
sum	98.83	96.84	97.20	93.62	98.92	97.91	98.23	97.73	95.44	97.83	96.23	98.52
S							0.02		0.27		0.01	
C												
CIA	53.08	61.23	55.90	55.52	55.20	59.40	60.95	57.83	65.57	55.92	55.51	58.35
$K_2O:Na_2O$	0.33	1.38	1.20	0.74	0.54	1.12	1.19	0.83	3.30	0.61	0.57	0.74
Zr	232	163	283	180	272		210	200	192	150	200	213
Ni				20			30	30	40	20	20	25
Sr	440	169	244	210	174	96	100	110	115	120	200	147
Ba	374	944	750	450	2350	530	640	520	1093	330	290	490
V	72	86	166	100	99		80	60	186	40	50	55
Zn	68	92	122	80	79	64	40	40	126	40	50	64
Cu				30			10	10	80	20	0	6
Y									23			16

NÄSIJÄRVI PROFILE

MYLLYNIEMI FORMATION

	Jukonniemi													Kupinniemi			
	502-YKÄ/88	503-YKÄ/88	504-YKÄ/88	526a-YK/89	524-YK/89	527-YK/89	528-YK/89	531-YK/89	531-YK/89	505-YKÄ/88	506-YKÄ/88	533-YK/89	532-YK/89	507-YKÄ/88	508-YKÄ/88	509-YKÄ/88	534-YK/89
rock type	gr (GSF)	gr	gr	cgl/cgr	cm	cm	sm/fgr	gr	gr (Br)	gr	gr	fgr	ftm	gr	gr	gr	cm
SiO_2	65.54	71.30	67.80	75.30	61.70	61.60	68.00	69.10	70.69	70.90	68.00	71.10	70.30	71.70	64.80	68.50	57.50
TiO_2	0.64	0.48	0.49	0.31	0.71	0.71	0.58	0.57	0.60	0.57	0.66	0.62	0.44	0.52	0.71	0.59	0.75
Al_2O_3	16.42	13.90	14.40	11.90	18.70	19.40	16.10	13.90	13.02	12.50	12.20	13.60	13.10	13.20	15.60	14.90	20.90
FeO	4.71	3.82	3.63	2.16	5.84	5.96	4.50	4.39	4.73	4.67	5.20	3.33	4.00	3.35	5.75	4.38	6.74
MnO	0.06	0.04	0.06	0.05	0.05	0.05	0.04	0.06	0.04	0.03	0.06	0.05	0.07	0.04	0.06	0.06	0.05
MgO	1.89	1.43	1.40	0.78	2.84	2.07	1.70	1.89	2.05	1.44	2.08	0.93	1.30	1.17	1.68	1.56	2.60
CaO	1.02	1.08	1.85	2.52	0.45	0.93	1.20	1.10	1.16	1.79	1.40	2.31	2.63	1.26	3.06	2.67	0.81
Na_2O	2.71	2.37	4.14	3.26	1.38	1.24	1.48	2.88	2.81	3.34	3.03	3.99	3.12	2.46	3.88	3.50	1.43
K_2O	4.02	3.30	2.05	0.85	5.15	5.91	4.33	3.17	2.97	1.94	2.41	1.58	1.66	2.53	2.12	2.12	5.44
P_2O_5	0.17	0.16	0.19	0.21	0.16	0.11	0.14	0.18	0.14	0.28	0.20	0.28	0.11	0.17	0.26	0.23	0.10
sum	97.18	97.89	96.02	97.35	96.98	97.98	98.07	97.23	98.21	97.47	95.23	97.80	96.72	96.40	97.92	98.52	96.33
S	0.03	0.10		0.07	0.08	0.01	0.01	0.03	0.05	0.02		0.00	0.19		0.37	0.04	0.04
C				0.45	0.38		0.48			0.51	0.59						
CIA	60.59	59.54	53.72	52.25	68.30	65.66	63.34	57.72	56.66	53.51	54.59	52.13	52.77	59.23	52.25	53.56	68.23
$K_2O:Na_2O$	1.48	1.39	0.50	0.26	3.73	4.77	2.93	1.10	1.06	0.58	0.80	0.40	0.53	1.03	0.55	0.61	3.80
Zr	281	180	200	170	150	160	170	210	211	260	320	230	130	230	270	190	160
Ni	31	30	30	20	70	50	40	40	28	20	30	20	30	30	30	20	40
Sr	211	190	400	400	100	150	190	230	233	280	270	360	290	290	620	430	200
Ba	1144	670	410	370	1150	850	580	750	812	210	360	310	270	580	300	290	880
V	119	70	80	50	150	150	90	90	89	100	140	80	80	90	140	100	160
Zn.	87	80	70	50	130	80	70	70	65	70	100	70	90	80	110	60	110
Cu	13	2	0	10	60	30	10	20	23	30	10	0	40	0	80	40	100
Y	26								22								

Table 2. (cont.)

NÄSIJÄRVI PROFILE

	TUULINIEMI FORMATION			TERVAKIVI FORMATION										KOLUNKYLÄ	
	535-YK/89	537-YK/89	540-YK/89	541-YK/89	511-YK/89	513-YK/89	514-YK/89	514-YK/89	515-YK/89	517-YK/89	518-YK/89	519-YK/89	520-YK/89	2-Kisala	1-Kisala
rock type	sm	cm	sm	m	gr	gr	gr	gr (Br)	gr	gr	gr	gr	am-gr	m	m
SiO_2	65.10	60.50	60.00	62.90	67.20	64.60	65.40	66.94	67.40	67.50	65.80	65.50	61.90	60.30	61.30
TiO_2	0.57	0.69	0.63	0.64	0.59	0.71	0.68	0.80	0.60	0.52	0.63	0.62	0.73	0.68	0.68
Al_2O_3	16.80	20.30	16.70	16.80	14.80	14.40	14.40	13.91	14.50	14.40	15.60	15.10	14.00	18.30	17.80
FeO	4.89	5.80	6.78	5.83	4.95	5.80	5.43	6.11	4.93	4.26	5.24	5.06	7.08	6.45	6.07
MnO	0.06	0.06	0.10	0.06	0.05	0.07	0.07	0.18	0.05	0.07	0.06	0.05	0.10	0.06	0.06
MgO	2.07	2.34	2.85	2.56	2.00	2.25	1.94	2.13	1.88	1.47	1.98	2.04	4.02	2.65	2.56
CaO	1.48	1.46	2.58	1.44	1.81	3.30	2.99	2.82	1.27	2.91	1.47	1.93	3.58	1.73	1.85
Na_2O	2.92	2.45	3.31	1.99	2.40	2.88	3.44	3.17	2.03	3.48	2.29	2.84	2.58	2.27	2.60
K_2O	3.54	4.15	3.10	4.72	3.30	2.39	2.43	2.49	3.75	2.04	3.88	3.13	2.12	4.71	4.26
P_2O_5	0.13	0.12	0.16	0.26	0.22	0.24	0.24	0.18	0.20	0.23	0.22	0.24	0.26	0.25	0.28
sum	97.56	97.88	96.21	97.20	97.33	96.65	97.02	98.73	96.60	96.89	97.18	96.51	96.37	97.39	97.46
S	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.01	0.00	0.00	0.04	0.07
C															
CIA	59.70	64.46	55.28	60.39	57.75	51.91	51.17	51.59	59.86	52.10	59.42	56.59	51.73	60.40	59.20
$K_2O:Na_2O$	1.21	1.69	0.94	2.37	1.38	0.83	0.71	0.79	1.85	0.59	1.69	1.10	0.82	2.07	1.64
Zr	180	130	160	150	170	180	180	201	160	140	170	170	140	160	160
Ni	40	50	50	50	30	30	30	26	20	20	30	30	40	50	50
Sr	230	250	310	300	340	460	420	410	270	470	290	380	500	320	380
Ba	810	900	350	920	670	620	540	621	870	410	1050	740	470	1060	1000
V	80	130	100	110	110	140	120	112	110	100	120	100	180	130	140
Zn	90	110	120	120	90	90	100	94	90	70	90	80	110	120	120
Cu	10	30	10	10	60	20	20	23	30	50	10	20	40	50	70
Y								20							

PULESJÄRVI PROFILE

MYLLYNIEMI FORMATION

	Viinaränninnotko		Ahvenlammi						Talvineva				Pynnölänkangas			
	14-Ahv/85	16-Ahv/85	1-Ahv/84	21-Ahv/85	22-Ahv/85	23-Ahv/85	24-Ahv/85	Tre 53	Tre 59	Tre 60	Tre 61	Tre 62	Tre 77H	Tre 77S	Tre 76H	Tre 76S
rock type	gr	gr	gr	cgl	cgl/cgr	cgr	gr	gr	cgr	gr	gr	sm	gr	m+fgr	gr	m
SiO_2	69.57	70.32	73.72	74.54	74.84	72.63	73.93	71.50	70.60	70.00	70.00	63.10	74.00	66.90	67.10	56.30
TiO_2	0.46	0.57	0.42	0.37	0.36	0.36	0.45	0.45	0.51	0.45	0.41	0.61	0.47	0.55	0.67	0.71
Al_2O_3	14.58	13.33	11.49	11.11	11.10	12.00	11.78	11.20	11.30	12.80	12.80	15.00	11.30	14.90	13.00	18.30
FeO	3.57	4.77	3.61	3.97	3.49	3.58	3.96	3.42	3.91	3.84	3.19	4.92	2.82	3.98	4.84	5.98
MnO	0.07	0.09	0.04	0.08	0.07	0.06	0.07	0.06	0.06	0.07	0.06	0.07	0.03	0.04	0.06	0.07
MgO	0.99	1.24	1.41	1.24	1.21	1.55	1.65	1.58	1.79	1.79	1.71	2.72	1.16	1.78	1.99	2.48
CaO	1.90	2.10	1.14	1.92	1.25	1.67	1.76	1.96	2.00	1.36	2.12	1.73	1.57	1.24	1.97	2.55
Na_2O	3.87	3.36	3.00	2.31	2.39	2.68	2.29	2.77	2.85	2.28	3.73	2.86	2.56	1.91	2.88	3.50
K_2O	2.43	2.21	2.38	2.65	3.55	3.22	3.17	2.18	1.91	2.97	1.66	3.39	1.85	3.52	2.40	3.47
P_2O_5	0.17	0.18	0.14	0.25	0.23	0.17	0.15	0.16	0.20	0.18	0.18	0.25	0.13	0.12	0.19	0.13
sum	97.61	98.17	97.35	98.44	98.49	97.92	99.21	95.28	95.14	95.73	95.86	94.65	95.90	94.94	95.09	93.49
S							0.01	0.05	0.01	0.01	0.01	0.00	0.00		0.00	0.00
C																
CIA	53.91	53.15	54.50	52.20	52.46	52.30	53.08	51.63	52.06	57.53	52.03	56.53	55.45	61.77	54.32	56.36
$K_2O:Na_2O$	0.63	0.66	0.79	1.15	1.49	1.20	1.38	0.79	0.67	1.30	0.45	1.19	0.72	1.84	0.83	0.99
Zr	160	190	200	150	170	180	240	260	250	180	170	160	230	180	350	200
Ni	0	10	20	20	20	30	30	30	20	30	30	30	30	40	30	40
Sr	380	370	130	160	140	160	140	170	250	180	260	240	280	220	340	450
Ba	1040	550	510	880	770	720	750	440	310	920	290	730	390	890	440	760
V	90	120	70	70	70	70	90	80	80	80	70	90	80	90	120	140
Zn	70	90	50	40	40	40	50	40	60	60	50	80	60	90	110	130
Cu	10	10	0	30	10	20	0	0	20	0	0	0	0	0	0	0

