Precambrian volcano-sedimentary sequences and related ore deposits, with special reference to the Gautelisfjell carbonate-hosted, disseminated gold deposit, Rombaken basement window, northern Norway.

EF/NTNF-project "Gold in Early-Proterozoic volcano-sedimentary belts".

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Tittel:

Precambrian volcano-sedimentary sequences and related ore deposits, with special reference to the Gautelisfjell carbonate-hosted gold deposit, Rombaken basement window, Northern Norway.

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Kartbladnavn (M. 1:250 000) Narvik	Kartbladnr. og -navn (M. 1:50 000) 1431 III (m.fl.) Skjomdal
Forekomstens navn og koordinater: Rombakvinduet	Sidetall: 47 Pris: Kr. 76.- Kartbilag:

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Sammendrag:

Sammendrag på norsk:
Suprakrustalene i Rombakvinduet består av en kompleks serie med vulkanske bergarter, pelittiske sedimenter, gråvakker, med mindre innslag av karbonater og kvartsitter. De intruderes av mafiske ganger, mafiske-intermediære plutoner og granitoide batolitter (1700-1800 mill. år).

Området har gjennomgått nedre amfibolittfacies metamorfose etterfulgt av retrogradering til grønnskiferfacies langs et N-S-gående lineament. Skjærsoner langs dette lineamentet har virket som kanaler for H_2O-CO_2 førende løsninger.

Forskjellige typer av malmforekomster opptrer i karakteristiske geologiske miljøer: (1) disseminert gull i karbonater innenfor en vulkanitt-sediment serie (Gautelisfjell forekomst), (2) disseminerte til massive Zn-Pb mineraliseringer innenfor kalk-silikat horisonter i tuffitt/gråvakke-sekvenser og assosiert med skjærsoner, og (3) disseminerte til massive Cu-Fe mineraliseringer assosiert med mafiske vulkanitter.

Interessante målområder for gull er: (1) karbonat +/- sulfid-anrikede horisonter av mulig exhalativ-hydrotermal opprinnelse i sure vulkanitter og (2) skjærsoner som har virket som kanaler for hydrotermale løsninger.

Emneord	gull	
berggrunnsgeologi	zink	
malmgeologi	fagrapport	

PRECAMBRIAN VOLCANO-SEDIMENTARY SEQUENCES AND RELATED ORE DEPOSITS, WITH SPECIAL REFERENCE TO THE GAUTELISFJELL CARBONATE-HOSTED, DISSEMINATED GOLD DEPOSIT, ROMBAKEN BASEMENT WINDOW, NORTHERN NORWAY.

Are Korneliussen, Jan Inge Tollefsrud,
Boye Flood og Edward Sawyer

Abstract

The supracrustals in the Rombaken window consist of a complex sequence of volcanic rocks, pelitic sediments, greywackes, and lesser amounts of carbonates and quartzites. They are intruded by mafic dykes, mafic to intermediate plutons and a variety of granitoid batholites at approximately 1700-1800 Ma. The region has experienced lower amphibolite metamorphism followed by retrogression to greenschist facies along shear zones which have acted as channels for H_2O-CO_2 bearing fluids.

Various types of ore-deposits occur in distinct geological environments within basement rocks : (1) disseminated arsenopyrite-associated Au mineralizations in carbonate within a basic to acidic volcano-sedimentary sequence (the Gautelisfjell deposit), (2) dissemminated to massive Zn-Pb mineralizations within calc-silicate layers in tuffite/greywacke-black shale sequences and as fracture fillings in shear zones, and (3) disseminated to massive Cu-Fe mineralizations associated with mafic volcanics.

A combination of geological investigations and stream-sediment sampling has delineated anomalous target areas for both gold and zinc-lead. Potential sites for gold mineralizations are: (1) carbonate +/- sulphide horizons that are believed to represent chemical sediments interbedded with felsic volcanics, and (2) shear zones that have acted as channels for hydrothermal fluids.

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10.THE CARBONATE-HOSTED, DISSEMINATED GOLD MINERALIZATION AT GAUTELISFJELL

1. INTRODUCTION

This report is based on the results from recent geological investigations by the Norwegian Geological Survey (NGU) and the companies Folldal Verk A/S and ARCO Norway Inc. Folldal Verk has consentrated its activities on gold prospecting mainly in the southern and southeastern parts of the window, while ARCO's activities have been aimed at Zn-Pb and Au mainly in the middle and northern parts. The purpose of NGU's work has been to evaluate the regions potential for gold, and with this in mind their activities has been concentrated on the volcano-sedimentary sequences in the southern half of the window.

The aim of the report is to give a general review of the geological features of the region and its various types of metal deposit. Special attention will be paid to the Gautelisfjell carbonate-hosted, disseminated gold deposit which is the first gold deposit of this type found in Norway. Secondly, targets for continued prospecting and geological research will be delineated.

2. PREVIOUS WORK

The southern parts of the Rombak Window have been mapped by Birkeland (1976) and the norhern parts by Vogt (1950; in Gustavson 1978), both in scale 1:100000. Rb-Sr age determinations on granitoid rocks from the northern part of the window have given 1691 Ma (Heier & Compston 1969), and 1780 Ma (Gunner 1981) from the southern part of the window.

During the 1970's and early 1980's NGU carried out several minor investigations on Zn-Pb and U mineralizations in the window (Lindahl & Furuhaug 1977, Lindahl 1978, 1980, Singsaas 1977, Grønlie 1982, Håbrekke 1983, Næss 1983). In 1983-1984 ARCO Norway carried out extensive investigations on Zn-Pb, and to a lesser degree on gold, but their main activity concentrated on the northern parts of the window (Flood 1984, 1985). Folldal Verk A/S started a regional gold prospecting program in the southern parts of the window in 1983 (Priesemann 1983). From 1984 they concentrated their activities on the Gautelisfjell carbonate-hosted gold deposit (Priesemann 1984, Tollefsrud 1985).

Detailed descriptions of lithology and rock-geochemistry are presented by Korneliussen & Sawyer (1986), based on NGU's recent investigations. The metamorphic and structural geology is described by Sawyer (1986) and Sawyer (in prep.).

3. LITHOLOGY

In the Rombaken basement window (Fig.1) old supracrustal sequences are intruded by large volumes of granites and syenites with lesser amounts of basic to intermediate intrusives. The volcanic portion of the supracrustals range from ultramafic (Mg-tholeiites/komatiites) through basic and intermediate varieties to rhyolites. Some of the basic and intermediate volcanites are tuffaceous in origin. Clastic sediments are mainly greywackes. Carbonates/marbles, conglomerates and quartzites are also present, but are relatively uncommon. A group of quartzites and pelites in the Muohtaguobla area were previously considered to belong to the late Proterozoic-Cambrian Dividal Group by Birkeland (1976). The stratigraphic status and age of these rocks is uncertain, but never the less they are crucial in determining the age of structural and metamorphic events in the window.

The composition of the different supracrustal areas or belts (Fig.1) varies: The Sørdalen supracrustal belt in the southwestern part of the window is composed of predominantly porphyritic basic, intermediate and felsic volcanics.

The Stasjonsholmen-Cainhavarre supracrustals further to the east contain thick sequences of pelitic sediments and greywackes with horizons of basic/intermediate volcanics. Thick amygdaloidal flows occur in the central to northern parts of the Stasjonsholmen belt. The south and southeastern part of this area contains two units of rhyolite, each 1 km thick.

East of Cainhavarre and in the Muohtaguobla area, mafic, intermediate and felsic volcanics (mainly tuffites), pelites, graphitic schists, quartzites (+/- graphite +/- carbonate) and quartz-pebble conglomerates are complexely intermixed. The complexity is at least partly of tectonic origin. In the Muohtaguobla area extensive hydrothermal activity along N-S trending shear-zones has retrograded (hydrated) lower-amphibolite facies mineral assemblages to lower-greenschist facies assemblages (see chapt. 5 and 6).

Towards the east the Muohtaguobla sequence gives way to the Ruvssot (-Sjangeli) sequence, which is more typical of a greenstone belt association with ultramafic (Mg-tholeiites/komatiites) and mafic volcanics, thin alternating quartzite and carbonate horizons, pelitic sediments and greywackes. The contact relations between the Muohtaguobla and Ruvssot areas are unknown.

The Gautelisvatn supracrustals in the southern part of the window are dominated by a greywacke sequence, but horizons of tuffitic mafic and felsic volcanics, thin conglomerates and carbonates are also present. The Gautelisfjell Au deposit is associated with a carbonate horizon in this sequence (see chapt. 10).

The supracrustal sequence north of Rombaken fjord in the northern part of the window, is dominated by greywackes and pelites with a minor volcanic component (as tuffites).

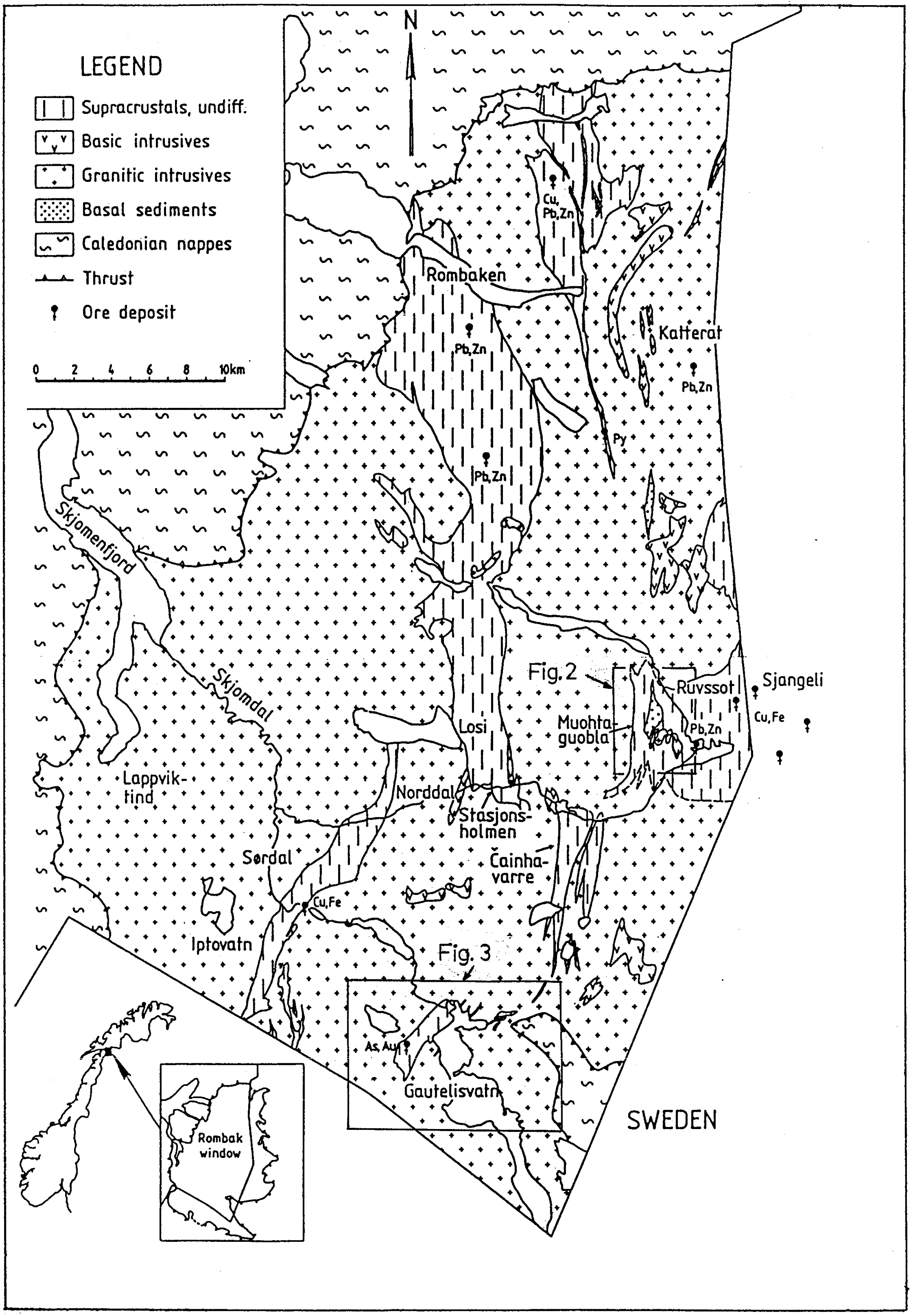

FIG. 1 Geological map, Rombak Window. Modified from Birkeland (1976) and Vogt (1950).

