The geochemistry of Lower Proterozoic siliciclastic turbidites from the Rombak Window: implications for palaeogeography and tectonic settings

EDWARD W. SAWYER & ARE KORNELIUSSEN

Lower Proterozoic metamorphosed, siliciclastic turbidites at Rombaksbotn and Gautelis in the western part of the Rombak Window have a high sand/clay ratio, whereas those from Ruvssot in the east have a larger silt- and clay-size component. The source rocks to the turbidites experien-ced little chemical weathering, and the presence of unweathered feldspar in the clay-sized fraction of the Gautelis and Rombaksbotn turbidites suggests either a contribution of material directly from volcanic eruptions or weathering in a cold climate. The presence of thin calc-alkali volcanic layers in the turbidites at Gautelis and Rombaksbotn favours the volcanic source.

The Gautelis and Rombaksbotn bulk sediments contain both a large component of material derived from a high K_2O calc-alkaline intermediate to felsic volcanic suite (SN volcanites), and a small component (<5%) chromite-bearing ultramafics. However, the characteristic smooth REE patterns of the Gautelis turbidites (and their lower K_2O and Rb contents) indicate an additional component of material derived from a tonalitic source, similar to that exposed near Gautelisvatnet and believed to be the basement to the supracrustals. The large component of SN volcanites is consistent with formation of the Rombaksbotn and Gautelis turbidites in an active marginal basin adjacent to a mature volcanic arc. In the case of the Gautelis turbidites the associated volcanic arc formed on continental crust, and an active continental margin setting of Andean-type is proposed.

The geochemical signature of the Ruvssot turbidites indicates that they formed in a basin that received material from mafic to intermediate sources, but not from evolved felsic volcanic or conti-nental sources. An intra-oceanic setting near to primitive calc-alkaline volcanism is therefore sugge-sted for the Ruvssot turbidite basin.

Compositional fractionation due to sorting in the graded turbidite beds is considerable. The Rombaksbotn and Gautelis pelites are enriched in a variety of major and trace elements and the HREE relative to the greywackes, similar, though less pronounced features are seen in the Ruvs-sot turbidites.

E.W. Sawyer, Sciences de la Terre, Université du Québec à Chicoutimi, Chicoutimi, Québec G7H 2B1, Canada.
A. Korneliussen, Norges geologiske undersøkelse, P.O.Box 3006-Lade, N-7002 Trondheim, Norway.

Introduction

The composition of any particular clastic sedi-ment can, in general, be related to the cumula-tive effect of four principal factors:

1) Bulk composition of the provenance area; this is determined by the rock types present and their relative abundances.

2) The degree of chemical weathering that occurred in the provenance area, including weathering during sediment transport.

3) Sedimentary processes occurring during sediment transport and deposition.

4) Post-depositional modification by element redistribution during diagenesis, metamor-phism or deformation.

Thus, in order to use the compositions of ancient clastic sediments to infer the characte-ristics of provenance, areas, such as their tectonic setting (Bhatia 1983, Bhatia & Crook 1986), or the rock types present (Jenner et al. 1981), the compositional variations due to the other three factors must be considered, as pointed out by Bhatia (1983), Reimer (1985, 1986), Sawyer (1986a) and Argast & Donnelly (1987).

Some degree of chemical weathering is to be expected in all clastic sediments as weath-ering is the principal means of rock disaggrega-tion. However, there are some exceptions

such as island arc volcaniclastics where vol-
canic fragmentation has a dominant role (Crook
pers comm, 1988). Nesbitt et al. (1980) have
shown that the relative degree of chemical
weathering between samples can be estimated
because of the chemical fractionation between
certain elements (e.g. CaO and K_2O) increases
with the degree of weathering. Similarly, by
sampling all the grain-size fractions in their
correct abundances, and by using sediment
types that have not been extensively rework-
ed, the modification to the bulk composition
of disintegration products due to sedimentary
processes can be recognised (Sullwold 1961,
Reimer 1985, Sawyer 1986a). The post-deposi-
tional redistribution of elements is, however,
more difficult to assess, but by sampling to
exclude clearly altered rocks from near ore
deposits, fractures and shear zones, and by
considering the less mobile elements such as
TiO_2, Al_2O_3, REE, Th, Zr, Y, Sc and Cr, the
problem may be lessened (Nesbitt 1979, Rei-
mer 1986, Sawyer 1986a, Bhatia & Crook
1986). Argast & Donelly (1987) compared the
compositions of North American Palaeozoic
turbidites with unlithified turbidites from the
Black Sea, and concluded that little, if any,
major element mobility occurred during tur-
bidite diagenesis.

The purpose of this study is to use the
geochemistry of Lower Proterozoic metatur-
bidites from three localities to investigate the
Early Proterozoic geological evolution of the
Rombak Window in northern Norway (Fig. 1).
However, before the contribution of source
rock types to the sedimentary detritus is evalu-
ated, the effects of other processes on sedi-
ment composition, most notably chemical
weathering and sediment transport/deposition,
are considered. The composition of the tur-
bidites is then compared to the possible sour-
ce rocks found in the Rombak Window, and
differences between the three turbidite sequen-
ces discussed in terms of their tectonic and
geographic settings during the Early Proterozo-
ic.

Geological Setting

The Rombak Window is a slightly elongated
culmination of Lower Proterozoic rocks that
are exposed within the Caledonian Nappe
sequence 20 km southeast of Narvik (Fig. 1).
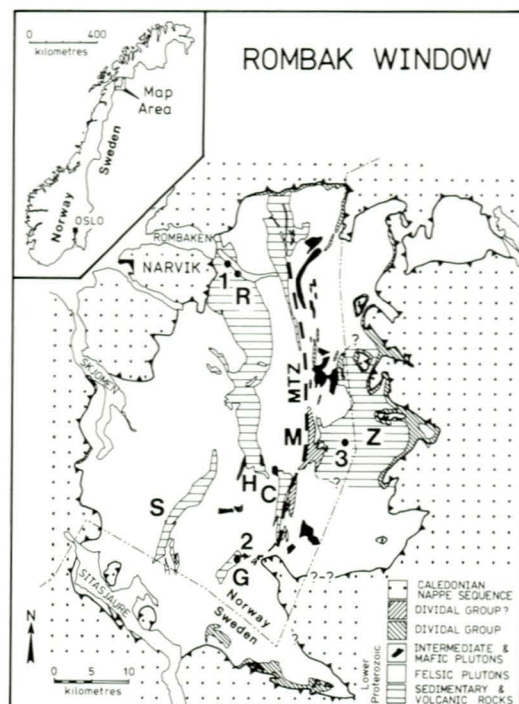Much of the window consists of large plutons

Fig. 1. Geological map of the Rombak Window, in part
after Birkeland (1976) with modifications based on the pre-
sent writers' field mapping. Sample locations of the Rom-
bak turbidites: (1) Rombaksbotn, (2) Gautelis, and (3) Ruvs-
sot. Other locations mentioned in the text: C - Cainhajavrre,
G - Gautelis, H - Stasjonsholmen, M - Muohtaguobla, R -
Rombaksbotn, S - Sørdalen, Z - Sjangeli. The dashed line
labelled MTZ marks the western limit of the Muohtaguobla
Tectonic Zone.

of coarse-grained granite and syenite that intru-
ded older volcanosedimentary rocks at 1.78Ga
(Rb-Sr method, Gunner 1981). Only relatively
small north-south oriented remnants of the
volcanosedimentary sequences are preserved.
The Lower Proterozoic rocks are locally overla-
in by a thin autochthonous sequence of Late
Proterozoic to Early Cambrian sediments cal-
led the Dividalen Group (Birkeland 1976). The
Lower Proterozoic rocks together with their
Dividalen Group cover were subsequently over-
ridden by Caledonien nappes at about 400Ma.

At present, correlation of the Lower Protero-
zoic supracrustal sequences within the Rom-
bak Window and with the adjacent parts of
Norway and Sweden is restricted by the lack
of reliable age dates. The sedimentary and
volcanic rocks of the Ruvssot-Sjangeli area in

the east of the window, for which Romer (1987) has obtained and Rb-Sr date of 2.3Ga, have compositions that are markedly different from those in the west (this paper; Kornelius-sen & Sawyer, this volume). The volcanic rocks in the western part of the Rombak Window have geochemical similarities with the 1.91-1.88 Ga volcanic rocks of northern Sweden reported by Frietsch & Perdahl (1987). Unfortunately the contact relationship between the two geochemically distinct supracrustal sequences in the Rombak Window is obscured by a major N-S tectonic zone between Muohtaguobla and Ruvssot (MTZ, Fig. 1).