Table 2. (cont:)

PULESJÄRVI PROFILE

	MULTIVUORI			TERVAKIVI FORMATION at Puolamäki						PULESJÄRVI						
	Tre 82	51-JEL/86	Tre 85	Tre 103	79-IV-JEL/86	80-IIIA-JEL/86	80-IIIB-JEL/86	80-V-JEL/86	81-JEL/86	Tre 112	Tre 149	Tre 149B	Tre 192	Tre 217	Tre 262	Tre 266
rock type	fgr+m	sm/fgr	ftm	gr	gr	gr	gr	gr	am-gr	am-gr	am-gr	am-gr	am-gr	am-gr	am-gr	am-gr
SiO_2	66.50	63.15	70.90	65.50	64.28	63.98	65.08	62.34	58.86	51.80	51.60	50.90	53.30	50.20	58.10	50.80
TiO_2	0.48	0.54	0.12	0.51	0.69	0.68	0.66	0.67	0.90	0.90	0.62	0.70	0.44	0.61	0.63	0.61
Al_2O_3	14.00	15.97	13.60	14.90	14.44	15.82	13.56	15.20	14.51	14.60	10.50	13.50	17.50	15.10	15.30	13.00
FeO	4.05	5.27	1.43	4.56	6.40	5.92	6.08	6.52	8.44	9.24	9.29	9.24	5.93	8.46	6.91	9.67
MnO	0.05	0.06	0.07	0.05	0.08	0.07	0.08	0.09	0.12	0.15	0.21	0.18	0.11	0.20	0.13	0.20
MgO	1.81	2.53	0.23	1.68	2.33	2.19	2.23	3.00	4.23	5.73	9.03	6.79	6.08	7.08	5.42	8.38
CaO	1.99	1.48	1.78	3.44	3.72	1.73	4.39	3.92	4.79	4.96	9.41	6.78	6.50	8.02	4.54	6.77
Na_2O	3.70	4.56	2.46	2.27	2.95	1.51	2.28	2.71	2.34	2.28	1.41	3.51	2.98	2.32	3.65	1.74
K_2O	2.11	2.79	5.18	2.44	2.78	4.95	2.59	2.86	2.78	3.36	1.72	2.12	1.79	2.19	1.93	3.48
P_2O_5	0.19	0.17	0.03	0.24	0.27	0.24	0.26	0.33	0.33	0.36	0.23	0.35	0.31	0.51	0.43	0.34
sum	94.89	96.52	95.80	95.59	97.94	97.09	97.21	97.64	97.30	93.38	94.02	94.07	94.93	94.69	97.04	94.98
S	0.00	0.00	0.02	0.06					0.01	0.01	0.00	0.01	0.00	0.00	0.00	
C																
CIA	53.84	54.70	51.30	54.09	49.65	58.97	48.23	50.83	48.20	47.05	32.99	39.79	48.36	42.06	48.31	40.66
$K_2O:Na_2O$	0.57	0.61	2.11	1.07	0.94	3.28	1.14	1.06	1.19	1.47	1.22	0.60	0.60	0.94	0.53	2.00
Zr	200	190	170	150	210	200	230	190	220	100	100	100	80	70	110	60
Ni	30	40	10	30	30	40	40	30	30	40	100	70	70	80	60	90
Sr	270	220	290	600	400	120	220	450	270	640	890	880	1350	1230	1030	830
Ba	290	860	720	310	710	1460	490	660	720	920	410	790	1240	700	680	750
V	70	100	10	90	160	140	130	150	220	230	230	250	130	190	160	210
Zn	80	100	40	80	100	100	100	100	120	140	100	100	80	100	100	120
Cu	0	20	0	30	30	20	20	40	50	20	40	10	20	30	0	20

DATA OUTSIDE THE STUDY PROFILES

	Pohtola			Vihola		Karppi			Osara					Tohloppi		Mauri		
	Tre 350	Tre 351	Tre 352	61-A-RWO/82	2-Vih/84	1-Karp/84	2-Karp/84	4-YKÄ/86	11-YKÄ/86	12-B-YKÄ/86	13-A-YKÄ/86	13-B-YKÄ/86	13-C-YKÄ/86	18-YKÄ/83	5-3-YKÄ/83	10-A-YKÄ/86	10-B-YKÄ/86	10-C-YKÄ/86
rock type	am-gr	m	sm	gr	cgr	cgr	cgr	gr	gr	gr	gr	gr	gr	gr	m	arkose	arkose	arkose
SiO_2	54.90	56.20	61.90	71.50	71.06	77.07	75.37	57.78	65.62	69.59	69.08	69.98	71.34	59.94	55.77	74.28	75.93	76.31
TiO_2	0.77	0.69	0.53	0.50	0.57	0.36	0.40	0.90	0.58	0.45	0.56	0.45	0.41	0.54	0.87	0.37	0.30	0.41
Al_2O_3	14.60	17.70	15.80	12.90	12.64	10.38	10.77	14.59	15.62	13.90	12.82	13.38	13.22	17.60	18.76	13.24	12.97	11.97
FeO	7.86	6.27	5.24	4.16	4.92	3.22	3.19	8.85	5.39	4.04	5.57	3.70	3.45	5.10	7.05	2.86	2.47	2.45
MnO	0.13	0.07	0.06	0.06	0.07	0.07	0.06	0.15	0.06	0.05	0.07	0.05	0.06	0.09	0.06	0.02	0.01	0.02
MgO	4.40	3.16	2.61	1.56	2.06	1.15	1.30	3.46	2.39	1.88	2.47	1.91	1.69	1.85	3.54	0.32	0.29	0.24
CaO	5.19	2.74	1.56	1.84	2.47	1.24	1.70	3.10	1.73	1.75	1.54	2.09	1.67	4.09	2.02	0.37	0.37	0.37
Na_2O	3.20	2.60	2.31	3.05	2.64	2.18	3.05	2.16	3.13	2.72	2.78	3.51	2.64	3.70	1.46	1.93	1.95	2.09
K_2O	2.06	3.94	4.14	2.39	2.27	2.96	1.63	4.01	3.53	2.97	2.93	2.16	3.52	4.70	6.91	5.54	5.22	4.36
P_2O_5	0.26	0.36	0.29	0.17	0.37	0.11	0.11	0.34	0.19	0.16	0.17	0.18	0.17	0.45	0.48	0.04	0.04	0.04
sum	93.37	93.74	94.44	98.13	99.07	98.74	97.58	95.35	98.24	97.51	97.99	97.41	98.17	98.06	96.92	98.97	99.55	98.26
S	0.01	0.00	0.00	0.13			0.01											
C																		
CIA	46.27	56.65	58.66	54.06	52.79	53.40	52.15	51.85	56.29	56.08	54.84	52.87	54.13	48.57	58.01	57.31	57.60	57.51
$K_2O:Na_2O$	0.64	1.52	1.79	0.78	0.86	1.36	0.53	1.86	1.13	1.09	1.05	0.62	1.33	1.27	4.73	2.87	2.68	2.09
Zr	120	170	140	180	240	220	280	250	180	180	220	190	180	220	270	200	200	210
Ni	40	40	30	40	40	20	30	20	50	40	30	20	20	30	50	10	10	10
Sr	770	440	310	240	170	140	140	330	190	180	150	180	150	670	260	80	80	70
Ba	760	830	770	510	370	1020	200	1040	710	670	390	390	970	1140	820		1240	1060
V	220	140	100	90	110	70	70	180	120	80	120	80	80	100	130	50	50	50
Zn	100	110	90	70	90	50	80	120	90	60	60	60	40	70	110	60	40	40
Cu	50	50	20	30	90	0	0	40	40	30	30	30	20	90	70	10	10	0

Table 3. REE and other trace element data (in ppm) for the sedimentary rocks of the Tampere Schist Belt. Analyses mostly by INAA, La by ICP for the Vaarinniemi samples. Eu* is an approximation based on the Sm-Tb trend of the chondrite-normalized patterns. Rock types as in Table 2.