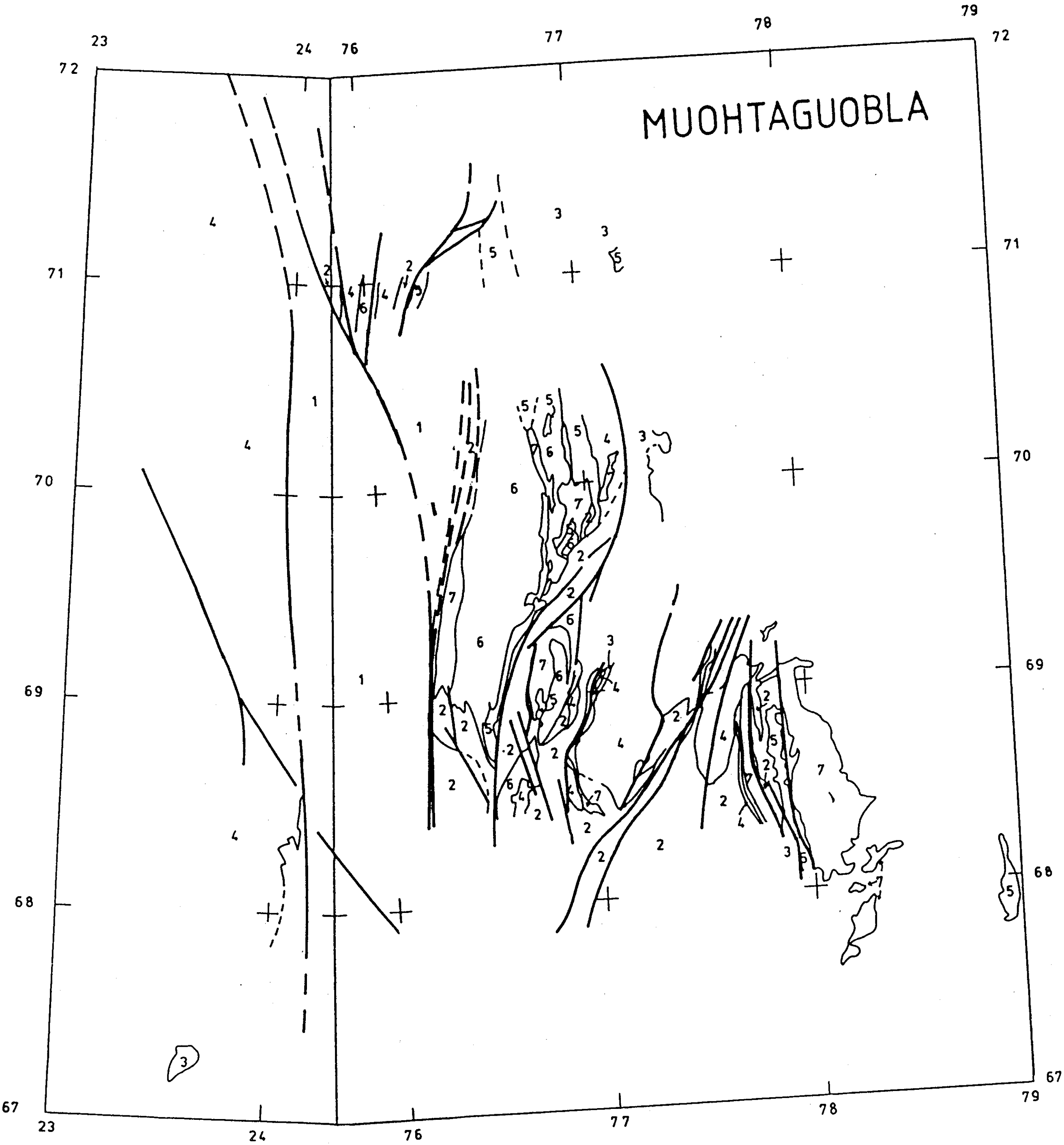

FIG. 2 Preliminary geological map, Muohtaguobla, with the pattern of shear zones indicated (thick lines).

1: Undifferentiated grey schists and psamites with minor quartzites and conglomerates.
2: Blue-grey fine grained schists and quartzites.
3: Intermediate volcanics and basic schists.
4: Coarse porphyritic granite and syenite (often foliated)
5: Pink and grey medium grained to fine grained granite "microgranite".
6: Coarse-grained porphyritic melanocratic granite.
7: Diorite, foliated near shear-zones.

See Korneliussen and Sawyer (1986) and E.Sawyer (in prep.) for further information on the area.

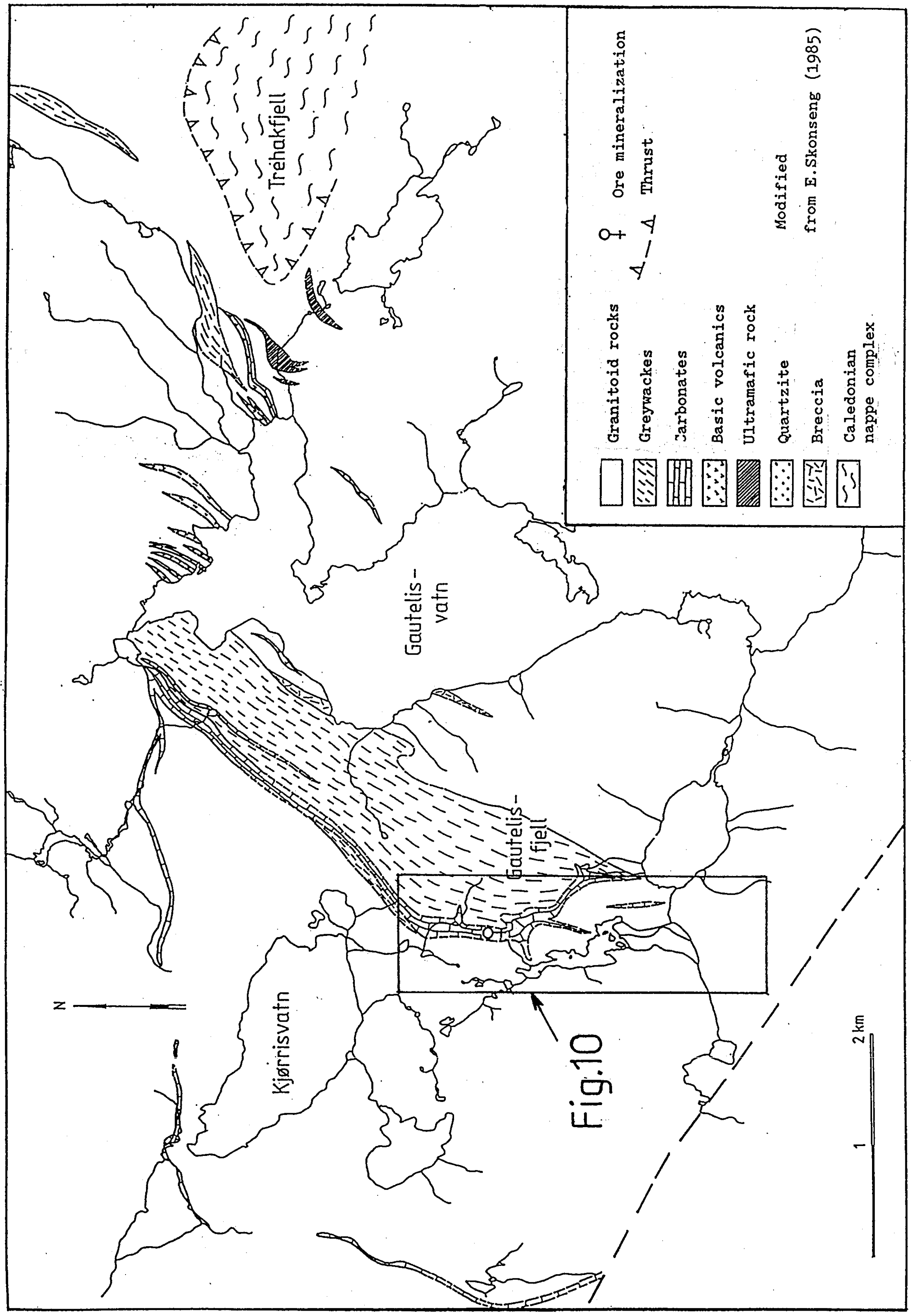

FIG. 3 Geological map, Gautelisvatn. Based on Skonseng (1985).

4. GEOCHEMISTRY

IGNEOUS ROCK-TYPES

On the basis of their petrographic and geochemical characteristics the volcanic and intrusive rocks of the window can be divided into 3 types or series:

(1) The *Ruvssot(R)-type* Mg-tholeiites (komatiites) are characteristic of the Ruvssot - Sjangeli area.

(2) The *Sordalen-Nordalen(SN)-series* are fairly pottassic with alkaline affinities; they range from basic through intermediate (andesitic) varieties to rhyolites. Basic/intermediate varieties are often porphyritic, some are amygdaloidal flows. The acidic members of this series are chemically similar to the abundant medium to coarse grained, porfyritic granites in the window.

(3) *Gautelisvatn(G)-type.* Felsic volcanics and acidic intrusive rocks in the Gautelisvatn area are tonalitic in composition with their main and trace element characteristics clearly different from the felsic members of the SN-series.

The SN-series plots along an alkali-calcic geochemical trend (Fig.4 b). The original definition of the term alkali-calcic came from Peacock's (1931) alkali-lime index, which for a series of related rocks with a continuous compositional range, is the percentage of SiO_2 at which the abundances of CaO and Na_2O+K_2O are equal. Calc-alkaline rocks were defined as those with an index (given as percentage of SiO_2 by weight) between 56 and 61; suites with an index greater than 61 are calcic, those with an index less than 56 are alkali-calcic (51-56) or alkalic (less than 51; Brown 1982). Intrusive rocks from different tectonic settings have characteristic alkali-lime indices as indicated in Fig.4 b. In Phanerozoic environments alkali-calcic igneous rocks are characteristic for relatively mature magmatic systems, i.e. fairly continentized magmatic arcs (Brown 1982). Thus, if compared to Phanerozoic magmatic systems, the SN-series have main element characteristics which indicate a continental environment. A high K/Na-ratio also indicate a relatively continental environment for the SN-series, when compared to Phanerozoic igneous rock suites (Fig.4 c).

This is in agreement with the location of these samples in the "within plate" field on discrimination diagrams used for both basic and acidic rocks (Fig.5 a and b). In discriminant diagrams the G-type rocks tend to plot in the volcanic-arc field, as examplified with the (Y+Nb)/Rb-plot in Fig.5 b.

DIFFERENTIATION TRENDS FOR THE ALKALI-CALCIC VOLCANIC ROCKS

As indicated in Fig. 6 a & b the Sørdalen basic/intermediate volcanics may be the product of a continuous differentiation process due to early crystallization of Fe,Mg-rich minerals (olivine, orthopyroxene). The break in the Al_2O_3-trend probably indicates clinopyroxene fractionation.

The felsic volcanics from Muohtaguobla, Cainhavarre and Stasjonsholmen plot along a trend that is believed to be controlled by plagioclase fractionation. This is indicated in Fig.6 a & c, since aluminium and sodium follow plagioclase in these rocks. A correspondingly strong enrichment of incompatible trace elements (Rb, Ce, La, Zr, Y, Nb) in the acidic end members of the series is characteristic for the Stasjonsholmen volcanics, as examplified by the Zr-SiO_2 plot (Fig. 6 d). This is in good agreement with the REE-patterns for the Cainhavarre and Stasjonsholmen volcanics (Fig.8 d); the stronger negative Eu-anomaly for Stasjonsholmen shows that more Eu has been removed from the melt by fractional crystallization of plagioclase. The parallell patterns for LREE and HREE from the Cainhavarre and Stasjonsholmen volcanics respectively, are consistent with a close genetic relationship. The Muohtaguobla REE-pattern is typical for feldspar enriched rocks, and may indicate that these rocks have originated from a feldspar cumulate part of a magma-chamber, presumably by melting of the cumulate before extrusion. The genetic relationships will not be further discussed in this report.

GREYWACKES

Turbiditic greywackes with well-preserved graded bedding were sampled in 3 areas: Rombaken (Stasjonsholmen belt; 6 samples), Gautelisvatn (4 samples) and Ruvssot (4 samples). The greywackes from Rombaken and Gautelisvatn show very similar chemical compositions (Table 1), while the Ruvssot greywackes are somewhat more mafic. They were derived from a comparatively unweathered detritus (low "Chemical Index of Alteration", Nesbitt and Young 1982) and hence have low Al_2O_3 and K_2O contents. All the greywackes are characteristically enriched in Fe, Mg, Ni, Cr and V and depleted in Ce, La, Y, Nb and Zr compared to volcanic rocks with the same SiO_2-content. This indicates that their source regions have been dominated by mafic/intermediate rock. The high Ni-content of the greywackes compared with volcanics with the same MgO-content (Fig.7 b), suggests that very Ni-rich rocks, presumably of the same type as the Ruvssot Mg-tholeiites, have been a significant Ni-source. The REE-patterns for greywackes from the different areas are very similar (Fig.8 f,g & h), which is in accordance with the interpretations presented above.

In summary:

The dominating extrusive and intrusive rocks in the window are pottassic with alkaline affinities (alkali-calcic), while Mg-tholeiites (komatiites) and tonalitic intrusive and extrusive rocks are less widespread. The chemical composition of greywackes suggest that they are derived from the volcanic rocks similar to those in the supracrustal sequences. Furthermore the relatively mafic character of the greywackes reflects a geological environment in which mafic volcanism was significant at the early stage of this region's geologic history. The region has evolved to less mafic composition with time e.g. intrusion of large volumes of granites.

Table 1. Representative analyses of rocks from the Rombak Window.