Volumetrically the two most important constituents of the supracrustal sequences of the Rombak window are siliciclastic turbidites and volcanic rocks. Generally the turbidites and the volcanic rocks occur in distinct domains separated by the later plutons, but at Rombaksbotn and Gautelisvatnet volcanic and tuffite layers are present in the turbidites. In the areas where volcanic rocks predominate (e.g. Sørdalen) volcaniclastics and conglomerate/debris flows are interbedded with lavas.

Field and petrographic relations of the turbidite sequences

Rombaksbotn area

Lower Proterozoic metasedimentary rocks are well exposed along the south side of Rombaksbotn (Fig. 1). In the west they are overthrust by Caledonian nappes, but to the east they are interbedded with, and grade into, a volcanic sequence of intermediate to acidic composition. Beds are typically 2 cm to 1 m thick and are right way up (i.e. they young to the west) and dip steeply to the west or northwest. The metasediments sampled are metagreywackes and metapelites that commonly exhibit graded bedding and, in places, preserve structures chartacteristic of Bouma sequences found in turbidites. Small scours at the base of the coarsest beds are present in some outcrops. Several thin, bluish-green, calc-silicate beds are also present in the metagreywacke-pelite sequence, but are volumetrically minor (<0.5%).

The original mineralogy and textures of the sediments have been severely modified by metamorphism, and to a lesser extent by pene-trative deformation. In the metagreywackes the maximum grain-size is about 4mm, although 0.5mm is typical; generally the largest grains consist of quartz or plagioclase of equant or slightly elongate form. A schistosity is present in all the samples examined and is of the domainal type. Grain-size in the pelites is comparatively uniform, and the schistosity penetrative and planar. A few of the Rombaksbotn samples contain the greenschist-facies minerals chlorite, quartz and muscovite, but because these phases have not been observed to be in mutual contact they are not regarded as diagnostic of metamorphic grade. Plagioclase compositions in the metagreywackes and metapelites are in the range An_{18} to An_{25}. Metamorphism took place at lower amphibolite facies conditions since the interbedded calc-silicate layers contain the assemblage:

calcite + quartz + diopside + clinozoisite + hornblende.

Chemical compositions of the metagreywackes and metapelites are presented in Table 1 and details of the analytical methods used is given in Appendix I. An estimate of the bulk chemical composition of the turbidite sequences is given in Table 2, and is based on the field observation that they contain about 80% metagreywacke and 20% metapelite. Samples ES68 and ES69 represent the two extremes of composition resulting from the depositional process.

Gautelis area

Well-bedded, graded metagreywackes and metapelites are exposed at the northern end of Gautelisvatnet. It is thought that the Gautelis metasediments (Fig. 1) rest unconformably on a tonalitic basement and its overlying cover sequence of dolomitic carbonates, but shear zones in the area preclude a clear interpretation of the contact relationships. The clastic rocks are thin- to thick-bedded, graded units that contain remnants of Bouma sequence structures, hence they are interpreted as turbidites. Dips are generally steep and to the west or northwest, but younging directions are to the east; thus the beds are inverted, at least locally. The foliation in the metasediments dips steeply to the west-northwest. Several thin conglomeratic layers are present and contain predominantly tonalitic clasts.

The principal minerals in both the metagreywackes and metapelites — quartz, plagioclase

Table 1. Analyses of greywackes (g) and pelites (p) from the Rombak Window

	GAUTELIS					ROMBAKSBOTN			ROMBAKSBOTN				RUVSSOT		
	ES57g	ES58g	ES60p	ES61p	ES67g	ES68g	ES69p	ES70p	ES72g	ES73g	ES71*	ES131p	ES132g	ES133g	ES134g
SiO_2	72.25	70.57	57.17	54.70	66.15	69.40	53.17	60.12	69.08	68.37	54.88	51.85	55.04	58.47	58.37
TiO_2	0.74	0.65	0.92	1.00	0.75	0.70	0.84	0.75	0.62	0.88	0.45	1.27	0.85	0.90	0.88
Al_2O_3	11.84	12.59	16.60	17.74	14.08	13.23	18.08	16.07	13.69	12.78	12.21	13.39	13.97	14.55	14.61
Fe_2O_3	6.38	5.80	9.15	10.27	6.95	6.26	10.40	7.97	5.73	7.05	4.83	12.82	11.09	9.63	9.74
MnO	0.06	0.06	0.09	0.09	0.06	0.05	0.08	0.07	0.05	0.07	0.58	0.13	0.09	0.08	0.09
MgO	2.36	2.42	4.22	4.65	3.27	3.01	5.33	4.20	2.78	3.08	2.43	8.67	6.75	5.65	4.61
CaO	2.71	2.78	2.75	2.86	1.44	1.07	2.40	1.06	2.31	1.85	20.66	6.00	1.58	1.99	2.86
Na_2O	2.30	2.50	3.20	3.60	3.00	3.50	3.40	3.60	2.90	bd	bd	2.97	2.55	3.57	2.71
K_2O	1.82	1.86	3.41	1.90	2.70	2.44	4.17	3.73	2.27	2.59	bd	1.80	5.27	4.36	4.79
P_2O_5	0.13	0.06	0.12	0.12	0.13	0.12	0.13	0.11	0.11	0.15	0.17	0.12	0.15	0.13	0.13
LOI	0.71	0.79	1.25	1.27	1.04	0.86	1.54	1.36	0.70	0.72	4.57	0.78	1.18	0.70	0.91
TOTAL	101.30	100.15	98.88	102.20	99.57	100.64	99.54	99.04	100.44	100.44	100.78	99.81	99.52	100.04	99.69
V	139	118	229	273	144	131	198	158	112	155	67	254	141	128	132
Cr	262	187	230	255	245	301	212	210	215	387	138	503	332	279	228
Sc	12	12	23	23	15	14	24	21	14	13	21	37	22	21	23
Zn	111	111	188	144	103	82	147	123	86	91	68	132	62	47	48
Ni	45	54	113	135	75	72	124	82	67	63	48	211	139	109	98
Cu	84	51	bd	5	6	11	109	18	59	35	32	84	67	76	12
Co	14	13	28	23	20	19	35	19	18	21	10	46	39	30	32
La	36.0	25.0	30	22.3	52	33.1	28.7	16.4	28.0	61	27	10.8	23.9	20	27.3
Ce	73.9	52.0	54	53.6	91	77.3	62.4	36.7	59.3	109	46	26.0	50.8	50	57.8
Nd	24.8	22.4	-	15.0	-	28.0	23.9	10.0	22.8	-	-	12.0	19.0	-	24.0
Sm	5.30	4.42	-	4.18	-	4.91	4.82	2.64	4.34	-	-	3.20	3.60	-	4.12
Eu	1.00	0.92	-	1.00	-	0.92	0.93	0.69	0.90	-	-	1.00	0.86	-	1.00
Tb	0.87	0.80	-	0.67	-	0.57	0.53	0.51	0.40	-	-	0.70	0.54	-	0.52
Yb	2.21	1.62	-	2.57	-	1.91	2.07	2.32	1.85	-	-	2.37	1.49	-	1.67
Lu	0.31	0.29	-	0.44	-	0.29	0.34	0.39	0.34	-	-	0.44	0.37	-	0.30
Y	20	18	26	24	24	25	18	22	15	30	33	28	19	16	18
Zr	252	167	141	132	173	201	106	134	147	297	127	103	112	114	125
Hf	5.75	3.98	-	3.32	-	5.10	2.20	3.24	3.37	-	-	2.30	2.86	-	3.13
Nb	8	9	12	14	12	11	17	11	8	11	10	9	7	9	8
Ta	0.74	0.70	-	1.01	-	0.84	0.99	0.99	0.85	-	-	0.47	0.75	-	0.85
Ba	773	622	956	995	704	873	598	876	697	775	bd	785	660	429	726
Cs	2.5	2.9	-	4.0	-	5.3	13.7	12.1	7.0	-	-	5.6	8.1	-	8.5
Rb	75	77	133	125	110	88	205	151	105	102	bd	66	190	161	191
Sr	231	246	283	251	149	173	227	155	247	168	205	157	118	153	112
Th	9.8	7.6	bd	5.9	bd	10.7	10.7	10.4	8.1	17	bd	2.6	9.8	5	10.3
U	3.2	2.7	bd	4.0	bd	2.8	3.11	2.7	2.5	bd	bd	1.4	1.9	3	2.4
Pb	25	28	32	22	22	23	32	21	19	24	bd	13	9	10	12
CIA	52.6	53.0	54.3	53.6	57.3	56.1	55.6	57.5	53.8	53.9	-	43.0	52.3	50.6	49.6
Eu/Eu*	0.58	0.62	-	0.74	-	0.65	0.68	0.76	0.77	-	0.88	0.76	-	-	0.82
Qtz	44.3			15.4		35.6	10.9								
Plag	33.7			45.3		37.1	41.9								
Bte	21.1			42.9		27.0	46.4								

Legend: - =not determined; bd=below detection level.