	MYLLYNIEMI FORMATION										TUULINIEMI FORMATION
	Vaarinniemi			Alasenlahti		Jukonniemi			Kupinniemi		
	1-B-YK/91	1-Bm-YK/91	10-YK/91	1-YKÄ/84	525-YK/89	502-YKÄ/88	524-YK/89	531-YK/89	508-YKÄ/88	534-YK/89	537-YK/89
rock type	gr	sm	gr	gr	cm	gr	cm	gr	gr	cm	cm
La	32	32	26	18.8	14.6	27.6	24.1	35.6	42.7	26.1	35.4
Ce				34	25.6	47.2	40.3	51.1	66.6	38.1	50.2
Nd				17.7	13.7	21.4	20	23.9	33	18.9	21.4
Sm				3.4	4.17	5.86	4.75	5.3	7.15	4.06	4.69
Eu				0.76	1.09	1.67	1.04	1.08	1.78	1.1	0.945
Tb				0.31	0.578	0.615	0.612	0.491	0.734	0.546	0.552
Yb				1.47	1.88	2.14	2.02	1.68	2.28	2.14	2.03
La_N:Yb_N				8.42	5.12	8.50	7.86	13.96	12.34	8.03	11.49
Tb_N:Yb_N				0.92	1.35	1.26	1.33	1.28	1.41	1.12	1.19
Eu:Eu*				0.81	0.84	1.01	0.72	0.75	0.88	0.91	0.69
Ta				0.67	1.21	0.968	1.16	0.778	0.92	1.23	1.43
Hf				5.4	5.2	7.16	4.63	7.17	7.89	4.98	4.26
Th				9.4	12.9	12	13.6	8.7	11.1	14.1	16.6

	TERVAKIVI FORMATION				KOLUNKYLÄ	MYLLYNIEMI FM. at Ahvenlammi and Talvineva		TERVAKIVI FM. at Puolamäki		PULESJÄRVI			OSARA
	541-YK/89	513-YK/89	518-YK/89	520-YK/89	2-Kisala	1-Ahv/84	Tre 60	79-IV-JEL/86	81-JEL/86	Tre 149	Tre 217	Tre 262	13-A-YKÄ/86
rock type	m	gr	gr	am-gr	m	gr	gr	gr	am-gr	am-gr	am-gr	am-gr	gr
La	38.4	34	30.6	24.6	38.6	49	8.17	31	30	22.1	22	31.3	68
Ce	58.4	61	46	40.1	55.9	63	18.2	57	53	35.4	36.7	49.3	107
Nd	27.5	27.8	22.7	18.4	27	15	6.59	29	28	18.7	18.5	23.5	43
Sm	5.65	4.86	5.55	4.27	5.9	2.6	1.23	5.4	5.2	3.69	3.81	5.2	7.5
Eu	1.32	1.21	1.11	1.12	1.28	0.91	0.55	1.33	1.35	1.18	1.36	1.53	1.26
Tb	0.57	0.577	0.53	0.51	0.589	0.28	0.4	0.55	0.57	0.518	0.445	0.569	0.6
Yb	1.83	1.85	1.82	1.62	1.93	1.68	2.16	1.95	1.86	1.34	1.14	1.78	2.4
La_N:Yb_N	13.82	12.11	11.08	10.00	13.17	19.21	2.49	10.47	10.62	10.86	12.71	11.58	18.66
Tb_N:Yb_N	1.37	1.37	1.28	1.38	1.34	0.73	0.81	1.24	1.34	1.69	1.71	1.40	1.10
Eu:Eu*	0.83	0.84	0.72	0.87	0.79	1.12	1.09	0.89	0.92	1.01	1.23	1.03	0.65
Ta	0.908	0.823	0.817	0.718	1.02	0.77	0.866			0.533	0.36	0.67	1.07
Hf	5.78	6.68	5.39	4.48	5.18	3.9	5.28			2.55	1.76	3.2	5.7
Th	8.78	9.95	8.16	6.91	10.7	11.5	18.3			3.47	2.93	4.39	22

mostly from 0.7 to 1.1, but, since the non-smooth patterns may indicate analytical uncertainties, some of these values should be discussed with caution (see p. 134).

We do not have data from true graywacke-mudstone pairs, but the Tervakivi mudstone tends to be higher in REE than the associated graywackes, and the Kisala mudstone from Kolunkylä is higher in most REE than the Pulesjärvi graywackes. This agrees with the typical turbidites in which muds are mostly enriched in REE relative to the associated sands (McLennan et al. 1990). In contrast, the mudstones of the Myllyniemi formation tend to be lower in REE than the associated graywackes. Data from true graywacke-mudstone pairs are needed for further discussion.

The differences and variation trends in Fig. 2 can largely be explained by leaching during weathering, and by mixing and sorting during transportation and deposition. During weathering, Ca, Sr and Mn are leached into the solutions while Al and K are retained in the clayey products of weathering. The difference in Zr is attributed to detrital zircon in the graywackes. A part of the variation is controlled by stratigraphic position. For instance, the mudstones and graywackes of the Tervakivi formation are higher in P_2O_5 than the typical mudstones and graywackes of the Myllyniemi formation (Figs. 4 and 5). It is also evident that the variation trends in Fig. 2 can largely be explained by the mixing of four major components during sedimentation: (1) clays, (2) a silica- and quartz-rich sand-sized component, (3) an intermediate volcanic component, and (4) a component derived from fairly mafic volcanic rocks. Based on petrography, the silica-rich component comprises felsic volcanics, granitoids, vein quartz, and quartz arenites (Ojakangas 1986, observations by the authors). The mafic volcanic component, prominent in the Pulesjärvi graywackes, is rich in K_2O and Sr and thus has shoshonitic characteristics.

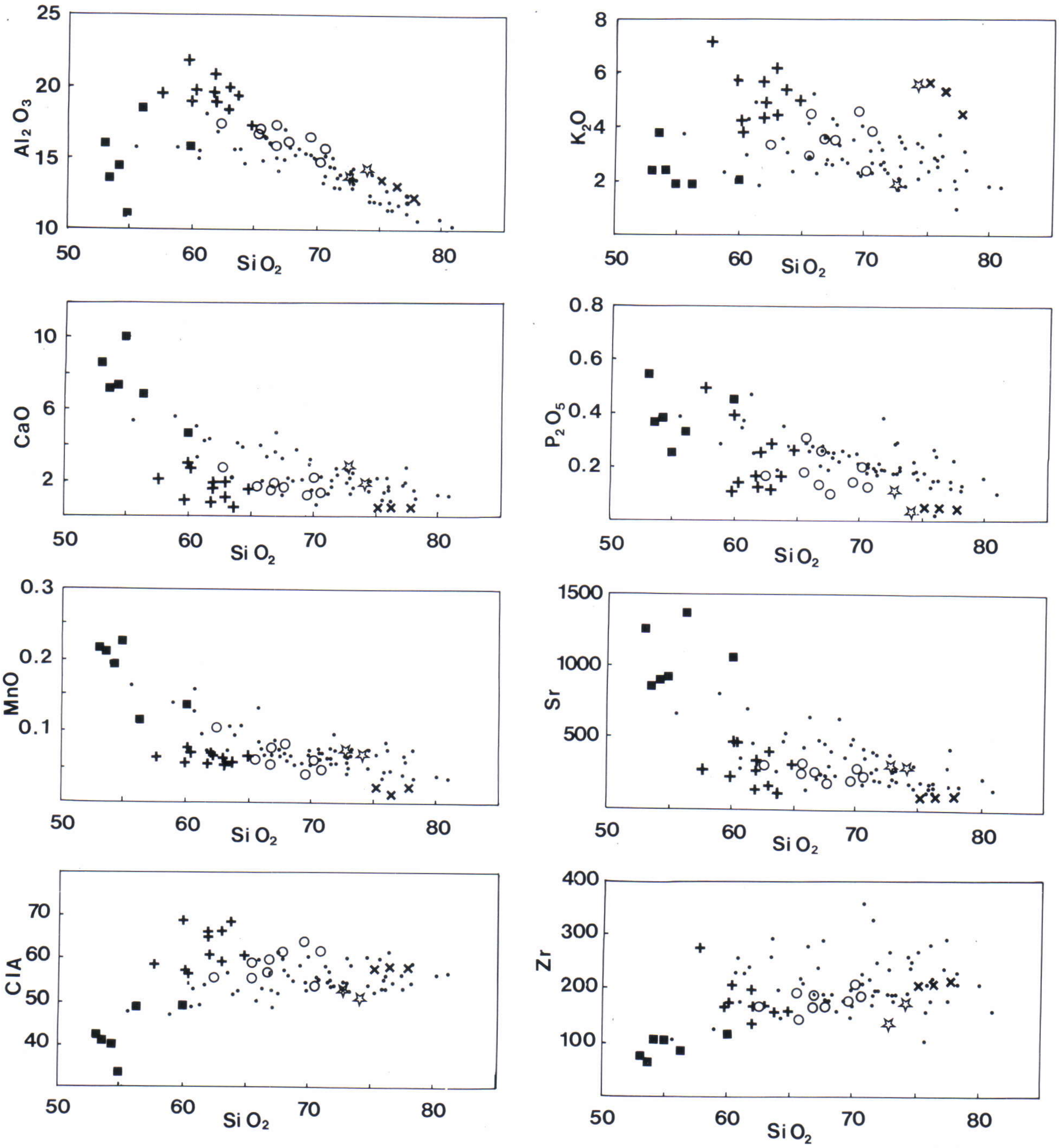

Fig. 2. Selected Harker diagrams of the TSB sedimentary rocks. Data from Table 2. Dots = graywackes and conglomerates in general, closed squares = Pulesjärvi graywackes, crosses = mudstones in general, open circles = silty mudstones and transitional or mixed mudstones - fine-grained graywackes, stars = felsic tuffaceous mudstones, inclined crosses = Mauri arkoses.