	Intrusive rocks			Extrusive rocks							Greywackes		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
SiO_2	72.87	67.26	50.39	76.78	68.77	62.61	74.68	45.66	55.35	51.37	63.74	64.45	56.19
Al_2O_3	13.77	15.91	14.68	11.13	14.12	18.51	13.30	6.40	15.63	15.57	14.69	14.61	14.13
Fe_2O_3	2.50	3.35	12.96	3.05	4.47	2.47	1.43	9.38	8.05	9.79	7.90	7.39	10.82
TiO_2	.27	.46	1.83	.20	.54	.74	.25	.20	1.23	1.09	.83	.76	.98
MgO	.37	1.29	5.43	.13	.51	.59	.87	26.03	4.18	6.47	3.41	3.61	6.42
CaO	1.05	2.65	7.99	.84	1.75	2.09	1.58	6.87	5.95	5.83	2.78	1.69	3.11
Na_2O	3.54	6.14	2.65	1.76	3.23	5.56	5.20	.17	3.90	2.48	2.90	3.25	2.95
K_2O	5.15	1.78	1.99	5.60	5.68	6.08	1.69	.02	3.49	2.78	2.75	2.98	4.06
MnO	.03	.05	.19	.06	.06	.05	.02	.17	.12	.19	.08	.06	.10
P_2O_5	.06	.13	.60	.01	.11	.24	.04	.02	.45	.36	.13	.13	.13
L.I.	.42	.79	.83	.58	.64	.88	.68	4.28	.84	3.60	1.01	1.04	.89
Total	100.03	99.81	99.54	100.14	99.87	99.82	99.74	99.20	99.19	99.53	100.22	99.97	99.78
Sr	83	478	383	112	180	335	291	<12	738	350	263	187	135
Rb	285	48	73	260	239	75	46	-	148	136	103	127	152
Ba	500	692	694	51	979	1680	1542	38	1289	921	835	754	650
Zn	74	32	145	49	78	<30	9	66	125	112	139	105	72
Cu	-	5	50	-	<31	-	-	19	<9	<10	<47	40	60
Pb	31	13	13	25	27	-	13	-	<18	<14	na	na	11
La	79	35	29	94	57	23	23	-	52	22	28	39	14
Ce	166	64	56	191	122	46	48	-	118	56	47	71	18
Zr	239	179	140	705	326	20	188	21	251	116	173	176	114
Y	60	17	27	85	49	9	21	27	27	21	22	22	20
Nb	19	15	8	35	17	<7	18	-	17	<7	9	12	8
Th	40	11	-	25	21	-	11	-	-	-	-	-	-
Sc	-	7	25	<4	8	<7	5	24	15	24	17	11	20
Co	-	5	42	-	<10	-	<7	85	24	35	na	na	34
Ni	-	10	42	<6	8	-	4	1334	58	45	88	81	139
V	-	42	190	<8	30	18	21	151	138	145	189	150	164
Cr	-	11	68	<12	14	-	-	2600	124	236	236	262	336
n	23	4	16	5	4	5	3	3	23	4	4	6	4

(1) Granite, SN-type
(2) Tonalite, G-type
(3) Basic intrusives
(4) Felsic volcanics, Stasjonsholmen, SN-type
(5) Felsic volcanics, Cainhavarre, SN-type
(6) Felsic volcanics, Muohtaguobla, SN-type
(7) Felsic volcanics, Gautelisvatn, G-type
(8) Mg-tholeiites/komatiites, Ruvssot, R-type
(9) Mafic/intermediate volcanics, Sørdal, SN-type
(10) Mafic volcanics (strongly altered), Muohtaguobla
(11) Greywackes, Gautelisvatn
(12) Greywackes, Rombaken
(13) Greywackes, Ruvssot

n : Number of analyses
\- : More than 1/3 of the samples have values under detection limit
<27: Less than 1/3 of the samples have values under detection limit. The number (27) is average of the remaining values.
na : Not analysed

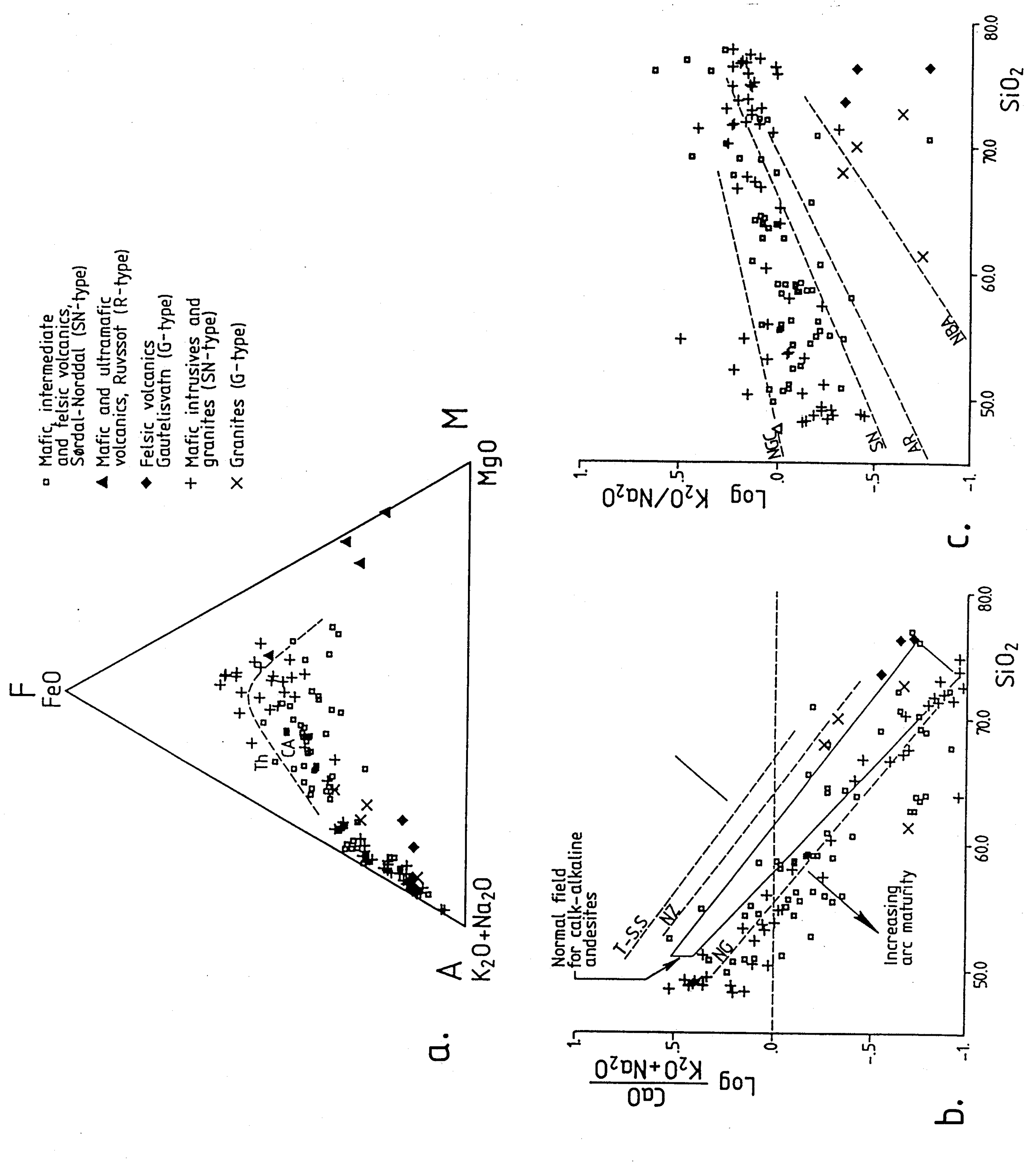

FIG. 4 Major geochemical characteristics for Skjomen-Rombaken igneous rocks. (a) AFM diagram. Th - tholeiitic; CA - calc-alkaline. (b) Calc-alkali ratio - silica plots for Skjomen-Rombaken intrusive and extrusive rocks compared with trends for volcanic suites from modern magmatic arcs showing the change from calcic to calc-alkaline (abundant) suites with increasing maturity (after Brown 1982). The alkali-lime index (SiO_2 concentration where CaO = $Na_2O + K_2O$) lies between 51 and 56 for alkali-calcic suites (see text). T-SS - Tonga-S.Sandwich; NZ - New Zealand; NG - New Guinea. (c) Alkali ratio - silica plots for Skjomen-Rombaken intrusive and extrusive rocks compared with trends for intrusive suites from Mesozoic and Tertiary magmatic arcs (after Brown 1982). NGC - New Guinea Continental; SN - Sierra Nevada; AR - Alaska Range; NBA - New Britain Arc.

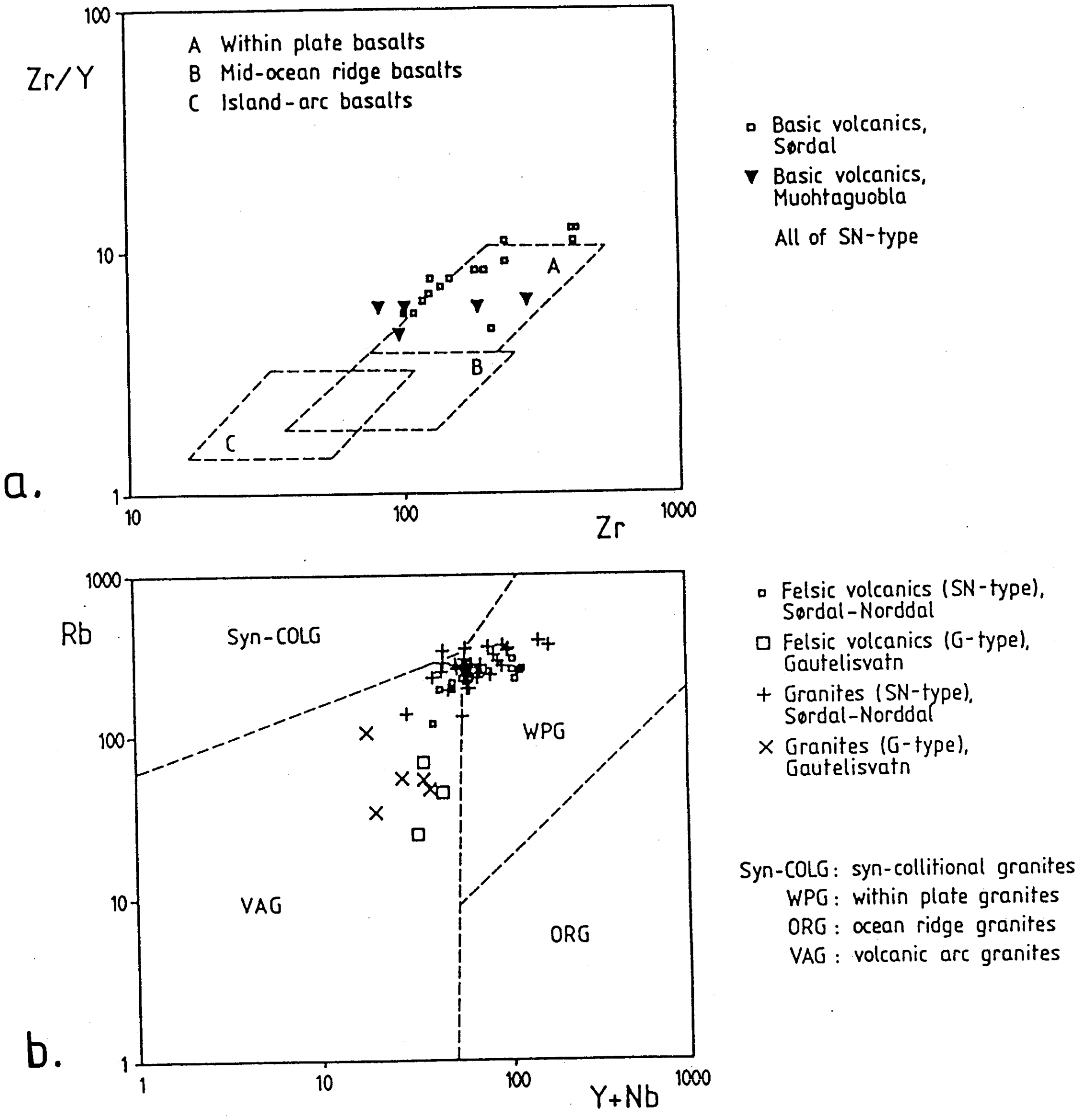

FIG. 5 Two selected discrimination diagrams for basic and acidic rocks: (a) Zr - Zr/Y relations for basic rocks (SiO_2 < 56 %). Diagram after Pearce & Norry (1979). (b) (Y + Nb) - Rb relations for acidic rocks (SiO_2 > 56 %). Diagram after Pearce et al. (1984).