(An$_{18}$ to An$_{30}$) and biotite — are not diagnostic of metamorphic grade. However, a metamorphosed mafic dyke in the turbidites contains the amphibolite-facies assemblage:

biotite + epidote + ilmenite + plagioclase (An$_{30-55}$) + diopside + hornblende.

Field estimates indicate that, like the Rombaksbotn turbidites, about 80% of the clastic material is metagreywacke and 20% metapelite. Thus, although samples ES57 and ES61 represent the extremes of composition observed (Table 1), the bulk sediment composition lies close to the metagreywackes with about 68% SiO$_2$ (Table 2).

Ruvssot area

Siliciclastic rocks are part of a supracrustal succession that is exposed on the south side of Ruvssot. Generally, the siliciclastic rocks are pervasively foliated, but locally graded bedding and structures of the Bouma sequen-

ce are preserved, from which deposition by turbidity currents is inferred. Minor, thin, blue-green, calc-silicate bands are present in the turbidites, but are usually disrupted into trains of boudins.

Two types of mineral assemblage occur in the Ruvssot turbidites. In the coarsest-grained and lightest-coloured metagreywackes the principal phases are:

ilmenite + biotite + quartz + plagioclase (An$_{30-40}$).

In contrast some darker metagreywackes, and most of the metapelites, contain the more complex amphibolite-facies assemblage:

epidote + ilmenite + hornblende + quartz + biotite + plagioclase (An$_{30-40}$).

The bulk composition of the amphibole-bearing rocks is Al$_2$O$_3$- and K$_2$O-depleted, but CaO-enriched relative to the amphibole-free assemblages.

Field observations indicate that the lighter-coloured, least mica-rich parts of the turbidites

Table 2. Estimates of bulk sediment compositions for
Gautelis (1), Rombaksbotn (2) and Ruvssot (3) turbidites.

	1	2	3
SiO$_2$	68.32	65.23	56.19
TiO$_2$	0.75	0.76	0.97
Al$_2$O$_3$	13.21	14.38	14.13
Fe$_2$O$_3$	6.81	7.28	10.82
MnO	0.07	0.06	0.10
MgO	2.80	3.50	6.42
CaO	2.76	1.82	3.11
Na$_2$O	2.60	3.18	2.95
K$_2$O	2.20	2.83	4.06
P$_2$O$_5$	0.10	0.13	0.13
LOI	0.85	0.97	0.89
TOTAL	100.47	100.14	99.77
V	154	148	164
Cr	230	272	336
Sc	15	16	26
Zn	122	102	72
Ni	65	80	139
Cu		44	60
Co	17	23	37
La	28.9	39.3	20.5
Ce	60.3	77.3	46.2
Nd	22.7		18.3
Sm	4.72		3.64
Eu	0.97		0.95
Tb	0.81		0.59
Yb	2.05		1.84
Lu	0.33		0.37
Y	20	22	20
Zr	195	185	114
Hf	4.56	3.83	2.76
Nb	10	12	8
Ta	0.78	0.88	0.69
Ba	754	729	650
Cs	3.0	7.7	7.4
Rb	87	122	152
Sr	249	193	135
Th	8.9	11.7	6.9
U	3.2	2.8	2.2
Pb	27	24	11
CIA	53.1	55.3	48.7

No estimates of the Nd, Sm, Eu, Tb, Yb and Lu contents in
the Rombaksbotn bulk sediment are made because samples ES67 and
ES73 (for which these REE were not determined) have much higher
La and Ce contents than the samples for which the REE were
determined.

predominate over the finer-grained and more micaceous parts. Unfortunately the scattered outcrops and degree of deformation (the change in relative proportion between mica-rich and mica-poor units during deformation is discussed by Sawyer & Robin 1986) precludes an accurate estimate of the relative abundance of metapelitic and metagreywacke material, although the coarse material predominates. Samples ES133 and ES131 (Table 1) represent the extremes of grain-size, colour and mica content observed in the field. The bulk chemical composition of the sediment is estimated by a simple average (Table 2), but is similar to the dominant rock type, ES 132.

Interpretation of the geochemistry of the Rombak turbidites

In a simplistic model the provenance area bulk composition is the starting composition from which the composition of clastic sediments diverge through the action of various processes. Firstly, the provenance area bulk composition is modified by the process of chemical weathering, which breaks the source rocks down to a detritus consisting of a mixture of clay weathering products and unweathered grains (quartz, feldspar, etc.). Secondly, during sediment transport and deposition a further modification takes place because the coarse- and fine-grained material have different hydraulic properties. Thirdly, there is the preferential preservation of grains that are mechanically resistant to abrasion; quartz and zircon, for example.

The effect of chemical weathering

Because the constituent elements of a rock undergoing chemical weathering are not equally accommodated in the clay weathering products, a chemical fractionation occurs during weathering. Those elements not accommodated in the weathering products are lost to the weathering solutions (Nesbitt et al. 1980). Thus, it follows that the more intense the chemical weathering, the greater is the difference between provenance area bulk composition and the composition of the detritus derived from it. Since feldspars are the dominant labile mineral type in the earth's crust, Nesbitt & Young (1982) have argued that the main effect of chemical weathering is the breakdown of feldspar to clay. Therefore, the ratio of the least easily removed element in feldspar (i.e. Al) to the more easily mobilized elements (i.e. Ca. Na and K) provides a measure of chemical weathering. Nesbitt & Young (1982) proposed a chemical index of alteration (CIA) based on the molecular proportions of the major oxides:

CIA = Al$_2$O$_3$ / (Al$_2$O$_3$ + CaO* + Na$_2$O + K$_2$O) / 100 where CaO* represents CaO in the silicate phases only.

The CIA values for the Rombak clastic sediments (Table 1) range between 43 and 58, and are comparable to the CIA values obtained from unweathered feldspar and igneous rocks (feldspar 50; basalts 40; granites 45-55). It is concluded that the detritus from which the Rombak clastic sediments were derived had undergone little chemical weathering. Low CIA values could be due to rapid erosion and deposition preventing extensive chemical weathering, or they could also result from erosion in a cold (Nesbitt & Young 1982) and/or arid

climate. Table 2 shows that the CIA value for the Rombaksbotn bulk sediment (55.3) is slightly higher than that for the Gautelis detritus (53.1); this may indicate a greater degree of chemical weathering for the Rombaksbotn detritus, as also indicated by a higher illite content (Fig. 2A).

The Ruvssot samples are enriched in K_2O (Fig. 2A) and Rb relative to their Al_2O_3 contents when compared to the other turbidites; this could be due to either an additional K-rich detrital phase, or to the introduction of K_2O and Rb. A K_2O-rich detrital mineral would imply an acidic source area, which is not supported by the SiO_2, Hf, Zr, and MgO contents of the turbidites. The metasomatic introduction of K_2O and Rb during regional metamorphism seems unlikely since nearby marbles and basic rocks are not affected. An alternative, and perhaps more likely explanation for the K_2O and Rb enrichment is the introduction of a phillipsite cement, or the replacement of volcanic glass fragments by phillipsite, during early diagenesis on the sea floor. Thus, the lower CIA values of the Ruvssot samples when compared to either the Gautelis or the Rombaksbotn turbidites (Tables 1 & 2) may be due to diagenetic effects, or a more mafic source, rather than to a lower degree of chemical weathering.

The effect of sorting

Sorting selects material by grain-size, but for any chemical fractionation to occur there must also be a sorting by phase. If detritus contains a complete range of grain-size for each phase present, then it is possible that no chemical differences develop when grain-size sorting occurs. However, if certain elements are enriched in a particular size fraction (e.g., Al_2O_3, Fe_2O_3, MgO, K_2O, Sc, HREE in clays, or SiO_2, CaO and Na_2O in coarse quartz and plagioclase), then a chemical fractionation will occur during grain-size sorting.