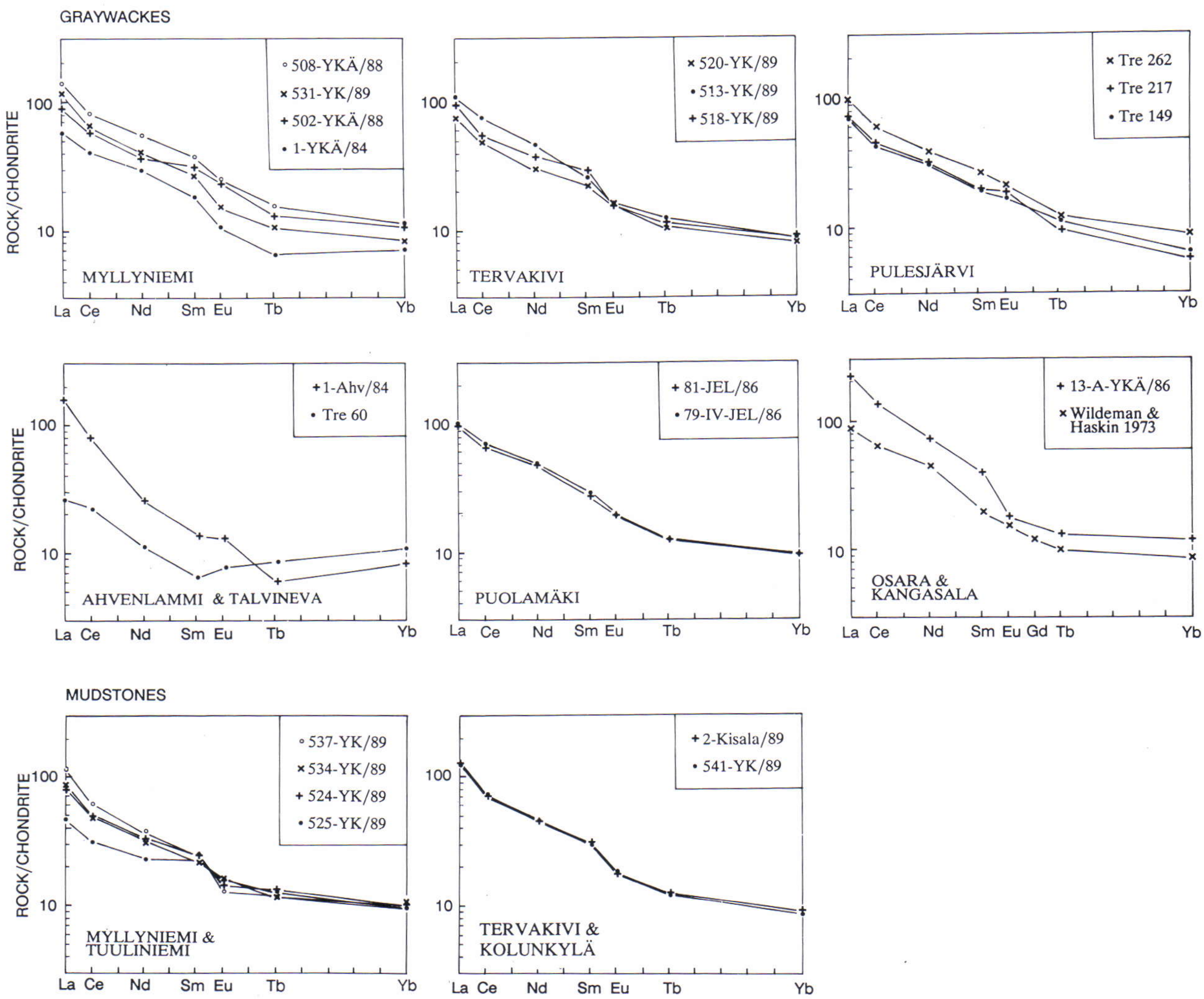

Fig. 3 Chondrite-normalized REE diagrams of the Tampere graywackes and mudstones. Chondrite values: Leedey-6 divided by factor 1.2 (Jahn et al. 1980, Tb from Koljonen & Rosenberg 1975). Sample 13a-YK-/86 is from the Osara Formation ca. 35 km NW from Tampere. The sample of Wildeman & Haskin (1973) is from the area of migmatites and veined gneisses south of the TSB.

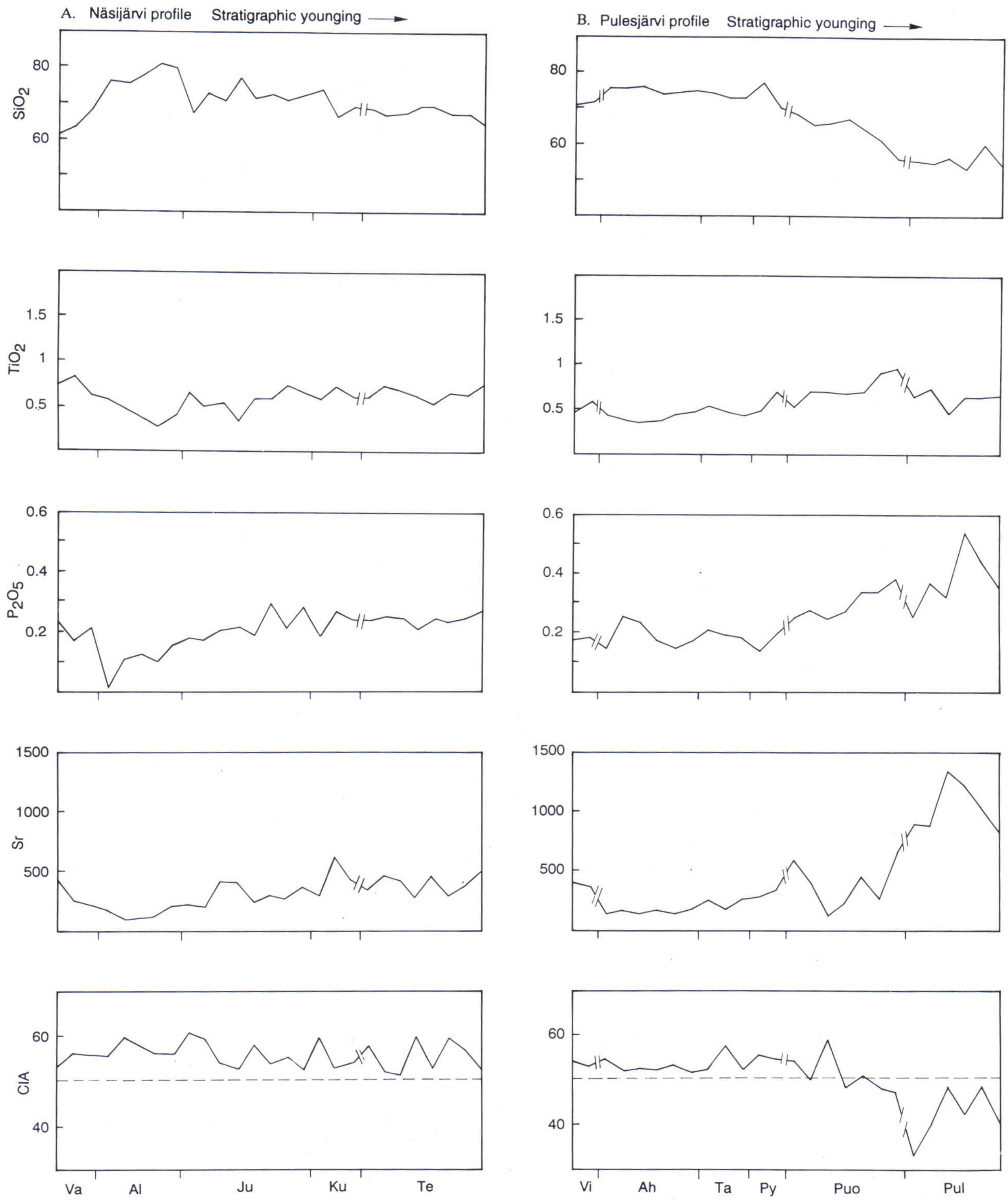

Fig. 4. Upward variation in the composition of the graywackes of the Näsijärvi and Pulesjärvi profiles. The distances between sample points not to true scale. Data from Table 2. Note that in the calculations for the CIA values, no corrections for carbonate and apatite were made. However, since the contents of P and C are low (Table 2) and since carbonate is generally absent or a minor component, the error is not severe. For the samples analyzed twice the diagrams show the analyses by Rautaruukki, and for sample 1-YKÄ/84 the second analysis is used. Oxides recalculated to 100%. Units and localities: Va = Vaarinniemi, Al = Alasenlahti, Ju = Jukonniemi, Ku = Kupinniemi, Te = Tervakivi, Vi = Viinaränninnotko, Ah = Ahvenlammi, Ta = Talvineva, Py = Pynnölänkangas, Puo = Puolamäki, Pul = Pulesjärvi.

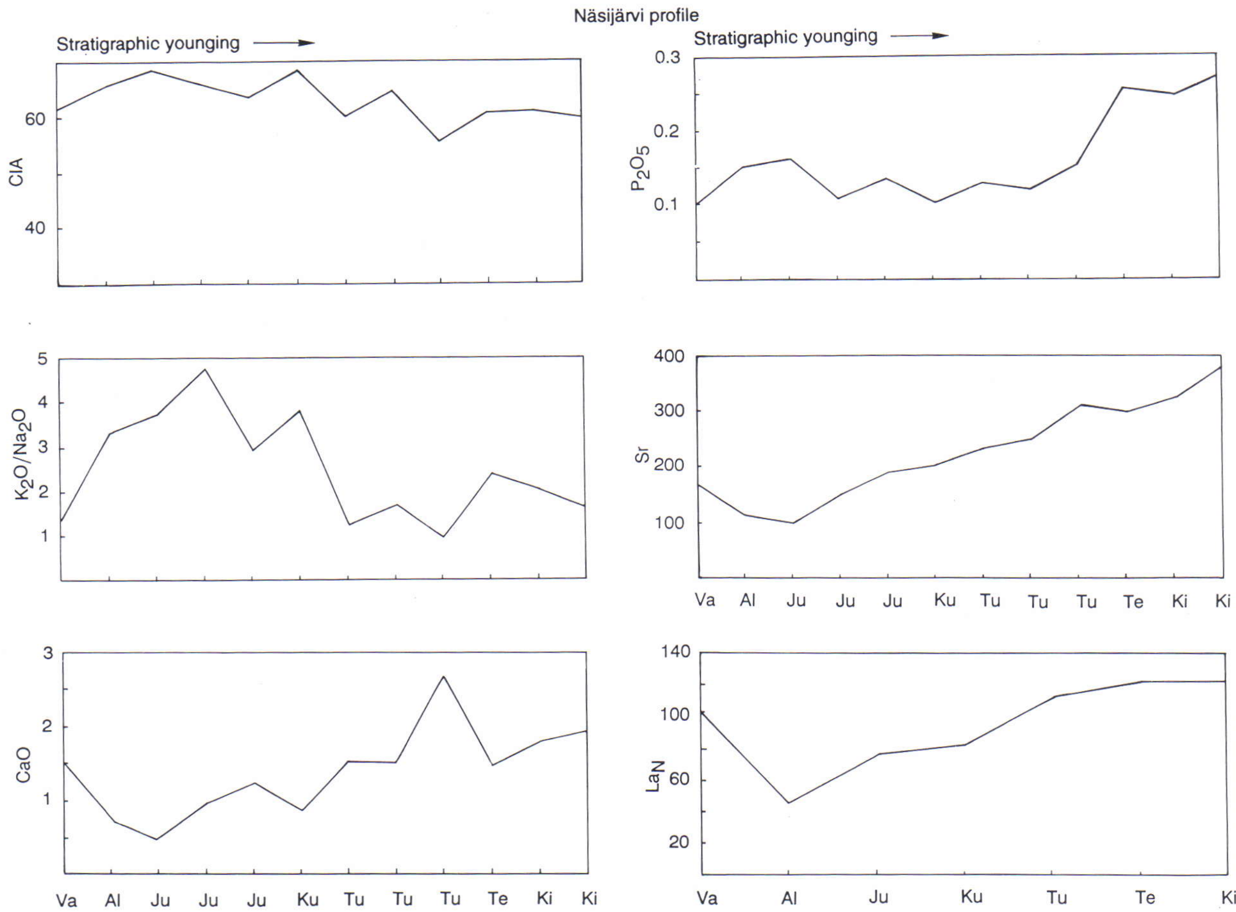

Fig. 5. Upward variation in the composition of mudstones of the Näsijärvi profile. The distances between the samples not to true scale. Oxides recalculated to 100%. Data from Tables 2 and 3. La_N is the chondrite-normalized value of La (Fig 3). Units and localities: Va, Al, Ju, Ku, Te as in Fig. 4. Tu = Tuuliniemi, Ki = Kisala from Kolunkylä.

