Geology of the southern part of the Kautokeino Greenstone Belt: Rb-Sr geochronology and geochemistry of associated gneisses and late intrusions.

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The southern part of the Kautokeino Greenstone Belt is divided into four volcanic formations separated by sedimentary units. The formations represent a development from Archaean komatiitic sequences to Middle Proterozoic possible rift-forming environments. The earliest volcanism is represented by basaltic komatiitic enclaves within the eastern gneiss complex, and may be equivalent to parts of the lowermost formation within the greenstone belt. The latter consists of up to 50 % basaltic to peridotitic komatiites (12 - 30 % MgO) and was probably deposited after the formation of the gneiss complex.

The tonalitic-trondhjemitic gneisses are dated to 3.0 ± 0.2 b.y. and represent primary magmas resulting from the crust-forming events at that time. They are similar in age and composition to gneisses in East and North Finland. The late plutonic complexes are ca. 1700 m.y. old and may be the Middle Proterozoic counterparts to the Archaean gneisses. Regional metamorphism within the belt reached middle to high amphibolite facies and occurred ca. 1950 m.y. ago on the basis of Rb-Sr radiometric dating on metasediments and amphibolites. Granitic gneisses southwest of the main greenstone belt are very uniform geochemically and represent products of differentiation. Widespread and intensive brecciation, shearing and carbonatization are later than the main deformation and metamorphism, and may be associated with faulting and block movements in connection with possible rift tectonics.

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Introduction

The Kautokeino Greenstone Belt constitutes a 30-50 km wide N-S striking complex situated between two granite-gneiss terrains in the western part of Finnmark, North Norway. The eastern gneiss dome separates the Kautokeino Greenstone Belt from the Karasjok Greenstone Belt with a possible connection between the two north of the dome. The Kautokeino Greenstone Belt consists of sequences of tholeiitic basalts or tuffaceous greenstones and amphibolites alternating with sedimentary units. The volcanic and sedimentary rocks also occur as remnants or infolded lenses in the gneiss terrains, especially in the eastern gneiss dome.

During 1984 and 1985, Prospektering A/S and the Geological Survey of Norway (NGU) cooperated in regional geological mapping in the southern part of the region, and it is intended that Prospektering A/S will contribute a number of geological maps at a scale of 1:50,000 in connection with NGU's Finnmark Programme. This project initiated a geochemical and geochronological study on the greenstones and associated gneisses and granites of the region.

The paper presents the stratigraphy and structural features within the region and the geochronology and geochemistry of the associated gneisses and late intrusions. Petrogenetic implications are discussed and some limits on the ages of the different formations are set. Some considerations are presented concerning the development of the greenstone belt.

Regional setting

The southern part of the Kautokeino Gneiss-Greenstone Terrain is divided into 8 formations and plutonic complexes. These are shown in Figs. 1 and 2 and listed in Table 1 along with correlations with sequences in neighbouring regions (Siedlecka et al. 1985, this volume).

We question the correlation with the Gål'denvarri Formation (Solli 1983), which will be discussed later. The relative positions of the Stuorajav'ri and Lik'ča Formations are also questionable. We propose, as a working hypothesis, that these units were deposited quite late,

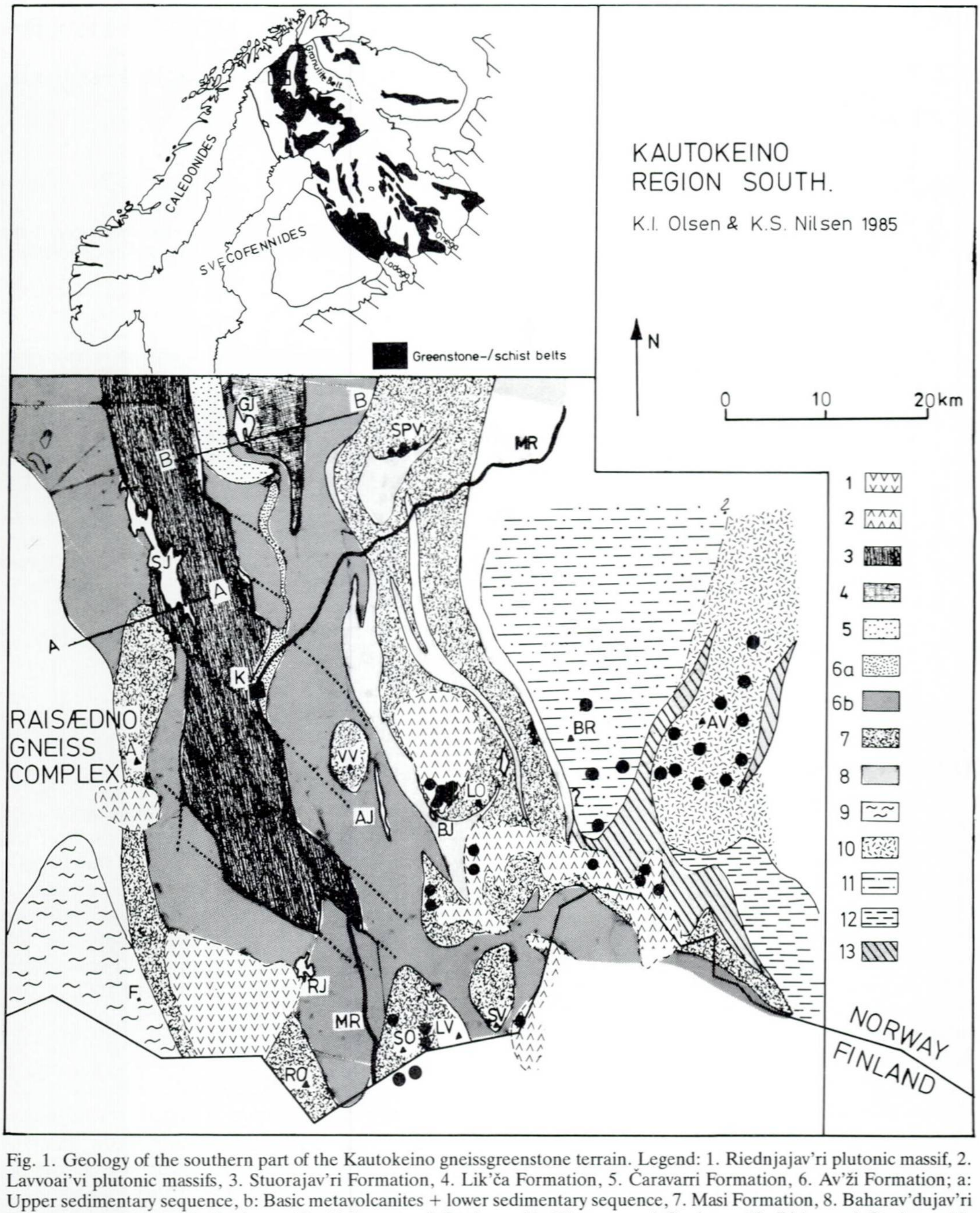


Fig. 1. Geology of the southern part of the Kautokeino gneissgreenstone terrain. Legend: 1. Riednjajav'ri plutonic massif, 2. Lavvoai'vi plutonic massifs, 3. Stuorajav'ri Formation, 4. Lik'ča Formation, 5. Čaravarri Formation, 6. Av'ži Formation; a: Upper sedimentary sequence, b: Basic metavolcanites + lower sedimentary sequence, 7. Masi Formation, 8. Baharav'dujav'ri Formation, 9. Favrusjåk Gneisses, 10. Ak'kanasvarri Gneisses, 11. Biennaroavvi Gneisses, 12. Bis'suvarri Gneisses, 13. Sådnabæi Formation; ······Breccia-/Shear zones, faults. ● - Sampling loclitites for Rb/Sr isotope analysis.
Abbreviations: Mr, main road; SPV, Spiel'gavarri; SJ, Stuorajav'i, GJ, Gæšjav'ri; K, Kautokeino, A, Addjit; F, Favrusjåk; RJ, Riednjajav'ri; VV, Vuorašvarri: AJ, Av'žijav'ri; BJ, Baharav'dujav'ri; LO, Lavvoai'vi; SO, Spal'loai'vi; LV, Liigavarri; SV, Suvčaganvarri; BR, Biennaroavvi; AV, Ak'kanasvarri.

i.e. later than the main metamorphism of the other volcanic formations.

The Stuorajav'ri Formation constitutes the upper part of the Časkias Group, defined by

Holmsen et al. (1957) as the lowest volcanic sequence west of the Čaravarri Sandstone and associated argillites. It is equivalent to the eastern part of the Čas'kejas Formation (Siedlecka et al. 1985). Sandstad (1983), from field and geochemical data and from metamorphic petrology (Sandstad, in prep.), has not observed any features which support our subdivision.

The relative position of the Čaravarri Formation is problematic both from a tectonic point of view and from the lack of observed sedimentary contacts to the volcanic formations. Other authors (Holmsen et al. 1957, Sandstad 1983, Solli & Sandstad 1984, Torske & Bergh 1985, and Siedlecka et al. 1985) have interpreted rocks equivalent to the Čaravarri and Bik'kacåk'ka Formations as the youngest deposits in the region. Holmsen et al. (1957), however, placed a fault close to the border against the western volcanic rocks, north of the present study area (near Čuol'bmajav'ri). Here, a breccia zone separates strongly recrystallized quartzites to the east and tuffaceous greenstones and schists to the west.

Sådnabœi Formation

This formation occurs as a ca. 2 km broad NNE-SSW striking zone within the gneisses east of the main Kautokeino Greenstone Belt (Fig. 1). It thins out northward from its type area (east of Sådnabæiskai'dijav'ri, east of Ak'kanasjåkka), but south of the type area it is folded eastwards further into the gneiss terrain, and westwards towards the main greenstone belt. To the south the formation is intruded by younger granites (Lavvoai'vi Massifs); to the north intrusive relationships are observed to tonalitic/trondhjemitic gneisses (Akkanasvarri Gneisses, see later). To the southeast possible intrusive relationships are also observed between the metasediments and trondhjemitic gneisses (Bis'suvarri Gneisses, see later).

In the type area the formation consists mainly of basaltic komatiites, but to the south and east it is made up increasingly of more tuffitic and sedimentary sequences. The sedimentary part, which seems to make up the stratigraphic upper part of the formation, becomes more dominant towards the southeast where the volcanic component may become totally absent. It appears as if the latter has been more or less replaced by coarse metagabbroic intrusions.

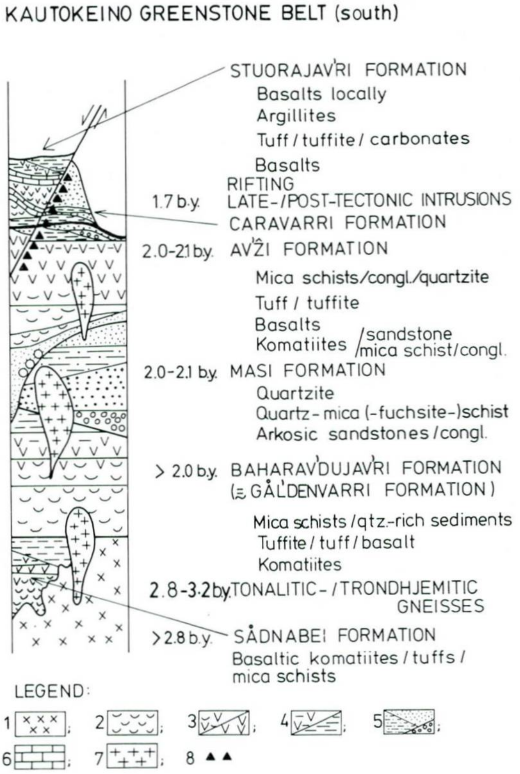
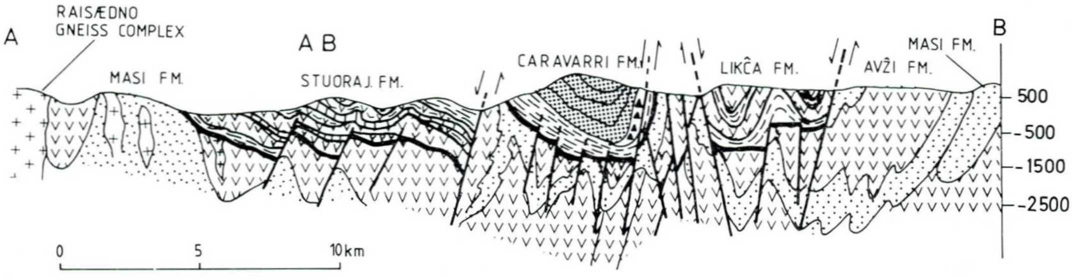


Fig. 2 (a) Illustration of geological successions and events. Legend: 1. Gneisses; 2. Basalts or komatiites; 3. Mixture of tuff and lava/tuff; 4. Tuff, tuffite, pelite/peltitic sediments; 5. Sandstone + pelite/quartzite/conglomerate; 6. Carbonate rocks; 7. Late granites; 8. Breccias. *Heavy solid lines:* Possible discontinuites.



(b) Section through the northern part of the study area (see Fig. 1). *Legend as in Fig. 2(a).*

TABLE 1. Regional correlation of formations and complexes from oldest to youngest.

	The present area	Mainly lithology	Northern part of the greenstone belt (Siedlecka et al. 1985)
1.	Sådnabæi Fm.	Basic volcanites	Gål'denvarri Fm. (?)
2.	The Gneiss Complexes		
	Eastern Gneiss Complex		
	a) Ak'kanasvarri Gneisses	Trondhjemites	
	b) Biennaroav'vi Gneisses	Tonalites	Jer'gul Gneiss Complex
	Western Gneiss Complex		
	Favrusjåk Gneisses	Granitic gneisses	Raisædno Gneiss Complex
3.	Baharav'dujav'ri Fm.	Komatiites/metabasalts	Gål'denvarri Fm. (?)
4.	Masi Fm.	Quartzites/feldspathic sandstones	Masi Fm.
5.	Av'ži Fm.	Basic volcanites	NE: Suolovuobmi Fm. NW: Western part of Čas'kejas Fm.
6.	Čaravarri Fm.	Sandstones/argillites	Čaravarri Fm./Bik'kačåkka Fm.
7.	Stuorajav'ri Fm. Lik'ča Fm.	Basic volcanites	Eastern part of Čas'kejas Fm. Lik'ča Fm.
8.	*Plutonic Massifs*		
	Lavvoai'vi Massifs	Granodiorite	Datkuvarri Granite
	Riednajav'ri Massif	Quartz-monzonite	(Holmsen 1957)

The basaltic komatiites (12-16 w% MgO) are characteristically of LILE(large-ion-lithophile element-), (LREE-) enriched nature. In the type area the basaltic komatiites exhibit primary volcanic features such as gas vesicles and an abundance of pyroclastic material (Fig. 3a). The paragenesis is mainly pargasite ± plagioclase ± opaques.