For the Rombak turbidites the effects of grain-size sorting are most clearly seen in the Gautelis and Rombaksbotn samples. Comparing the coarse-grained base of graded units with the fine-grained top, it can be seen (compare ES57 with ES61 and ES68 with ES69, Table 1) that the metapelites are enriched in TiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, P_2O_5, Rb, Nb, V, Sc, Co, Ni, Zn and the HREE (Fig. 3) relative to the metagreywackes. With the exception
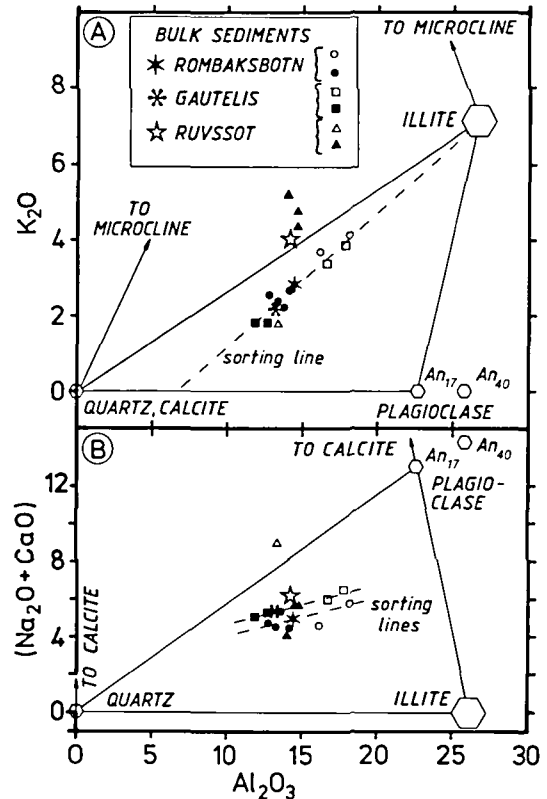

Fig. 2. Feldspar and clay components in the Early Proterozoic clastic turbidites of the Rombak Window. (A) Al_2O_3 versus K_2O; the difference in K_2O contents between the pelites and greywackes from Rombaksbotn and Gautelis can be related to illite separation along the sorting trend (dashed line). The Ruvssot samples may have contained detrital K-feldspar. (B) Al_2O_3 versus ($CaO+Na_2O$); for the Rombaksbotn and Gautelis samples the sorting trends (dashed lines) show that quartz, plagioclase and illite are affected by sorting. Note that quartz tends to occur in the coarser-grained size fraction, but that plagioclase and illite occur in the fine-grained fraction. Symbols: circles - Rombaksbotn, squares - Gautelis, triangles - Ruvssot, open symbols indicate fine-grained rocks (pelites) and closed symbols indicate coarse-grained samples (greywackes).

of P_2O_5 and Nb, metapelites are enriched in the elements found in, or adsorbed on, clays derived from chemical weathering. Metagreywackes are enriched in SiO_2, LREE (Fig. 3), Zr, Hf, and Cr relative to pelites. With the exception of the LREE, these elements probably reflect the preferential preservation of mechanically resistant quartz and zircon and dense chromite grains in the metagreywacke portion of graded beds.

Figure 2A shows that the metapelites and metagreywackes from Rombaksbotn and Gautelis lie on a trend away from the illite apex. Thus, the difference in K₂O contents between the coarse- and fine-grained portions of graded beds from Rombaksbotn and Gautelis is due to the concentration of illite into the pelitic part during sorting of the bulk sediment. However, the elements associated with plagioclase show an interesting relationship. Both CaO and Sr have similar abundances in the coarse-grained and fine-grained fractions of the Rombaksbotn and Gautelis turbidites. In the Gautelis clastics Na₂O is actually enriched in the metapelites, but has comparable levels in both the Rombaksbotn metapelites and the metagreywackes. Furthermore, the total feldspar content of the metapelitic portions of the graded beds from Gautelis and Rombaksbotn is greater than in the metagreywacke portions (Table 1). This is contrary to the normal relationship (Blatt 1985) where pelitic rocks have lower feldspar contents than greywackes (e.g. the Archaean Quetico metaturbidites, Sawyer 1986a fig. 2).

Because neither CaO, Na₂O nor Sr are accommodated in the clays resulting from chemical weathering they are removed in the weathering solutions (Nesbitt et al. 1980). Thus, rocks with a large proportion of weathered material (i.e. clay-rich pelites) should be Na₂O, CaO and Sr depleted relative to rocks containing a large proportion of unweathered material (i.e. greywackes). The metagreywacke-bulk sediment-metapelite sorting lines in Fig. 2B show that all three components are affected by sorting; quartz is enriched in the metagreywackes, but illite and plagioclase are enriched in the metapelites. Quartz must, therefore, occur mainly in the coarse grain-size fraction, but a large proportion of the plagioclase is present in the same size fraction as illite (i.e. clay-sized). Therefore, it is concluded that the Rombaksbotn and Gautelis bulk sediment contained a large proportion of clay-sized, unweathered feldspar in addition to clay produced by the chemical weathering of feldspar. Fine-grained unweathered feldspar implies a mechanical disaggregation process, two possibilities are explosive volcanic eruptions near to the sedimentary basin, or that erosion in the provenance area took place in a cold climate. An alternative explanation that the high modal plagioclase contents in the metapelites may result from zeolitic alteration of silt-sized
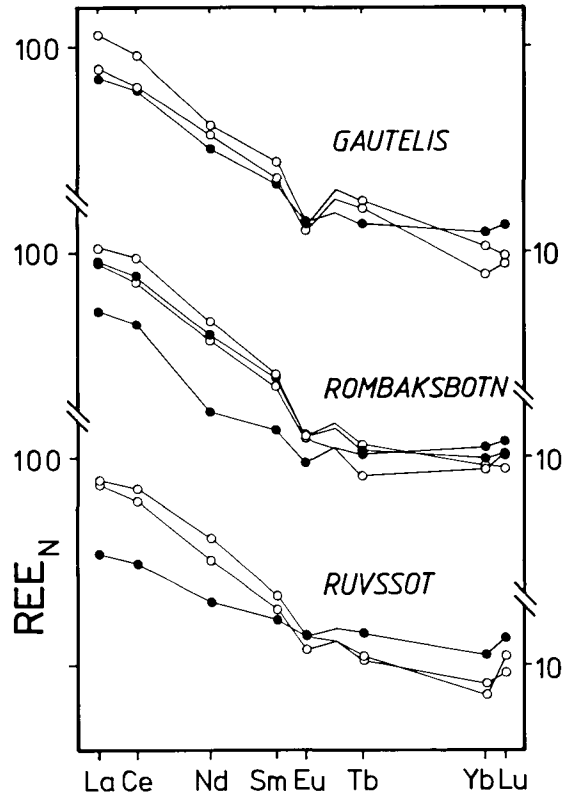

Fig. 3. Chondrite-normalized REE contents of the Rombak clastic turbidites. Open circles indicate greywackes, closed circles indicate pelites. Chondrite-normalizing factors from Taylor & Gorton (1977), and Gd values interpolated.

volcanic ash, has been pointed out to us by one of the reviewers (Crook). Such an explanation is in accord with our inference of explosive volcanic activity close to the sedimentary basin.

The more pelitic parts of the Ruvssot turbidites are depleted in SiO₂, LREE, Zr, Ta, and Th, but enriched in TiO₂, Fe₂O₃, MgO, V, Cr, Sc, Zn, Ni, Co and HREE (Fig. 3) relative to the coarser grained portions. In contrast to the Rombaksbotn and Gautelis turbidites both Ni and Cr are enriched in the Ruvssot metapelites, and it is inferred that, in this case, both elements are contained in the clays. The high CaO, but low Al₂O₃, K₂O and Rb contents of sample ES131 may indicate the presence of a fine-grained carbonate component and less clay in the original sediment (Fig. 2B).

