Svecokarelian Thrusting with Thermal Inversion in the Karasjok-Levajok Area of the Northern Baltic Shield

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Krill, A.G. 1985: Svecokarelian thrusting with thermal inversion in the Karasjok-Levajok area of the northern Baltic Shield. *Nor.geol. unders. 403,* 89-101.

Recent mapping, isotopic dating, and metamorphic and structural observations from the Karasjok-Levajok area, lead to a tectonic interpretation that is similar in many ways to Phanerozoic plate tectonic models. Three major belts of Early Proterozoic rocks lie between two Archean gneiss complexes: the Jer'gul Gneiss Complex on the west and the Baišvarri Gneiss Complex on the east. The E-dipping Early Proterozoic belts are, from west to east: the Karasjok Greenstone Belt, the Tanaelv Migmatite Belt, and the Levajok Granulite Belt. Earlier geochemical studies suggested that the Tanaelv Migmatite Belt consists mainly of tholeiitic metavolcanites of an outer volcanic arc, and that the Levajok Granulite Belt represents geosynclinal metasediments intruded by calc-alkaline rocks of an inner magmatic arc. It is suggested here that basaltic rocks related to the Karasjok Greenstone Belt were subducted eastward, generating the arc magmatism, and contributing heat and CO_2 to produce the granulite-facies metamorphism. During later stages of the Svecokarelian event, thrusts developed parallel to the subduction zone. The granulites were thrust westward over the migmatites, which were in turn thrust over the greenstones. West-directed thrusts also developed within and beneath the Karasjok Greenstone Belt.

Thrusting of the granulite belt occurred at granulite-facies conditions and the heat from these rocks contributed to an inverted regional metamorphic gradient within the underlying Tanaelv Migmatite Belt and Karasjok Greenstone Belt. The metamorphic grade within the Karasjok Greenstone Belt increases from low grade in the western, deepest parts, to medium grade and migmatitic high grade upward, near the overlying Tanaelv Migmatites. Kyanite-bearing rocks in the deeper parts of the Karasjok Greenstone Belt contrast with sillimanite-bearing rocks in the shallower parts, and demonstrate that the metamorphism was *in-situ*, and not the result of thrusting of previously cooled high-grade rocks.

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Introduction

General tectonic models, now available for the Precambrian crystalline rocks of the Baltic Shield, help to evaluate the degree of regional thrusting and the possible role of plate tectonics in older Precambrian terranes. Within the southwestern Baltic Shield, regional thrusting may have occurred during the Sveconorwegian/Grenvillian orogenesis, about 1200 - 850 Ma ago (Berthelsen 1985). Although most of the rocks of the Baltic Shield were strongly deformed during the c. 2000 - 1700 Ma Svecokarelian/Svecofennian event, only in the far northern parts of the Baltic Shield is there definitive evidence for such old thrusting. The most recent models for these areas agree (Barbey et al. 1984, Berthelsen 1985) that a significant thrust fault, possibly a suture, marks the western border of the large Levajok Granulite Belt. The granulite belt (Fig. 1) extends from the Norwegian Caledonides over 300 km to the southeast, and the postulated thrust continues well beyond.

The models are rather general, because much work is yet to be done. The lack of relevent basic geological data is most apparent in Finnmarksvidda, within and west of the granulite belt. It is the most inaccessible and poorly exposed part of Norway, and few previous detailed studies have been made.

A large project by the Geological Survey of Norway (Finnmark Program) and another in cooperation with the Geological Surveys of Norway, Sweden and Finland (Nordkalott Project) now provide improved opportunities to study and compare the rocks of these areas. With logistical support and the new tectonic models, even outcrop hunting in marshy, forested areas seems worthwhile, and the following results are basedly largely on relatively basic geologic observations in areas currently being mapped in detail (1:50,000) for the first time. Much of the area was originally mapped and described by Wennervirta (1969), Skålvoll (1971, 1978) and Meriläinen (1965, 1976).