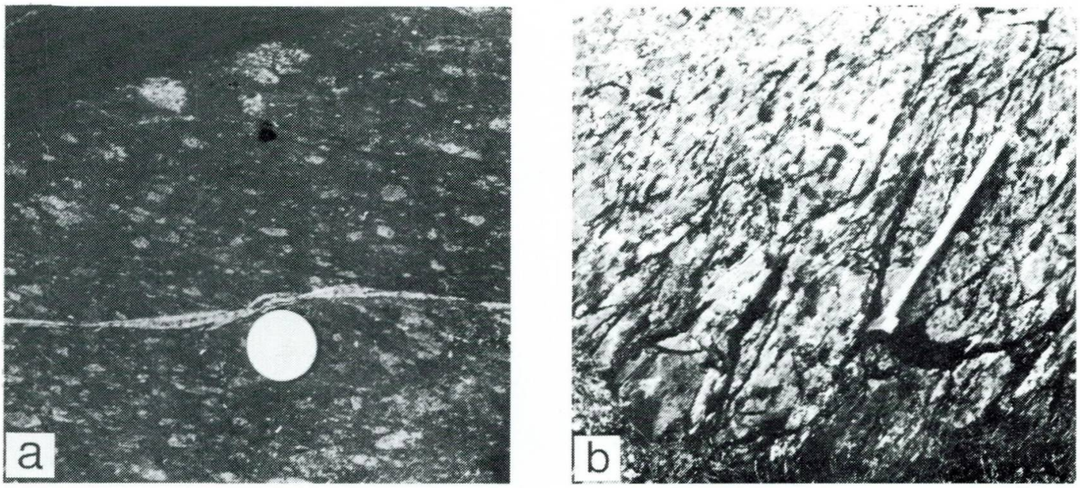
Arkosic sediments are represented by biotite gneisses. Quartzites are present locally. Pelitic sediments occur partially as coarse, massive to foliated, cordierite gneisses and mica schists. Lower parts may contain conglomerate units of intraformational origin which contain pebbles of the same material as the matrix quartz-mica-schists. Retrogression of the cordierite assemblages may occur in intense shear zones (ca. NNE-SSW), where cordierite breaks down to chlorite ± biotite (reaction with muscovite).

The formation, which in the south is deflected westwards around the gneisses (see Fig. 1), may join and form parts of what we have mapped as the Baharav'dujav'ri Formation beneath the Masi Formation further north (see p. 136).

The Gneiss Complex

The eastern gneisses and their relationship to the metavolcanites

The gneisses east of the Kautokeino Greenstone Belt belong to the Jer'gul Gneiss Complex (Krill 1984, Siedlecka et al. 1985). The gneisses are homogeneous on the kilometre scale, but may show compositional banding of mafic minerals on a 1 cm to 10 m scale. On a larger regional scale (tens of km), however, three main types of gneisses, differing in field appearance, can be recognised.



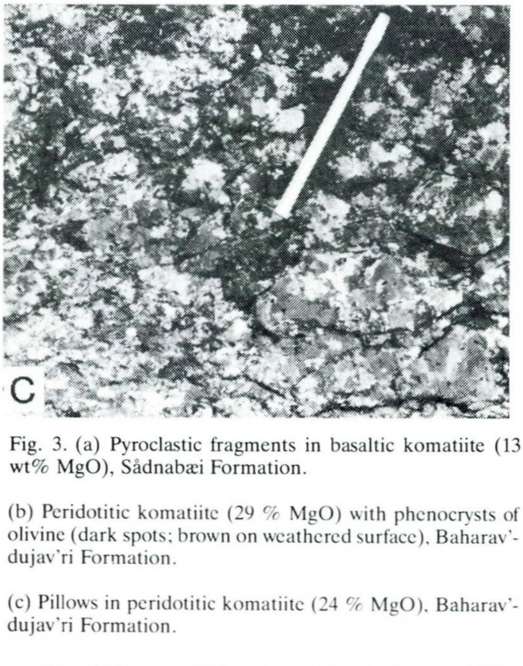


Fig. 3. (a) Pyroclastic fragments in basaltic komatiite (13 wt% MgO), Sådnabæi Formation.

(b) Peridotitic komatiite (29 % MgO) with phenocrysts of olivine (dark spots; brown on weathered surface), Baharav'-dujav'ri Formation.

(c) Pillows in peridotitic komatiite (24 % MgO), Baharav'-dujav'ri Formation.

The Bis'suvarri Gneisses (BvG) have a light appearance, often banded on cm-scale, with darker more mafic material. The gneiss is usually relatively fine-grained, and the more mafic (biotite-rich) banding may be totally absent over several kilometres. Amphibolitic lenses and inclusions are observed, but are relatively rare. The gneiss constitutes the southernmost area of the Eastern Gneiss Complex. Although possible intrusive relationships to parts of the Sådnabæi Formation have been observed, the foliation in gneisses and metamorphic fabric in metasupracrustals are concordant. However, the southeast extension of the Masi Formation seem to show discordant relations to the BvG. Secondary deformations in the gneisses parallel to the foliation in the Masi Formation are observed on approaching these metasediments.

The Biennaroavvi Gneisses (BG) are dark brownish, strongly foliated biotite (hornblende) gneisses, and constitute the core of an antiformal structure (Fig. 1) which is surrounded by the Sådnabæi and Baharav'dujavri Formations (see p. 136). Contact relationships to the former in the south are obliterated by late granitic intrusions (Lavvoai'vi Massifs, p. 148).

The Ak'kanasvarri Gneisses (AG) are coarse- to medium-grained typically containing aggregates of biotite and hornblende, thus making it appear spotted in the field. They are homogeneous on a local scale and lack the typical regular

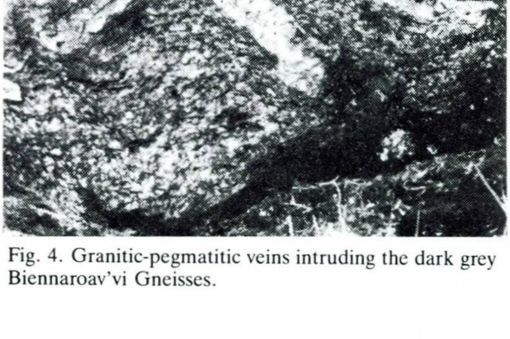


Fig. 4. Granitic-pegmatitic veins intruding the dark grey Biennaroav'vi Gneisses.

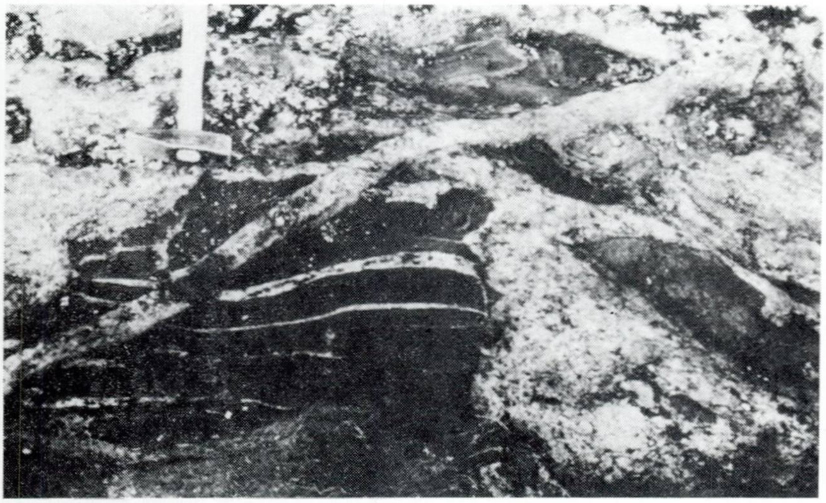


Fig. 5. The intrusive relationships between the Ak'kanasvarri Gneisses and amphibolites of the Sådnabæi Formation.

layering of the BG. However, more irregular variations in the amount of mafic minerals occur over a somewhat larger scale, and these minerals may become almost absent. The AG occupies a large area east of the infolded volcanites, which thus separates the two types of gneisses. Inclusions and lenses of amphibolite are relatively common. Rocks correlative to the Sådnabæi Formation seem to recur east of the Ak'kanasvarri Gneisses (Fig. 1).

The BG contains zones of relatively intense pegmatization and granitization (Fig. 4), especially along the central parts of the dome structure and to a less extent closer to the supracrustal sequence to the east. The gneisses, however, become intensively sheared and retrograded, and no clear contact relationship between AG and BG can be observed.

Contact relationships between the Sådnabæi Formation and the AG are indicated as two larger exposures. Intrusive contacts between the two are demonstrated by xenoliths of komatiitic rocks occurring as lenses a few tens of metres away from the contact in one exposure (1932 I, UTM 803412), and by cross-cutting veins and features of partial melting within the amphibolites (Fig. 5) in the other exposure (1932 I, UTM 846.5/562.5). Intrusive breccias are also observed in the gneiss close to the contact.

Contact relationships between the Sådnabæi Formation and the BvG are observed to the southeast (1932 I, UTM 826/386). Here it is more unclear, but observations indicate that the border to the mica schists is discordant to the general foliation, which is paralel in the metasediments and dioritic gneisses. The border is exposed over a distance of some decimetres. However, the observation does not necessarily imply intrusive relationships.

The western gneisses

The Favrusjåk Gneisses (FG) constitute a region in the southernmost part of the Raisædno Gneiss Complex (see Siedlecka et al. 1985), and comprise a homogeneous unit of granitic gneisses (Fig. 1). They are typically layered with coarser granitic material (1-5 cm), but in some regions the layers are absent. The rocks are usually intensively foliated, generally in a NW-SE trend. More massive pegmatitic material is commonly present as concordant lenses and bands. Biotite is the main mafic mineral phase.

Granodiorite dykes and bodies similar to the Riednjajav'ri Massif (see p. 148) intrude the gneiss and its concordant belts of metasediments (Masi Formation) and amphibolites.

Baharav'dujav'ri Formation

This formation appears as an antiformal N-S striking zone bordering the main zone of the Masi Formation to the west, east of Av'žijav'ri, where it has its type area (Fig. 1). It is correlated with rocks occurring in narrower zones, folded up in the central parts of the Masi Formation further east, and in a smaller zone which overlies the eastern gneisses and stratigraphically underlies the Masi Formation (see p. 138).

The formation consists of a series of metavolcanic amphibolites characteristically represented by peridotitic to basaltic komatiites which occupy the centre of the antiformal zone. The komatiites grade upwards into more basaltic extrusives, becoming more tuffaceous towards the top of the sequence where tuffs and tuffites are increasingly intercalated with more sedimentary material and carbonates. A thin quartzite/schist unit (c. 50 m) is interlayered with the tuffites, which, however, make up the upper few hundred metres until quartz-mica schists and quartzites of the Masi Formation are encountered to the east in the type area.

The full sequence is about 1000 m thick, c. 50 % of which is composed of komatiitic rocks. No base of the sequence has been recognised. The komatiitic rocks underlying the Masi Formation to the east cannot be distinguished in appearance (Fig. 3b) and chemistry from the characteristic rocks of the type area. The eastern zone is a natural continuation of the Gål'denvarri Formation further north (Solli 1983) in the Masi region, where it occupies a similar position.

The relationship to the Sådnabæi Formation is unclear. The latter has a characteristic chemistry, showing basaltic komatiitic compositions with LILE-enriched patterns. Compared to the typically LREE-depleted nature of the peridotitic to basaltic komatiitic compositions of the Baharav'dujav'ri Formation, this may indicate different events for the extrusion of the two formations.

The rocks occur as different varieties of homogeneous or layered amphibolites. The most basic komatiites (peridotitic, 23-30 wt% MgO) vary from light green to green, whereas basaltic amphibolites are dark green. Pillows (Fig. 3c) and pillow breccias are observed in the komatiites. Olivine appears as phenocrysts (see Fig. 3b), brown-red on weathered surfaces, mainly in a light green amphibole matrix. The basaltic lavas occur as fine- to medium-grained dark amphibolites. The light- and dark-layered amphibolites are interpreted as metatuffs and tuffites. The sedimentary units are garnet-mica schists and biotitequartz gneisses and schists.

Typical parageneses are as follows: -

Komatiites:
1) Pargasitic hornblende ± ol ± chlor ± serpentine + spinel + pyrrh/pentl.
2) Pargasitic hornblende ± plag ± chlor + spinel +
pyrrh/pentl.
Basalts:
Hornbl + plag ± qz + mgt + pyrrh + py
Tuffs/tuffites:
Hornbl + plag ± cpx ± qz + mgt + py/pyrrh.
Sediments:
Qz + fsp + bio ± musc ± gnt.

Chlorite and serpentine are secondary replacement products after olivine and reaction products between olivine and hornblende. Olivine occurs in komatiites having more than 23 % MgO. In the field its mode of occurrence indicates a magmatic origin (porphyric lavas, Fig. 3b): e.g. in a 75 cm-thick section of what we have interpreted as a lava flow, olivine phenocrysts occur abundantly at the bottom and become gradually less abundant towards the vesicle-rich top of the layer.

Microscopically, the phenocrysts show a granular metamorphic appearance. However, a possible magmatic texture may have been replaced by metamorphic olivine. In one thinsection olivine shows a crystal habit of randomly oriented thin needles. These are interpreted as spinifex textures, which are commonly found in less metamorphosed ultrabasic lavas (e.g. Donaldson 1982). The scarcity of spinifex textures may be due to the high degree of recrystallization.

Diopside associated with hornblende, plagioclase and quartz appears in the banded amphibolites. The mineral is especially abundant when occurring together with larger amounts of sulphides (pyrite pyrrhotite). This is attributed to a reduction of H_2O-activity by liberation of S_2 during metamorphism.

Masi Formation

The rocks of this formation were described by Holmsen et al. (1957) from the Masi area (mainly quartzites), and were correlated with the metasediments occurring in the western zone, at Addjit, and to the south close to the Finnish border. The Masi Formation as defined by Solli (1983), (see also Siedlecka et al. 1985), is correlated with rocks in the c. 10-15 km broad zone striking NNW-SSE in the present area and also with rocks in the domal structures within the metavolcanic sequences, near the western margin of the zone, and near the Finnish border.

The Masi Formation consists of biotite gneisses (meta-arkoses), mica schists, quartz-muscovite (-fuchsite) schists and quartzites. The lithologies vary laterally and are dominantly arkosic in the northernand eastern parts of the area with quartzite of variable thickness in the stratigraphic uppermost part. The quartzites become more dominant around Lavvoai'vi and make up the major rock-type to the *southeast* along the Finnish border. The rocks in the domal structures and at Addjit consist mainly of quartz-muscovite-fuchsite schists. The amount of fuchsite is variable. This fuchsite-bearing schist seems to replace the quartzite unit as a westerly and southerly developed facies variant. At Liigevarri - Spalloai'vi the quartz-mica schists overlie arkosic biotite-muscovite gneisses.