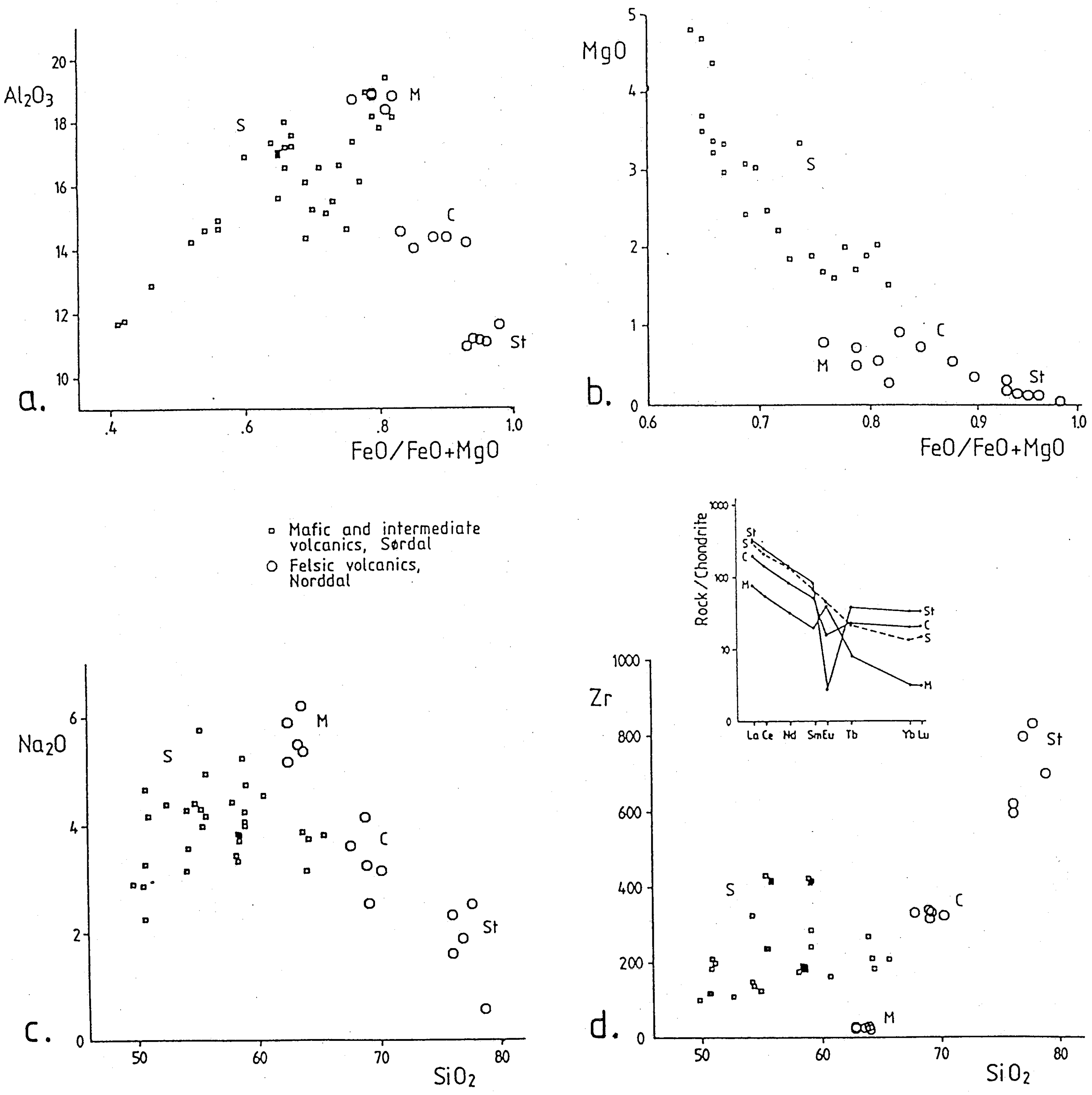

FIG. 6 Differentiation trends for Sørdalen - Nordalen volcanic rocks presented in (a) FeO/(FeO+MgO) - Al_2O_3, (b) FeO/(FeO+MgO) - MgO, (c) SiO_2 - Na_2O and (d) SiO_2 - Zr diagrams. S - Sørdalen; M - Muohtaguobla; C - Cainhavarre; St - Stasjonsholmen.

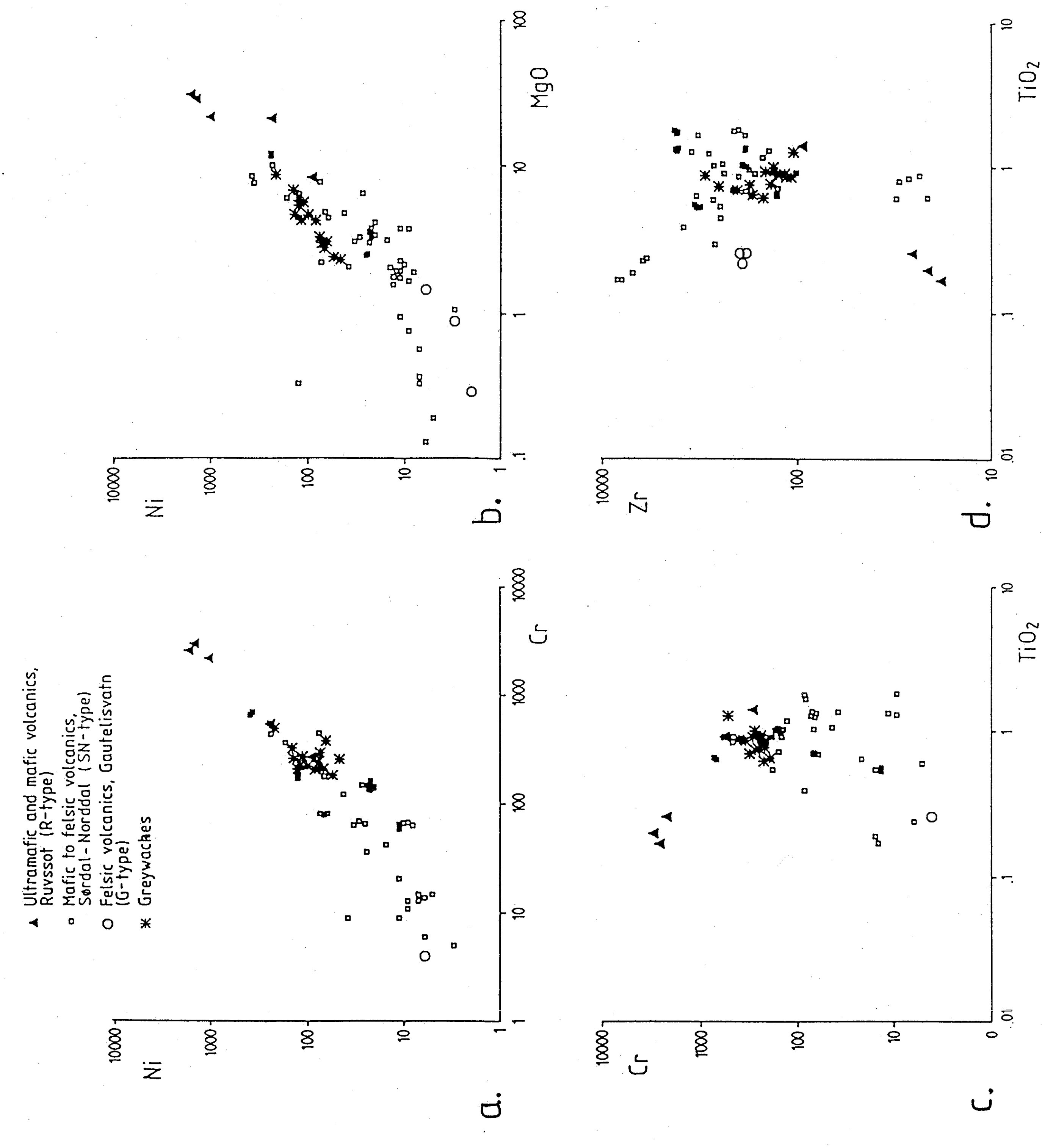

FIG. 7 The composition of greywackes compared with the volcanic rocks presented in (a) Cr - Ni, (b) MgO - Ni, (c) TiO_2 - Cr and (d) TiO_2 - Zr diagrams.

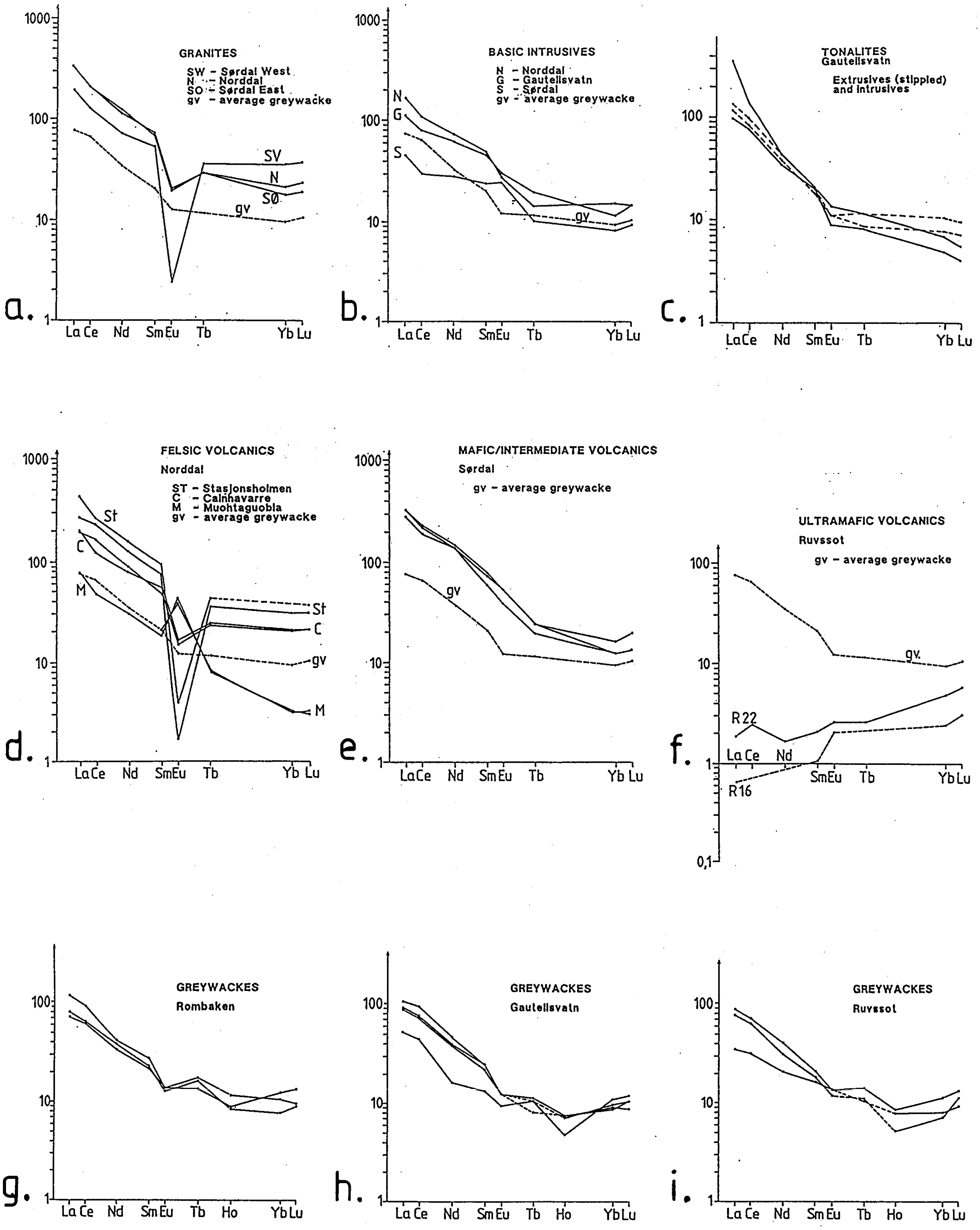

FIG. 8 Chondrite normalized REE patterns for Skjomen-Rombaken intrusive and extrusive rocks and greywackes. Chondrite values after Taylor & Gorton (1977).

5. METAMORPHISM

The Rombak Window, at least in its central, western and southwestern parts, has been metamorphosed to epidote-amphibolite/amphibolite facies grades (P>6 kb, T 575 to 600 °C; see Sawyer 1986). Evidence for this is widely preserved in the mineral zonation patterns found in the intermediate and basic volcanics. Thus basement metamorphism was of similar grade to that which affected the overlying Caledonian nappes. A later greenschist facies retrogression, possibly also of moderate to high pressure, has affected the window to varying degrees. In most places retrograde reequilibration of minerals is absent or minor. However, in the Muohtaguobla area the greenschist retrogression has virtually obliterated evidence of the earlier higher grade metamorphism. The intensity of retrogression in the Muohtaguobla area may be related to the existance of a major N-S trending structural lineament in the vicinity (Figs.2 and 9).

6. STRUCTURAL CONTROL OF FLUID FLOW.

The channelling of fluid flow along tectonic structures such as shear zones has been proposed as the means of mobilization and the potential site of the deposition of ore deposits. However, since fluid flow is from region of high to low pressure, a shear zone must contain a connected pathway to a low pressure region (it must be dilatent) before fluid flow will occur. The condition under which and the mechanism by which shear zone deformation takes place determines whether significant dilatency can occur.

Field and petrographic observations of the shear zones (early set) from the Skjomdal - Sørdal - Gautelis area indicate that they are deformed in a ductile manner with very little associated dilatency. On the microscopic scale quartz forms long ribbons typical of high-strain plastic deformation, but feldspars show low strain effects such as undulose extinction, fracturing and kinking. This difference arises from the contrasting mechanical properties of quartz and feldspar, but since quartz is abundant, strain is partitioned into quartz. Dilatency in fractured feldspars is probably transient since, in most cases, cracks are filled by quartz. On the macroscopic scale the lack of veins, tension gashes and boudinage structures all indicate little dilatency. Analysis of the shearzones from

Sørdalen indicate some mobility of certain elements, but this appears to be relatively minor. Although individual shear zones in the Sørdalen area were not dilatent there is evidence to indicate that large en echelon tension fractures did develop in the less sheared rock between shear zones.

Younger, subvertical shear zones that are prevalent in the Muohtaguobla area (Fig.2) are accompanied by dilatent features such as quartz veins and tension gashes. Furthermore, there is also petrographic evidence for large scale fluid (H_2O-CO_2) flow associated with these structures. Thin sections from the Muohtaguobla area all show some degree of greenshist facies retrogression (i.e. hydration) of epidote-amphibolite or amphibolite facies assemblages. In many cases the higher grade assemblage has been completely altered to chlorite + albite + epidot + calcite + quartz greenschist assemblages. The subvertical shear zones at Muohtaguobla therefore appear to have acted as the channels for extensive fluid infiltration.

7. AGE RELATIONS

The volcano-sedimentary sequences previously described are the oldest rocks known in the Rombak Window. They are intruded by basic, intermediate and acidic plutons: the granites have been dated at 1691 +/- 90 (Heier & Compston 1969) and 1780 +/- 85 Ma (Gunner 1981). These ages are believed to represent crystallization, though the possibility that they represent early Proterozoic metamorphism cannot be ruled out. The basic and intermediate intrusives tend to be older than the granites and syenites, though basic dykes intrude granite in a few places. The intrusive relations are complex since both the basic and acidic rock-types occur in various generations, but in general the various intrusive rocks are believed to be of more-or-less the same age i.e. early Proterozoic.

Post intrusion regional deformation is accompanied by lower amphibolite facies metamorphism, while the later retrogression to greenschist facies is significant along a major N-S trending lineament in the Muohtaguobla area. Deformation and metamorphism may be Caledonian in age but no absolute ages are available.