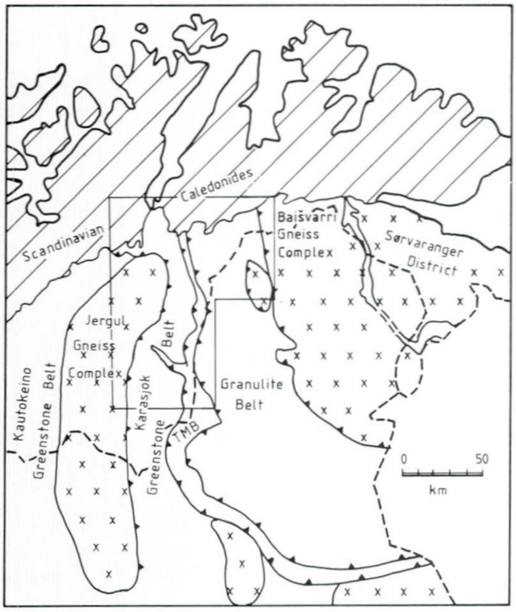


Fig. 1. Geologic sketch map of northern Norway and Finland showing the location of the Karasjok-Levajok area.

Main Tectonic Units of the Karasjok Area

The Karasjok-Levajok area (Fig. 2) includes both 'granite-greenstone' and 'high-grade' terranes - common elements in early Proterozoic and Archean crust (Condie 1981). All the rock units were metamorphosed and deformed during the Svecokarelian event, but uncertainties regarding the ages of deposition and possible earlier deformations have hindered tectonic models. Recent isotopic results (Bernard-Griffiths et al. 1984, Krill et al. 1985) now show that the three main supracrustal units - the Karasjok Greenstone Belt, the Tanaelv Migmatite Belt, and the Levajok Granulite Belt - are all probably Early Proterozoic. The supracrustal units apparently were deposited and deformed in the same orogenic cycle, between about 2200 - 1700 Ma. The two basement gneiss complexes - the Jer'gul Gneiss Complex, and the Baišvarri Gneiss Complex - are presumed to be largely Archean.

The *Jer'gul Gneiss Complex* forms the basement margin for two supracrustal series - the Kautokeino Greenstone Belt beyond the Karasjok-Levajok area to the west, and the Karasjok Greenstone Belt to the east. The Jer'gul Gneiss Complex consists mainly of tonalitic to granitic orthogneiss, with some parts showing diffuse migmatitic layering. Attempts at U-Pb and Rb-Sr isotopic dating have yielded errorchrons suggesting Archean ages for the oldest rocks (Meriläinen 1976, Olsen 1985). Svecokarelian (c. 1800 Ma) intrusions appear to dominate the western part (Solli 1983) and the rocks locally intrude the unconformity and the western greenstone belt as in the classic mantled gneiss domes well known elsewhere in the Baltic Shield (Eskola 1948). Also the southern part of the Jer'gul Gneiss Complex, in Finland, is dominated by Svecokarelian intrusions, collectively known as the Hetta Granite.

On the eastern margin of the Jer'gul Gneiss Complex, Svecokarelian intrusions are minor, and a nearly undisturbed angular unconformity is locally preserved (Skålvoll 1964). Granitic rocks below the unconformity yielded a Rb-Sr whole-rock isochron indicating a date of 2110 ± 105 Ma (Krill et al. 1985). The date is interpreted as the age of granitic intrusion, and establishes a maximum age for this unconformity and for the overlying clastics and volcanics of the Karasjok Greenstone Belt.

The *Karasjok Greenstone Belt* includes various metamorphosed sediments, amphibolites, and komatiitic pillow lavas and breccias, all above a basal clastic sequence. Often (1985) summarizes the geology and presents a regional stratigraphic interpretation. A komatiitic dike and abundant N-S oriented diabase dikes within the northern part of the Jer'gul Gneiss Complex (L.P. Nilsson, pers.comm. 1984) suggest that some of the Karasjok volcanics were intruded through the sialic gneissic basement. Small gabbros within the Karasjok Greenstone Belt may be coeval with the volcanism. One large gabbro appears to be syntectonic (Elvebakk et al. 1985) and one 15 km long diabase dike is clearly post-tectonic. Except for the lithofacies similarity of the basal psammites, there are no obvious stratigraphic correlations between the greenstone belts on either side of the gneiss dome, and it is not known whether the deposits formerly extended across the 40 km width of the gneiss complex.