Conglomerates have been observed some kilometres north of the main road (just south of Spiel'gavarri). They occur close to the base of the formation overlying basic volcanites and can be correlated with the Masi Conglomerate (Holmsen et al. 1957), also described by Solli (1983) and Siedlecka et al. (1985). The pebbles are mostly finegrained metasandstones and quartzite, and the matrix is grey biotite gneiss.

Just above the eastern metavolcanic zone west of Biennaroavvi a unit of coarse greywacke with abundant granite fragments (up to 5 mm) is present, which is similar to basal units in the Masi Region. Occurrences of cross-bedding confirm its stratigraphic position, overlying the Baharav'dujav'ri Formation.

Parts of the formation have locally undergone migmatization, the site of which was determinded by the local stress system. The latter has controlled the water paths and concentrated the water in 'stress shadows', which are identified by highly ductile deformation and folding along variable trends. The migmatization may be confined to small pockets (100-200 m long and 50 m wide) bordered by more schistose gneisses with no anatectic veins. The ductile zones are commonly intermingled with granitic anatectic veins and may develop into a rock consisting of circular or ellipsoidal quartz-muscovitesillimanite 'pebbles' set in a granitic groundmass. Migmatization led to the following paragenesis in the quartz-mica-rich part of the formation: Qtz + musc ± sill ± K-spar ± biotite. K-feldspar may locally grow as porphyroblasts, but then no sillimanite is found; however, potassium has been mostly concentrated in the neosome during migmatitization. The migmatitization occurs more commonly southwards and becomes most widespread towards Suvĉaganvarri, Liigevarri, Spal'loai'vi and Roavvoai'vi. It is only locally developed in the northern parts of the area.

Av'ži Formation

This formation comprises a series of sediments and volcanic rocks with an estimated thickness of 1500-2000 m. It occupies the largest area of the greenstone belt in the central and western districts. The formation is correlated with the Suolovuobmi Formation to the north and northeast (Solli 1983), and with the western part of the Čas'kejas Formation to the northwest (see Siedlecka et al. 1985).

The type area lies along the eastern side of Av'žijav'ri and in the hillside above the lake where it is relatively well exposed. The formation starts with a sedimentary sequence of 100-500 m thickness, consisting of feldspathic siltstones and biotite schists, grading upwards locally to thin quartzites. Polymictic conglomerates occur locally at the bottom of the sequence. Pebbles of volcanic material are observed, but the conglomerate consists mostly of quartzite pebbles set in a feldspathic biotite-muscovite schist. The sedimentary sequence is bordered by the Baharav'dujav'ri Formation just east of the Av'ži valley, and by the Masi Formation west of the valley. Here the border relationships are obliterated by a thick amphibolitic metadiabase dyke (pre-tectonic) which may have intruded as a sill subparallel to the border between the Masi Formation and the overlying metasediments of the Av'ži Formation.

The Av'ži Formation occurs in a tight synformal structure with the fold axis striking along the east side of Av'žijav'ri. Further north the Baharav'dujav'ri Formation wedges out and here the sedimentary sequence borders the Masi Formation to the east.

The volcanites consist mostly of tholeiitic basalts, tuffs and tuffites, gradually developing from sedimentary basaltic tuffs to dominantly tuff and tuffite. Locally, thin horizons (up to three of 20-30 m thickness each) of basaltic to pyroxenitic komatiites, which are lighter green than the basaltic amphibolite, occur at the bottom of the sequence, directly on top of the lower sedimentary unit. The formation ends with a sedimentary sequence consisting of feldspathic biotite schists, mica schists, and feldspathic and quartzitic metasandstones, which has a thickness of up to a few hundred metres. The sediments are correlated with the Kautokeino Conglomerate, which appears to lie on top of the volcanic sequence and has possible connections northwards to a 50-200 m-thick unit concordantly overlying amphibolitic tuffites of the Av'ži Formation. This unit contains locally strongly strained conglomerates, quartzites, siltstones and mica schists.

Carbonate sediments have been observed only at Riednjajav'ri further south and locally in the western part of the Čas'kejas Formation.

The volcanites are amphibolites of various types as in the Baharav'dujav'ri Formation, but deformation in generally somewhat less intense. The fact that the Av'ži Formation borders against different formations (the Masi and Baharav'dujav'ri Formations, see above) may indicate the presence of an original depositional unconformity, in which case the Masi and Baharav'dujav'ri Formations may have suffered a deformation episode prior to the deposition of the Av'ži Formation. The observations, however, can also be explained by later tectonic mechanism. A more detailed structural analysis will be undertaken to reveal possible differences in the deformation histories. However, mineral lineations together with pebble lineations can be correlated in all formations, and the mineral parageneses observed are clearly the result of the same metamorphic episode in all three formations.

The upper tuffitic units are composed of light and dark banded amphibolites, often coarsely porphyroblastic with hornblende and/or Al-silicate in a fine-grained groundmass of biotite, feldspar, quartz and hornblende.

Laterally northwestwards, the volcanites seem to grade into dominantly tuffitic or sedimentary rocks, while in the east and southwest more basaltic components dominate. The latter appears to be the case in proximity to larger metagabbroic massifs and sills (medium- to coarsegrained homogeneous amphibolites) which are intrusive into the lower sedimentary sequence and the other older formations. They occur especially in and below the Masi Formation, e.g. south of Spiel'gavarri and around the Vuorašvarri dome and similar domal structures further south and southeast, and can generally be correlated with relatively strong magnetic signatures on geophysical maps.

Čaravarri Formation

This formation has been described by several geologists, e.g. Holmsen et al. (1957), Sandstad (1983), Solli (1983) and Torske & Bergh (1984a), and is regarded as the youngest unit of the Kautokeino Greenstone Belt, occupying a N-S trending zone in the north-central part of the belt (Fig. 1).

The formation consists of clastic sediments up to about 5000 m thick in northern areas. The bedding usually dips moderately to the east, becoming steep or westward dipping close to the eastern border which is a major fault zone. South of Gæšjav'ri the unit appears to terminate southeast of Gæšjav'ri (Fig. 1).

The lower part of the formation (see profile, Fig. 2b) consists mostly of argillites with layers of siltstone and sandstone, locally with debris flows at Gæšjav'ri. These sediments can probably be correlated with the Bik'kačåkka Formation further north (Sandstad 1983, Siedlecka et al. 1985). The upper part consists mainly of sandstones with coarse clastic sediments (conglomerates and debris flows) and three major units of different clastic material are distinguished (Torske & Bergh 1984a). In northern areas these sediments are in the order of 4 km thick and only very slightly deformed.

Along the eastern contact (at localities on the southern and western sides of Gæšjav'ri) observations indicate a primary sedimentary unconformable contact between undeformed sandstones and pockets of argillite and underlying strongly deformed amphibolitic tuffites and recrystallized quartzite supposedly belonging to the Av'ži Formation. The latter become increasingly brecciated eastwards from this sedimentary contact until undeformed metavolcanic rocks belonging to the Lik'ča Formation are suddenly encountered ca. 1 km east of the observed sedimentary base of the Čaravarri Formation. The coarse clastic sediments are most common in the eastern part of the formation and indicate sedimentation in an unstable tectonic environment with basin formation and subsidence to the east.

The contact relationship to the western volcanites north of our study area may likewise be tectonic, which is also indicated by the observations of Holmsen et al. (1957). There, metatuffs and tuffites are separated from strongly recrystallized quartzites by a breccia, similar to that along the eastern contact zone, above which there are argillites of the Bik'kačåkka Formation (Siedlecka et al. 1985). An observed intense breccia zone in the northern part of the present area may represent a continuation of the one further north, but here it is bordered by amphibolitic tuffites to the east (Av'ži Formation?).

The Čaravarri Formation has been correlated with the Skoadduvarri Formation in the Alta-Kvænangen Window (Torske & Bergh 1984b). A possible correlation exists further east, in the Komagfjord Window, with the Saltvann Group (Pharaoh 1983). In this case the Nussir Group, which overlies the Saltvann Group, may be correlated witht the Stuorajav'ri Formation (see below).

Stuorajav'ri and Lik'ča Formations and their tectonic deformation

Descriptions of the formations

Stuorajav'ri is the name of a lake to the northwest of Kautokeino village. The formation is defined by a weakly deformed sequence of volcanites, pelitic sediments and carbonates metamorphosed under very low grade conditions. It occupies an 8-10 km wide NNW-SSE striking zone in the west-central part of the Greenstone Belt, terminating towards the Finnish border in the south (Fig. 1).

The type area is the eastern shore of Stuorajav'ri (at Balgatnjar'ga and Čuojavarri). The lower part of the formation is dominated by basalts and associated tuffs with sedimentary intercalations. The lava piles are up to several 100 metres thick, but seem to be of limited lateral extent. Volcanic structures are commonly well preserved. The basalts are usually vesicular, in some places with pillow structures (well exposed at Balgatnjar'ga). The tuffs are usually fine grained, greenish and well laminated, sometimes with graded bedding (Fig. 6), coarser pyroclasts or accretionary lapilli.

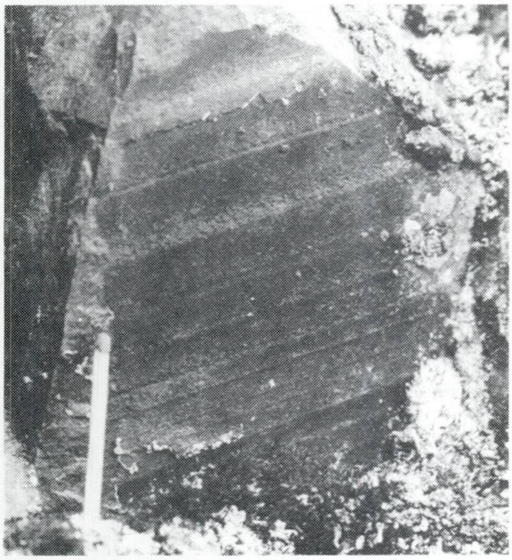


Fig. 6. Laminated tuff/tuffite with graded bedding (a match serves as scale), Stuorajav'ri Formation.

The upper part of the formation is dominated by fine-grained sediments, varying from tuffs and tuffites to argillites, graphite schists and carbonates. Argillite units with graphite schists and thicker carbonates (more than 100 m thick) occur at the top in the eastern part of the formation.

The formation and its surrounding rocks are intruded by numerous diabase dykes and sills, up to 100 m thick and up to several kilometres in strike extent.

The main deformation occurred locally along extensive shear zones of NW-SE to NNW-SSE trend, associated with close to almost isoclinal symmetrical folds with axial planes dipping steeply to the east. Regionally the formation is folded in more open folds along the same trend. Fold axes are flat-lying or gently dipping to the north or south, dependent on later E-W trending regional open folds.

The Stuorajav'ri Formation has been subjected to very low grade metamorphism with growth of chlorite and locally biotite (stilpnomelane?) along shear zones and folds with well developed axial planar schsitosity. Actinolite occurs together with calcite or dolomite in the vesicles of basalts and as randomly orientated needles in some tuffs.

The contact relationships to the underlying Av'ži or Masi Formations to the west are not observed because of lack of exposures. Brecciated and altered rocks close to the margins in southern areas suggest tectonic relationships. However, along the western contact (below the basalts at Stuorajav'ri and further north) geophysical measurements show the presence of a schist unit with graphite indicating a primary sedimentary contact in northern districts. The eastern contact is observed at two localities north of Kautokeino. Thinner, almost undeformed basalts (interpreted as the top unit of the formation) lie in contact with strongly brecciated quartzite at one locality (UTM 805/680). Huge blocks of quartzite and fragments of altered amphibolite in a matrix of argillite, interpreted as larger mudflows, occur at the other locality (UTM 757/757.5), bordering undeformed basaltic greenstones. The mudflows may have developed along a fault margin, where simultaneous eruptions of basalt occurred. The position and age of these rocks relative to other units in the Stuorajav'ri Formation are unclear.

Regional geophysical surveys indicate the existence of larger block faulting movements (NW-SE), where EM and magnetic anomaly zones abruptly terminate or are displaced. These lateral faults terminate at the border to the Stuorajav'ri Formation and are related to the severe brecciation which occurred just north of Kautokeino (see below).

The block faults and breccia zones illustrated in Fig. 1 indicate the formation of a younger rift zone.

The Lik'ča Formation (east of Čaravarri) is described by A. Solli (in Siedlecka et al. 1985) as a separate unit of basaltic rocks with some sediments (mudstone with graphite, dolomite and sandstone) which thins out southwards towards Kautokeino (Fig. 1). The lithology, metamorphism and tectonics of the formation are similar to those of the Stuorajav'ri Formation.

The formation has fault-bounded contacts to highly brecciated and altered amphibolites and quartzites in the west, near Gæšjav'ri, above which the Čaravarri Formation may lie with sedimentary contact (see p. 139). Also, where the Lik'ča thins out southwards (Fig. 1), undeformed basaltic rocks are observed in contact with strongly deformed quartzites (at the western border) (UTM 833.5/723).

Near the northern limit of the present area (Fig. 1), the Čaravarri and Lik'ča Formations have a mutual tectonic contact which displays intense brecciation.

The eastern contact of the Lik'ča Formation is not exposed in the present area, but observations here show a metamorphic gradient corresponding to low to medium amphibolite facies in the bordering Av'ži Formation 1.5 km away from very low-grade facies metamorphism in greenschists and argillites of the Lik'ča Formation. This may indicate a metamorphic break.

The Stuorajav'ri Formation, which extends north of the present area, seems to continue beneath the Caledonian cover and can be correlated with the Kvenvika greenstone in the Alta-Kvænangen Window (Bergh & Torske 1984) and the Nussir Group of the Komagfjord Window (Pharaoh et al. 1983). The Stuorajav'ri Formation may have the same stratigraphic position relative to the Čarajav'ri Formation as the Nussir Group to the Saltvann Group.