8. ORE MINERALIZATION TYPES IN THE ROMBAK WINDOW

The following types of metal deposits/mineralizations have been found in the supracrustal sequences in the window:

A. GOLD. A carbonate/marble horizon at Gautelisvatn (Chapt. 10) contains 3 types of gold-bearing mineralizations: (1) one body of semi-massive arsenopyrite, (2) disseminated pyrite +/- chalcopyrite in calc-silicate lenses and layers in the carbonate, and (3) larger volumes of more or less invisible pyrite in impure parts of the carbonate. In all these varieties the gold commonly grades are up about 10 ppm, exceptionally up to 300 ppm Au in type 2 mineralization. In variety (3) which is the only one presently of economic interest, gold values over 3 m thickness may reach 6-7 ppm. Over thicknesses of 10-20 meters the grades are higly variable. Associated elements are As, W, Bi, Te, Bi, Cu and $C_{graphite}$.

B. COPPER. (a) Exhalative deposits of disseminated and massive bornite + chalchopyrite +/- magnetite are associated with mafic volcanics in the Ruvssot-Sjangeli area in the southeastern part of the window, (b) low-grade, disseminated chalcopyrite + pyrite occur in the Gautelisvatn area within an impure quartzite, and (c) minor, disseminated chalcopyrite +/- bornite +/- magnetite in mafic/intermediate volcanics in Sørdal. The gold content in these mineralizations generally range from 0.2 to 0.5 ppm. Copper deposits in the window often contains several percent copper, but since they are also relatively small with low contents of precious metals, they represent no economic potential at present.

C. ZINC-LEAD. Haugfjellet: Zn-Pb-(Cu) mineralizations in the Haugfjellet area north of Rombakfjord occur as disseminations, massive lenses and fracture fillings which in places resembles stockworks (Flood 1984, 1985). They occur mainly within carbonate beds but do also occur within greywackes and mafic tuffites. Average metal grades are generally < 1.3 % Zn, < 0.5 % Pb, < 0.5 % Cu, < 15 ppm Ag and < 0.1 ppm Au, although higher grades occur locally. In general Au and Ag show their highest concentrations (up to 1.3 ppm Au and 420 ppm Ag) associated with high base metal values (10-20 % Zn+Pb). However, samples assayed up to 0.4 ppm Au without associated base metals. Arsenopyrite is present as fine-grained disseminations and thin bands in black shales and bedded tuffs. Pyrite and pyrrhotite occur as thin bands, disseminations and fracture fillings, particularly in the black shales. Their presence is characteristic for the area in general, but higher consentrations are normally seen deficient in precious and base metals.

Klubbvatnet: Compared to Haugfjellet the Klubbvatnet area (northern part of Stasjonsholmen belt) has more greywackes and less black shales. Thich amygdaloidal flows of andesite with associated sedimentary breccias, indicate a more proximal situation compared to the Haugfjellets green tuffs. Exhalites, as thin magnetite-banded iron formations and garnet-quartzites, are associated with the andesites. The mineralization types are generally similar to Haugfjellet, but arsenopyrite is less common and shear-zones do to a larger extent control the mineralizations (Flood 1985).

The variation in the element correlation coefficients between the Haugfjellet and Klubbvatnet samples (Table 2) illustrates that the two areas represent distinct different geochemical environments. The difference may reflect differences in the principal ore concentration mechanisms, for example a larger component of shear-zone controlled mineralizations at Klubbvatnet compared to Haugfjellet.

Table 2. Comparison of correlation coefficients for Klubbvatnet and Haugfjellet (rock samples). After Flood (1985).

	Klubbv. (n=195)	Haugfj. (n=587)
Ag-Au	0.63	0.21
Au-As	0.01	0.55
Ag-Pb	0.65	0.90
Pb-Au	0.73	0.25
Pb-Zn	0.23	0.87
Zn-Cu	0.06	0.68
Cu-Pb	0.13	0.60

ARCO's model consept, Rombaken area.

The type of mineralization and geological setting at Rombaken has led ARCO to the following model consept (Flood 1985):

(1) The most likely targets will be sedimentary-hosted and/or volcanogenic, massive Zn-Pb-Ag deposits. The Zn/Pb-ratio will be approximately 3/1 and the ore will contain around 5% of iron sulphides.

(2) The ores and their host rocks have probably been deposited on an Archaean crust in an intracratonic basin. Reactivation of Archaean fractures extending into the overlying package caused formation of second and possible third order basins with deposition of sedimentary breccias. The active fractures were also channel-ways for volcanic extrusive material and hydrotermal fluids.

(3) Klubbvatnet is probably part of a basin with proximal deposition of volcanics while Haugfjellet is assumed to represent a different basin with a more distal character. The geochemical characteristics of these two areas are also different, especially with respect to base metals.

(4) The fractures and/or faults along the basin margins may also have controled the granitic intrusions. Hence the supracrustals from different basins to day appear as separate inliers in the granites.

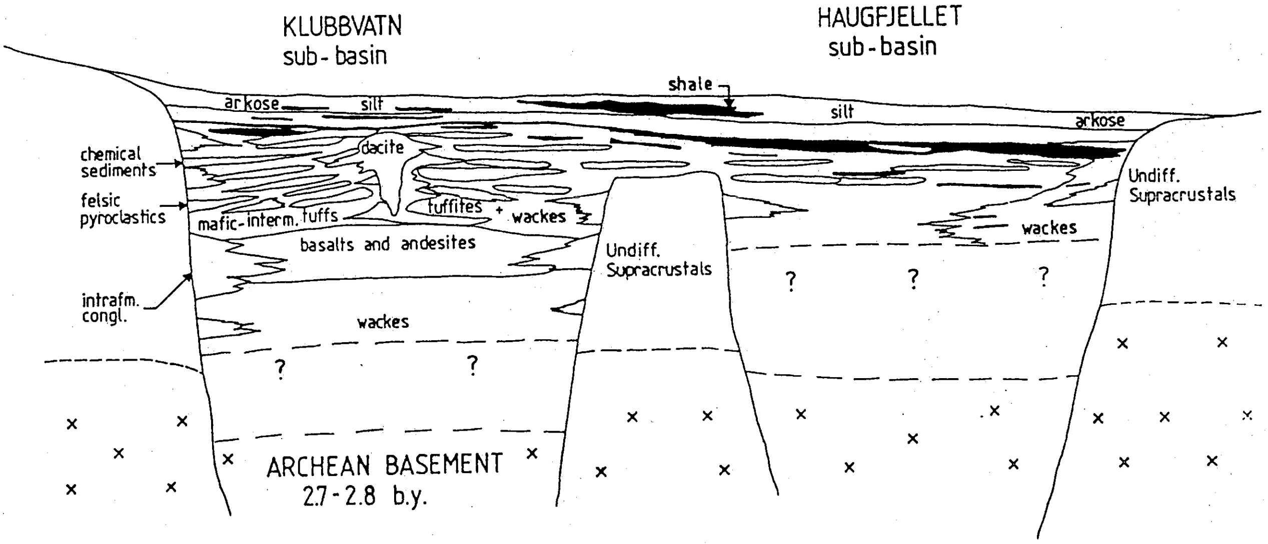

FIG.9 Inferred depositional environment, Rombak basin (not to scale, from Flood 1985).

Favorable gelogicical environments for gold-mineralization in general.

The formation of economic gold deposits have been episodic in the Earth's history; the majority are associated with Archaean greenstone belts either directly or indirectly, few occur in early Proterozoic rocks, they are absent in middle Proterozoic rocks, but occur again in late Proterozoic and Phanerozoic environments (Hutchinson & Burlington 1982). Important types of gold deposits are: hydrotermal quartz-veins and exhalative deposits, gold in Precambrian quartz-pebble conglomerates of Witwatersrand type, and recent placer deposits formed by erosion of gold-bearing rocks. Additionally a siginificant amount of gold is produced as by-product from a variety of sulphide deposits.

The formation of an economic gold deposit is the result of a combination of different favorable circumstances. Firstly, a source-rock is needed; this may be gold-enriched sediments or hydrated ultramafic volcanics which are generally accepted as the most favorable primary source-rock for gold. Secondly, a favorable combination of leaching, transportation and concentration/precipitation mechanisms are required.

Ultramafic rocks may be favorable source-rocks for gold primarily because they are highly susceptible to hydration/dehydration reactions; an hydrated ultramafic rock will lose gold dissolved in metamorphic fluids (mainly H_2O) as it dehydrates during progressive metamorphism (Kerrich 1980, Fyfe & Kerrich 1982). Deep-seated brittle-ductile shear zones, which can act as channels for such metamorphic fluids, represent a favorable precipitation environment at higher levels in the crust. Vein-type gold deposits may form within such shear zones. In some deposits (Carlin type) primary control of ore deposition are high-angle faults that transects a favorable host-rock type, typically a thin-bedded silty to sandy carbonaceous siltstone or carbonate rock. Gold precipitation are assosiated with replacement reactions between the gold-bearing fluids from the shear zone and the carbonate.

Alternatively, if rocks are hydrothermally altered in a sea-floor environment, gold is precipitated within a chemical sediment near the hydrotermal vents from which the fluids escape. Such exhalative deposits are often associated with acid volcanics.

Hydrothermal gold deposits tend to be distinctly enriched in rare elements such as B, As, Sb, W and Pd compared to exhalative Cu,Zn,Pb-sulphide deposits (Fyfe & Kerrich 1982). This indicates a fundamental difference in the hydrothermal mechanisms operating, and is an argument in favour of the metamorphic-fluid hypothesis for the formation of gold deposits.

According to this line of arguments, these sircumstances make this region favorable for gold deposits: (1) *Favorable source rocks.* Mafic and ultramafic volcanic rocks (R-type; Chapter 4), which are generally accepted as favorable source rocks for gold, have participated significantly in this region's early geologic evolution. (2) *Consentration mechanisms.* Chemical sediments associated with acid volcanics and shear zones which have acted as channels for hydrotermal fluids, indicate that consentration mechanisms for gold may have been active.

The Gautelisfjell gold deposit (Chapter 10) shows that effective consentration of gold have in fact happened at some stage (probably early) in the region's evolution. Which mechanism, however, that have been active, is unknown. Gold found in stream sediments elsewhere in the region (Chapt. 9) is another argument which make this region attractive for gold. The stream-sediment gold anoma lies indicate that gold mineralizations may excist at different places in the region.

9. STREAM SEDIMENT ANOMALIES

Anomalous sub-areas of Au, As, Zn, Pb and Cu (Fig.10) has been delineated by ARCO using stream sediment sampling of an area of 600-700 km^2 (800 samples) and on follow up stream sample heavy mineral concentrates (168 samples) from selected sub-areas. The follow-up investigations, including diamond drilling, have been concentrated in the Zn-Pb anomalies north of Rombakfjord, while less effort has been put into finding the sources of the gold anomalies.

The occurrence of gold in stream sediments in the Rombak window probably results from the weathering of several very fine grained invisible gold mineralizations of different types. Undoubtedly they will require a considerable effort to be found. Characteristically, the only gold deposit found in the window at present (Gautelisfjell) was revealed by the outcrop and workings on massive arsenopyrite, and was not found by the regional stream sediment sampling carried out by Folldal Verk. Follow up heavy fraction sampling in streams (panning) in areas which are anomalous in stream sediment gold, often confirm the anomaly (0.1 - 23 ppm Au; the background level is < 50 ppb Au). In some occations, however, the stream sediment anomaly is not confirmed. This may be due to a very fine-grained nature of the gold.

H1 & 2 (Haugfjell; Cu, Au, Pb, Zn, As): The source of the base metal and arsenic anomalies are described in Chapt. 8. Gold is partly associated with the base metals, but does also occur as descreet stream sediment anomalies. Follow up by stream heavy fraction and partly rock chip sampling has confirmed an anomalous background for Au (Mean=21 ppb and 90th percentile=45 ppb from 57 chip samples). Economic grades, however, has as yet not been found.

When exploring the area north of Rombaken statistical (grid) sampling was conducted over an area of around 6 km^2 with greywackes, black shales, tuffs and thin carbonates. The result is shown in table 3. Note the high mean values for Zn, Pb and As compared with average shale values (Krauskopf 1967). The highest values generally coincide with visual mineralization.

Table 3. Haugfjellet grid sampling (n=323).
Au in ppb, other elements in ppm.

	Mean	90%ile	Lowest	Highest	Krauskopf (1967) average shale
Cu	62	101	2	253	57
Pb	97	121	2	6483	20
Zn	261	379	83	5015	80
Au	5	13	1	446	<50
Ag	0.33	0.1	0.1	10	0.07
As	101	175	2	5030	7
Sb	14	25	2	353	1.5

Mf (Middagsfjell; Cu, Co, Pb, Zn, Au) and B (Beisfjord; Cu, Co, Pb, Zn, Au): These anomalies distinguish themselves by their position along and partly within the Caledonian nappes. They have the best concentration of anomalous Co values within the area (95 percentile = 32 ppm). Heavy fraction sampling on the Beisfjord anomaly confirmed the base metal, but not the gold anomalies.

S (Sildvikvatnet; Au: A moderate Au stream sediment anomaly in granitic terrain.

K (Klubbvatnet; Au, Pb, Zn, Cu, As) and Lv (Leirvatnet; Cu, Au, Pb, As, *Zn)*: The geological environment in the Klubbvatn area which is briefly described in Chapt. 8, extends south to Leirvatnet. The latter area show a more distal character with lack of andesitic lavaflows.

Follow up by heavy fraction sampling strongly confirm the Au anomaly at Klubbvatnet and a smaller stream sediment Au anomaly at Hunddalen between Klubbvatnet and Leirvatnet. Only a weak response on Au was the result from Leirvatnet.