Table 3. Representative analyses of possible source rocks to the Rombak turbidites

	SN-type volcanites			RS-type			G-type	T-type
	ES43	ES48	K104.4	K519.3	R1.3	R22.3	K101.5	K140.5
SiO2	58.35	65.33	68.41	72.16	48.57	45.55	75.70	67.29
TiO2	1.03	0.69	0.56	0.30	1.30	0.25	0.22	0.54
Al2O3	17.16	14.60	13.93	13.80	9.88	7.49	13.01	14.91
Fe2O3	7.22	6.63	4.94	3.38	13.04	10.63	1.27	4.47
MnO	0.10	0.14	0.07	0.04	0.09	0.16	0.02	0.05
MgO	3.29	1.95	0.76	0.29	7.75	20.56	0.29	1.54
CaO	6.00	4.19	1.46	1.09	6.86	8.85	1.36	3.60
Na2O	3.7	3.8	4.1	3.9	4.1	0.5	6.17	4.50
K2O	2.596	2.56	4.89	4.93	0.17	0.03	1.03	2.12
P2O5	0.25	0.14	0.10	0.04	0.12	0.02	0.03	0.13
LOI	0.91	0.64	0.75	0.35	6.86	4.28	0.53	0.83
TOTAL	100.60	100.67	100.07	100.28	98.74	98.32	99.62	99.98
V	117	83	30	15	213	168	13	56
Cr	136	60	13	bd	277	2200	bd	9
Sc	17	15	8	8	21	26	4	8
Zn	104	291	62	50	38	98	7	36
Ni	22	11	9	bd	80	1000	2	7
Cu	6	98	64	bd	11	8	3	11
Co	22	19	8	bd	36	89	11	6
La	35.5	44.6	61	80	14	0.6	43	31
Ce	76.9	94.4	132	13	425	2	79	63
Nd	29.7	38.9	53	56	16	1.0	26	21
Sm	6.61	7.66	8.8	12.1	3.4	0.4	4.0	3.9
Eu	1.30	0.93	1.10	0.97	0.97	0.19	0.78	0.98
Tb	0.77	1.10	1.20	1.4	0.27	0.13	0.58	0.58
Yb	2.82	3.47	4.19	5.1	1.4	1.0	2.25	1.44
Lu	0.390	0.568	0.71	0.85	0.26	0.19	0.32	0.18
Y	28	40	51	61	13	8	17	16
Zr	189	207	337	263	93	25	189	180
Hf	4.55	5.27	-	-	-	-	5.05	4.57
Nb	10	14	17	15	6	bd	17	12
Ta	0.91	1.09	-	-	-	-	1.62	1.13
Ba	650	435	882	667	56	25	886	957
Cs	6.3	12.0	-	-	-	-	0.4	1.4
Rb	125	259	228	252	bd	bd	25	55
Sr	562	202	116	98	107	9	290	377
Th	9.8	15.0	19	24	38	bd	11	8
U	4.6	6.8	bd	13	bd	bd	5	2
Pb	39	42	23	18	bd	bd	12	12

Legend: - = not determined: bd = below detection limit.
The major oxides were determined by XRF using fused glass discs. Y, Zr, Nb, Rb, Ba, Sr, Pb, V, Cu, Zn and Ni were determined by XRF using pressed powder pellets. Sc, Co, Cr, Cs, Hf, Ta, Th, U, La, Ce, Nd, Sm, Eu, Tb, Yb and Lu were determined by instrumental neutron activation analysis.

The carbonate was subsequently consumed during the metamorphic reactions that produced amphibole.

Rock types in the provenance area

Two possible sources can be considered for the detritus from which clastic turbidite formed: 1) Erosion of continental crust. 2) Erosion of coeval and predominantly volcanic rocks in the general vicinity. Within these two constraints, four possible source rock types can be recognised in the Rombak Window. Chemical analyses of a representative group of possible source rocks for the turbidites are presented in Table 3.

Tonalitic Complex (T-type). Clasts derived from tonalitic rocks in the conglomerates within the Gautelis turbidites indicate that sialic crust was exposed in the area during the Early Proterozoic. The Gautelis tonalitic complex consists of a suite of low-K_2O, but high Na_2O plutonic rocks containing from 60 to 72% SiO_2 (Table 3), that underlies the turbidite sequence. Thus, the tonalite could have contributed detritus to the turbidites.
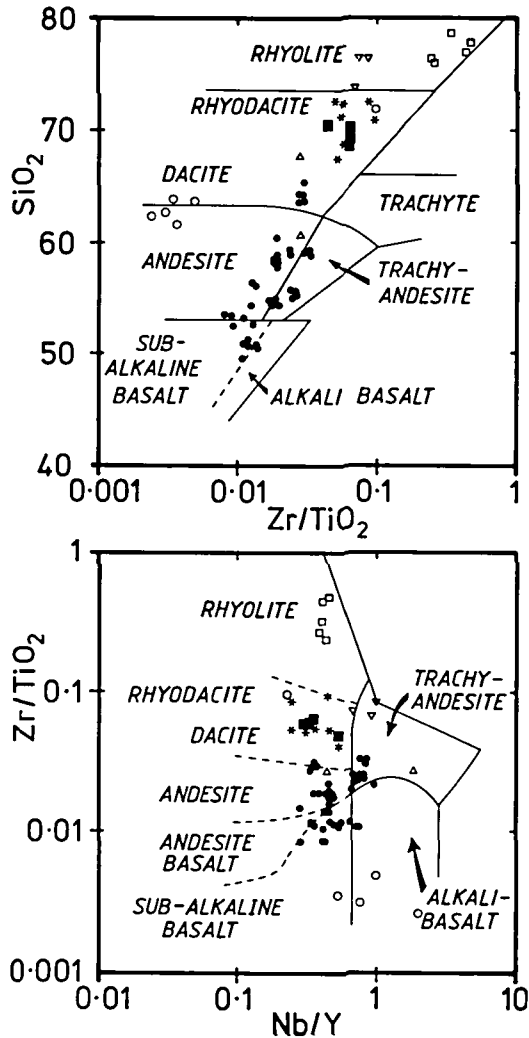

Fig. 4. Winchester & Floyd (1977) discrimination diagrams for volcanic rocks found in various parts of the Rombak Window. Symbols: ● and ☆ = Sørdalen, □ = Stasjonsholmen, ■ = Cainhavarre, △ = Rombaksbotn, o = Muohtaguobla, ▽ = Gautelis.

Gautelis felsic volcanites (G-type). Fine-grained felsic rocks that are thought to be of volcanic origin occur within the Gautelis tonalitic complex. It is possible that the G-type volcanites are intruded by the tonalite, but field relationships are not clear. These rocks have low K_2O but high Na_2O contents, and so resemble the Gautelis tonalitic complex, but contrast with the generally potassic composition of the SN-type volcanic rocks (Table 3). The G-type volcanites have LREE-enriched, calc-alkali-type REE patterns (Fig. 6).
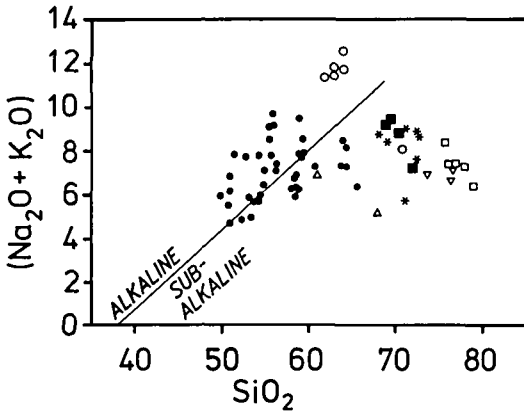
Fig. 5. SiO₂ versus (Na₂O + K₂O) diagram for the Rombak volcanic rocks showing the tendency of mafic and intermediate types to plot in the alkaline field, but felsic rocks to plot in the subalkaline field. Symbols as for Fig. 4.

Felsic to mafic volcanic suite (SN-type). In the western part of the Rombak Window (Sørdalen, Stasjonsholmen, Cainhavarri, Muohtaguobla and Rombaksbotn, Fig. 1) volcanic rocks that range from 49% to 76% SiO_2 (Table 3) are an important constituent of the supracrustal sequences. On the Winchester & Floyd (1977) variation diagrams (Fig. 4) these volcanites range in composition from subalkaline and alkali basalt through andesite and trachyandesite to dacite, rhyodacite and rhyolite. the mafic and intermediate members of the suite plot in the alkaline field, whereas the felsic members are distinctly subalkaline when considered on a SiO_2 versus (Na₂O + K₂O) diagram (Fig. 5). However, the andesites and dacites are K₂O-enriched and have LREE-enriched REE patterns (Fig. 6) similar to those shown by the calc-alkaline magma suite. Thus, the SN-type volcanic rocks are interpreted as K-rich, calc-alkali andesites and dacites similar to those described by Gill (1984).