Alteration and brecciation

Zones of very intense carbonatization, which also has caused simultaneous albitization of amphibolites and greenstones, are recognised locally, but less intense zones may be found over the whole area. They may be associated with quite intense brecciation, which also may occur as a later development of the alteration processes (see Fig. 7). The *carbonatization* is associated with a tectonically determined introduction of carbonate along well defined zones. The altered rock is crosscut by carbonate veins and becomes fragmented and totally recrystallized in the most affected zones. In the moderately intense zones, however, earlier structures (banding, folding, textures) have survived in spite of intense cabonatization. Brecciations which follow these zones have often resulted in a total crushing of the carbonatized rock, which produced a rock giving the appearance of conglomerate (Fig. 7). Fragments and matrix are almost indistinguishable in thin-sections. Where quartzites were similarly deformed they ac-

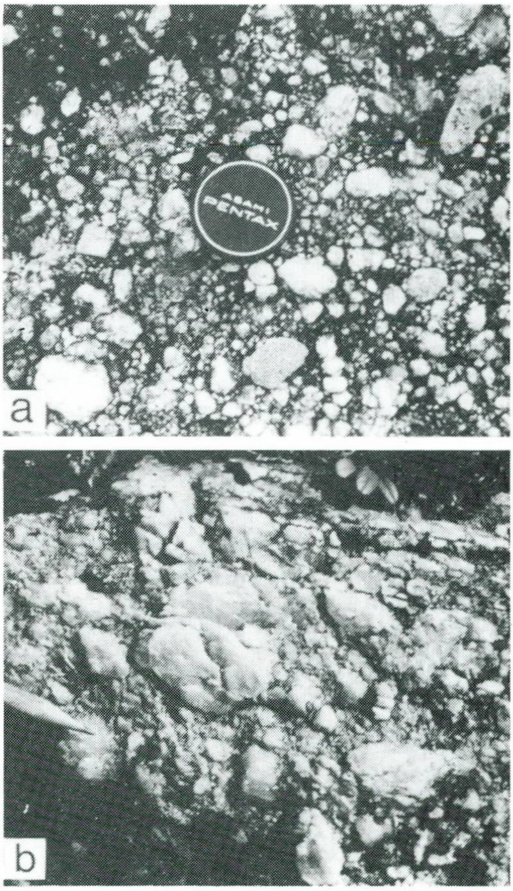


Fig. 7. (a) Brecciated albite-carbonate rock. (b) Brecciated quartzite (the matrix is a mixture of quartz fragments and albite-carbonate).

quired the same appearance, but with more or less rounded quartzite fragments in a quartz-carbonate-albite matrix.

The alterations and brecciations occurred mainly along NNE-SSW and WNW-ESE to NW-SE-striking zones. Brecciation seems to have occurred mainly along the last trend but also probably to a lesser extent along the former.

The regions of most intense alteration and brecciation occur along the border zones to the Stuorajav'ri Formation. North of Kautokeino carbonatization and brecciation are observed only along the eastern side of the formation, whereas in the south it occurs on both sides.

Alteration is also seen within the younger sequence but mostly as thinner, less intense and local zones, closely associated with carbonate sediments. Brecciation has occurred sporadically and only to a comparatively minor extent.

Along the Kautokeino river southwest of Kautokeino, very intense carbonatization and brecciation transect the metabasaltic rocks of the Stuorajav'ri Formation. Large lenses of quartzite occur sporadically among intensive carbonate breccias containing greenschist and argillite fragments. The breccias locally seem to have been formed explosively by a release of CO_2-gases under high pressure. This zone is probably a major tectonic zone which may have been reactivated several times.

The alteration zones described above show no signs of later deformations.

Chemistry of gneisses and late intrusions: petrogenetic relations

Eleven samples of the Biennaroavvi Gneisses and 14 samples of the Ak'kanasvarri Gneisses have been analyzed for major and trace elements (see Table 2). Here the compositional differences and possible source and mechanism for the formation of both types of gneisses will be discussed. Eight samples from the Riednjajav'ri and 3 samples from the Lavvoai'vi plutonic massifs will be treated in the same way. Six samples of the Favrusjåk Gneisses have been analyzed and will be treated in a more general way.

Analytical methods

Major and trace elements were analyzed by X.R.F. spectometry on glass beads or powder pellets at the Norwegian Geological Survey (NGU), Trondheim. Rb and Sr were analyzed by X.R.F. (Mo-tube) on pressed powder pellets at the Mineralogical-Geological Museum, Oslo, according to the techniques of Pankhurst & O'Nions (1973). The precision of the Rb/Sr ratio is in the order of 1 %. Sr-isotope ratios were analyzed on a Micromass 30 masspectrometer at the Mineralogical-Geological Museum in Oslo, where also the separation of Sr was undertaken with conventional dissolution and cation exchange procedures. The average Sr^{87}/Sr^{86} analyzed on the standard NBS 987 over the period concerned here is 0.71027 ± 2 (2SE). The regression of data sets was done according to the method of York (1966). The decay constant of Rb^{87} used is $1.42.10^{-11}y^{-1}$. Ages and intitial ratios are given with errors on the 2 -level.

Eastern gneisses

Normative feldspar-quartz plots in Fig. 8 (a) and (b) show the relatively plagioclase-rich and Na-rich nature of the gneisses. Following O'Connor (1985) these are classified as:

Biennaroavvi gneisses (BG) : Tonalitic - trondhjemitic

Ak'kanasvarri gneisses (AG): Dominantly trondhjemitic

Modally, after Streckeisen (1974), the AG would plot mainly as quartz-diorite varying to quartz-monzodiorite, and the BG mainly as quartz-monzonite/granite varying to quartz-diorite.

The BG are similar to other Archaean basement complexes around the world, while the AG are somewhat more Na-rich than most other complexes (Ab/An, ca. 2-5) and have a slightly lower normative quartz content (Fig. 8b). The dashed area in Fig. 8a encloses the compositions from areas in South Africa; Pilbara block (Shaw Batholith) and Yilgarn block, Australia; Suomussalmi-Kuhmo grey gneisses, eastern Finland; Koitelainen region, northern Finland; and Nòuk gneisses, Greenland. Trace elements (including REE) in combination with different isotope chronological data indicate the derivation of such suites of rocks by partial melting of pre-existing basaltic amphibolitic crust, e.g. the batholith of East Pilbara, Australia (Jahn et al. 1981); Tojottamanselkä gneisses, northen Finland (Jahn et al. 1984); Kivijärvi gneisses, eastern Finland (Martin et al. 1983) and O'Nions & Pankhurst (1978).

TABLE 2. Chemistry of gneisses and late plutons

	Ak'kanasvarri Gneisses											
	F19	F22	F24	F31	6381	7081	8181	9181	9281	201A83	201B83	20283
SiO_2	71.0	71.0	72.9	69.4	73.9	64.9	69.0	69.3	70.4	69.5	68.0	67.0
Al_2O_3	16.2	15.4	16.1	16.7	14.3	16.9	15.2	15.2	16.9	15.7	16.5	15.6
TiO_2	0.22	0.27	0.17	0.28	0.08	0.54	0.42	0.42	0.14	0.27	0.25	0.32
Fe_2O_3(t)	1.9	2.4	1.2	1.9	1.3	3.7	3.8	3.5	1.3	2.2	2.3	3.0
FeO	1.0	1.5	0.9	1.2	0.9	2.3	2.5	1.8	0.8	1.6	1.6	2.2
MgO	0.6	0.7	0.6	0.7	0.4	1.9	1.0	0.9	1.1	0.7	0.7	1.8
CaO	2.4	2.0	2.4	2.6	0.6	2.5	3.5	3.3	2.2	1.4	2.0	1.5
Na_2O	4.7	5.1	6.3	5.5	5.8	5.4	4.4	4.4	7.8	5.2	5.7	5.1
K_2O	2.6	1.6	1.0	1.5	3.6	1.8	1.4	1.3	0.8	3.4	2.0	2.8
SUM	99.8	98.7	100.5	98.7	100.0	98.2	98.9	98.5	100.5	98.4	97.6	97.2
Normative composition:												
Qtz	27	29	24	25	23	24	31	33	12	23	25	23
An	12	10	11	13	1	3	17	16	10	3	7	8
Ab	45	51	58	53	55	61	42	43	72	52	58	50
Or	16	10	7	9	21	11	9	8	6	22	13	19
Trace elements(ppm)												
Rb	66	62	25	51	70	57	48	50	22	93	74	91
Sr	487	380	428	599	225	361	408	333	430	390	366	355
Y	5	8	5	6	6	13	9	13	*5	15	17	9
Zr	181	143	78	118	105	140	193	175	112	121	121	136
Nb	9	5	9	6	7	9	8	8	9	12	11	8
La	11	18	*10	*10	16	43	17	26	11	22	22	31
Ce	21	43	15	*10	25	85	33	52	18	51	49	55
Ba	731	531	567	294	1050	431	320	276	235	694	532	701
Sc	*5	*5	*5	*5	2	8	6	4	0.4	*5	6	7

	Ak'kanas(ctd.)		Biennaroavvi gneisses										
	0583	20683	211a83	211b83	211c83	22683	241a83	241b83	241c83	251a83	251b83	251c83	3-80
SiO_2	71.6	70.5	70.2	71.2	70.7	70.0	73.4	68.2	72.0	64.2	72.6	61.6	66.0
Al_2O_3	15.8	14.4	13.8	14.2	14.1	15.5	14.3	15.0	14.4	15.9	14.4	16.6	15.3
TiO_2	0.13	0.26	0.29	0.28	0.29	0.22	0.18	0.44	0.25	0.32	0.13	0.56	0.32
Fe_2O_3(t)	1.2	2.9	2.6	2.3	3.0	2.1	1.8	4.5	2.4	5.9	2.0	6.3	4.6
FeO	0.9	1.7	1.7	1.6	2.1	1.5	1.2	2.1	1.5	4.2	1.5	4.2	2.8
MgO	0.4	0.6	0.7	0.5	0.9	0.4	0.4	1.1	0.5	1.6	0.4	2.2	1.6
CaO	2.8	2.9	2.2	2.0	3.3	1.6	1.9	3.0	2.3	4.4	1.8	6.0	4.6
Na_2O	5.6	4.4	4.3	3.6	4.7	3.9	4.5	4.3	4.4	3.8	4.7	3.7	4.1
K_2O	1.0	1.5	2.5	3.9	1.2	4.6	2.7	2.2	2.5	1.6	2.2	1.2	2.2
SUM	98.4	97.6	96.6	98.1	98.2	98.6	99.0	98.9	98.7	98.2	98.5	98.3	98.7
NORMATIVE COMPOSITION:													
Qtz	27	32	32	32	31	27	31	29	33	33	34	25	26
An	14	15	11	10	18	7	9	15	11	24	9	35	24
Ab	53	44	41	36	47	39	45	45	41	39	47	40	41
Or	6	9	16	22	4	26	15	11	15	4	10	0	9
TRACE ELEMENTS(ppm)													
Rb	36	51	172	157	64	273	121	111	135	92	90	55	150
Sr	438	322	245	225	210	234	210	271	193	328	177	303	243
Y	*5	*5	13	20	14	16	7	16	6	15	9	20	16
Zr	141	154	152	136	108	156	141	208	140	150	130	99	75
Nb	*5	7	12	17	7	30	*5	8	*5	6	9	9	13
La	*10	32	17	41	30	13	32	70	*10	14	11	11	16
Ce	*10	61	80	95	55	30	57	116	10	18	26	29	47
Ba	112	380	919	846	344	910	959	526	739	549	662	326	340
Sc	*5	5	6	*5	7	*5	*5	10	*5	14	*5	18	10

TABLE 2. Chemistry of gneisses and late plutons

	Favrusjiak Gneisses						Riednjajav'ri Pluton							
	124a83	124b83	14283	150a83	150b83	15183	8183	9283	9583	10483	11183	11983	12283	123??
SiO_2	70.5	69.0	68.4	69.4	68.9	69.0	56.2	59.2	63.0	56.1	57.2	56.0	61.1	57.?
Al_2O_3	12.4	12.0	12.3	12.4	12.5	12.0	16.8	15.9	15.9	16.8	16.3	17.1	15.9	16.?
TiO_2	0.58	0.59	0.64	0.82	0.82	0.64	1.13	0.70	0.58	1.07	0.82	0.82	0.64	0.8?
Fe_2O_3(t)	6.4	6.7	6.5	6.0	6.1	6.3	8.6	6.7	5.5	9.7	7.6	7.6	5.2	7.?
FeO	3.2	3.8	4.2	3.3	3.4	3.3	4.1	3.5	2.8	6.1	4.1	4.2	3.0	4.2
MgO	0.1	0.1	0.3	0.1	0.2	0.2	2.9	2.1	1.7	3.1	2.9	2.4	2.0	3.?
CaO	1.7	1.8	2.0	1.6	1.8	1.8	5.9	5.0	3.7	6.9	6.1	5.8	4.3	5.?
Na_2O	2.9	2.6	2.8	3.0	3.0	3.0	5.7	4.2	3.9	3.3	4.6	4.6	3.7	4.3
K_2O	5.2	5.1	4.8	5.0	4.9	4.6	1.3	3.0	3.9	2.0	2.2	2.2	4.5	2.4
SUM	100.0	98.0	97.9	98.2	98.0	97.8	98.9	98.1	98.4	99.5	98.2	97.0	97.7	98.?
NORMATIVE COMPOSITION:														
Qtz	32	33	33	32	31	32	2	9	12	18	3	7	13	14
An	9	10	11	9	10	10	21	18	13	25	21	20	14	19
Ab	30	28	31	32	31	31	68	52	46	44	55	58	42	51
Or	29	29	25	27	28	26	9	21	28	13	20	15	31	16
TRACE ELEMENTS(ppm)														
Rb	94	91	92	94	86	98	35	104	137	58	54	95	136	73
Sr	154	169	225	149	162	152	528	724	569	571	777	815	606	508
Y	108	105	98	104	103	112	33	33	24	33	32	28	25	18
Zr	835	959	843	801	773	810	202	253	247	191	246	291	243	144
Nb	37	36	32	36	35	39	12	17	14	10	12	16	13	11
La	121	121	114	62	100	122	39	41	34	42	31	33	34	20
Ce	361	339	3 2	298	274	245	62	74	74	73	65	68	70	42
Ba	2300	2400	2600	2200	2200	2000	645	789	915	814	876	895	1200	838
Sc	8	6	7	7	7	7	18	11	9	19	15	14	8	16

	Lavvoai'vi Massifs		
	171a80	3481	59a81
SiO_2	70.0	74.9	73.0
Al2O3	15.8	13.7	14.0
TiO_2	0.25	0.10	0.13
Fe_2O_3(t)	2.1	1.6	1.7
FeO	1.3	1.0	1.2
MgO	0.6	-	0.2
CaO	2.1	0.7	0.9
Na_2O	4.4	4.8	4.2
K_2O	3.8	4.1	4.3
SUM	98.8	99.6	98.4
NORMATIVE COMPOSITION:			
Qtz	24	27	30
An	11	4	5
Ab	42	45	41
Or	23	24	24
TRACE ELEMENTS(ppm)			
Rb	197	288	181
Sr	435	98	99
Y	10	15	9
Zr	198	170	142
Nb	21	18	14
La	20	18	42
Ce	38	14	83
Ba	1870	876	824
Sc	1.5	2	*5

The difference in major element compositions observed between the AG and the BG could reflect melts produced by different degrees of partial melting of a source, the partial melting of different types of source materials or the result of differentiation, notably BG being the more differentiated product by fractionation from an AG-type magma.