To the south in Finland, the Karasjok Greenstone Belt narrows, is intruded by rocks of the Hetta Granite, and, according to available mapping, then develops into the Kittilä greenstones. The recognition elsewhere in Finland of Archean greenstone belts with komatiites, and the presence of komatiites in both the Kittilä and Karasjok greenstones, suggested that both were of Archean age (Gaal et al. 1978). The only

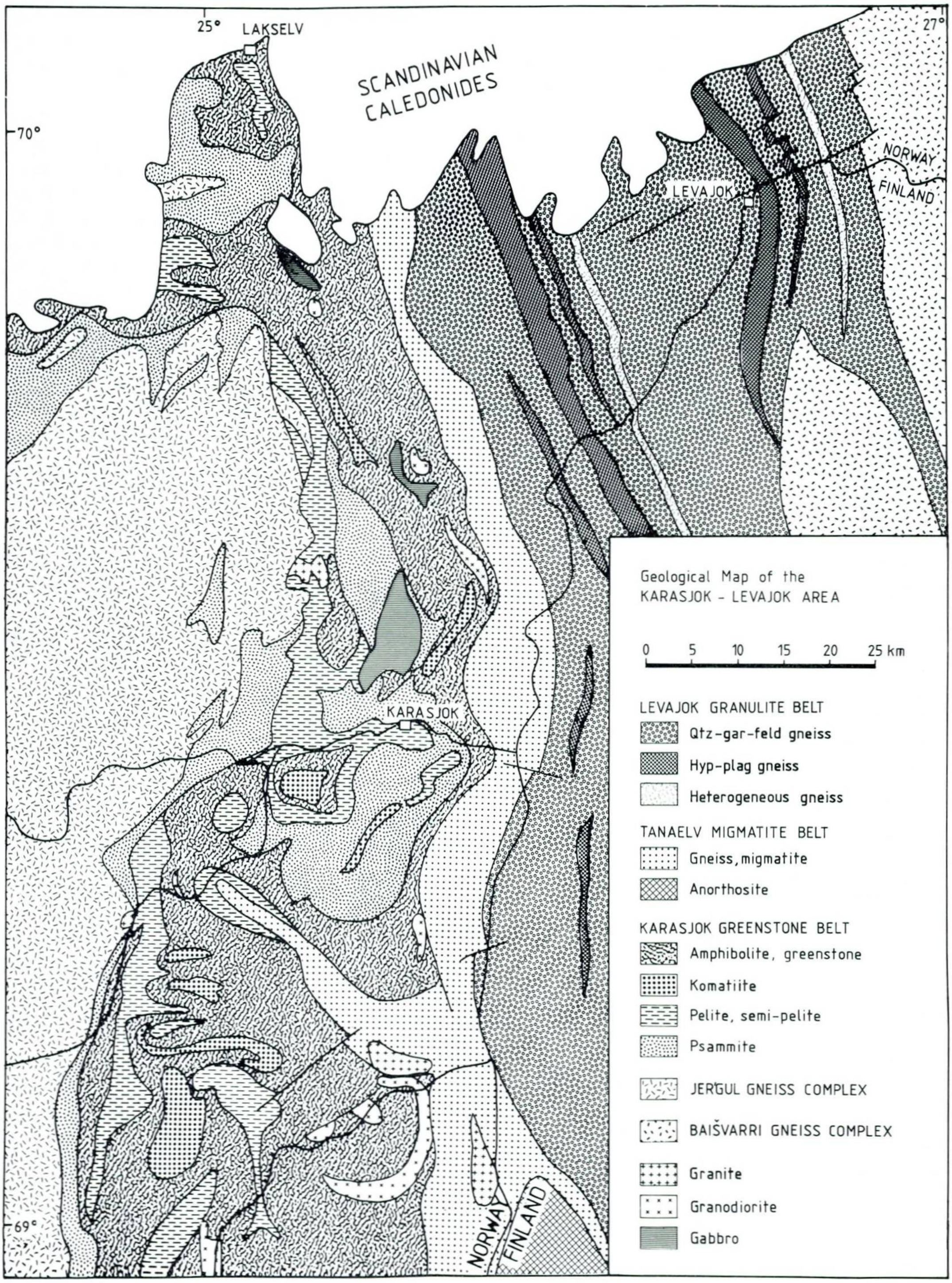


Fig. 2. Geological map of the Karasjok-Levajok area. Includes unpublished material by G. Elvebakk, H. Henriksen, S. Johnsen, A.G. Krill, M. Marker, K. Nilsen, L.P. Nilsson, M. Often, T. Pharaoh, A. Siedlecka, D.v.d. Wel.

available Archean date from the Karasjok belt was of an albite diabase dike (Meriläinen 1976), but the date was not reliable and the details were not published. Now a Sm-Nd whole-rock date of 2085 ± 85 Ma has been obtained from the Karasjok komatiites (Krill et al. 1985) and it is doubtful that any of the rocks of the Karasjok Greenstone Belt are Archean. Some significantly older dates (2.7 - 2.2 Ga) have been reported from rocks in the Kittilä greenstone complex (see Rastas 1980), and it is uncertain which rocks, if any, can be correlated with Karasjok rocks.