Significant SiO_2 mobility either into, or out of, the SN-type volcanites seems unlikely because most of the samples plot in the same fields in Figs. 4A & B. Notable exceptions are the intermediate volcanites from the Muohtaguobla area, which occur in a region of extensive greenschist-facies retrograde metamorphism (Sawyer 1986b). The Muohtaguobla samples appear to have had SiO_2 added and are, therefore, excluded from further consideration in this paper. The SN-type volcanic suite
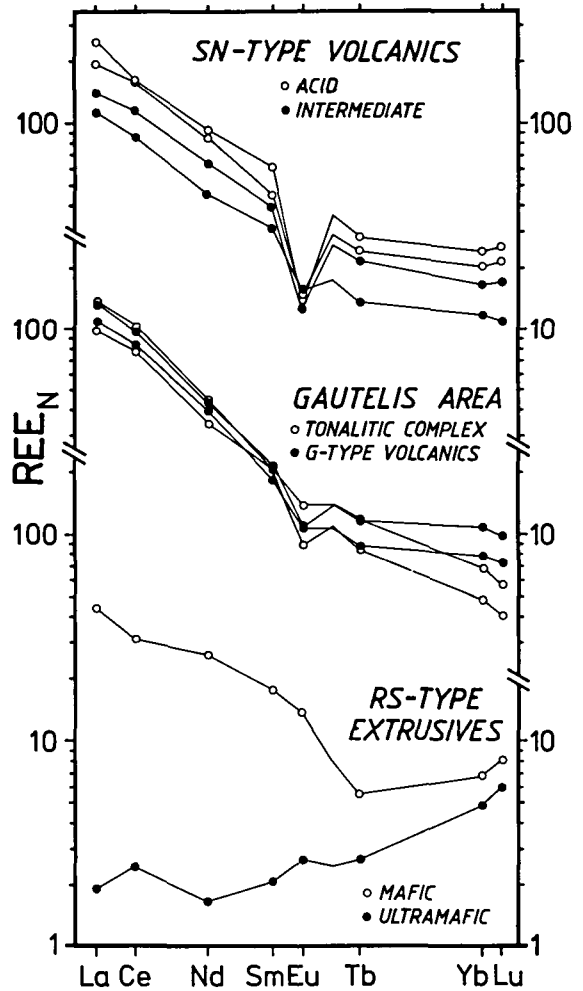

Fig. 6. Chondrite-normalized REE patterns for a representative group (Table 3) of possible source rocks to the Rombak turbidites. Note the LREE-enriched calc-alkali-like patterns for the SN- and G-type volcanic rocks, and the relatively smooth patterns from the tonalitic complex. Normalizing factors from Taylor & Gorton (1977), Gd values interpolated.

represents a significant proportion of the supracrustal sequence that includes the Rombaksbotn turbidites.

Low-potassium, mafic and ultramafic extrusives (RS-type)
In the eastern part of the Rombak Window, notably in the Ruvssot-Sjangeli area (Fig. 1),
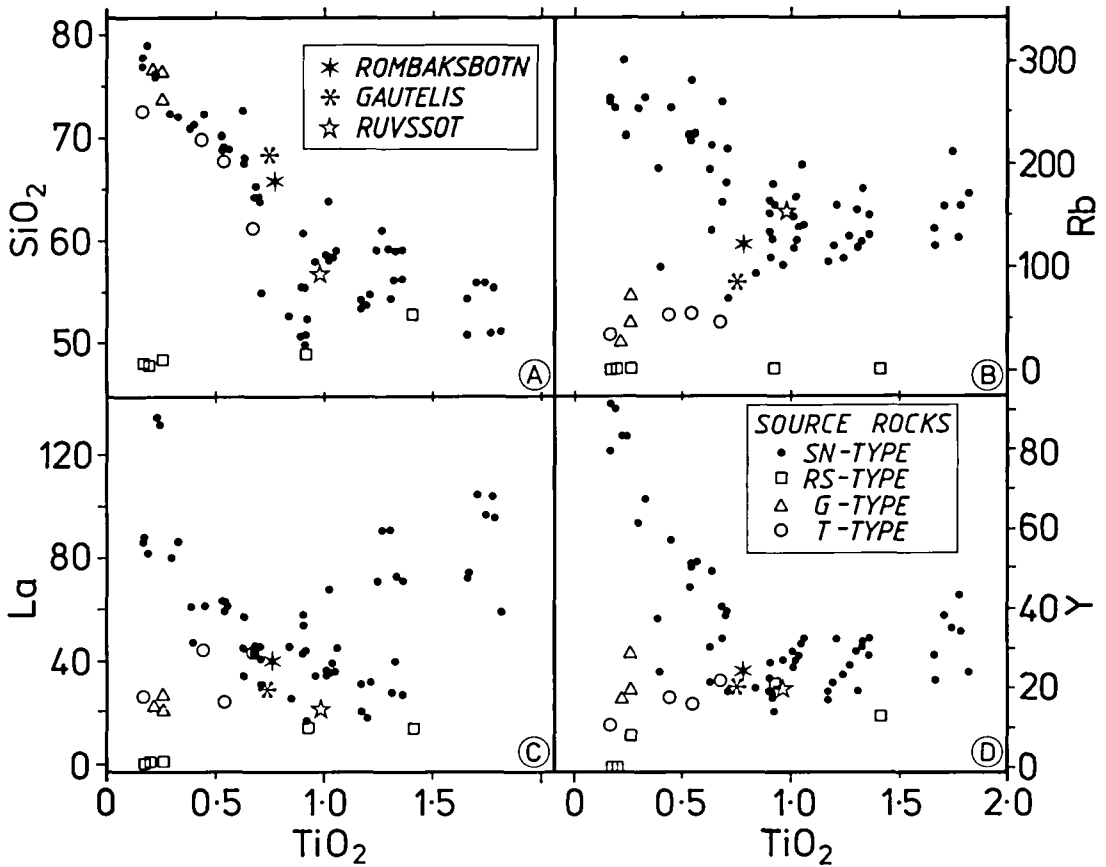
Fig. 7. TiO₂ versus SiO₂, Rb, La and Y variation diagrams comparing the Rombaksbotn, Gautelis and Ruvssot bulk sediment compositions (Table 2) with the four possible source rock types.

mafic to ultramafic rocks are an important constituent of the supracrustal sequence. The basaltic rocks show pillow structures in a few places. The basalts have low K_2O contents and REE patterns that are LREE-enriched; thus, they could be of calc-alkaline affinity. The ultramafic rocks, on the other hand, have REE patterns that are different (Fig. 6) and resemble those of ocean ridge material. On the basis of their noble element patterns (Barnes et al. 1988), major and trace element contents (Korneliussen & Sawyer this volume), the ultramafic rocks probably represent deformed and metamorphosed komatiites, or rocks of boninitic affinity (Korneliussen & Sawyer this volume). Romer (1988) also considers the ultramafic rocks to be of boninitic affinity on the basis of their ε Nd values.

Bulk sediment composition and source rock contributions

This section examines which, if any, of the possible source rocks could have contributed material to the detritus from which each of the Rombak turbidite sequences were derived. The approach adopted here is to compare the bulk sediment composition with the compositions of the potential source rocks. Use of the bulk sediment compositions eliminates the effects of sorting and maturity. The compositions of the source rocks in Figs. 7 and 8 are from Korneliussen & Sawyer (this volume), who discuss the geochemistry and petrogenesis of the Rombak igneous rocks.

In general, the contribution of a particular source rock to sedimentary detritus can only be recognised if that source rock has a distinc-

tive composition. Although Fig. 7A (TiO_2 versus SiO_2) clearly shows that acidic source rocks were the largest contributors to both the Rombaksbotn and the Gautelis bulk sediments, it cannot distinguish between the three possible acidic sources. However, the high TiO_2 but low SiO_2 contents of the Ruvssot turbidites indicates that neither the G-type, the T-type nor the felsic SN-type source rocks are a significant component in these sediments.

Mineralogically, the principal difference between the acidic source rock types is the type of feldspar they contain: Fig. 7B (TiO_2 versus Rb) differentiates between the K-feldspar-rich SN-type and the plagioclase-rich G-type volcanites and the tonalitic complex. The Gautelis bulk sediments are Rb- (Fig. 7) and K_2O-depleted relative to the trend of the SN-type volcanites and are displaced towards the field of low-Rb acidic source rocks. This implies that either the G-type volcanites or the tonalitic complex provided a significant acidic component to the Gautelis turbidites. The Rombaksbotn bulk sediment is also Rb- and K_2O-depleted relative to the SN-volcanic trend; however, the acidic component of the tonalitic complex and/or the G-type volcanites is much smaller, and may even be absent. In contrast, the Ruvssot bulk sediment plots within the SN-type volcanic trend, but because these turbidites may have experienced K_2O and Rb addition during diagenesis, the TiO_2 versus Rb plot cannot be used to distinguish between source components.