Further work was mainly confined to Klubbvatnet by mapping and rockchip sampling. The best Au values, up to 1.1 ppm, were encountered associated with the more conspicious base metal mineralization, but Au up to 0.2 ppm also occur without obvious base metal support.

L1 & 2 (Losi; Au): The geology resembles the Leirvatn area. Within the supracrustal belt extending from Rombaken southwards to Losi, iron sulphides are playing a significant role leaving a marked ruststaining on the weathered rock surfaces, particularly along some horizons.

At Losi heavy fraction sampling and limited rockchip sampling was carried out. The heavy fraction result showed a weak response.

C1, 2 and 3 (Cunojokka; Au, As): The geology of this area is both lithologically and structurally very complex with a mixture of supracrustals and intrusives, with shear-zones. Heavy fraction sampling of all three localities confirm the anomalous state of gold in this area, but without revealing the source.

M (Muohtaguobla; Au, Cu): The geology of this area is very complex with a variaty of volcanis and sedimentary rocks and basic to acidic intrusions. Shear-zones in the area have acted as channels for hydrotermal fluids (Chapt. 6). Resampling of the streams by the heavy fraction method did not confirm the gold anomaly.

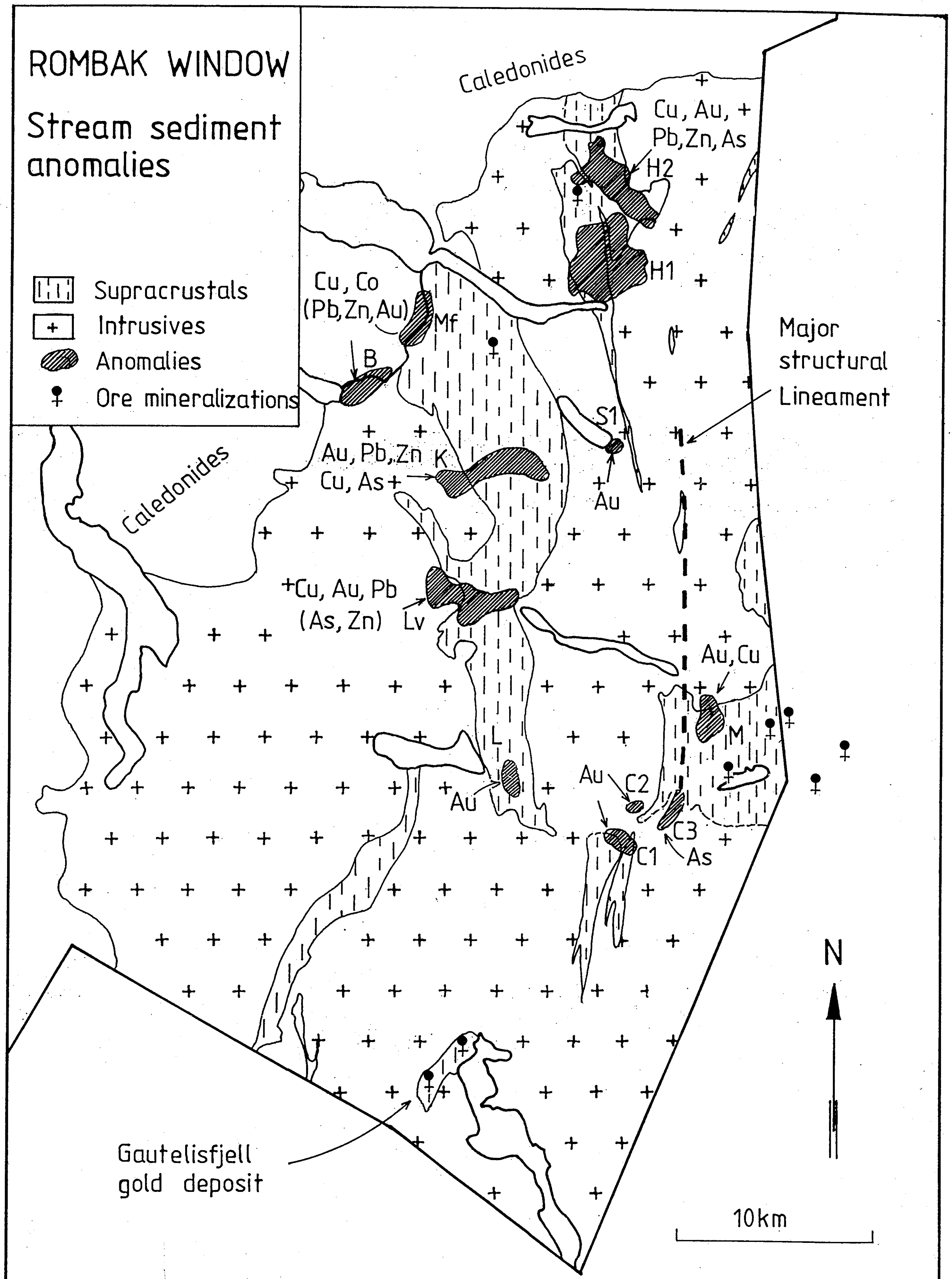

FIG.10 Stream sediment anomalies in the Rombak Window. Modified after Flood (1984, 1985). H1 & H2 - Haugfjellet 1 & 2; Mf - Middagsfjell; B - Beisfjord; K - Klubbvatnet; Lv - Leirvatnet; L - Losi; C1, C2 & C3 - Cunojokka 1,2 & 3; M - Muohtaguobla.

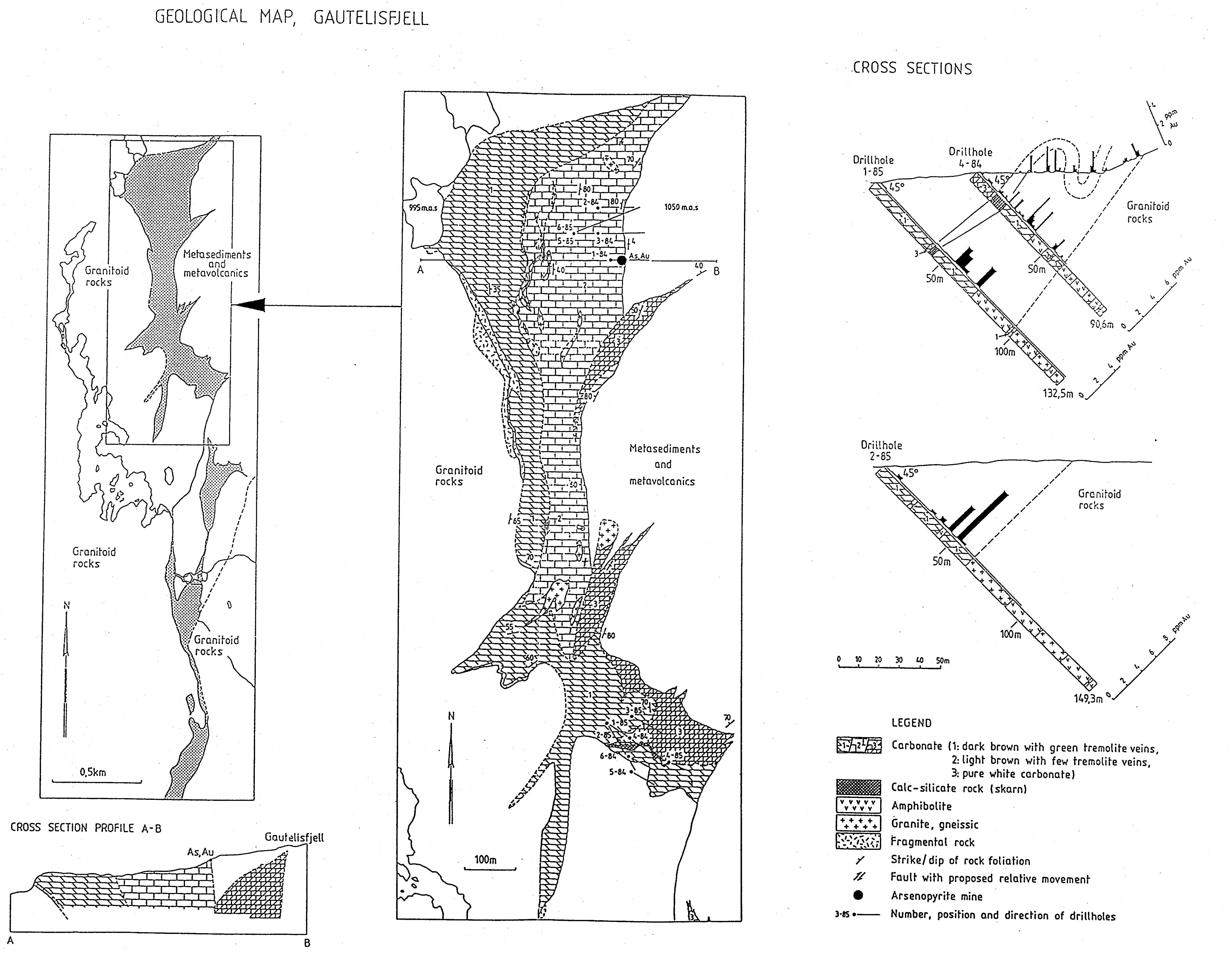

FIG. 11 Geological map of the Gautelisfjell gold deposit.

10. THE CARBONATE-HOSTED, DISSEMINATED GOLD MINERALIZATION AT GAUTELISFJELL

10.1. INTRODUCTION

The potential for gold mineralizations in the Gautelisfjell area were first recognized by Folldal Verk A/S after their investigation of a previously known semi-massive gold-bearing arsenopyrite mineralization during 1983 (Priesemann 1984). In 1984-1985 1500 m of diamond drilling were carried out which lead to the discovery of a variety of disseminated gold-bearing mineralizations in carbonates. These mineralization types have not previously been reported from Norway.

10.2. GENERAL GEOLOGICAL CHARACTERISTICS

The area (Fig. 3 and 11) is characterized by a supracrustal sequence dominated by greywackes with intercalations of (1) basic and acid volcanics in the western parts, (2) conglomerates, some of which are interpreted as debris flows, (3) breccias, and (4) carbonates. The area have been mapped in a regional scale by Skonseng (1985).

The supracrustals are generally trending N-S with vertical dip, though in detail large variations occur due to folding. Graded bedding in the greywackes generally indicates way up towards the east. They are intruded by subparallell (N-S) porfyric basic dykes and minor bodies, and granitoid intrusives. In general the basic dykes are older than the acidic intrusions though they do occationally intrude the granitoid rocks. The basic dykes probably occur in two generations. Pebbles in the conglomerates are composed of finegrained basic and felsic rocks of presumable volcanic origin and tonalitic-granodioritic rocks equivalent to granitoids west of Gautelisfjell (not mapped). The contact relations between the Gautelisvatn tonalites and the supracrustals are cruical in determining the geologic evolution of the area, and may also be important in the interpretation of the geneses of the ore-mineralizations.

10.3. ROCK DISCRIPTIONS

Carbonates: In the Gautelisfjell area two main sequences are dominating: greywackes and volcanics to the east and a thick carbonate horizon to the west. The carbonate rocks are subdivided into two main varieties: pure, white carbonate and impure, brownish, dolomitic carbonates. The carbonate type 2 which is marked on the geological map og the deposit area (Fig.10) is a variety of the impure carbonates. The pure carbonate is found in the eastern and structurally upper parts of the carbonate horizon, preferably where the carbonates are folded into the sedimentary/volcanic sequence. It consists of coarse-grained calcite and dolomite, and weather into smooth, white to greywhite slabs. Internal structures are insignificant. The impure carbonates which predominate structurally below this unit, make up the dominating part of the carbonate horizon and has a banded banded appearance due to light greenish bands and veins of coarse-grained tremolite. These bands are from 1 cm to 1m wide and occur in both cross cutting and concordant situations relative to a diffuse banding in the carbonate. In places they are intensely folded.

The impure, silica-bearing carbonate has a dark brown to beige color when weathered. Characteristically well-developed cubic and octahedral crystals of pyrite occur unevenly distributed in tremolite veins (distorted layers ?) and in the impure carbonate. The brownish weathered surface is due to alteration of pyrite. The intensity of the color is strongest in the western part of the horizon towards the contact against the granitoid rocks. The impure carbonates have been subdivided into two varieties based on color and tremolite veins. Unevenly distributed muscovite and chlorite add to a diffuse, banded appearance.

Calc-silicate rocks: Layers or benches of a green rocktype with diopside, tremolite, garnet (grossular) and epidot are up to a few meters wide. This rock may represent primary layers of impure limestone that has been altered to calc-silicate rocks (skarn). Various types have been found: In the Gautelisfjell-area the skarn occur as irregular, finegrained aggregates. Further to the south towards the swedish border, the skarn-rocks occur as lenses or boudins up to a few meters wide. In places the lenses show zoning with a rim of diopside/tremolite and a core of garnet and epidot in between. Aggregates of coarse-grained garnet occationally contains magnetite on fractures as a late mineralization face. The skarn lenses are generally tightly folded.

Fragmental rocks: Various types of "fragmental rocks" occur along the border between the carbonate rocks and the tonalitic rocks. The fragmental rock is next to the tonalite composed of rounded to subrounded fragments (< 15 cm) of quartzite and tonalite in a chlorite-rich matrix. The contact to the underlaying tonalite is gradational. Occationally there is a distinct graded bedding showing upwards away from the tonalite. This graded sequence grades into a 1-3m well layered sequence with small quartz-pebbles (up to a few cm) in a chloritic matrix. This layered sequence is characterized by alternating bands of finegrained tremolite-skarn and quartz-pebbled fragmental rock. The quartzitic fragments contains polygonal quartz-grains that generally lack optical strain features. Due to these arguments the fragmental rocks are believed to represent a sedimentary sequence formed after the erosion of the tonalite.