A common feature of the gneisses is that they plot in the plagioclase field in the normative pl-qtz-or diagram (Fig. 8b). Fractionation would lead a melt composition to the plag + qtz cotectic curve corresponding to H_2O 4 kb, and most of the BG plot along this curve. The latter could thus indicate a fractionation mechanism for BG. However, partial melting of granodioritic to dioritic material would also produce such a trend. The AG cluster around a mean composition equal to P137/Qz25/Or10 and display no trend. A rapid estimation shows that around 30-100 % partial melting of the average AG composition is needed to produce the range in BG compositions observed. A pressure of around 4 kb is probable for the emplacement of the BG (Fig. 8b). The AG, however, may more likely have been produced by different degrees of partial

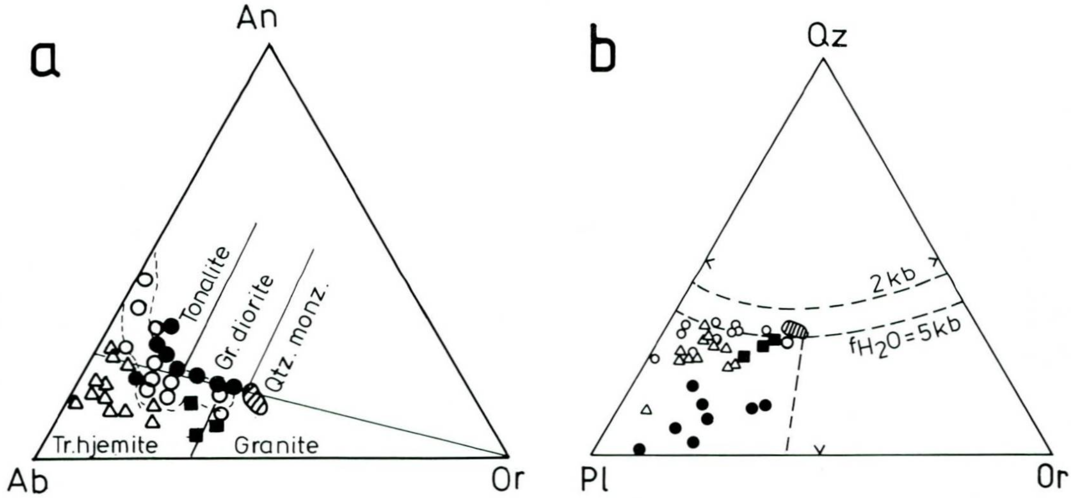


Fig. 8. (a) & (b) Quartz-feldspar normative composition of gneisses and late intrusive massifs. *Symbols: O,* Biennaroav'vi gneisses; ∇, Ak'kanasvarri gneisses; •, Riednjajav'ri massif; ■, Lavvoai'vi massifs; shaded area, Favrusjåk Gneisses. Classification according to O'Connor (1965). Dashed area in (a) represent common compositions of some Archaean gneisses around the world (see text; taken from Martin et al. 198å).

melting of more basic material (with plagioclase as a less dominant phase residue). In the following we present some trace element data in order to reduce the number of possibilities for sources and mechanisms of formation.

K/Rb, Sr/Rb, Ba/Rb, Sc/Rb and Sr/Ba ratios are plotted against a factor, F, which is presumed to indicate the degree of melting (Fig. 9a). F=Rb(source)/Rb(sample) has been calculated for each sample. As an amphibolitic source has been deduced for most gneisses of TTG suites around the world, we use a value for Rb (source) equal to 7 ppm, assuming an amphibolitic source with a Rb content similar to the average of apparently chemically unaltered volcanic material contained in the Sådnabæi and Baharav'dujav'ri Formations. Secondary Rb- and K-enrichment seems to have occurred partially during metamorphism (see geochronological section and Fig. 13) and samples with K/Rb 500 are used to obtain the average 'Rb source'. Similarly, the average concentrations of K, Sr, Ba and Sc are obtained for the assumed amphibolitic source material, for which the respective five different ratios above were thus found (R_0=element(source)/Rb (source) and R_0=Sr (source)/Ba (source); see Fig. 9a).

Trends of equlibrium partial melting of different minerals in residue, and of plagioclase fractionation are shown, using partition coefficients presented by Hanson (1978).

The different plots (Fig. 9a) are compatible with amphibolite as a source for the TTG (trondhjemite-tonalite-granodiorite) gneisses. The calculated partial melting curves indicate the involvement of hornblende and plagioclase in the melting process forming the magmas which the gneisses represent, with hornblende possibly being the dominating solid phase (see the Sr/Rb and Sr/Ba plots). However, the possibility of any fractionation mechanism occurring to produce BG cannot be deduced from these diagrams.

The possibility for source materials other than amphibolite may, however, still be present also for the AG. Melting of upper mantle material or fractionation from tholeiitic magmas are relevant mechanisms. The former possibility involves phases such as diopside, hypersthene, olivine, plagioclase and/or spinel of residual material (with hornblende as a minor phase). K and Rb have very low partition coefficients (K_D) for the first of these minerals (~0.01) and for plagioclase it is a bit higher, but as a minor phase in the mantle it will contribute only a small effect on K_D. The solid curve in the K/Rb plot would be a more representative trend for a magma produced in the upper mantle with corresponding initial K/Rb ratio (~550). The latter in either case is a minimum value for mantle domains. This is seen in the primary komatiitic lavas, which form a part of the Kautokeino greenstone sequence.

The other possibility, which involved eventual

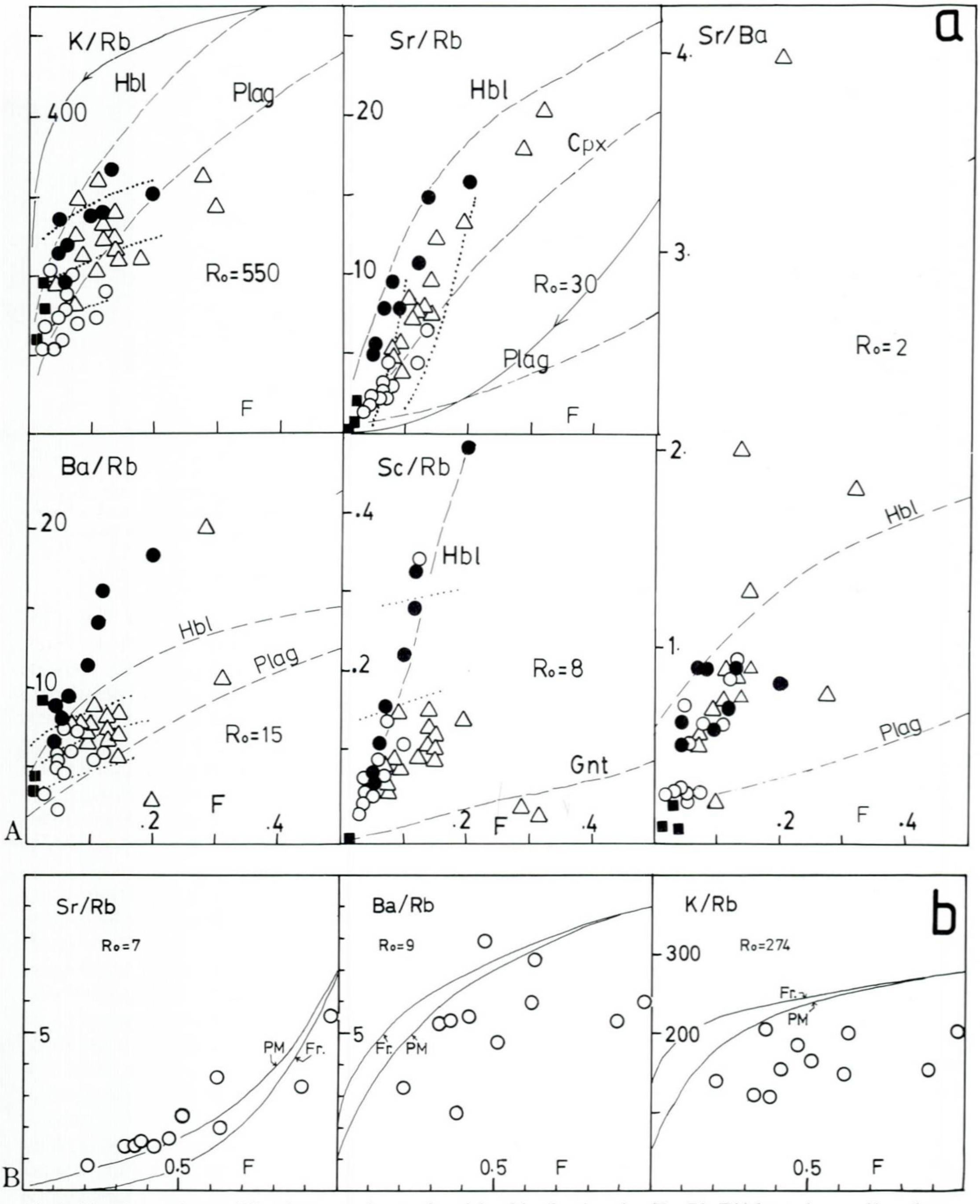


Fig. 9. Plot of trace element/Rb ratios versus degree of partial melting/fractionation (F = Rb_o/Rb) for gneisses and late plutons. Rb is the initial concentration (ppm) of Rb, and R_o is the initial trace element/Rb ratios of source material (see text). (a) Assuming a basic/ultrabasic source. *Dashed curves;* paths of melt compositions during equlibrium partial melting of different minerals. *Dotted curves:* paths of melt compositions during fractionation of plagioclase from different starting compositions. The curves are constructed by using the distribution coefficients of Hanson (1978) (taken from Nagasawa & Schnetzler (1971) and Philpotts & Schnetzler (1970)). *Solid curves (with arrow):* the path of melt composition during the fractionation of olivine + diopside + hypersthene + plagioclase from a tholeiitic magma with an average plagioclase: mafics ratio of 1:1. The starting composition are similar to those assumed for an amphibolitic source. Symbols as in Fig. 8. (b) Biennaroav'vi Gneisses assuming a source of AG-type dioritic composition (see text). *Solid curves:* Paths of melt compositions during partial melting (PM) of a dioritic or fractionation of plagioclase (Fr.) from a melt of initial dioritic composition.

fractionation from a basaltic magma somewhere in or close to the crust, would demand crystallization of relatively large amounts of diopside, hypersthene and plagioclase. Plagioclase would become more and more dominant as crystallization proceeded. Sr partitions relatively strongly into diopside ($K_D \approx 0.5$) and very strongly into plagioclase ($K_D \approx 3.5$). The solid curve in the Sr/Rb plot represents a trend correspondig to a crystallization of diopside and plagioclase, averaging the proportions; di : pl = 1 : 1, from a magma initially with Sr/Rb = 30. This does not prove that fractionation did not produce the AG. Many factors may be involved, but a factionation mechanism would probably deplete the magmas in Sr to greater degrees than that actually observed for the AG.

The position that the BG take can be tested. In Fig. 9b fractionation from, and partial melting of an average AG type magma are modelled. The variation in the K/Rb, Sr/Rb and Ba/Rb ratios as a function F, the ratio of melt left or produced respectively ($\approx$Rb(source)/Rb(melt); Rb(source) = Rb(AG) = 57 ppm), are shown as the solid curves in Fig. 9b, using the partition coefficients for plagioclase. The latter must be the main solid phase involved in these processes, as quartzdioritic material is the starting composition. As can be seen, the plots of BG show more or less clear trends. The Sr/Rb plot displays a relatively well defined trend, and the curvature for the trend quite strongly suggests that plagioclase was involved as the main phase. A source of dioritic composition similar to the AG is therefore probable. The more likely mechanism is partial melting of, rather than fractionation from such a source, but this is still questionable. All these plots show trends towards a ratio, at F=1, falling below the average AG composition. The discrepancy, however, is not very large. In the Sr/Rb and Ba/Rb plots the standard deviation of the trends overlap with the modelled curves. The K/Rb trend falls significantly below R_0. It is, however, most likely that an eventual BG produced from AG by partial melting was not in equilibrium with the total AG. The latter appear to show broader regional compositional variations, and partial melting of these would probably affect only the less basic varieties. In that case lower R_0 and larger Rb(source) values would have been more appropriate for the modelling.

The Sc/Rb plot in Fig. 9a shows that garnet has been present in possible residues during production of the AG. Garnet is the major phase in an amphibolite that will cause depletion of Sc in a co-existing magma (K_D^{Sc} is in the same order of magnitude as K_D^{HREE}; i.e. K_D^{Sc}(garnet-magma)$\approx$10). 5-10 % garnet in residue would fit the observed compositions (two of the samples may have had quite large amounts of garnet involved). The same plot for the BG displays a trend which fits more with an almost garnet-absent source. This again is compatible with the probable dioritic source,, which was tentatively suggested above for the BG.

The presented major and trace elements are thus compatible with a production of the AG by 5-32 % partial melting of a garnet amphibolite. A mantle origin is less probable. The BG have more probably been produced by partial melting of material equivalent to an average AG composition (garnet absent). 20-100 % partial melting of such a source is compatible with both major and trace elements.

Western gneisses

The granitic composition of the Favrusjåk Gneisses is shown in Fig. 8 and Table 2. They display a very uniform chemistry, both in major and in trace elements. Characteristically, K/Rb and Ba/Rb, together with Zr, Y, Nb, La and Ce/Rb ratios, are very high (K/Rb~450, Ba/Rb~25-30). The Sr/Rb (~2) is also higher than expected for a rock of granitic composition. These chemical features are probably due to primary magmatic processes rather than a result of metamorphic alteration. Transport of large amounts of Rb out of a large system (min. 50 km²) which has not undergone dehydration is improbable. Magmatic differentiation would lead to Rb enrichment as K_D^{Rb} for the majority of solid phases involved in granitic compositions (feldspars) is very small compared to that for K, Ba and Sr. Rb would act approximately as an incompatible element like Zr, Y, Nb, La and Ce. Relative to e.g. the TTG series of the eastern gneisses, the granitic Favrusjåk Gneisses should have lower K/Rb, Ba/Rb and Sr/Rb ratios (e.g. K/Rb <200). One probable explanation for the relatively low Rb concentration is that the gneisses may represent an accumulation of the crystallizing phases, mainly quartz, plagioclase and orthoclase, at a certain stage of crystallization.

Considering partition coefficients for plagioclase and K-feldspar, the contents of K, Ba, Rb and Sr are compatible with a mixture of these phases, the latter being the dominant one. Rb has low partion coefficients (mineral-magma) for both phases (pl~0.1 and or~0.6), while the three other elements have very high partion coefficients (1 into both phases). Concering the other incompatible trace elements mentioned above (Zr, Y, Nb, La, Ce), other phases must be included to be accounted for, and zircon and allanite(?) are observed in relatively large amounts in thin-sections. Minor amounts of biotite present would affect only the Sr/Rb ratio and to a very minor extent.

The minimum melt composition for the gneisses as illustrated in Fig. 8b (shaded area) fits with a eutectic correspondig to f H_2O~4 kb, which thus may represent a portion of the crystallizing phases rather than the magma composition. The residual interstitial magma and the crystals may in some way have been separated, the former being mobilized and emplaced separately, higher up or elsewhere in the crust. The granitic stripes and pegmatitic lenses and veins observed may be residues of the segregated magmas.