The *Tanaelv Migmatite Belt* consists of granites and high-grade metamorphic rocks of uncertain origin. Barbey et al. (1980, 1982, 1984) first defined such a belt, the Tana (River) belt, showing it to extend along the entire southeastern edge of the granulite belt. Their sketch maps delimiting the Tana belt include rocks previously mapped as the Karasjok or West Inari Schist zone, the Vaskojoki anorthosite and the Marginal Zone of the granulite complex, and some gneisses of the Archean basement (Mikkola 1941, Meriläinen 1965, 1976, Skålvoll 1971). Geochemical studies led to interpretations that the rocks were originally tholeiitic basalts, diorites, andesites and graywackes, and may represent a tholeiitic island arc (Hörmann et al. 1980, Barbey et al. 1980, Raith et al. 1982). More recent results show a greater variety of rock types, including troctolitic, anorthositic and granitic metaplutonic rocks, as well as tholeiitic, calc-alkaline and rhyodacitic metavolcanites (Barbey et al. 1984).

In the northern part of the Karasjok-Levajok area, the Tanaelv Migmatite Belt consists of grey intermediate to mafic hornblende gneiss (Henriksen 1983). In the central parts, it includes more quartzofeldspathic gneiss, and in the southern parts, granite-veined amphibolites are dominant. Small ultramafic bodies are common. The large Vaskojoki anorthosite (Fig. 2) is interpreted as a syn-metamorphic intrusion (Moreau 1981, Barbey et al. 1984).

The Tanaelv rocks are now thought to be mainly Early Proterozoic, and not Archean as previously suggested. A lens of concordant granitic gneiss in Finland has yielded the oldest date, a zircon upper intercept of about 2360 Ma (Meriläinen 1976). The Vaskojoki anorthosite has been dated at 1906 ± 14 Ma (zircon discordia, Bernard-Griffiths et al. 1984), and a mafic metavolcanic rock is dated at 1816 ± 172 Ma (Rb-Sr whole-rock, Bernard-Griffiths et al. 1984). Late-tectonic granites in the Karasjok-Levajok area are about 1750 Ma and have relatively high initial Sr ratios (c. .713) (Rb-Sr whole-rock, Krill et al. 1985).

The *Levajok Granulite Belt* is the northern part of the Lapland granulite belt. It forms an arch 50 km wide and over 300 km long, and is one of the best-known parts of the northern Baltic Shield. The relatively early description of these granulites by Eskola (1952) clarified his definition of granulite facies and established the belt as a classic granulite terrain. His work was later followed by more detailed mapping and description of the rocks (Meriläinen 1965, 1976) and then by detailed geochemical and petrologic studies (Hörmann et al. 1980, Barbey et al. 1980, 1982, 1984, Raith et al. 1982).

The newer results confirm and expand Eskola's interpretation that the granulites were produced largely from Al-rich sediments and intrusive igneous rocks that were strongly deformed and metamorphosed under granulite-facies conditions. The most abundant rock types are quartz-feldspar-garnet (±biotite, ±sillimanite, ±cordierite) gneisses, interpreted as metamorphosed greywacke-shale sequences (Barbey et al. 1982). Hypersthene-plagioclase gneisses are also abundant, and from the geochemical studies they are interpreted as metamorphosed quartz-tholeiitic basalts and calc-alkaline dacitic to andesitic rocks, similar to rocks of modern magmatic arcs (Hörmann et al. 1980, Raith et al. 1982, Barbey et al. 1984).