Amphibolites: The rocks consideres here are cross cutting dikes of two generations. The younger generation are cutting the granites, whlie the older one predate the granites.

Granitoid rocks: The granitoid rocks in the Gautelisfjell-Gautelisvatn area are of two main types: (1) The by volume dominating type is middle to coarse-grained porphyric K-rich granite which is similar to the common type of granites elsewhere in the Rombak Window. These granites are believed to be the intrusive equivalents of the SN-type K-rich volcanics (Chapt.4).
(2) The other type is tonalitic-granodioritic. It occurs in middle to coarse-grained quartz-porphyric varieties. The contact relations between the different granitoid rocks have not been mapped. Felsic volcanic rocks (not mapped) next to the carbonate unit west of Gautelisvatn are chemically very similar to the tonalite (see Chapt. 4). Pebbles of similar tonalitic rocks are frequent in conglomerates in the supracrustals. This indicate that these rocks have been eroded during the volcano-sedimentary period. This is in good accordance with the above interpretation of "the fragmental rocks" as being the product of erosion of the tonalite.

Table 4. Main element analyses of carbonate and calc-silicate rocks.

	White carbonate	Brown, impure carbonate		Calc-silicate rock
Sample	84-04-2-3	84-51	84-04-60	84-45
SiO_2	3.00	24.30	19.40	40.70
Al_2O_3	0.72	2.24	1.94	6.99
CaO	46.90	25.90	29.10	28.90
MgO	6.84	16.60	16.60	3.83
Na_2O	0.04	0.07	0.06	0.16
K_2O	0.07	0.06	0.16	0.47
Fe_2O_3	0.80	6.90	3.04	15.00
MnO	0.10	0.21	0.25	0.59
TiO_2	0.05	0.17	0.14	0.53
P_2O_3	0.03	0.10	0.05	0.09
LOI	42.00	19.80	29.20	2.00
Total	100.55	96.35	99.94	99.26

10.4. ORE MINERALIZATIONS

The gold-mineralizations associated with the carbonate rocks on Gautelisfjell can be divided into three main types:

1. Au associated with semimassive to massive arsenopyrite.
2. Au associated with distinct impregnations and semi-massive mineralizations of other sulfides, mainly pyrite and chalchopyrite.
3. "Invisible" disseminations of gold in large areas of the carbonate horizon.

The *type 1* arsenopyrite-gold mineralization is located in the northern part of the western slope of the Gautelisfjell, at the boundary between the metasedimentary/metavolcanic series and the carbonate horizon. It has a lensoid geometry 50 m long and maximum 2.5 m wide, based on drill-cores. Massive/banded arsenopyrite dominate the central part of the orebody while disseminations and veins (distorted bands ?) occur at the rim. The host-rock is a light grey, fine grained, tremolite-bearing quartz-feldspar rock with subordinate sericite, apatite, sphene and clinozoisite. Brecciation with infiltration of arsenopyrite-mineralized carbonate is common. Priesemann (1984) have interpreted the mineralization to be of exhalative-hydrothermal origin deposited in a proximal position to a hydrothermal vent.

The semimassive arsenopyrite have up to 25 % As with the corresponding gold up to 11 ppm Au. A samples with 4.16 % As contain 2.1 ppm Au and 7.1 ppm Sb. The mineralization was mined for arsenic during the period 1916-1920. Approx. 400 tons of ore were produced.

The *type 2* mineralization is generally less than a few meters long and a few decimeters wide, and is easily seen because of a relatively high content of sulfides (5-25 %). The sulfides are most often pyrite and/or chalchopyrite (/malachite). Pyrrhotite, sphalerite, galena and magnetite occur in variable but minor amounts. The host rock may be either of (a) a quartz-phyllitic type as fragments in the carbonate rocks or (b) as relatively diffuse, flat lenses of tremolite-rich carbonate. This type of mineralization can be found everywhere in the impure carbonate but most often in the upper (eastern) part. They are strongly tectonized.

One of these lenses (a distorted band ?) were found to have exceptionally high gold contents, as shown in Table 5.

Table 5. Analyses from one selected gold mineralization of type 2 (see text).

Sample no.	Au ppm	Cu %	Pb %	Zn %	As ppm	Ag ppm	Te ppm	Bi ppm	W ppm	S %
GAU-85-401	49.45	3.28	.00	.05	6	52	370	600	2400	4.44
-402	1.74	.81	.01	.01	13	10	2.4	4	150	1.02
-403	329.66	.52	2.4	.69	780	61	240	460	<3	1.58
-404	4.35	2.73	.02	.02	14	24	9	7	2	2.30

The *type 3* mineralization is the only one that are believed to have an economic potential due to its larger volume. It occurs within impure, dark carbonates in the lower, western part of the carbonate unit. In addition to pyrite scheelite is recognized macroscopically.

Samples have been analysed for As, Sb, W and S. The As-grades in the gold-mineralized carbonates (type 3 mineralization) vary from 2 to 28 ppm, Sb is less than 0.3 ppm. W is generally less than 10 ppm although values up to 0.2 % have been detected. There is no direct connection between high values of Au and W in the rock. The sulfur content is also highly variable from under detection limit (0.01 % S) to 2.43 % S. There is no close correlation between the high gold and high sulfur values. For example do one sample with 4.7 ppm Au contains 2.14 % S, another 1 ppm Au and 2.43 % S, while a sample with a content of 1.7 ppm Au did not have detectable amounts of sulfur. The distribution of some selected elements in diamond drillhole 4-84 is presented in Fig. 12.

A variety of minerals have been identified by electron microprobe (Krause 1985): (1) Small grains (<0.01 mm) of the Pb,Bi-sulfosalt cosalitt ($Pb_2Bi_2S_5$; which may have formed by alteration of galenabismutite, $PbBi_2S_4$). (2) Some grains of hessite (Ag_2Te, < 10 mm) occur associated with cosalite. (3) Argentite (Ag_2S) is closely assosiated with galena. (4) Native Bi occur along fractures and on grain boundaries of pyrite. (5) Barite ($BaSO_4$) occur on fractures, on grain-boundaries of amphibole and associated with sulfides. (6) Thorianite and uraninite have also been identified. Pyrite, native Bi and chalchopyrite have been examined by electron microprobe for gold without the element being detected (detection limit 1000 ppm). Only one very small, dusty grain of native gold have been observed in polished section. This grain - an inclusion in carbonate, was not directly associated with sulfides or any of the native elements mentioned.

10.5. CONCLUSION

The highest grades of gold (up to 329 ppm Au), which are found in type 2 mineralization, show that an effective consentration mechanism for gold have been active in the area. Unfortunately the corresponding mineralization is small.

The type 3 mineralization that is the only one presently believed to have an economic potential - due to its larger volume, is pyrite-gold with generally less than 2 % S. The gold grades are strongly variable. Average gold grades may reach 6-7 ppm over 3 m drill-core. The economic potential of the mineralization has not yet been fully investigated. Further diamond drilling of the impure carbonates is needed to define the economic potential more precisely.

The geneses of the Gautelisfjell gold mineralization is unknown; it may be of exhalative-hydrothermal origin associated with the felsic volcanism in the area, as suggested by Priesemann (1984), or it may be epigenetic and associated with later shear-zones or with the intrusive rocks. In any case the primary depositional characteristics are obscured by later tectono-metamorphic events.

However, the stratabound dissemination in carbonate, the "invisible" gold, the high Au/Ag ratio, graphite, and the low content of sulfide, are characteristic features which are broadly similar to those of the Carlin-type hydrotermal-replacement gold deposits (see Bonham 1985). Primary control of ore deposition in Carlin-type deposits are high-angle faults that transect a favorable host-rock type, typically a thin-bedded silty to sandy carbonaceous siltstone or carbonate rock.

Continued lithologic and structural mapping in both detail and regional scales and geochemical studies of the ore mineralization and the related rock-types, is needed to determine the source of and depositional mechanism of the gold. Special attention is required on the comparison with the Carlin-type deposits.

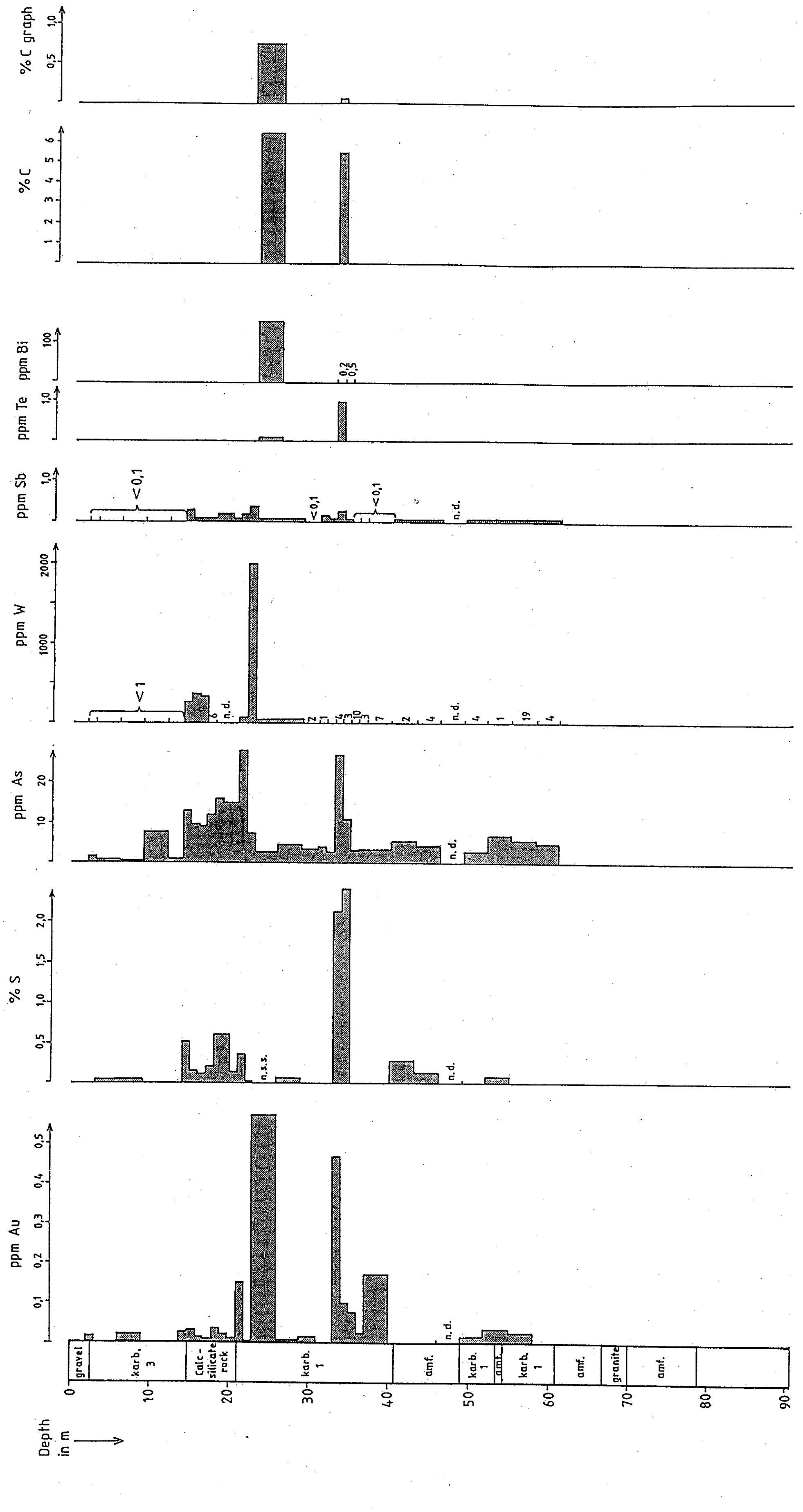

FIG.12 Distribution of some selected elements in diamond drillhole 4-84.

11. GEOLOGICAL EVOLUTION

Some main features of this regions's geological evolution are:

The volcano-sedimentary sequence are the oldest rocks known in the window. These are intruded by different generations of basic and acidic plutons at about 1700-1800 Ma. The different intrusive rocks are believed to be more or less syngenetic. The chemical composition of greywackes from different sub-areas gives a strong indication that their source-regions consists of rocks of similar types to the volcanic rocks presently found in the window. This indicates that these rocks have evolved during a continuous large-scale geologic process with volcanism, erosion, sedimentation, new volcanism, etc.

The dominating volcanic and intrusive rocks are alkali-calcic and relatively pottassic (the SN-series), ranging continuously from mafic through intermediate to acidic varieties. The granites and rhyolites especially, are geochemically practically identical and may represent intrusive and extrusive eqvivalents derived from the same magma-source. In Phanerozoic environments similar magma-series are believed to have originated at deeper levels in the mantle than tholeiitic or calc-alkaline source-magmas, and have, in addition, experienced both fractional crystallization and crustal contamination (see Petro et al. 1979). A similar evolution is suggested for the Skjomen-Rombak alkali-calcic igneous rocks. An extensional environment is nessecary for this type of petrogenesis (Brown 1982).

Another type of felsic extrusive and intrusive rocks are tonalitic and calc-alkaline in character (G-type). Similar rocks are frequent in Archaean and Phanerozoic volcano-sedimentary regions elsewhere in the world. A third type (R-type) of igneous rocks are Mg-tholeiites (komatiites) which are common in Archaean greenstone belts around the world.

The window has experienced epidote-amphibolite to amphibolite facies metamorphism ($P > 6$ kb, T 575 to 600 ^{o}C). A greenschist facies retrogression has affected the window to varying degrees. Strong retrogression in the Muohtaguobla area is related to shear zones within a major N-S trending lineament.