The composition of the Favrusjåk Gneisses is thus compatible with an interpretation that they represent a crystal mush from which the rest magma, of eutectic composition, had become separated: K-fsp + qtz + plag + zircon + allanite

The late plutonic massifs

The two compositionally different massifs, the Riednjajav'ri and Lavvoai'vi plutons, are also plotted in Fig. 8 and can be classified (O'Connor 1968) as follows:

Riednjajav'ri Massif (RM) : Granodioritic - tonalitic
Lavvoai'vi Massif (LM) : Granitic - trondhjemitic

Modally, after Streckeisen, they would plot as monzonitic to quartz monzondioritic/monzonitic and granitic, respectively. The rocks are generally more K-rich and have a lower quartz content (RM) than the eastern gneisses. Examining Fig. 8 (a) and (b), the two massifs apparently together represent a continuous series of magmas, and may represent different degrees of partial melting of amphibolitic material, as was the case for the Ak'kanasvarri Gneisses. However, the limited data for the LM make it difficult to discern its precise relationship to RM, because they may not be representative for the massif. The different plots in Fig. 9a show that the composition of the RM and LM is compatible with an origin by partial melting of amphibolitic source material. A mantle origin is improbable using the same arguments as for the Eastern Gneisses. An origin by partial melting of dioritic-granodioritic material, similar to the Eastern Gneisses, is ruled out, especially when examining the Sr/Rb, Ba/Rb and Sc/Rb plots in Fig. 9a.

The Sr/Ba ratios are very sensitive to the hbl/pl ratio of the source (Fig. 9a). The Sr/Ba plot therefore indicates that the source material for the RM and LM was probably quite similar to that for the Eastern Gneisses. However, there was no or very little garnet involved in the melting process which produced the RM. As far as LM is concerned, however, the very low Sc concentration may indicate the possible involvement of garnet.

The K/Rb, Sr/Rb and Ba/Rb ratios indicate a significant difference in the relative trace element contents of source material between that for the late magmas (RM + LM) and that for the Eastern Gneisses. The former generally plot above the latter. This can be attributed either to a more LILE (large-ion lithophile element, e.g. Rb)-depleted source or to a source having generally highly trace element contents for the late magmas (e.i. element (source)/Rb(source) or Rb(source) higher).

Summary

The eastern gneisses, BG and AG, constitute two different clearly defined regions, and have compositions which are typical for TTG suites of many Archaean terrains around the world. The AG has probably been producd by 5-30 % partial melting of a garnet amphibolite. The BG shows indications both from major and trace elements of having been formed from material equivalent to the AG probably by 20 to 100 % remelting of the latter.

The FG underlie a large region in the southernmost part of the Raisædno Gneiss Complex and display a very uniform composition which is indicative of a minimum melt composition (eutectic at ca. 4 kb H_2O). The gneisses probably represent a crystal mush residue after magma segregation at a stage during differentiation. The highly developed melt, as indicated by the possible crystallization of zircon and allanite, could have been formed by partial melting of earlier granitoid material. It is assumed that the FG could have been equivalents of the eastern gneisses, at least compositionally.

The late intrusions were formed partly in the same way as the eastern gneisses. Somewhat different trace element compositions were probably exhibited by the amphibolite source material (LILE-depleted or initially higher total trace element concentrations).

Rb-Sr Geochronology. Petrogenetic relations

Sampling sites are marked on the map (Fig. 1). Up to three samples may be included at one site. Samples of the LM may also include dykes within supracrustals within the same area.

Eastern gneisses

Rb-Sr isotope compositions of 10 samples of Biennaroavvi- and 12 samples of Ak'kanasvarri Gneisses are presented in Table 3 and Fig. 10. A regression of 19 of the samples gives an errorchron of 2993 ± 195 m.y. (MSWD = 64) and I.R. 0.7014 ± 6. Nine samples of the BG were selected from 3 different localities. Three samples at each of these localities were thus collected within an area of ca. 25 km^2. The BG is in part quite severely affected by late pegmatite intrusions and related hydrothermal activity and a very careful sampling had to be performed to minimize effects of this event. Loc. 211 (see Figs. 1 and 10), however, is situated relatively close to an area of intense pegmatitization and some pegmatite veins and dykes cut through the gneisses ca. 10 m away from the sampling sites. The samples falling beneath the regression line (loc. 211, Fig. 10) show a faint bleaching which may be due to hydrothermal activity associated with the late pegmatites. Thus, we have omitted loc. 211 in the calculation of the age, as the effect from later events probably have caused re-equilibration of isotopes. The relatively large deviation also seen for some of the other samples (large MSWD) is probably caused by the same effects.

Regression through samples from each of the two types og gneisses results in quite large errors.

AG: 2.7 ± 0.4 b.y. (MSWD = 117, n = 12)
BG: 2.8 ± 0.3 b.y. (MSWD = 46, n = 6)

A more careful Rb-Sr study would possibly reveal thermal events occurring around 2.7 b.y. as reported from northern Finland (Jahn et al. 1984).

The age of 3.0 b.y. for the combined AG + BG plot may be taken as the time of formation of the TTG suite, the very low I.R. being indicative of a mantle origin or a melting product from basaltic crustal material of limited crustal residence time (Fig. 14). The close agreement between regression lines for the AG and the BG indicate probable contemporaneity or a short time period between the formation of the two types of gneiss. Geochemical considerations indicated a possible formation of the BG by remelting of AG-type material (p. 00).

If the BG were formed by remelting of AG, the maximum age for the latter is 3.1 b.y. and the BG could have been produced up to 300 m.y. later (see error-ellipses in Fig. 14). An almost contemporaneous origin for the AG and BG could have occurred between 3.1 b.y. and 2.7 b.y. and the common regression of 3.0 b.y. is therefore compatible with such an interpretation. Without the above limitation that the BG are formed from the AG, the minimum age for AG is ca. 2.5 b.y., depending on the initial isotopic composition of the basaltic source. It is tempting, however, to favour the interpretation that the AG were formed at around 3.0 b.y., and that the BG were developed by remelting of AG during a thermal event 300 m.y. later at ca. 2.7 b.y., which at the same time caused partial homogenization of isotopes in the AG.

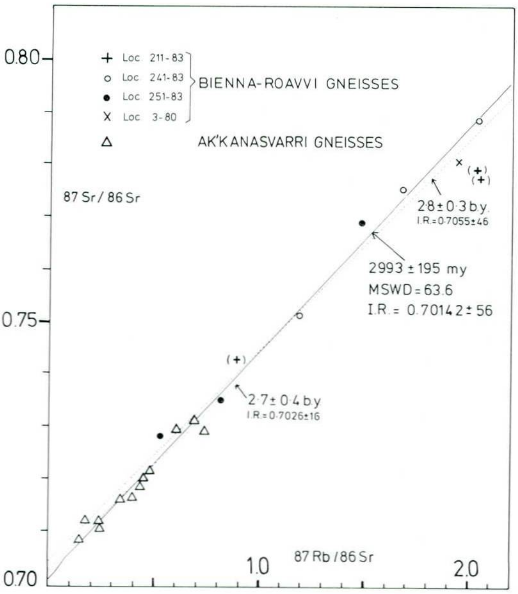


Fig. 10/ Olsen/Nilsen

Fig. 10. Rb-Sr isotope evolution diagram for the eastern gneisses. *Dotted lines:* Regression of BG and AG separately. ( ): Data not included in the regressions.

TABLE 3a. Rb-Sr isotopic compositions

Sample no.	Rb(ppm)	Sr(ppm)	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}	SE x 10^5
Ak'kanasvarri gn.					
F19	66	487	0.400	0.71660	6
F22	62	380	0.472	0.72157	8
F24	25	428	0.172	0.71199	10
F31	51	599	0.244	0.71061	5
8181	48	408	0.342	0.71614	8
9181	50	333	0.435	0.71854	7
9281	22	430	0.145	0.70840	3
201a83	93	390	0.692	0.73142	7
201b83	74	355	0.604	0.72952	5
20283	91	355	0.743	0.72863	3
20583	36	438	0.238	0.71184	5
20683	51	322	0.459	0.72016	4
Biennaroavvi gn.					
3-80	149	223	1.946	0.78074	6
211a83	172	245	2.045	0.77668	8
211b83	157	225	2.033	0.77951	8
211c83	64	210	0.885	0.74293	4
241a83	121	210	1.678	0.77581	4
241b83	111	271	1.190	0.75147	7
241c83	135	193	2.040	0.78867	6
251a83	92	328	0.814	0.73511	5
251b83	90	177	1.480	0.76912	7
251c83	55	303	0.526	0.72822	6
Lavvoai'vi plutons					
69-80	22	533	0.120	0.70611	6
9980	188	72	7.688	0.89290	6
10680	276	123	6.562	0.86169	7
13480	89	230	1.116	0.73233	5
138a80	96	53	5.294	0.83752	9
138b80	52	66	2.280	0.76421	6
161a80	46	51	2.632	0.76724	9
164b80	257	59	12.88	1.01555	7
17080	142	407	1.014	0.73001	6
16081	230	17	43.65	1.66205	13
15881	133	20	20.20	1.11610	8

The age and compositions of Ag and BG are similar to those of rocks from two areas in Finland: the Tojottamanselkä Gneisses of the Koitelainen Region, northern Finland, and the Kivijärvi and Naavala Gneisses of the Kuhmo-Suomussalmi Region, eastern Finland. Jahn et al. (1984) reported a Sm-Nd age of the TTG suite of 3.1 b.y. (εNd = -3.7), which is interpreted as a possible age of remelting of a pre-existing TTG suite which was formed at ca. 3.6 b.y. by partial melting of basaltic crust. Pb-isotopes (Krøner et al. 1981, Jahn et al. 1984) and Sr-isotopes (Krøner et al. 1981), however, give only younger ages without the evidence for any much older crustal pre-history. the low εNd-value could also be interpreted as being the composition of the basaltic source material at 3.1 b.y., i.e. with a LREE-(LILE-)enriched nature.

The Rb-Sr age of these Finnish gneisses reported by Krøner et al. (1981) is 2960 ± 250 m.y. (I.R. = 0.7007). This is practically the same age as that obtained on the eastern gneisses in Kautokeino, though with a somewhat lower initial ratio.

The Tojottamanselkäa Gneisses in North Finland may be equivalent in age to the AG. The Kivijäarvi- and Naavala grey gneisses in eastern Finland (Vidal et al. 1980, Martin & Querré 1984, Martin et al. 1985 3b) have yielded Rb-Sr and Sm-Nd ages of 2.85 b.y. and 2.65 b.y., respectively, and I.R. values which are comparable to or somewhat higher than those

TABLE 3. (continued) Rb-Sr Isotopic compositions.

Sample no.	Rb(ppm)	Sr(ppm)	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}	SE x 10^5
Lavv. (ctd.)					
171a80	197	435	1.314	0.73706	9
171b80	158	459	0.996	0.72893	4
34d81	242	80	8.910	0.91458	5
34e81	288	98	8.637	0.91133	4
59a81	181	99	5.370	0.83853	7
59b81	194	68	8.460	0.91107	10
12381	2.5	475	0.015	0.70431	5
15181	118	75	4.602	0.81648	7
16781	155	113	4.006	0.79581	3
17081	180	283	1.843	0.75235	8
Masi Formation					
141a80	125	48	7.768	0.94313	4
141b80	129	21	18.95	1.17542	130
141c80	132	243	1.584	0.74768	5
141d80	151	8.7	56.56	2.01327	9
151a80	113	46	7.330	0.91700	6
151b80	108	29	11.30	1.01300	8
15280	81	77	3.067	0.79337	3
15880	154	89	5.070	0.84700	7
16380	78	7.4	32.15	1.37408	21
24-81	132	69	5.607	0.86400	8
26-81	111	67	4.816	0.84331	5
Amphibolites					
Low K/Rb: 29-80	12	146	0.237	0.70844	5
8780	20	292	0.198	0.70750	7
98-80	36	86	1.210	0.73410	5
160b80	18	163	0.323	0.71130	3
F 17	48	186	0.750	0.72476	7
F 32	7.8	43	0.522	0.71948	3
83-81	54	122	1.277	0.73726	2
10081	29	295	0.284	0.71202	9
10281	53	255	0.597	0.71878	5
163c81	20	212	0.273	0.71093	5
HighK/Rb: 22-80	15	240	0.177	0.71369	4
160a80	11	252	0.121	0.70942	6
95-81	5.8	182	0.093	0.70919	7

of the Kautokeino Gneisses, relative to the mantle evolution curves (see Fig. 14). The older gneiss has been interpreted to have acted as basement for the neighbouring greenstones, and may have been correlatives of gneisses in northern Finland and Kautokeino originally. The younger gneiss is interpreted to be contemporaneous with associated greenstones. The gneisses in eastern Finland may be comparable with the BG in the Kautokeino region, if the latter were formed ca. 300 m.y. after the AG at about 2.7 b.y. as discussed above.

Remnants of a source (mafic crust) have not been found in northern Finland. The Kittiläa Greenstones seem to postdate the tonalites (Krøner et al. 1981) which probably acted as basement for the former, and may be of similar age to the Kuhmo-Suomissalmi Greenstones (2.65 b.y., Vidal et al. 1980, Martin & Querré 1984). A probable source for the Kautokeino eastern gneisses may be equivalents to the easternmost enclaves of LREE-enriched basaltic komatiitic rocks (Sådnabæi Formation), as these show indications of being older than the gneisses. The lower greenstone formation, Baharav'dujav'ri Formation, within the main greenstone belt has a different chemical character to that of the Sådnabæi Formation and is interpreted to be younger than the latter. The chronostratigraphic position of the Baharav'dujav'ri Formation may be similar to the late Archaean greenstones in Finland; an alternative is that the formation may be younger than these greenstones.

TABLE 3b. Location of samples for Rb-Sr isotope analysis.

Map-sheet no. in the M 711-series together with UTM-coordinates are given.