The granulites were thought to be Archean because of the consistently high metamorphic grade, and a Pb-Pb date of about 2500 Ma (Meriläinen 1976), but the validity of this date has been questioned (Bernard-Griffiths 1984). Recent Rb-Sr, Sm-Nd and Pb-Pb isotopic dating studies show that the hypersthene-plagioclase orthogneisses are 2000 - 1900 Ma old, and that they intruded during the granulite-facies metamorphism (Bernard-Griffiths et al. 1984). The primary age of the metasediments and metavolcanics is unknown, but an attempt at Sm-Nd whole-rock dating of metasediments yielded an errorchron date of about 2060 ± 200 Ma (Bernard-Griffiths et al. 1984).

These rocks are very poorly exposed in Finland, where most of the petrologic samples have been taken from rather isolated outcrops. The well exposed Norwegian area, currently being mapped, allows better observation of field details. The metasediments are very monotonous; no sharp lithologic contacts or primary textures are seen. Most of the hypersthene-plagioclase orthogneisses are remarkably homogeneous, forming large continuous units of consistent thickness and appearance. The mapping supports the interpretation that most of the orthogneisses were intrusions (Bernard-Griffiths et al. 1984) and not volcanites, as suggested by Hörmann et al. (1980). However, two of the orthogneiss units are more heterogeneous (Fig. 2), and may represent thick metavolcanic units. Additional hypersthene-plagioclase gneisses within the western part of the granulite belt are currently being mapped (K. Nilsen, in prep.) and are not shown in Figure 2.

The *Baišvarri Gneiss Complex* is the new term for the rocks in Norway bordering the granulite belt to the east. To the south in Finland, it has been called the 'granite-gneiss complex' and includes both Archean and Svecokarelian gneisses (Meriläinen 1976).

In Norway, the Baišvarri Gneiss Complex consists of various orthogneisses, with metasediments and amphibolites as layers, lenses and xenoliths of all dimensions. The metamorphic grade appears to be transitional toward the granulite belt. Within a few kilometers of the granulites, hypersthene is found in some of the orthogneisses. The Baišvarri metasediments also include cordierite-sillimanite gneisses, but they contain prograde muscovite, unlike the granulites.

The well exposed rocks in Norway show that the lithologic contact is remarkably sharp. Orientations of foliation in the Baišvarri Gneiss Complex are irregular due to large-scale folding, but the foliation becomes concordant to the granulite foliation within about 1000 meters of the contact. Stable hypersthene, sillimanite and garnet along the contact show that deformation occurred under the high-grade metamorphic conditions.

The Baišvarri Gneiss Complex may have formed the crustal basement to the deposition of some of the metasediments and the minor metavolcanic rocks of the granulite belt. In Norway, the Baišvarri gneisses now lie above the granulites with a tectonic contact. Relatively massive intrusive bodies are common in the Baišvarri Gneiss Complex, but are not found in the underlying granulites. The Baišvarri Gneiss Complex was presumably thrust upward against the granulites after emplacement of these Svecokarelian intrusions.

Regional Metamorphism and Svecokarelian Deformation

A description of the tectonics of the Karasjok-Levajok area logically begins with the Levajok Granulite Belt. It is the most intensely deformed and metamorphosed part of the northern Baltic Shield, and now appears to be the key to the structural development of the nearby rocks as well.

Only one high-grade metamorphic event has been shown for the granulites. Hörmann et al. (1980, Raith et al. 1982) studied samples collected along a profile across the central part of the granulite belt in Finland. Their abundant mineralogic and petrologic data showed consistent peak metamorphic conditions at hornblende-granulite facies (700-800°C, 6-8Kb, $XH_2O<0,3$). In a simular study of samples from throughout the Finnish granulites, Barbey et al. (1984) show similar peak metamorphic conditions, as well as several stages of minor retrograde metamorphism down to 550°C, 3Kb and lower.

The prograde metamorphic developement of the granulites is not well preserved. Early textures recognized during current mapping in Norway show an early stage of migmatization with cordierite as a stable phase. Such early migmatization was noted by Scheumann et al. (1961) but recent reports have mentioned only late local migmatization. The early migmatitic rocks are preserved as lensoid structural relicts surrounded by typical quartz-garnet-feldspar gneiss. The cordierite apparently was replaced by biotite, sillimanite and garnet during strong deformation.

A several m^3 boudin of coarse-grained gneiss containing garnet, quartz, biotite, chlorite and abundant kyanite was also found (Fig. 4) as a structural and petrologic relict, surrounded by typical sillimanite-bearing granulites. Although sillimanite is common throughout the granulite belt, this is the only known occurrence of kyanite, except for the southeastern part of the granulite belt in the Soviet Union. The early stability of kyanite is considered to be petrologically significant. Kyanite may have been the stable prograde Al_2SiO_5 phase in much of the granulite belt before extensive recrystallization under the peak metamorphic conditions.