VARIATION IN COMPOSITION WITH STRATIGRAPHIC POSITION

The chemical composition of the sedimentary rocks of the Näsijärvi and Pulesjärvi profiles varies according to stratigraphic position. In the graywackes, the contents of SiO_2, TiO_2, P_2O_5 and Sr show quite systematic trends (Fig. 4). The CIA value also shows certain, although minor and fluctuating, variation. In addition, rather consistent variations are observed in the mudstones of the Näsijärvi profile.

Graywackes

In the Näsijärvi profile, the Vaarinniemi graywackes are lower in SiO_2 but higher in TiO_2, P_2O_5 and Sr than the overlying Alasenlahti graywackes (Fig. 4). Upward from Alasenlahti, the graywackes show a general decrease in SiO_2 and increases in TiO_2, P_2O_5 and Sr. The CIA trend fluctuates but, on the average, the Alasenlahti and the lowermost Jukonniemi graywackes have higher CIA values than the other graywackes. The LREE contents increase from the Alasenlahti member upward to the Kupinniemi member, but a similar trend is not observed in the Tervakivi formation.

The variation in the Pulesjärvi profile largely resembles that in the Näsijärvi profile. The Ahvenlammi conglomerates and graywackes are similar to the Alasenlahti graywackes in being relatively rich in SiO_2. The upward change towards less silicic compositions is accentuated in the Pulesjärvi graywackes.

The Ahvenlammi and Talvineva conglomerates and graywackes tend to have slightly lower CIA and SiO_2 than the Alasenlahti graywackes. Petrographically, the difference in CIA is attributed to the higher amount of sericite/muscovite, reflecting a higher proportion of clayey matrix at Alasenlahti. In general terms, the divergences may be due to differences in distal vs. proximal turbidites (see Sawyer 1986). The detritus in distal turbidites has experienced more weathering than that in proximal ones but progressive weathering also increases the relative abundance of the weathering-resistant minerals, e.g. quartz. Another explanation may be that the Ahvenlammi and Alasenlahti members represent different fans. If they would belong to the same fan there should occur thickly bedded quartz-rich graywackes at Sorila, a village halfway between Ahvenlammi and Alasenlahti (Fig. 1). According to the observations by Y. Kähkönen, graywackes of this type are absent at Sorila.

The upward compositional variations are readily observed in petrography. The relatively high SiO_2 contents in the Alasenlahti and Ahvenlammi graywackes are indications of the abundance of quartz clasts. According to tentative observations by Y. Kähkönen, they also seem to be richer in granitoid clasts than the other graywackes studied. The upward decrease of the SiO_2 content within the Tervakivi and Puolamäki graywackes is related to the occurrence of hornblende in the uppermost graywackes (Appendix). Based on petrography only (Rautio 1987, unpublished data of Y. Kähkönen), it is also clear that the graywackes at Kolunkylä are less silicic than the Myllyniemi graywackes and most of the Tervakivi graywackes.

The CIA values of the graywackes vary systematically according to the stratigraphic position but the trend in part fluctuates. The oscillations are partly due to analytical uncertainties since the samples analysed twice show differences of 0.5-3 CIA units (Table 2). There are also differences within beds. For instance, samples Tre 59-61 are from a single bed and show a range of 52-58 in CIA (Table 2). In addition to analytical uncertainties, these divergences may be due to sorting effects. The rather low CIA and high SiO_2 in sample 526a-YK-/89 is a result of washing; the rock is poor in intergranular mica which represents an original muddy matrix.

The composition of the TSB graywackes is partly controlled by sorting and grain size but other factors, such as differences in the provenance, must also be considered. For instance, the Alasenlahti and Jukonniemi graywackes are similar in grain size but the former are higher in SiO_2 than the latter. Also, the graywacke sample 1-Ahv/84 resembles the associated conglomerates in its SiO_2 content.

Mudstones

The data on the mudstones of the Näsijärvi profile are less abundant than the graywacke data but, in general, the Myllyniemi mudstones are lower in P_2O_5, CaO, Sr and LREE contents but higher in CIA values and K_2O/Na_2O ratios than those at Tervakivi and Kolunkylä (Fig. 5). The Tuuliniemi mudstones are intermediate between these types. The silty mudstone from Vaarinniemi has higher CaO and La contents, and lower CIA and K_2O/Na_2O values than the other Myllyniemi mudstones. Silt/clay grain-size effects explain a part of the oscillation of the variation trends in the Myllyniemi and Tuuliniemi mudstones (Table 2). The non-consistent upward variation in the mudstones of the Pulesjärvi profile (Table 2) is attributed to the problems of precise determination of the original grain size and character of the fairly recrystallized fine-grained schists.

GEOCHEMISTRY AND TECTONIC SETTING

Sedimentary basins may be classified according to their plate tectonic setting into some twenty types (Ingersoll 1988, Miall 1990) but in the classifications based on chemical composition of graywackes three to four plate tectonic settings are discerned (Bhatia 1983, Bhatia & Crook 1986, Roser & Korsch 1986). McLennan et al. (1990) distinguished six tectonic settings of depositional basins. These authors also emphasized that the plate tectonic setting of the provenance is more important than the tectonic setting of deposition in controlling the composition of turbidites. While the basin and provenance generally have comparable tectonic settings, sediment may be transported into a tectonically distinctive basin and a basin may receive material from various source areas (see McLennan et al. 1990). This is one source of uncertainty when the discrimination diagrams (Figs. 6-9) are applied. A further problem in diagrams based on a K_2O/Na_2O ratio is the eventual post-depositional mobility of alkali metals. Consid-

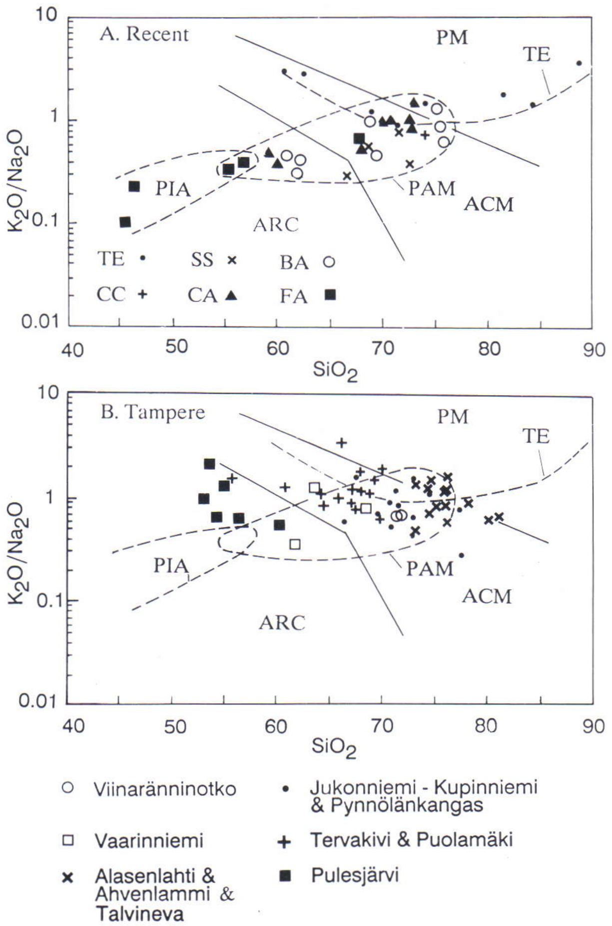

Fig. 6. K_2O/Na_2O vs. SiO_2 diagram of modern turbidite sands and Tampere graywackes. SiO_2 values recalculated to 100%.

A. Young sands and graywackes. Continuous lines indicate boundaries of the fields of graywackes derived from passive continental margins (PM), from active continental margins (ACM) and from oceanic island arcs (ARC), according to Roser & Korsch (1986). Symbols for modern sands: TE = trailing edge margins; CC = continental collision basins; SS = strike-slip margins; BA = back-arc basins; CA = continental arc basins; FA = forearc basins; data from MacLennan et al. (1990), recalculated to 100%. Based on these symbols, we discriminate with dashed lines the fields of trailing edge (TE), primitive island arc (PIA) and pooled active margin (PAM) basins. The FA sample from Japan is excluded from the PIA field because its Nd isotopes show a significant component of old crust in the provenance and because northern Japan is not a primitive island arc. The sands from continental collisions are included in the PAM group (cf. Maynard et al. 1982), not in the TE group (cf. McLennan et al. 1990).

B. Tampere graywackes from the Näsijärvi and Pulesjärvi profiles. Data from Table 2. The TE, PAM, PIA, PM, ACM and ARC fields from Fig. 6A.

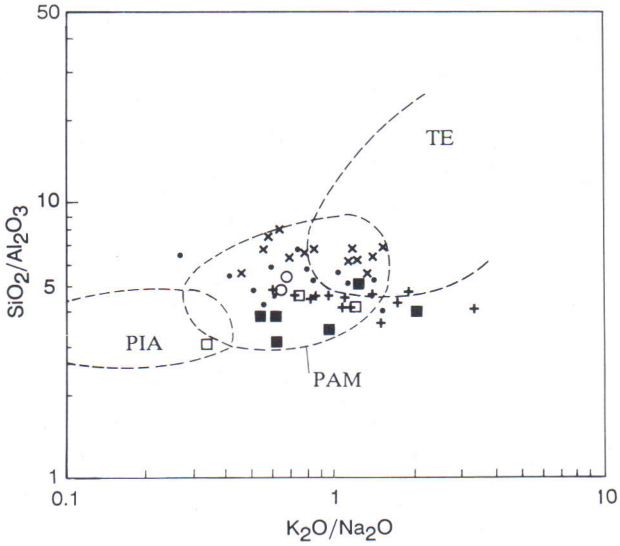

Fig. 7. SiO_2/Al_2O_3 vs. K_2O/Na_2O diagram of the Tampere graywackes from the Näsijärvi and Pulesjärvi profiles. Data and symbols as in Fig. 6B. The TE, PAM and PIA fields of recent sands were drawn according to Fig. 4 of McLennan et al. (1990) using criteria similar to those in Fig. 6A.