Sample no.	Map-sheet no.	UTM-coord.	Sample no.	Map-sheet no.	UTM-coord.
A'kanasvarri Gneiss					
F19	*1932 I*	*877-540*	*9281*	*1932 I*	*877-600*
F22	*1932 I*	*807-532*	*20183*	*1932 I*	*803-512*
F24	*1932 I*	*878-516*	*20283*	*1932 I*	*811-510*
F31	*1932 I*	*845-506*	*20583*	*1932 I*	*852-532*
8181	*1932 I*	*882-560*	*20683*	*1932 I*	*854-534*
9181	*1933 II*	*924-698*			
Biennaroav'vi Gneiss					
3-80	*1932 IV*	*158-454*			
21183	*1932 IV*	*180-517*			
24183	*1932 IV*	*498-143*			
25183	*1932 IV*	*142-558*			
Masi Formation					
14180	*1932 IV*	*006-382*	*16380*	*1832 II*	*955-235*
15180	*1932 III*	*996-226*	*2481*	*1832 II*	*963-188*
15280	*1932 III*	*982-224*	*2681*	*1832 II*	*966-191*
15880	*1832 II*	*959-241*			
Lavvoai'vi Massifs			*Type of occurrence*		
6980	*1932 IV*	*048-315*	*Smaller massif within Masi Formation*		
9980	*1932 III*	*083-242*	*Larger massif within Av'ži Formation*		
10680	*1932 IV*	*025-451*	*Part of large massif within Baharav'dujavri Fm.*		
13480	*1932 IV*	*995-465*	*Large massif bordering Masi Formation*		
13880	*1932 IV*	*988-391*	*Smaller intrusion within undifferentiated amphibolites.*		
16480	*1932 IV*	*008-452*	*1-2 m thick dyke within quartzite of Masi Fm.*		
17080	*1932 IV*	*014-463*	*Large massif within Masi Formation*		
17180	*1832 IV*	*011-466*	*Large massif within Masi Formation*		

Late plutonic massifs

Table 3 and Fig. 11 present the Rb-Sr results of 21 samples of the Lavvoai'vi Massifs, 19 of the samples giving an age of 1727 ± 40 m.y. (MSWD = 21. I.R. = 0.7037). The Riednja'jav'ri Massif has been dated by Krill et al. (1985) to 1821 ± 143 m.y., I.R. = 0.703. Another intrusion further north within the greenstone belt, the Datkuvarri Granodiorite, gives an age of 1830 ± 320 m.y. and I.R. = 0.703 (Krill et al. 1985). These various dates are comparable, with a quite narrow range of ages or a single age for the intrusions with uniformly low initial ratios, indicating the primary nature of these magmas; and they are compatible with the conclusions made earlier of derivation of the late plutons by partial melting of basaltic material (greenstones).

Masi Formation

Isotope results on 11 samples are shown in Fig. 12 and Table 3. The sediments originally consisted of arkoses with a variable pelitic component, but were subsequently metamorphosed in middle to high amphibolite facies. The age is calculated to 2033 ± 90 m.y., I.R. = 0.7017, omitting the three samples with high Rb/Sr ratios. The three omitted samples may have been reset at later stages (loss of radiogenic Sr). A possible resetting age of ca. 1700 m.y. indicates the influence of late intrusions.

TABLE 3b. (contd.)

Sample no.	*Map-sheet no.*	*UTM-coord.*	*Type of occurrence*
3481	*1932 IV*	*168-420*	*Large massif within gneisses and/or Sådnabæi Formation*
5981	*1932 IV*	*204-413*	*Large massif bordering Sådnabæi Formation*
12381	*1832 II*	*847-191*	*Smaller intrusion within Masi Formation*
15181	*1932 IV*	*056-369*	*1 m thick dyke within Masi Formation (part of smaller intrusion)*
15881	*1932 IV*	*085-391*	*1 m thick dyke within Masi Formation*
16081	*1932 IV*	*082-388*	*1 m thick dyke within Masi Formation*
16781	*1932 IV*	*028-421*	*Larger massif*
17081	*1932 IV*	*027-415*	*Larger massif*

Amphibolites

Low K/Rb:			*Interpreted origin*	*Formation name*
2980	*1932 IV*	*118-375*	*Volcanic*	*Av'ži Formation*
8780	*1932 IV*	*112-329*	*Volcanic*	*Av'ži Formation*
9880	*1932 III*	*070-251*	*Volcanic*	*Av'ži Formation*
160B80	*1832 II*	*978-252*	*Gabbroic*	*Av'ži Formation*
F17	*1932 I*	*873-545*	*Undifferentiated*	*Sådnabæi Formation*
F32	*1932 I*	*800-507*	*Basaltic komatiite*	*Sådnabæi Formation*
8381	*1932 I*	*847-562*	*Undifferentiated*	*Sådnabæi Formation*
10081	*1932 IV*	*053-324*	*Volcanic*	*Av'ži Formation*
10281	*1932 IV*	*981-323*	*Gabbroic*	*Av'ži Formation*
16381	*1932 IV*	*020-440*	*Volcanic*	*Baharav'dujav'ri Fm.*
High K/Rb:				
2280	*1932 IV*	*010-382*	*Gabbroic*	*Av'ži Formation*
160A80	*1832 II*	*978-252*	*Gabbroic*	*Av'ži Formation*
9581	*1932 IV*	*995-305*	*Gabbroic*	*Av'ži Formation*

The interpretation of an age obtained on metasedimentary rocks is difficult. The provenance area for the sediments may have been underlain partly by Archaean tonalitic gneisses and partly by amphibolites of different ages. The sediments will originally represent mainly a detrital mixture of plagioclase, quartz, mica and argillaceous erosion products, and different proportions of these phases will cause the sediment to contain varying relative amounts of radiogenic Sr depending on the Rb concentration relative to Sr. On a broad scale there will be a positive correlation between Sr^{87}/Sr^{86} and Rb^{87}/Sr^{86} in the original sediment. The dotted line in Fig. 12 represents the isotopic composition of detritus at 2.0 b.y. assuming a provenance area composed solely of the AG and BG type gneisses (see p. 138). This starting point is improbable as the age would then be too low (granites of 1700 m.y. intrude the sediments). If the age represents metamorphic resetting an I.R. of ca. 0.79 would be the result, which is very high compared to the one observed. The other limiting factor is that highest amount of radiogenic Sr contained in the sediments should correspond to the average Sr^{87}/Sr^{86} of the gneisses at 2.0 b.y. Starting compositions would then lie close to the stippled line in Fig. 12, and the I.R. would have lain within the range of error of the date attained for the Masi Formation.

The real initial compositions, however, would more probably scatter between the dotted and the stippled lines in Fig. 12, i.e. a mixture of argillaceous erosion products of average gneiss composition (stippled line) and coarser detrital grains from different gneiss compositions (dotted line). The expected result would then have become meaningless, while a metamorphic homogenization would have resulted in a too high I.R. (0.72). A large amount of basaltic material, as source for the sediments, has to be inferred to account for the observed low I.R. for the sediments.

In Fig. 14 it can be seen from the I.R. that if the age of ca. 2.0 b.y. represents the time of sedimentation, then a mixture of amphibolite and gneiss material must have constituted the provenance area. However, this would have resulted in a large scatter of initial isotopic compositions in the origin sediments and a data set fitting a regression line could not have been obtained. The relatively good fit of the data to the regression line, however, implies a probable homogenization of isotopes during the medium to high amphibolite facies metamorphism. The age of 2.0 b.y. is thus probably a minimum age of sedimentation. If the 'bulk earth evolution line' in Fig. 14 represents the lower limiting initial composition, i.e. basaltic material of a similar Rb/Sr ratio as this line, then maximum age of sedimentation is 2.1 b.y.

Amphibolites

The present study of amphibolites was undertaken to investigate the nature of secondary enrichment of K and Rb, which is accompanied by a significant lowering of the K/Rb ratios from mantle values (500-1000) down to 200-300 (Fig. 13b). Ten samples from apparently chemically altered amphibolites (Fig. 13b) were analyzed for Rb-Sr isotopes (Table 3 and Fig. 1å). Three of the samples (83, F17 and F32) are from the Sådnabæi Formation, one (163c) from the Baharavdujav'ri Formation, while the rest belong to the Av'ži Formation. The Av'ži samples include four metavolcanic rocks (29, 87, 98 and 100) and two medium-grained homogeneous amphibolites of gabbroic origin. A regression through 8 of these samples (Fig. 1å) gives an errorchron of 1950 ± 190 m.y., I.R. = 0.7023 (MSWD = 42).

Three samples of amphibolitic metagabbroic rocks from the Av'ži Formation have normal mantle K/Rb values (500). These are also plotted in Fig. 1å and a significant deviation from the regression line of the low K/Rb samples is observed. This implies that a probable process for the secondary introduction of K and Rb may have occurred some time after the formation of the original gabbroic/basaltic material. The age obtained is thus interpreted as the time of metamorphism. Skiöld & Cliff (1984) obtained a Sm-Nd age of 1932 ± 45 m.y. on amphibole and plagioclase from metabasaltic rocks belonging to the Kiruna greenstones. This must be a metamorphic age, and agrees very well with the Rb-Sr age obtained in the present study.

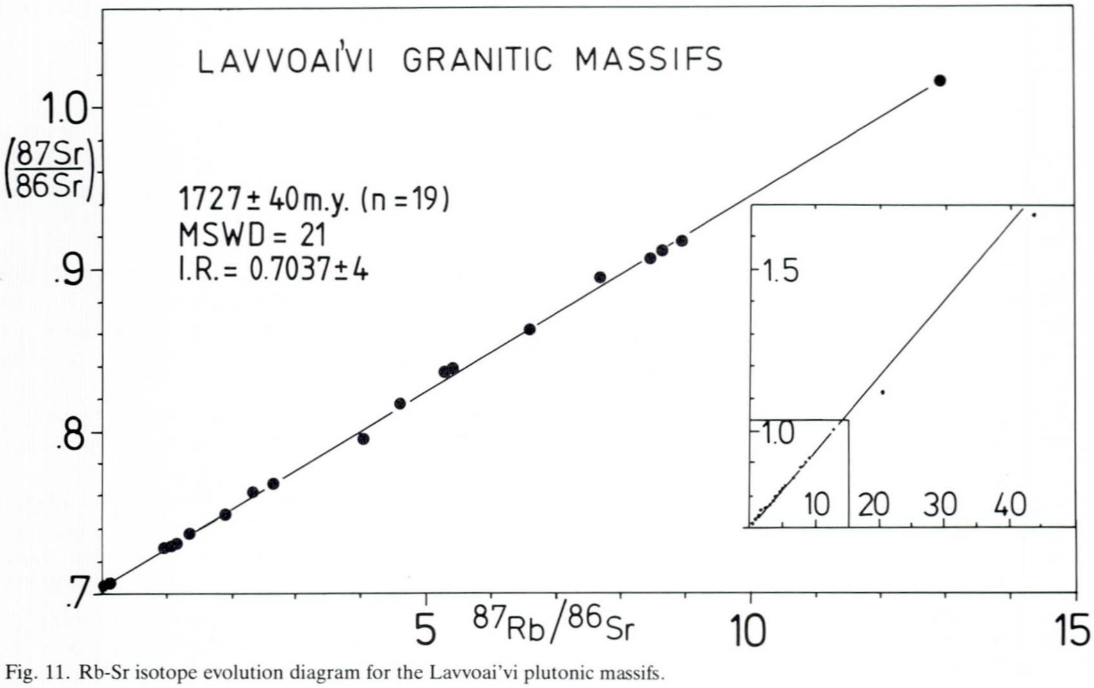


Fig. 11. Rb-Sr isotope evolution diagram for the Lavvoai'vi plutonic massifs.

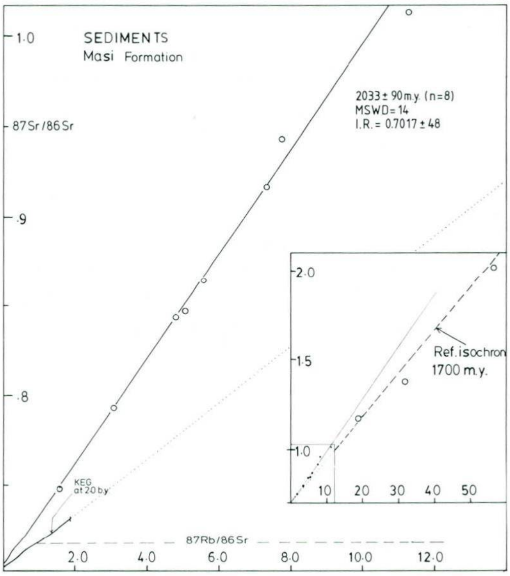


Fig. 12. Rb-Sr isotope evolution diagram for the metasedimentary rocks of the Masi Formation. 'KEG' indicates the isotopic composition of Kautokeino Eastern Gneisses 2.0 b.y. ago (AG + BG, see Fig. 10). *Dotted line:* Isotopic compositions of mineral constituents in KEG, 2.0 b.y. ago. *Dashed line:* Hypothetical isotope compositions of a mixture of argillaceous erosion products derived from KEG 2.0 b.y. ago.

Summary

The isotopic results are compatible with the conclusions drawn from the major and trace elements, and show the primitive nature of both the eastern gneisses and the young plutonic massifs within the greenstone belt. The former have their equivalents in Finland, both in age and in composition.

No conclusion can yet be reached concerning the relationship of these rocks to the associated greenstone belt, but the source material may have been equivalents of the amphibolitic enclaves which occur within the eastern gneisses and have possible connections with the belt (Sådnabæi Formation).

The dates from the young plutons also confirm the geochemical interpretations made earlier. The melting of amphibolitic material occurred at depth during a relatively late stage in the Svecofennian orogeny.

The age derived from the metasediments and the amphibolites are of similar magnitude, and are interpreted to represent the age of metamorphic homogenization of isotopes and of simultaneous secondary introduction of K and Rb. The three samples which have retained high K/Rb ratios show that the Rb/Sr range is quite close to that representing the 'bulk earth evolution line' in Fig. 14. The Sr^{87}/Sr^{86} ratio for the bulk of the amphibolites may thus have developed close to this line before eventual metamorphic alteration. The original formation of the amphibolitic material therefore probably cannot be traced by the Sr-isotopes.

If the interpretation of these ages is correct, a maximum age of 2.1 b.y. for the sedimentation of the Masi Formation is implied; but then very little erosion products from the now partly bordering old gneisses in this southern region were involved. The regionally extensive presence of fuchsite in the metasediments also indicates that extensive metavolcanic units, including larger

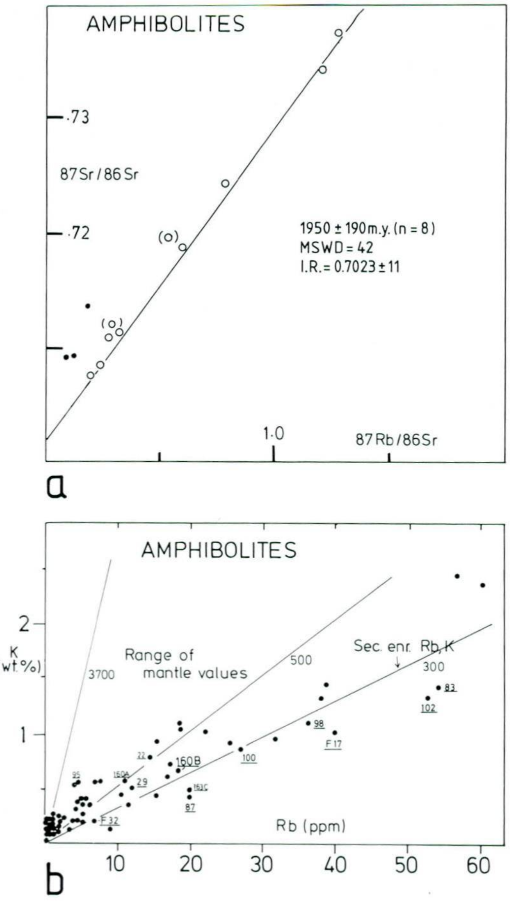


Fig. 13. a) Rb-Sr isotope evolution diagram for metavolcanites: O: K/Rb 150-400, ~: K/Rb > 500. b) K-Rb plot for amphibolitic volcanites. Different K/Rb ratios are indicated. *Underlined numbers:* Sample no., ref. to Table 3 and Fig. 13a.

amounts of komatiitic rocks, almost certainly constituted the provenance area (source of Cr). The latter may have been composed in part of equivalents to the Baharav'dujav'ri and Sådnabæi Formations. Siedlecka (1984) reported a high Na/K ratio for the Masi Formation, which may be attributed to erosion products mainly from basic material.