The Ruvssot-Sjangeli mafic and ultramafic rocks also have low K_2O and Rb contents, and plot close to, but separately from, the G-type volcanites and the tonalitic complex in Fig. 7B, nevertheless, a greater dispersion between the source rock types with low Rb contents is desirable. The high Ni and Cr content of the RS-type source rocks (particularly the ultramafic rocks) is distinctive, and in Fig. 8 the RS-type rocks form a separate field. All three bulk sediment compositions are enriched in Ni (Fig. 8) and Cr relative to the tonalitic complex, the G-type and the SN-type volcanites. Hence, the presence of a component derived from a Ni- and Cr-enriched source is inferred for all three bulk sediments. However, the Ni- and Cr-enriched members of the SN-type volcanites cannot be the source for the Ni and Cr present in the Gautelis and Rombaksbotn bulk sediments. This is because the large volumes required of such a source rock type
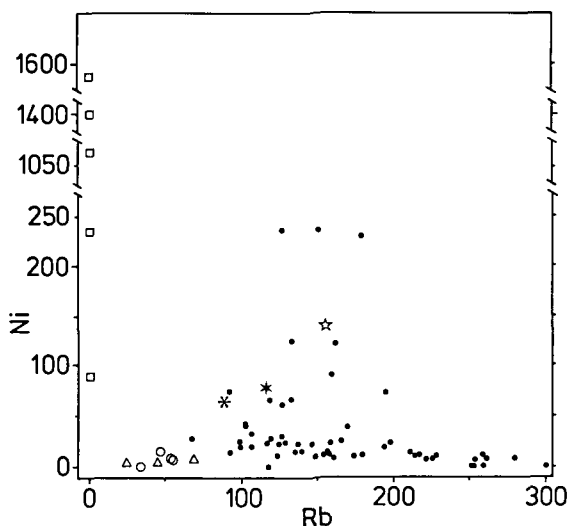

Fig. 8. Rb versus Ni diagram for discriminating possible source rock types to the Rombak clastic turbidites, showing that the bulk sediment compositions are Ni-enriched relative to the SN- and G-type volcanites and the T-type source. Note breaks on the vertical axis. Symbols as for Fig. 7.

would give rise to much higher MgO (>4%), CaO (>4.5%) and Sr (>400ppm) contents in the sediments than is observed. Although it can be argued that both CaO and Sr would be lost to the weathering solutions, this is not the case for MgO (Nesbitt et al. 1980, Sawyer 1986a). The Rombaksbotn and Gautelis bulk sediment compositions could be more sucessfully modelled if the bulk sediment contained a small component (2 to 5%) of a very Ni- and Cr-enriched (1400ppm and 2600ppm, respectively) source, such as the RS-type ultramafics. Unfortunately, no distinction can be made between a small component of an RS-type ultramafic source for the Ruvssot bulk sediment, and a large component of the Ni- and Cr-enriched SN-type volcanic source, on the basis of either Rb, K_2O, Sr, CaO, MgO or TiO_2 contents.

The REE and other high ionic potential elements (e.g. Th, Zr, Y, Ta and Nb) have been useful for determining metasediment sources (Jenner et al. 1981, Taylor & McLennan 1981a, Sawyer 1986a), or tectonic settings (Bhatia & Taylor 1981, Bhatia 1981, Bhatia & Crook 1986) of clastic sediments because they are the least mobile elements during weathering,

diagenesis and metamorphism (Nance & Taylor 1976, McLennan et al. 1980).

Figure 7C (TiO_2 versus La) shows considerable range of La contents within the possible source rock types, especially for the SN-type. Inspection of Fig. 7C shows that most of the mafic and intermediate members of the SN-type sample set have La contents between 25 and 50ppm, although some samples have in excess of 100ppm. Because the frequency distribution of La contents in the intermediate to mafic members of the SN-type volcanites is not Gaussian but log-normal, a representative value is more accurately given by the estimated geometric mean (43ppm) of the data set, and not by the arithmetic mean (51ppm). Similarly for the acidic members (SiO_2 >66%) the estimated geometric mean is 67ppm La. The REE patterns for the SN-type volcanites (Fig. 6) are, therefore, of samples closest to these estimated geometric means. The variation in Y contents (Fig. 7D) suggests that the HREE are also log-normally distributed.

The comparatively low total REE contents of the Gautelis bulk sediment indicates that a large component of the bulk sediment was derived from a source rock having low REE contents, such as the G-type volcanites or the tonalitic complex (incidently, confirming the TiO_2 versus Rb data). Alternatively, a large component of REE-deficient material, such as quartz, is diluting the REE levels in all the sediments. It can be argued that the shape of the Gautelis bulk sediment REE pattern (smooth from La to Lu) implies that the tonalitic complex (smooth REE pattern) and not the G-type volcanites (LREE-enriched REE pattern) was the principal source of acidic material. The Gautelis bulk sediment composition can be derived from a mixture of tonalitic complex, SN-type volcanites (intermediate to mafic composition and without extremely fractionated types) and a small component of RS-type ultramafic rock.

The Rombaksbotn sediments all have REE patterns that are flat from Tb to Lu, and hence resemble those of the SN-type volcanic rocks (compare Figs. 3 and 6). The REE pattern is, therefore, consistent with a large proportion of SN-type material in these sediments, and confirms the conclusions based on the distribution of other trace elements (e.g. Fig. 7). The Ni and Cr data indicate the presence of a RS-type ultramafic source component. There is no conclusive evidence for

either tonalitic complex or G-type volcanite derived material in the Rombaksbotn bulk sediment.

The Ruvssot sediments have lower and flatter REE patterns than either the Rombaksbotn or the Gautelis bulk sediments, and so must have had a different provenance area. The low La and total REE contents of the Ruvssot turbidites excludes the possibility that the Cr- and Ni-enriched SN-type volcanites form a significant component in the sediments because such volcanic rocks contain >43ppm La. However, on the basis of their REE contents the RS-type extrusives are a suitable source for the Cr, Ni and MgO in the Ruvssot turbidites. The REE patterns of the Ruvssot turbidites are sufficiently low as to exclude the SN-type volcanites as a source component altogether. This is because if the SN-type volcanites were a source component, then considerable dilution by phases lacking REE (e.g. quartz and carbonate) would be required to produce the observed low REE contents, and the major elements contents of these turbidites does not support this. It is concluded that a major component of the sediment in the Ruvssot turbidites came from a source that is not presently recognised. However, it is possible to infer that this principal source for the Ruvssot turbidites was volcanic and had an intermediate, LREE-enriched bulk composition with 20-30ppm La: we suggest a calc-alkaline arc volcanic source that was more primitive (less evolved) than the SN-type.

Tectonic setting and basin development

The field and compositional characteristics of the turbidites in the Rombak Window provide constraints on the palaeogeography and type of tectonic environment in which they formed. However, the lack of precise age determinations from the volcanic sequences in the window precludes any meaningful interpretation of the sequence of basin development. The age of basin formation is poorly constrained by the 2.3 ± 0.08Ga Rb-Sr age for the RS-type extrusives (Romer 1987) and the 1.78 ± 0.085 Ga Rb-Sr age for the granites and syenites that intrude the supracrustal sequences (Gunner 1981). Outside the Rombak Window two periods of Lower Proterozoic volcanism are known; the first, in northern Norway between 2.5 and 2.1 Ga, and the second, in north-

central Sweden, between 1.91 and 1.88 Ga (Skiöld & Cliff 1984, Pharaoh & Pearce 1984, Claesson 1985; Skiöld 1986, 1987). By analogy with volcanic rocks of similar composition described from Sweden (Frietsch & Perdahl 1987, Widenfalk et al. 1987) the SN-type volcanites of the Rombak Window may belong to the younger 1.91–1.88 Ga event.

The Rombaksbotn and Gautelis turbidites are comparatively thinly bedded with a large sand/clay ratio; thus they resemble turbidites from active margin basins rather than Atlantic-type passive margins. However, other factors, e.g. denudation rates, can affect sand/clay ratios (Stow et al. 1985, Normark et al. 1985). The Rombaksbotn and Gautelis turbidites are interbedded with andesitic and dacitic volcanic rocks and have compositional characteristics which suggest that part of their fine-grained size fraction was either volcanic glass, or unweathered feldspar. Hence, an origin near to paroxymal volcanism is inferred, and consequently these metasediments are unlikely to represent trailing edge-type passive margin basins.