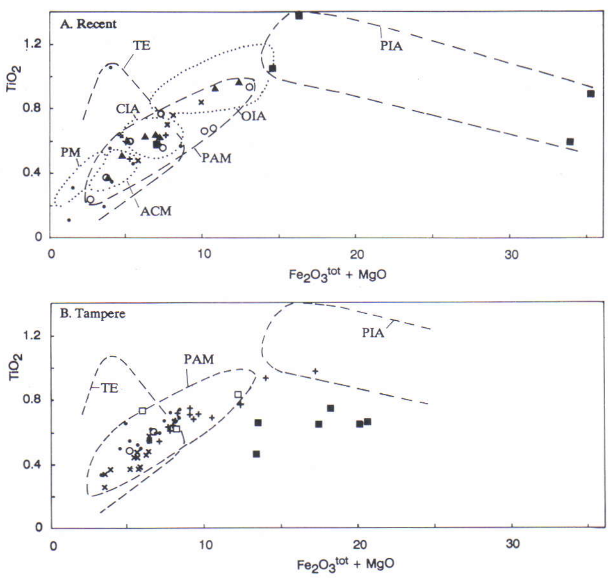

Fig. 8. TiO_2 vs. $Fe_2O_3^{tot}$+MgO diagram of modern turbidite sands and Tampere graywackes. Data recalculated to 100% on a volatile-free basis. Total Fe as Fe_2O_3. **A**. Modern sands, data from McLennan et al. (1990), symbols as in Fig. 6A. The TE, PAM and PIA fields (dashed lines) were drawn using criteria similar to those in Fig. 6A. Dotted lines give the major fields of sandstones from oceanic island arc (OA), continental island arc (CIA), active continental margin (ACM) and passive margin (PM) settings according to Bhatia (1983).

B. Tampere graywackes from the Näsijärvi and Pulesjärvi profiles. Data and symbols as in Fig. 6 B. The TE, PAM and PIA fields from Fig. 8A.

ering the overlappings and uncertainties, a simple three-fold classification is used here: trailing edge settings (TE), settings close to primitive island arcs (PIA), and the pooled active margin (PAM) settings. It should be emphasized that the discrimination is tentative and future revisions will probably be necessary. We do not use mudstone data for tectonic setting discrimination (cf. Roser & Korsch 1986) since seawater salt may comprise a significant part of sodium in muds (McLennan et al. 1990).

In general, the graywackes of the Näsijärvi and Pulesjärvi profiles resemble PAM graywackes and sands (Figs. 6-9). The relatively silicic graywackes and conglomerates of Alasenlahti, Ahvenlammi and Talvineva fall closer to the TE field than the other TSB graywackes. Nevertheless, they may be classified as PAM sedimentary rocks. The TE imprint is slighter in the Tervakivi and Vaarinniemi graywackes than in most of the Myllyniemi graywackes, and it is weakest in the Pulesjärvi graywackes.

The Pulesjärvi graywackes resemble PIA graywackes due to their low SiO_2 contents. However, features such as high ratios of K_2O/Na_2O, high La/Yb and high La/V distinguish them from the latter. They are evidently associated with a mature arc. The Vaarinniemi graywackes, the lowermost graywackes studied in the Näsijärvi profile, are also mainly derived from a mature arc, not from a primitive arc.

The TSB graywackes are more silicic than modern forearc sands of immature arcs. However, the forearc setting suggested by Ojakangas (1986) cannot be confirmed or refuted on this basis because some modern forearc basins, e.g. off northern Japan, contain fairly silicic sands which have a significant component of old continental crust in the provenance (Figs. 6, 8 and 9 in McLennan et al. 1990).

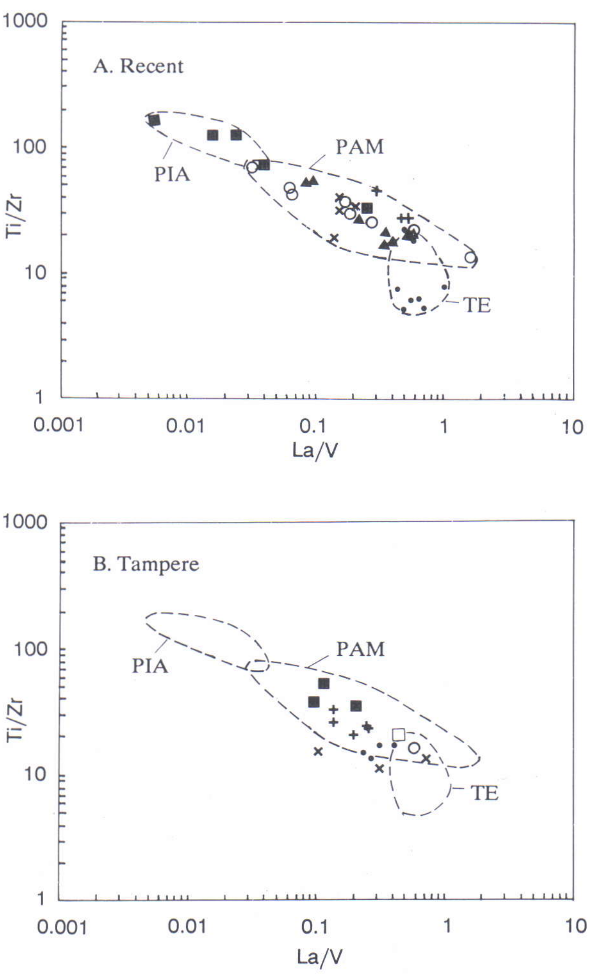

Fig. 9. Ti/Zr vs. La/V diagram of modern turbidite sands and Tampere graywackes. **A.** Modern sands. Data, symbols and fields as in Fig. 6A. **B.** Tampere graywackes. Data from Tables 2 and 3. Symbols as in Fig. 6B, but the open circle indicates sample 13-A-YKÄ/86 from Osara. The TE, PAM and PIA fields from Fig. 9A.

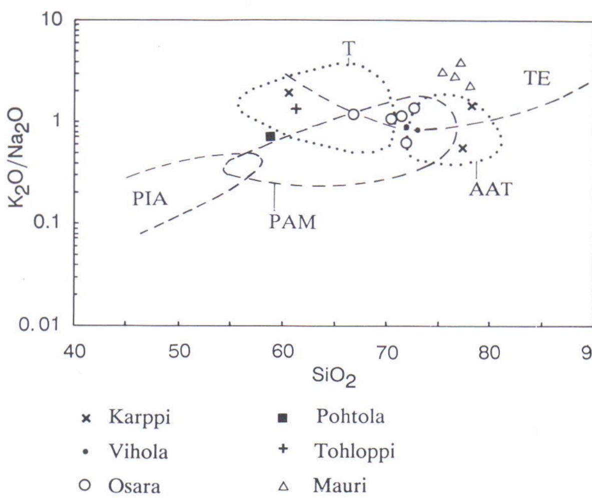

Fig. 10. K_2O/Na_2O vs. SiO_2 diagram of the Tampere graywackes from dispersed localities, and of the Mauri arkoses. Data from Table 2. The PIA, PAM and TE fields from Fig. 6A. AAT gives the field of the Alasenlahti-Ahvenlammi-Talvineva graywackes, and T that of the graywackes of the Tervakivi formation.

COMPOSITION OF THE TSB SEDIMENTARY ROCKS OUTSIDE THE MAJOR PROFILES

The composition of the TSB sedimentary rocks outside the Näsijärvi and Pulesjärvi profiles emphasizes some of the features observed in the major profiles (Fig. 10). See Fig. 1 for the location of these samples.

The volcanic and sedimentary rocks at Tohloppi are considered lateral equivalents of the Kiviranta volcanic and sedimentary rocks but their stratigraphic position is problematic (Kähkönen, this volume). The Tohloppi graywacke is low in SiO_2, high in alkalis and high in P_2O_5. It resembles the Vaarinniemi graywackes more than the other Myllyniemi graywackes but it also has similarities with the Tervakivi graywackes. The Tohloppi mudstone differs from the typical Myllyniemi mudstones due to the high P_2O_5 and Sr contents and the low CIA value. In these respects, it is similar to the mudstones of Tervakivi and Kolunkylä, but has a higher K_2O/Na_2O value.

According to the grade of recrystallization, the Vihola turbidites at Nokia are intermediate between the well-preserved TSB rocks and the migmatites to the south of the TSB. Their stratigraphic correlation is not definite since they lie south of the fault which separates the TSB from the migmatites. In general, the Vihola graywackes are like the Myllyniemi graywackes in chemical composition.

The graywackes of Karppi, in the southern limb of the major syncline at Orivesi, are lateral equivalents of the Myllyniemi formation. The two lower samples are rich in SiO_2 and thus similar to the graywackes at Alasenlahti and Ahvenlammi. The third sample, ca. 100 m above the former in the succession, is low in silica.

The Osara graywackes (p. 119) are stratigraphically above the pillow-basalt bearing Haveri formation (Mäkelä 1980, Kähkönen & Nironen, this volume). They largely resemble the Myllyniemi graywackes, particularly those at Jukonniemi, in chemical composition. However, the Osara sample analyzed for REE deviates from most of the TSB sedimentary rocks due to its relatively high LREE and low Eu/Eu*.

The sedimentary and volcanic rocks at Pohtola are stratigraphically above the Pulesjärvi sedimentary and volcanic rocks. The Pohtola graywacke is low in SiO_2 and resembles the Pulesjärvi graywackes. Since the Pohtola mudstones have high P_2O_5 and Sr contents, low K_2O/Na_2O ratios and low CIA values, they differ from those of the Myllyniemi formation and are like the Tervakivi and Kolunkylä mudstones. The sedimentary rocks at Pohtola confirm the idea that the source areas of the uppermost TSB sedimentary rocks differ from those of the typical Myllyniemi turbidites.

As can be expected, the Mauri arkoses deviate from the TSB graywackes in many respects. They are fairly rich in SiO_2 and Ba, low in Sr and P_2O_5, and the K_2O/Na_2O ratios are high. The differences are attributed partly to the arkosic character and partly to different source areas since clasts of K-feldspar are common and clasts of mafic volcanics are absent in the Mauri arkoses (see also Matisto 1968).