The maximum age for the Av'ži Formation, which was deposited above the Masi Formation, is thus 2.1 b.y. A summary of the results and interpretations is given in Table 4.

Discussion and conclusions

The similarity between the Kautokeino and Finnish gneisses, both compositionally and geochronologically, supports the hypothesis that the Archaean craton extended into, and is preserved in West Finnmark. Thus, the possibility exists that Archaean greenstone belts may also be found in Finnmark.

Four volcanic formations have been defined in the Kautokeino Greenstone Belt. All of them are similar in the character of their volcanic

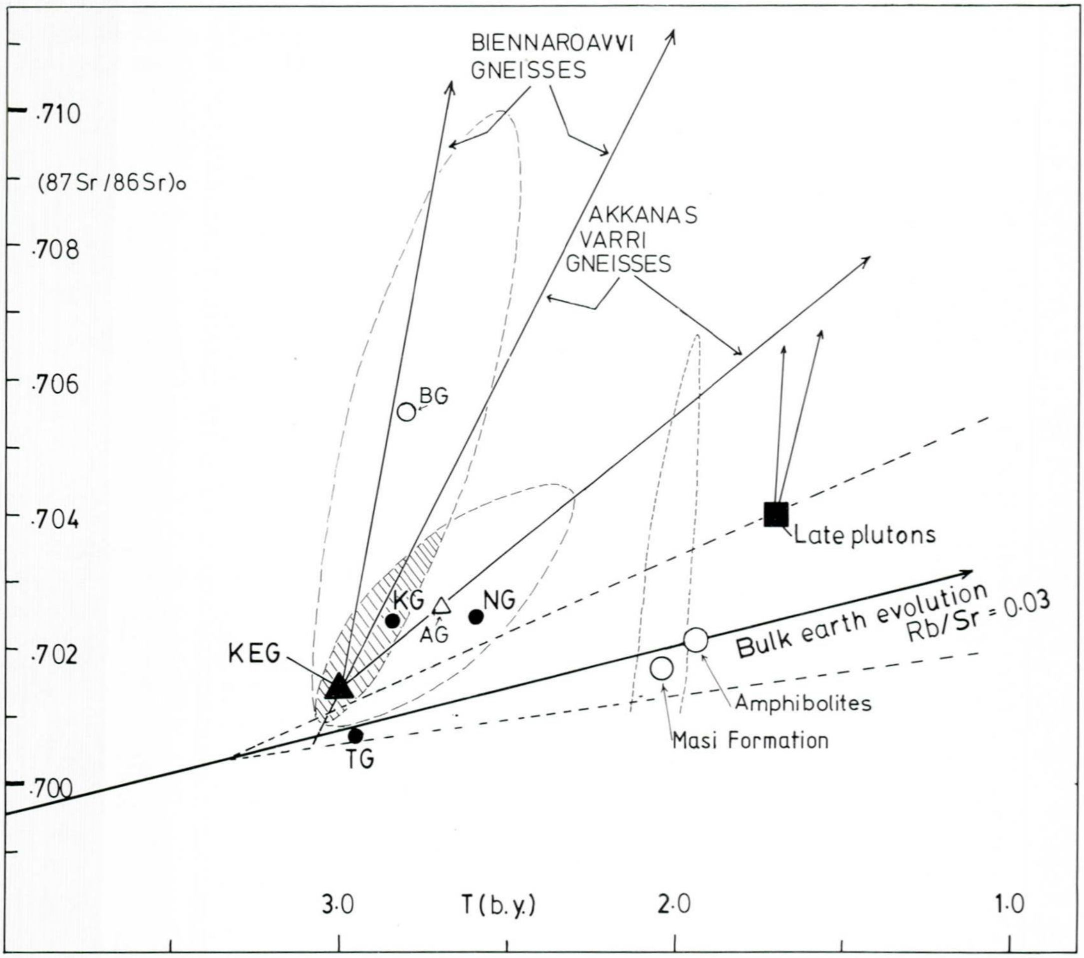


Fig. 14. Initial Sr isotope compositions versus age for the different rock units described. Finnish gneisses are included for comparison (KG = Kivijärvi Gneisses; NG = Naavala Gneisses; TG = Tojottamansälkä Gneisses); KEG = Kautokeino Eastern Gneisses; AG = Ak'kanasvarri Gneisses; BG = Biennaroavvi Gneisses. *Dashed lines* comprise the main range of composition of amphibolites which may possibly be present in the Kautokeino region. *Dashed ellipses* comprise possible combinations of ages and I.R.'s according to uncertainties of the regression (2 -level). *Dashed area* represent the possible ages and I.R.'s if BG has been formed from AG either by partial melting of the latter or by fractionation from the AG-melt.

activity starting with basaltic eruptions and ending up with tuff, tuffite and sediments. Chemically, however, they differ in the existence or amount of komatiitic lavas, which have not been observed in the Stuorajav'ri Formation, and in the chemistry of the komatiitic rocks. The Sådnabæi Formation contains basaltic komatiites of a different chemical nature, and is interpreted to represent an earlier episode of volcanism than the Baharav'dujav'ri Formation. Carbonate rocks, which are very common in the Stuorajav'ri Formation, are with few exceptions not observed in the Av'ži Formation. The amount of carbonate present indicates varying conditions during sedimentation.

The Ak'kanasvarri Gneisses show intrusive relationships to the Sådnabæi Formation, which may represent equivalents to the source material for the gneisses. These enclaves within the gneisses, which can be followed towards the main belt, may be part of the Baharav'dujav'ri Formation in the easternmost zone of the latter. Together with the gneisses they probably constituted a continental crust (basement) during the deposition of all the younger formations.

The Sådnabæi Formation contains volcanic rocks of similar chemical composition to the volcanites which constitute a larger part of the Gål'denvarri Formationto the north (Solli 1983). However, where this formation accidently lies in contact with the Baharav'dujav'ri Formation, it would probably be difficult to distinguish the two separate formations.

The Baharav'dujav'ri Formation is composed of about 50 % komatiitic rocks with characteristically high MgO-content (up to 30 %), occurring in a rather narrow zone northwards from its type area. It is correlated with similar rocks occurring close to the Eastern Gneiss Complex and stratigraphically underneath the Masi Formation. The amount and composition of the komatiites and the old basement gneiss complex are similar to those in the eastern and northern Finnish Late Archaean Greenstone Belts (dated to c. 2.6 b.y.) and may be correlated with them.

The Favrusjåk Gneisses of the Raisædno Gneiss Complex have a relatively high amount of veins, lenses and bands of granitic or pegmatitic material. The probably have in part an intrusive relationship to the supracrustals, but they are also cut by younger intrusion (Riednjajav'ri Massif).

The Av'ži Formation, regionally, has indications of having been deposited unconformably upon the Masi and Baharav'dujav'ri Formations, starting and ending with sedimentary sequences. Locally, the lower parts of the volcanic units may contain thin komatiitic layers. The age of deposition of the Av'ži Formation lies in the range 1.9 - 2.1 b.y., the higher limit being the maximum age for deposition of the Masi Formation.

The main regional metamorphism of the supracrustals occurred at 1.95 ± 0.1 b.y., i.e. early in the Svecofennian orogenic period. This age is comparable to metamorphic ages obtained on the Kiruna Greenstones and on the lower volcanic unit in the Holmvatn Group (Pharaoh et al. 1982).

The Čaravarri Formation shows indications of having been deposited unconformably on older quartzites and now altered amphibolites along the eastern border (at Gæšjav'ri), with argillites or sandstones/ siltstones, locally with debris flows, overlying this basement. These features probably imply that the formation, in this region and northwards, must be different and of a later deposition than the uppermost part of the Av'ži Formation which lies concordantly upon the volcanic rocks.

Observations by Holmsen et al. (1957) also point to a sedimentary contact at Gæšjav'ri, in that a possible synformal structure in the Čaravarri Formation is indicated in one of their illustrations SSW of the lake where the underlying argillites (corresponding to the Bik'kacåkka Formation, Siedlecka et al. 1985) reappear (Fig. 2b).

Further north from the northernmost limit of our present area, the observed basement for the Čaravarri Formation wedges out against a fault breccia, which in the south separates the volcanite belonging to Lik'ča Formation from this 'basement'. To the north this fault cuts into the Čaravarri Formation and separates it from the volcanic rocks. A similar base (of older quartzites), or remnants of it, is possibly present west of the formation, along the brecciated contact to the Čas'kejas Formation (correlated with the Stuorajav'ri Formation), separating it from the volcanic sequences to the west.

The above observations may indicate an early event of basin formation and sedimentation prior to a more intense block faulting and rifting with subsequent volcanism and deposition of the Stuorajav'ri and Lik'ča Formations. These relationships are illustrated in Fig. 2b.

The Stuorajav'ri Formation, consisting of tholeiitic basalts, carbonates, tuff/tuffites and

TABLE 4. Summary of geochronological results and interpretations. Implications for different formations considering all evidence.

Formation or complex	Regression (b.y.) (this paper)	Interpretations of processes dated	Age-limits of formation (b.y.)	Probable preferred age (b.y.)	Interpreted mechanism of formation	Correlations in Finland
Sådnabæi Fm.	-	-	>2.7	>3.0	Basic volc.	?
A'kanasvarri Gneisses	2.7 ± 0.4	Thermal re--equilibration	2.7 - 3.1	ca. 3.0	Melting of basic material	Tojottamanselkä Gneisses
Biennaroavvi Gneisses	2.8 ± 0.3	Formation	2.7 - 3.1	ca. 2.7	Melting of AG	Kiivijärvi Grey Gneisses
Baharav'dujavri Fm.	-	-	>1.9	>2.0	Basaltic volc. Greenstone	Partially Kittilä or Kuhmo-Suomussalmi
Masi Fm.	2.00 ± 0.16	Metamorphism	1.9 - 2.1	2.0 - 2.1	Erosion products from mainly basic material	Not considered
Amphibolites	1.95 ± 0.10	Metamorphism	?	?	Diabase and basic volcanites	Partially Kittilä Greenstones
Av'ži Fm.	-	-	1.9 - 2.1	2.0 - 2.1		
Čaravarri Fm.	-	-	<1.9	<1.9	Erosion products from all the above rock-types.	Not considered
Stuorajav'ri Fm.	-	-	<1.9	<1.9	Diabase basic volc.	?
Late plutons	1.72 ± 0.03	Formation	1.69 - 1.75	1.7	Melting of basic material	?

argillites, may have been deposited along an active fault margin to the east and on a platform to the west. Northwards (north of our map-area), this possible active fault margin may partly be represented by the breccia zone described from Cuol'bmajav'ri against the contact to the Čaravarri Formation and its possible basement of quartzites. The western contact of the Stuorajav'ri Formation may be primary depositional, unconformably overlying the Masi and Av'ži Formations (part of the Čas'kejas Formation, see Siedlecka et al. 1985). These may still, together, make up one series of rocks, the Čas'kejas Formation, but we prefer to place the Stuorajav'ri Formation in a later episode after the main metamorphism. Sandstad (in prep.) concludes on mineral-chemical grounds that there is a continuous E-W metamorphic gradient eastwards from the margin against the Raisædno Gneiss Complex, the temperature conditions becoming equivalent to 'very low grade' metamorphism in the volcanic sequence correlated with our Stuorajav'ri Formation. We await more detailed studies on mineral equilibria before an eventual metamorphic gradient is deduced, and believe that the present data do not show any definite metamorphic gradient. The range in composition of amphibolites presented internally for individual samples is almost as large as the entire range obtained, and can thus most probably be ascribed to retrograde effects. Also, there is no systematic correlation between amphibole composition and distance from the gneiss complex. Using Sandstd's data more carefully, in our opinion they may speak more in favour of a metamorphic break to the east.

The very intense brecciation-alteration events must be younger than the main metamorphism (i.e. not be followed into the area underlain by the Stuorajav'ri Formation.

Strømberg (1978) reported major NW-SE-trending lineaments on the Baltic Shield which are of a transformal nature with strike-slip movements. He related them to important volcanogenic and ore-forming events. Being active during most orogenic events, they have resulted in the formation of aulacogens in connection with orogenesis. Brecciation (and shearing) is most intense along NW-SE-striking lineaments in the Kautokeino region (left-lateral movements). These fractures can be related to early rifting and formation of an aulacogen, with subsequent tholeiitic volcanism.

Several attempts have been made at dating correlative greenstones, both in the Kvænangen Window (Kvenvik Greenstones) and in the Komagfjord Window. Gautier et al. (1979) obtained K-Ar dates showing a wide range, but with a majority of the samples falling below ca. 1500 m.y. Pharaoh et al. (1982) reported a K-Ar age of 1980 m.y. for the metamorphism of the *amphibolites*, in the *lower volcanic unit* in the Komagfjord Window. The K-Ar system showed no signs of Caledonian reworking. They also mention a Rb/Sr age of 850 m.y. obtained on greenstones of the *upper volcanic unit* (Nussir Group), and attribute this to 'almost certainly' being caused by Caledonian reworking. (The Sr-isotopes, however, are more difficult to disturb than the Ar-system). Krill et al. (1985) present a Rb-Sr age of 1135 ± 880 m.y. on the Kvenvika Greenstones in the Kvænangen Window.

The young ages reported may be real ages if our interpretation for the Stuorajav'ri Formation is correct and this formation is correlated with the Kvenvika Greenstones and the Nussir Group.

The eventual rifting may be either a late development in connection with Svecofennian orogenesis, or an early event in the Sveconorwegian orogenesis. The latter could then indicate a correlation with the earliest Telemark supracrustals, and on the American continent with the formation of the Mid-Continental Rift and effusion of the Keweenawan Volcanics. In this connection the young ages reported, as mentioned above, fit with the latter interpretation.

The observations and indications which have led us to the hypothesis of a relatively late rift-forming event, clearly have be proved or disproved. More geochemistry, metamorphic petrology, age dating and structural analysis need to be carried out in more detail to help solve the problems, and it remains to be seen if our observations turn out to be coincidental and products of other effects rather than resulting from major geological events.

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