Comparison of the turbidite composition with possible source rocks found in the Rombak Window indicate that both the Rombaksbotn and the Gautelis sediments contain a large proportion of SN-type volcanic material and a small (<3%) Ni- and Cr-enriched mafic to ultramafic component. If the high Cr contents of the greywackes are indeed due to detrital chromite, then an ultramafic source is more likely. Korneliussen & Sawyer (this volume) argue that, on the basis of negative Ta, Nb and Ti anomalies shown by the SN-type volcanites when compared to primordial mantle, these volcanites are subduction-related magmatic arc rocks. Furthermore, by analogy with modern arc rocks described by Gill (1984), the calc-alkaline REE patterns and high K_2O and Rb contents of the SN-type volcanites suggest that they represent a late, or mature, stage of arc development.

The Gautelis turbidites contain, in addition, geochemical and field evidence (presence of clasts) of a component derived from tonalite. The tonalite, together with its associated, but volumetrically minor, G-type volcanites, is exposed near Gautelisvatnet and could either be part of the Archaean basement present in the Kiruna-Lofoten area, perhaps equivalent to the Soppero gneisses (Pharaoh & Pearce 1984, Öhlander et al. 1987), or alternatively,

it could be equivalent to the 1.89 Ga Kristineberg and Jörn subvolcanic complexes of Sweden (Öhlander et al. 1987).

The Rombaksbotn and Gautelis turbidites formed in active margin basins adjacent to a mature volcanic arc; in the case of Gautelis, the arc may rest on a tonalitic continental crust in an Andean-type continental margin setting. The detritus from which the turbidites formed came directly from volcanic eruptions and also from erosion of the arc complex.

The Ruvssot turbidites were derived from a source that was quartz-poor, LREE-enriched and generally of mafic to intermediate composition. This more mafic source is also the likely reason for the lower CIA values. The composition of the Ruvssot turbidites indicates that they formed in a basin close to ultramafic/mafic (RS-type) to intermediate rocks of calc-alkaline type, but distant from any source of acidic, or very fractionated, LREE-enriched material. This suggests either an intra-oceanic environment adjacent to primitive island arc volcanism, or perhaps a trench slope environment.

Bhatia & Crook (1986) have used the compositional characteristics of Palaeozoic greywackes from Australian turbidites to develop a series of ratio and triangular plots for the discrimination of the tectonic setting of sedimentary basins. Their diagrams for greywackes (grain-size 0.06–2.0 mm) can be tested with the Lower Proterozoic Rombak turbidites since their tectonic settings have been tentatively established above.

Although the individual greywacke samples show some scatter on the Bhatia & Crook (1986) plots (Fig. 9A to D), they, and the bulk sediment compositions, plot within the field compatible with the field observations and geochemical interpretation given above. The only exception is seen in the Sc/Cr versus La/Y diagram (Fig. 9E) where Rombak sediments plot out of the compositional fields altogether, except for some samples that lie in the passive margin field. This suggests that sediments derived from Cr- and La-enriched sources cannot be represented on such diagrams. Such a restriction excludes sediments derived from mature arcs: and probably also Archaean and Lower Proterozoic volcanic rocks, since evidence indicates a change in average composition through geological time (Condie 1981, Taylor & McLennan 1981b, Gill 1984), in particular higher MgO, FeO, Cr and

Ni contents compared with Phanerozoic arc rocks. Contamination of the Rombak samples with Cr and La during sample preparation can be excluded as the cause of the discrepancy in Fig. 9E (see Appendix).

The diagrams of Bhatia & Crook (1986) are intended for greywackes, and where the original silt- and clay-sized sediments can be recognised, as for example the tops of graded beds, the distinction between greywackes and pelites may be reltively simple. However, in the case of sediments metamorphosed to the amphibolite facies the original grain-size may be considerably coarsened by recrystallisation (e.g. Chipera & Perkins 1988, p. 41), and consequently the distinction between pelite and greywacke may be more difficult. The inadvertent plotting of pelites on these diagrams results in an increased scatter of samples on each of the plots, as can be seen when the Rombak pelites are plotted in Fig. 9. For example, in Fig. 9D the Rombaksbotn and the Gautelis greywacke bottoms of graded units plot in the fields of continental island arcs and active continental margins, but the pelitic tops plot in the oceanic island field. Therefore, in recrystallized metasediments care must be taken to exclude rocks that were originally mud-rich; these can then be treated separately (e.g. Bhatia 1985).

The separation of pelite from greywacke due to the sorting of fine-grained material from coarse-grained is apparent on all the diagrams of Fig 9, and illustrates a potential weakness of a grain-size based chemical classification scheme for sediments. This is the possibility that, even in the sand-sized fraction, the clay-rich distal facies of a turbidite fan sequence could be classified differently from the clay-poor proximal part, thus spuriouis correlations could result.

Conclusions

The tectonic setting in which the clastic turbidites of the Rombak Window formed can be inferred from their compositions by determining possible source rock types. However, the compositional variation due to sorting must be eliminated by using bulk sediment compositions. The turbidites from Rombaksbotn and Gautelis formed in an active marginal basin setting adjacent to a mature volcanic arc. The volcanic arc that supplied the Gautelis turbidite basin formed on a tonalitic crust; and
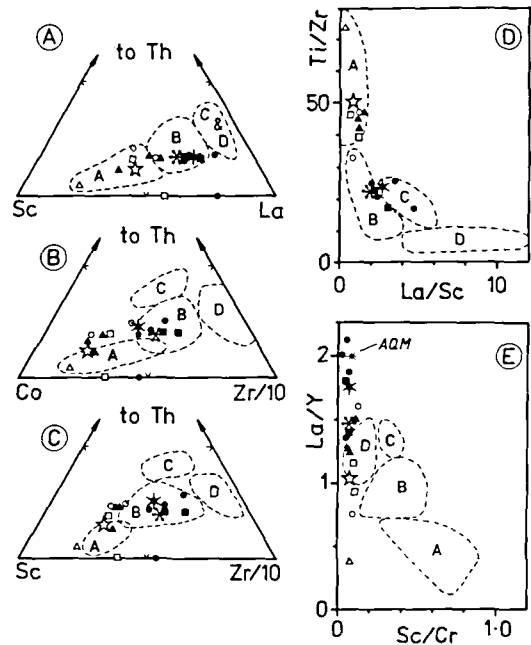

Fig. 9. Rombak turbidites plotted on the trace element discriminant diagrams for greywackes (grain-size 0.06-2.0mm) of Bhatia & Crook (1986). The fields outlined dashed are: A - ocean islands, B - continental island arcs, C - active continental margins, D - passive margins. On diagram (E), Sc/Cr versus La/Y, the Early Proterozoic Rombak and the Archaean Quetico (AQM, Sawyer 1986) turbidites are Cr- and La-enriched relative to the Palaeozoic turbidites upon which Bhatia & Crook (1986) base their discrimination diagrams, and hence plot out of the compositional fields of the various sedimentary basins. See text for discussion of the pelite samples plotted on these greywacke diagrams. Symbols as for Fig. 2.

an Andean-type setting is suggested. The Ruvssot turbidites are more primitive, and do not contain continental or fractionated acidic volcanic material. Thus, they may have formed in an intra-oceanic setting by the erosion of a primitive calc-alkaline volcanic arc far removed from a source of continental material.

Appendix
Analytical method
One to two kg of rock were collected and reduced to 2–5cm chips on the outcrop. Samples were then further reduced to 6 mm chips in a jaw crusher and pulverised to 400 mesh in a an agate mill at the Norges geologiske undersøkelse (NGU) in Trondheim. Major oxides were determined on fused glass discs and the trace elements Nb, Zr, Y, La, Ce, Th, U, Sr, Rb, Ba, Zn, Co, Cr, Cu, Ni, V, Sc and Pb on pressed powder pellets using standard XRF methods at NGU. La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Ta, Cs and Hf were determined by instrumental neutron activation analysis (INAA) on selected samples using Becquerel Laboratories of Toronto; for these samples the values for Cr, Co, Sc, Th, U given in Table 1 are also by INAA. A sample of Archaean greywacke from the Quetico metasedimentary belt was also chrushed and pulverised at NGU and analysed by XRF at NGU and by INAA at Becquerel, the results agree to within 10% with those obtained earlier by the first author at the University of Toronto. Previously pulverised and analysed powders (UTB-1, UTA-1 and UTR-1) were used as internal standards in all the analytical runs and also agreed to within 10% of previous estimates made at the University of Toronto. Thus, systematic contamination, or errors in the analysis, of Sc, Cr, La and Y are not likely.

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