DISCUSSION

Significance of the REE data

In general, three features are essential when discussing the chondrite-normalized REE patterns of siliciclastic sedimentary rocks (e.g. Taylor & McLennan 1985, McLennan & Taylor 1991). (1) Significant enrichment of LREE relative to HREE indicates evolved source areas while flat REE patterns are derived from geochemically primitive sources. (2) Steep REE patterns with HREE depletion are best explained by fractionation of garnet during the genesis of the igneous source rocks. Positively sloping HREE patterns may be due to the abundance of HREE-enriched clastic minerals such as zircon and garnet. (3) Significant Eu depletions in sedimentary rocks were formerly considered a post-Archean phenomenon (Taylor & McLennan 1985). This concept was partly due to sampling bias; the Archean samples came mainly from greenstone belts which largely represent active settings while the post-Archean samples typically were from cratonic areas (e.g., Gibbs et al. 1986). Indeed, the turbidites from Archean greenstone belts tend to be less depleted in Eu than post-Archean turbidites. However, it is also clear that post-Archean siliciclastic sedimentary rocks without prominent Eu depletion are more common than was previously thought, and there are also Archean sedimentary rocks with significant Eu depletions (McLennan & Taylor 1991). As a conclusion, post-Archean turbidites which have both a significant

LREE enrichment and no or minute Eu depletion (Eu/Eu^* more than 0.85) have not been reported frequently. The basic reason of the significant Eu depletions is cratonization and associated intracrustal differentiation since this process includes formation of K-rich granitoids with plagioclase as a residual or fractionating phase.

The Nd isotopes and detrital zircon ages of the TSB turbidites indicate predominantly Paleoproterozoic provenances with minor input from Archean sources (Huhma 1987, Huhma et al. 1991). The considerable LREE enrichments in most of the TSB sedimentary rocks indicate that the bulk sources were fairly evolved. The LREE enrichments might be attributed to the mixing of material from primitive arc(s) with Archean crustal material. However, volcanics of immature arcs have La_N values lower than 50 and average Archean crust has La_N values lower than 80 (Taylor & McLennan 1985, McLennan & Taylor 1991). Although the Archean crust is partly high in LREE (e.g. Hyvärinen 1985, Wang et al. 1990) and although an Archean cobble from the Ahvenlammi member shows a pronounced LREE enrichment (La_N ca. 450, Kähkönen & Huhma 1993), the La_N values typically of ca. 80-120 in the TSB sedimentary rocks cannot be yielded by mixing average Archean crustal material with material from immature Proterozoic arc(s). Therefore, the LREE enrichments of the TSB sedimentary rocks imply fairly evolved Paleoproterozoic source rocks.

The REE patterns of the turbidites of the Alasenlahti, Ahvenlammi and Talvineva members tend to be slightly distinguishable from those of the other TSB sedimentary rocks. Excluding one sample, they have relatively low LREE contents (La_N 25-60). Thus their proportion of evolved material is lower than that which is typical for the TSB sedimentary rocks. Considering the differences in the LREE enrichments in the cobbles from the Ahvenlammi member (Kähkönen & Huhma 1993), the relatively high LREE in sample 1-Ahv/84 may result from heterogeneous sources but the possible role of LREE-rich accessory minerals, e.g. allanite, may also be considered. The three graywackes of the Alasenlahti, Ahvenlammi and Talvineva members are also distinguished in having positive HREE patterns. These slight HREE enrichments might be due to clastic zircon.

McLennan & Taylor (1991) defined Eu depletions as significant when Eu/Eu^* is below 0.85. The Eu/Eu^* values in the TSB sedimentary rocks range from 0.65 to 1.23 but are mostly above or about 0.85 (Table 3). Based on the non-smooth Nd-Tb patterns in some samples, analytical uncertainities are possible. For instance, we infer that the actual $Eu:Eu^*$ value in sample 518-YK/89 is higher than the value given in Table 3. Considering the analytical problems, it is probable that significant Eu depletions are mostly absent in the TSB sedimentary rocks. Note also that the sample analyzed by Wildeman & Haskin (1973) has no Eu anomaly (Fig. 3). The data from the TSB sedimentary rocks indicate that the post-Archean siliciclastic sedimentary rocks, which are characterized both by no or minor Eu depletions and significant LREE enrichments, are more common that has been reported previously.

Because significant Eu depletions are rare in the TSB sedimentary rocks, the bulk of their provenance components were not cratonized, although the LREE enrichments indicate evolved sources. The obvious Eu depletions, particularly in the Osara graywacke (sample 13-A-YK-/86) which also has a strong LREE-enrichment, may be indications of a high proportion of intracrustally differentiated material. The data do not allow a conclusion as to whether the material was Archean or Paleoproterozoic. A certain, though not very wide, variation in the proportion of the Archean component is evident in the TSB sedimentary rocks (Huhma 1987, Welin 1987).

McLennan & Taylor (1991) consider the HREE depletions significant when Gd_N/Yb_N exceeds 2.0. The Gd_N/Yb_N value of 2.0 is equal to the Tb_N/Yb_N value of ca. 1.8. Thus the HREE depletions in the TSB sedimentary rocks are not significant in terms of McLennan & Taylor (1991). However, the Pulesjärvi graywackes have steeper HREE patterns (Tb_N/Yb_N = 1.4-1.7) than the other TSB sedimentary rocks (Tb_N/Yb_N = 0.7-1.4). Based on petrography, high alkali and phosporus contents, and K_2O/Na_2O ratios close to or above unity, the provenance of the Pulesjärvi graywackes was rich in potassic volcanic rocks or shoshonites. The relatively high Tb_N/Yb_N values agree with this interpretation since shoshonitic and potassic volcanic rocks tend to have higher Tb_N/Yb_N values than calc-alkaline volcanic rocks (Francalanci et al. 1989). Furthermore, a part of the volcanic rocks at Pulesjärvi have shoshonitic characteristics (unpublished data of the authors).

Reasons for the compositional differences between the units

The sedimentary rocks at Vaarinniemi, probably low in the succession, bear some compositional resemblances to the Tervakivi and Pulesjärvi sedimentary rocks, which are high in the succession. This might be interpreted to indicate repetition these of strata by overthrusting or by early recumbent folding. However, rocks resembling those of the Alasenlahti, Ahvenlammi and Talvineva members were not observed in the other parts of the profiles studied. It is also difficult to find evidence for structural repetition of this scale in the field (Nironen 1989) or on airborne geophysical maps. Therefore, the Vaarinniemi member most probably belongs to low stratigraphic levels.

The pronounced variation in the composition of the sedimentary rocks in the study profiles indicates that the material was not homogenized due to repeated redeposition. Therefore, a very long bulk transportation on a wide shelf is not probable.

The upward compositional change near Lake Näsijärvi indicates variation in volcanic activity and in the character of the predominant provenance. The lowermost sedimentary rocks (at Vaarinniemi) are derived from a mature arc. Volcanic interbeds are not frequent in the Myllyniemi formation. The proportion of mafic and intermediate shoshonitic volcanic provenances is relatively low in the fairly silicic Alasenlahti, Ahvenlammi and Talvineva graywackes. The sedimentary rocks of these members are mostly lower in LREE, i.e. they are geochemically less evolved than the TSB sedimentary rocks typically. The mudstones have relatively high CIA values. The Alasenlahti and Ahvenlammi graywackes seem to contain more granitoid clasts than the other Myllyniemi graywackes (p.130). Relatively advanced chemical weathering and deep erosion of provenances with a significant component of relatively primitive Paleoproterozoic material is probable. A marked contribution from Archean tonalite-trondhjemite-granodiorite-type sources is not evident since the HREE patterns are flat. Possibly a stage of relative quiescence in volcanic activity resulted in that relatively primitive sources characterize the composition of the Alasenlahti, Ahvenlammi and Talvineva sedimentary rocks.

From the Alasenlahti and Ahvenlammi members to the stratigraphically higher units, the graywackes change to more mafic. Coexistently, the CIA values decrease and the P_2O_5, Sr and La contents increase in the mudstones. These features are attributed to the increase in volcanic activity in the source areas. This activity was first mainly intermediate in composition but the provenance of the units above the Tervakivi formation was rather mafic and also largely shoshonitic. Direct indications of the increase in volcanic activity are provided the pyroclastic rocks of the Pirttiniemi formation and, particularly, the abundance of volcanic rocks at Pulesjärvi and Kolunkylä. The increased volcanic activity resulted in steeper relief, rapid volcaniclastic accumulations and limited chemical weathering, as indicated by the relatively low CIA values in the Tervakivi and Kolunkylä mudstones.

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APPENDIX. Sample description. xx cm indicates thickness of the bed. ø gives the maximum diameters of the clasts in sections approximately perpendicular to elongation. Am = amphibole. Cpx-clasts are now composed of amphibole. x and y give grid coordinates.

NÄSIJÄRVI PROFILE

MYLLYNIEMI FORMATION

Vaarinniemi member
1-B-YK/91. Graywacke. 11 cm, graded. ø to 1x2.2 mm. x 6825.82, y 2490.44.
1-Bm-YK/91. Silty mudstone. 5 cm, immediately above 1-B-YK/91.
4-YK/91. Graywacke. 40 cm, massive. ø to 1x1 mm. x 6825.86, y 2490.45.
46-RWO/82. Graywacke. 12 cm, graded. ø to 1.2x2 mm. x 6825.89, y 2490.42.

Alasenlahti member
10-YK/91. Graywacke. 30 cm, graded. ø to 1x1.5 mm. x 6825.95, y 2490.27.
11-YK/91. Graywacke. 20 cm, graded. ø to 0.8x0.9 mm. x 6825.97, y 2490.30.
1-YKÄ/84. Graywacke. 1.2 m, graded. ø to 0.9x1.6 mm. x 6826.20, y 2490.26.
525-YK/89. Clayey mudstone. Laminated. About 1.5 m above 1-YKÄ/84.
2-YKÄ/84. Graywacke. 1 m, graded. ø to 1.2x1.3 mm. Ca. 7 m above 1-YKÄ/84. x 6826.21, y 2490.27.
501-YKÄ/88. Graywacke. 30 cm Bouma A. ø to 0.8x1.2 mm. x 6826.55, y 2489.78.