A typical feature for many archaean volcano-sedimentary regions in the world is bimodal tonalitic-trondhjemitic and basaltic magmatism, while post-Archaean magmas may form a continuous sequence from basic to acidic types due to assimilation of crustal materials in mantle-derived magmas (Barker et al. 1981). The continuous variation from basic to acidic for Skjomen-Rombaken alkali-calcic igneous rocks is, according to this argument, a post-Archaean feature. The relatively high K/Na-ratio and the strong fractionation of REE, supports this interpretation (see Windley 1983). Alternatively, if the the volcano-sedimentary sequence is Archaean, then the Rombak area represent a stage of Archaean crustal evolution not recognized elsewhere in the world. Precise age determinations are needed to solve this problem.

12. CONCLUSION

Geologic environment:

It is concluded that the volcano-sedimentary and intrusive rocks are formed in an early Proterozoic continental environment, presumably either within a rift-controlled intra-continental basin or at a continental margin. The environment may be comparable to fairly mature stages in Phanerozoic ocean-continent collisions with rifting, magmatism and sedimentation on the continental side of a subduction zone, accompanied by basic to acidic plutonism. The window have then experienced epidot-amphibolite to amphibolite facies metamorphism. Strong retrogression to greenschist facies is related to shear zones within a N-S trending lineament which have acted as channels for hydrotermal fluids.

Ore mineralizations:

The Gautelisfjell stratabound, disseminated carbonate-hosted gold deposit demonstrates that effective concentration mechanisms for gold has been active in the region. This mineralization are believed to be of a type, either exhalative syn-volcanic or epithermal Carlin-type, which could lead to a economic deposit. The potential of the Gautelisfjell area is not yet fully investigated. Stream sediment anomalies including visible gold in heavy mineral fractions, elsewhere in the window show that gold mineralizations outside the Gautelisfjell area do occur also. Potential sites for gold mineralizations are shear-zones that have acted as channels for hydrotermal fluids, carbonate beds similar to those at Gautelisfjell, and carbonate +/- sulfide-bearing horizons in acid volcanics that are believed to be interbedded chemical sediments. Of particular interest is the N-S trending lineament in the eastern part of the window. Zinc, lead and silver are also of economic interest, particularly if associated with gold and copper as seen at one locality on Haugfjellet. The potential for Zn-Pb-Ag deposits is more strongly indicated in the middle to northern parts of the window.

Recommended further investigations:

The Gautelisfjell disseminated carbonate-hosted gold occurrence is the only significant gold mineralization presently known in the Rombak window. Knowledge of its characteristic features is essential for directing prospecting activities for similar mineralizations elsewhere in the window as well as in other regions. Continued lithologic and structural mapping, and microscopic and geochemical studies of the ore mineralizations are needed to characterize its features more fully.

Then effort should be put into studies of shear zones in the window in order to establish the different generations of shear zones, and to map the distribution of those shear zones which have acted as channels for hydrothermal fluids, and investigate their relationship to ore mineralization and stream sediment anomalies. The significance of the N-S trending lineament should also be investigated. The following areas which are anomalous in stream sediment gold, are given priority: Klubbvatnet (K), Haugfjellet (H1-2) and Cunojokka (C1-3).

General statement:

Since the geological evolution of a region in all scales, including the formation of ore-deposits, are parts of a continuous geologic process, it is our principal opinion that further investigations in the Rombak Window should include different aspects of geology, i.e. lithologic and structural mapping, geochemistry (including isotopes), age determinations, as well as detailed ore investigations. If coordinated, this will most certainly increase the possibilities of finding the different, and often practically invisible, ore-types. Valuable information that may be essential for investigations in similar terrains elsewhere in Norway, will also be obtained. This last aspect should not be underestimated.

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13. REFERENCES

Barker, F., Arth, J.G. & Hudson, T. 1981: Tonalites in crustal evolution. In Morbath, S. & Windley, B.F. (eds.), The origin and evolution of the Earth's continental crust. Philosophical Transactions Royal Society of London Series A, A 301, 293-303.

Birkeland, T. 1976: Skjomen, berggrunnsgeologisk kart N10 - M 1:100000. Nor. geol. unders.

Bonham, H.F. 1985: Characteristics of bulk-minable gold-silver deposits in cordilleran and island-arc settings. In Tooker, E.W. (ed.): Geologic characteristics of sediment- and volcanic-hosted disseminated gold deposits - search for an occurrence model. U.S. Geol. Surv. Bull. 1646, 71-77.

Brown, G.C. 1982: Calc-alkaline intrusive rocks: their diversity, evolution, and relation to volcanic arcs. In Thorpe, R.S. (ed.), Orogenic andesites and related rocks, 437-61. Wiley, London.

Flood, B.1984: The Rombak Project Area, North Norway. Summary of work done 1983 and work programme proposal for 1984. ARCO Norway, Inc., Hard Mineral Section. Report no. 84-670-19, 18 pp + 9 figs.

Flood, B. 1985: The Rombak Project Area, North Norway. Summary of work done 1984. ARCO Norway, Inc., Hard Minerals Section. Report no. 85-67-47, 14 pp + 15 figs.

Fyfe, W.F. & Kerrich, R. 1982: Gold: natural concentration processes. In R.P. Foster (ed.), Gold'82: The geology, geochemistry and genesis of gold deposits. Geol. Soc.

Zimbabwe, Spec. Publ. 1, 99-128.

Gunner, J.D. 1981: A reconnaissance Rb-Sr study of Precambrian rocks from the Skjomen-Rombak Window and the pattern of initial $^{87}Sr/^{86}Sr$ ratios from northern Scandinavia. Nor. Geol. Tiddskr. 61, 281-290.

Grønlie, A. 1982: Geologiske og radiometriske profiler i Tysfjord og Skjomen-området. Ballangen, Narvik og Tysfjord kommuner, Nordland. NGU-rapport nr. 1900/83B, 28s. + bilag.

Heier, K. & Compston, W. 1969: Interpretation of Rb-Sr age pattern in high-grade metamorphic rocks, North Norway. Nor. Geol. Tidskr. 49, 257-283.

Hutchinson, R.W. & Burlington, J.I. 1982: Some broad characteristics of greenstone belt gold lodes. In R.P. Foster (ed.), The geology, geochemistry and genesis of gold deposits. Geol. Soc. Zimbabwe, Spec. Publ. 1, 339-371.

Håbrekke, H. 1983: Geofysiske målinger fra helikopter over to områder - Ballangen og Skjomen, henholdsvis vest og syd for Narvik, Nordland fylke. NGU report 1836, 13 pp + 20 maps.

Kerrich, R. 1980: Archaean gold bearing chemical sediments and veins: a synthesis of stable isotope and geochemical relations. Gold sypphosium, Waterloo. Ontario geol. surv. open file report 5293, 137-211.

Korneliussen, A. & Sawyer, E. 1986: Berggrunns- og malmgeologi med særlig vekt på muligheter for gull, sydlige deler av Rombakvinduet, Nordland. Nor. geol. unders. Unpubl. report no. 86.167.

Krause 1985: Microprobe investigation of a gold-bearing sulfide mineralization at Gautelisfjell, Nordland. Internal report, Folldal Verk A/S.

Krauskopf, K.B. 1967: Introduction to geochemistry. McGraw-Hill, New York.

Lambert, I.B. 1983: The major stratiform lead-zinc deposits in the Proterozoic. Geol. Soc. America Mem. 161, 209-226.

Lindahl, I. & Furuhaug, L. 1977: Uranundersøkelser i Skjomen-området sommeren 1976. NGU report 1416/2, 9 pp.

Lindahl, I. 1978: Diamantboringer, geologiske- og geokjemiske undersøkelser ved ytre Sildvikskar Zn-Pb forekomst, Narvik, Nordland. NGU report 1430/4B, 20 pp.

Lindahl, I. 1980: Katteratvatn Pb-Zn forekomst, Narvik, Nordland. NGU report 1430/5A, 16 pp.

Nesbitt, H.W. and Young, G.M. 1982: Early Proterozoic climate and plate actions inferred from major element chemistry of lulites. Nature (London) 299, 715-717.

Næss, G. 1983: Geokjemisk undersøkelse i Skjomen og Ballangen (1980). Vol. I & II. NGU report 1800/5A & B, 6 pp + 26 maps.

Peacock, M.A. 1931: Classification of igneous rock series. J. Geol. 39, 54-67.

Pearce, J.A. & Norry, M.J. 1979: Petrogenetic implications of Ti, Zr, Y and Nb variation in volcanic rocks. Contr. Miner. Petrol. 69, 33-47.

Pearce, J.A., Harris, N.B.W. & Tindle, A.G. 1984: Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. Journ. Petrol. 25, 4, 956-983.

Petro, W.L., Vogel, T.A. & Wilband, J.T. 1979: Major-element chemistry of plutonic rock suites from compressional and extensional plate boundaries. Chem. Geol. 26, 217-35.

Priesemann, F.-D. 1984 a: Summary report, Rombak project (1983). Report, Folldal Verk A/S, 38p.

Priesemann, F.-D. 1984 b: Summary report, Rombak project. Report, Folldal Verk A/S.

Robyn, T.L., Flood, B. & Thomassen, B. 1985: A comparison of geophysical data and geological mapping, Rombak Precambrian window, northern Norway. 47'th. E.A.E.G. meeting in Budapest, manuscript 26 pp.

Sawyer, E. 1986: Metamorphic assemblages and conditions in the Rombak basement window. Nor. geol. unders. Unpubl. report no. 86.168.

Singsaas, P. 1977: VLF- og SP-målinger, Ytre Sildvikskar skjerp, Narvik, Nordland. NGU-report no. 1430/4A, 7 pp.

Skonseng, E. 1985: Berggrunnsgeologisk kartlegging i Gautelisområdet, Skjomen, Nordland. Feltrapport.

NGU report 85.214, 16 pp.

Taylor, S.R. & Gorton, M.P. 1977: Geochemical application of spark source mass spectrography - III. Element sensitivity, precision and accuracy. Geochem. Cosmoch. Acta 41, 1375-1380.

Tollefsrud, J.I. 1985: Rombak project. Folldal Verk A/S, report.

Vogt, T. 1950: Geologisk kart Narvik (1:100000). Nor. geol. unders.

Windley, B.F. 1983: A tectonic review of the Proterozoic. Geol. Soc. America Mem. 161, 1-9.

Appendix

Neutron activation analysis of rock-samples (values in ppm).

Analysed by IFE, Norway and Berquerel Lab., Canada.

	Greywackes, Gautelisvatn.				Greywackes, Rombaken.					Greywackes, Ruvssot.			
Sample	ES 57	ES 58	ES 61	$\bar{x}$	ES 68	ES 69	ES 70	ES 72	$\bar{x}$	ES 131	ES 132	ES 134	$\bar{x}$
La	36.0	25.0	22.3	27.8	33.1	28.7	16.4	28.0	26.6	10.8	23.9	27.3	20.7
Ce	73.9	52.1	49.6	58.5	77.3	62.4	36.7	59.3	58.9	26.0	50.8	57.8	44.9
Nd	24.8	22.4	19.0	22.1	28.0	23.9	10.0	22.8	21.2	12.0	19.0	24.0	18.3
Sm	5.30	4.42	4.18	4.63	4.91	4.82	2.64	4.34	4.18	3.20	3.60	4.12	3.64
Eu	1.00	0.92	1.00	0.97	0.92	0.93	0.69	0.90	0.86	1.00	0.86	1.00	0.95
Tb	0.87	0.8	0.67	0.78	0.57	<0.53	0.51	<0.40	<0.50	0.70	<0.54	<0.52	<0.59
Yb	2.21	1.62	2.57	2.13	1.91	2.07	2.32	1.85	2.04	2.37	1.49	1.67	1.84
Lu	0.31	0.29	0.44	0.35	0.29	0.34	0.39	0.34	0.34	0.44	0.37	0.30	0.37

	Granites			Mafic intrusives				
	Sørdal		Norddal	Sørdal	G.vatn	Norddal	Ultramafic volcanics, Ruvssot	
Sample	KS5.3	KS36.3	K272.3	KS11.3	K152.3	K273.3	R16.3	R22.3
La	63	105	106	14	35	53	0.2	0.6
Ce	104	172	170	25	65	88	<2	2
Nd	43	73	67	17	37	44	0.1	1.0
Sm	10.3	13.1	14.2	4.7	8.9	9.6	0.2	0.4
Eu	0.17	1.4	1.5	1.8	2.2	2.0	0.15	0.19
Tb	1.8	1.5	1.5	0.51	1.00	0.72	<0.05	0.13
Yb	7.4	3.7	4.4	1.7	2.5	3.3	0.5	1.0
Lu	1.23	0.61	0.76	0.31	0.50	0.50	0.10	0.19

	Felsic volcanics									
	Sørdal	Stasj.h.	Stasj.h.	Cainhav.	Cainhav.	Muohtaguobla		Mafic/intermediate volcanics, Sørdal		
Sample	KS19.3	K269.3	K101.4	K104.4	K254.3	K301	K302	KS9.3	KS12.3	KS17.3
La	80	135	86	61	63	25	24	104	105	91
Ce	134	220	191	132	98	38	38	176	187	156
Nd	56	92	73	53	46	17	18	84	88	68
Sm	12.1	18.3	14.3	8.8	10.7	3.7	3.3	14.8	15.4	11.5
Eu	0.97	0.29	0.12	1.10	1.2	2.8	3.2	3.9	3.7	2.8
Tb	1.4	2.1	1.84	1.20	1.2	0.41	0.39	1.2	1.2	0.97
Yb	5.1	4.7	6.63	4.19	4.5	0.65	0.66	3.3	2.6	2.6
Lu	0.85	1.18	1.04	0.71	0.68	0.10	0.11	0.67	0.46	0.45