Jukonniemi member
502-YKÄ/88. Graywacke. 70 cm Bouma A. ø to 1.5x2.1 mm. x 6826.65, y 2489.65.
503-YKÄ/88. Graywacke. 35 cm Bouma A. ø to 1x1.4 mm. Ca. 4 m above 502-YKÄ/88.
504-YKÄ/88. Graywacke. 2 m, massive. ø to 1x1.6 mm. Ca. 6 m above 503-YKÄ/88. x 6826.66, y 2489.66.
526-a-YK/89. Fine-grained conglomerate. 15 cm thick lense. Matrix-poor. ø to 3x8 mm. x 6826.64, y 2489.72.
524-YK/89. Clayey mudstone. 0.5 m, laminated. x 6826.79, y 2489.63.
531-YK/89. Graywacke. > 70 cm. ø to 1.5x1.5 mm. x 6826.89, y 2489.56.
527-YK/89. Clayey mudstone. Thinly laminated. x 6826.93, y 2489.62.
528-YK/89. Siltstone/fine-grained graywacke. 15 cm. ø to 0.25x0.32 mm. 40 cm above 527-YK/89.
505-YKÄ/88. Graywacke. 14 cm Bouma A. ø to 0.8x0.8 mm. x 6827.02, y 2489.71.
506-YKÄ/88. Graywacke. 35 cm, massive. ø to 0.7x1.6 mm. x 6827.08, y 2489.79.
533-YK/89. Fine-grained graywacke. Tuffaceous. ø mostly to 0.3x0.4 mm, rare clasts to 0.8x1.2 mm. x 6827.21, y 2490.03.
532-YK/89. Felsic tuffaceous mudstone. 10 cm. ø mostly to 0.1x0.15 mm; scarce oversized Pl-clasts to 1x1 mm, possible shards to 0.2x0.8 mm. x 6827.22, y 2490.04.

Kupinniemi member
507-YKÄ/88. Graywacke. 40 cm, massive. ø to 0.5x0.6 mm. x 6827.56, y 2489.82.
508-YKÄ/88. Graywacke. 20 cm. ø to 1x1.1 mm. Mud chips, 2-3%, ø to 0.6x 5 mm. 2 m above 507-YKÄ/88. x 6827.56, 2489.83.
509-YKÄ/88. Graywacke. 20 cm Bouma AB. ø to 0.8x1.5 mm. 5 m above 508-YKÄ/88. x 6827.57, y 2489.85.
534-YK/89. Clayey mudstone. Laminated. 1 m above 509-YKÄ/88. x 6827.57, y 2489.84.

TUULINIEMI FORMATION

535-YK/89. Silty mudstone. 70 cm, massive. ø to 0.2x0.2 mm. x 6829.41, y 2489.49.
537-YK/89. Clayey mudstone. Thinly laminated. x 6829.46, y 2489.47.
540-YK/89. Silty mudstone. Massive, rich in biotite. ø to 0.1x0.15 mm. x 6829. x 6829.51, y 2489.49.

TERVAKIVI FORMATION
541-YK/89. Mudstone. Laminated. x 6830.58, y 2489.77.
511-YK/89. Graywacke. 14 cm, graded. ø to 0.7x1.8 mm. 4 m above 541-YK/89. x 6830.59, y 2489.77.
513-YK/89. Graywacke. 1.4 m, massive. ø to 0.8x1.3 mm. 7.3 m above 511-YK/89. x 6830.60, y 2489.77.
514-YK/89. Graywacke. 60 cm, massive. ø to 0.5x1.6 mm. 4.5 m above 513-YK/89.
515-YK/89. Graywacke. 13 cm Bouma A. ø to 0.5x3 mm. x 6830.64, y 2489.81.
517-YK/89. Graywacke. 11 cm Bouma A. ø to 0.6x0.7 mm. 10.7 m above 515-YK/89. x 6830.65, y 2489.81.
518-YK/89. Graywacke. 35 cm, massive. ø to 0.6x1 mm. 4.1 m above 517-YK/89. x 6830.65, y 2489.82.
519-YK/89. Graywacke. 50 cm, massive. ø to 0.7x1.3 mm. 6.3 m above 518-YK/89. x 6830.66, y 2489.82.
520-YK/89. Graywacke. 80 cm Bouma AB. ø to 0.8x1.5 mm. Am-bearing. x 6830.70, y 2490.00.

KOLUNKYLÄ

2-Kisala/89. Mudstone. Laminated. 6831.54, y 2491.05.
1-Kisala/89. Mudstone. About 6 m above 2-Kisala/89.

PULESJÄRVI PROFILE

VIINARÄNNINNOTKO

Two samples from interbeds in a minor conglomerate:
14-Ahv/85. Graywacke. 20 cm. ø to 0.5x2 mm. x 6831.49, y 2502.97.
16-Ahv/85. Graywacke. ø to 0.8x1.1 mm. x 6831.48, y 2502.95.

MYLLYNIEMI FORMATION

Ahvenlammi member
1-Ahv/84. Graywacke. 5 cm, graded. ø to 0.9x5.5 mm. x 6831.56, y 2502.80.
Four samples from a 2 m thick graded conglomerate-graywacke; x 6831.58, y 2502.76:
21-Ahv/85. Conglomerate. 0.1 m above the base. ø to 7x17 mm.
22-Ahv/85. Conglomerate/coarse-grained graywacke. 0.55 m above the base. ø to 3x3.5 mm.
23-Ahv/85. Coarse-grained graywacke. 1 m above the base. ø to 1.5x3.7 mm.
24-Ahv/85. Graywacke. 1.5 m above the base. ø to 1.2x3 mm.
Tre 53. Graywacke. > 2 m. Massive. ø to 0.5 mm. x 6832.09, y 2503.31.

Talvineva member
Four samples from a 3 m thick Bouma AB unit; x 6832.36, y 503.26:
Tre 59. Coarse-grained graywacke. ø to 4 mm.
Tre 60. Graywacke. 0.4 m above the former. ø to 0.9x1.8 mm.
Tre 61. Graywacke. 2.2 m above the former. ø to 0.7x1.3 mm.
Tre 62. Silty mudstone.

Pynnölänkangas member
Four samples from a single outcrop; x 6832.04, y 2503.06:
Tre 77H. Graywacke. 2.5 cm, graded.
Tre 77S. Mudstone + fine-grained graywacke.
Tre 76H (stratified graywacke, ø to 1x1.2 mm) and Tre 76S (graded mudstone) from a 3 cm thick graded unit ca. 10 cm above Tre 77S.

MULTIVUORI

Tre 82. Fine-grained graywacke + mudstone. Laminated. 1 mm wide quartz-vein. x 6833.22, y 2502.61.
51-JEL/86. Silty mudstone/fine-grained graywacke. Massive. x 6833.25, y 2502.65.
Tre 85. Felsic tuffaceous mudstone. x 6833.33, y 2502.53.

TERVAKIVI FORMATION at Puolamäki

Tre 103. Graywacke. 5 cm, Bouma A. ø to 0.4x0.5 mm. x 6833.73, y 2502.12.
79-IV-JEL/86. Graywacke. 30 cm, graded. ø to 0.7x0.9 mm. x 6834.05, y 2502.16.
80-IIIA-JEL/86. Graywacke. 10 cm, graded. ø to 0.6x1.2 mm. x 6834.08, y 2502.16.
80-IIIB-JEL/86. Graywacke. > 1 m. ø to 0.9x1.8 mm. x 6834.08, y 2502.16.
80-V-JEL/86. Graywacke. > 25 cm, massive. ø to 0.6x1.4 mm. x 6834.08, y 2502.16.
81-JEL/86. Graywacke. Am-bearing. ø to 0.8x1.4 mm. x 6834.09, y 2502.11.
Tre-112. Graywacke. 26 cm. Am-bearing, few Cpx-clasts. ø to 0.7x2.0 mm. x 6833.74, y 2502.15.

PULESJÄRVI GRAYWACKES

Tre 149. Graywacke. Tuffaceous, stratified, rich in Cpx-clasts. ø to 2x2 mm. x 6834.23, y 2501.31.
Tre 149B. Graywacke. Tuffaceous, stratified, rich in Cpx-clasts. x 6834.23, y 2501.31.
Tre 192. Coarse-grained graywacke. Tuffaceous, stratified, rich in Cpx-clasts. ø to 2x3.5 mm. x 6834.80, y 2501.47.
Tre 217. Coarse-grained graywacke. Tuffaceous, stratified, rich in Cpx-clasts. ø to 2x3.5 mm. x 6835.37, y 2501.33.
Tre 262. Coarse-grained graywacke. Tuffaceous, stratified. Am-bearing. x 6835.69, y 2501.37.
Tre 266. Coarse-grained graywacke. Tuffaceous, stratified, rich in Cpx-clasts. x 6835.82, y 2501.30.

SAMPLES OUTSIDE THE STUDY PROFILES

Pohtola
Tre 350. Graywacke. 6 cm, graded. Am-bearing. x 6838.54, y 2499.85.
Tre 351. Mudstone. x 6838.44, y 2499.83.
Tre 352. Silty mudstone. Pronounced deformation. x 6837.52, y 2499.59.

Vihola, Nokia.
61-A-RWO/82. Graywacke. 1 m, graded. ø to 1.6x2.3 mm. x 6817.9, y 2474.5.
2-Vihola/84. Graywacke. 5x20 cm coarse-grained lense below a graded graywacke. ø to 2.5x4 mm. x and y as in the former.

Karppi
Two samples from a stratum > 1 m thick; x 6836.55, y 2516.94:
1-Karp/84. Coarse-grained graywacke. ø to 1.2x5.3 mm.
2-Karp/84. Coarse-grained graywacke. ø to 2x4.5 mm.
4-YKÄ/86. Graywacke. Tuffaceous. 25 cm, graded. ø to 1.3x2 mm. x 6836.61, y 2517.27.

Osara formation
11-YKÄ/86. Graywacke. From the upper part of a 2-3 m thick stratum. ø to 0.7x1.2 mm. One 1x5 mm clast rich in apatite. x 6844.00, y 2458.14.
12-B-YKÄ/86. Graywacke. Graded. ø to 0.9x1.1 mm. x 6844.40, y 2457.86.
13-A-YKÄ/86. Graywacke. 40 cm , graded. ø to 2.1x3 mm. x 6844.74, y 2456.78.
13-B-YKÄ/86. Graywacke. 20 cm above 13-A-YKÄ/86, same stratum. ø to 0.5x1 mm.
13-C-YKÄ/86. Graywacke. 50 cm bed below the two former. ø to 1x1.5 mm.

Tohloppi
18-YKÄ/83. Graywacke. 5 cm, graded. ø to 1x2 mm. Pl-clasts and fine-grained rock fragments dominate, one Qtz-clast. Underlies the Tohloppi conglomerates. x 6821.90, y 2481.40.
5-3-YKÄ/83. Mudstone. Faintly stratified. Overlies the lower Tohloppi conglomerate but underlies the Tohloppi Pl+Ur-phyric lava. x 6822.20, y 2479.88.

Mauri arkose, x 6818.7, y 2461.0.
10-A-YKÄ/86. Cross-bedded pebbly sandstone. 20 cm.
10-B-YKÄ/86. Sandstone from the same stratum as the former.
10-C-YKÄ/86. Pebble-bearing sandstone. 0.5 m below 10-B-YKÄ/86.