Barbey et al. (1984) point out the presence of kyanite in rocks east and west of the granulite belt. They suggest that the absence of kyanite in

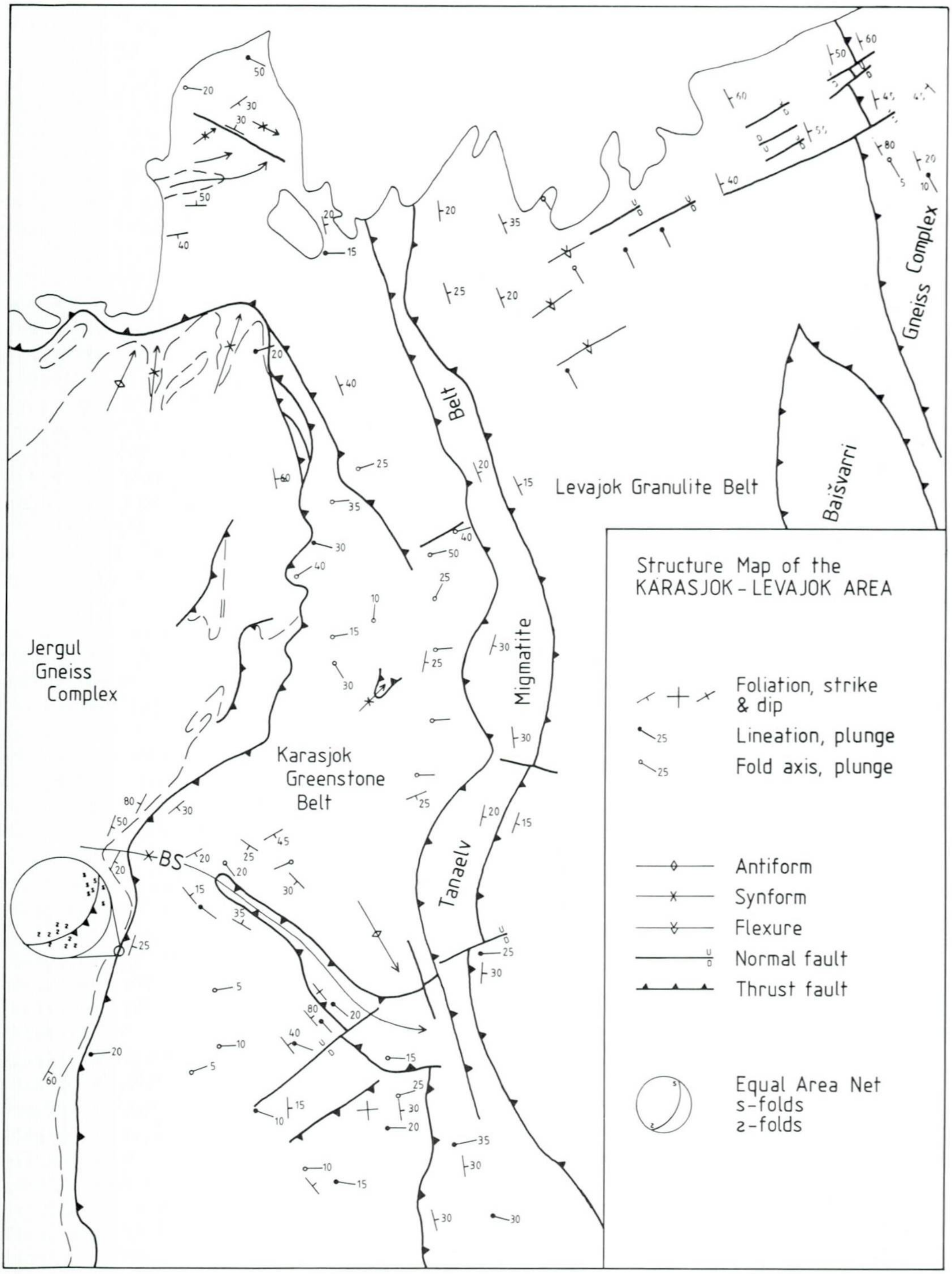


Fig. 3. Structural map of the Karasjok-Levajok area.

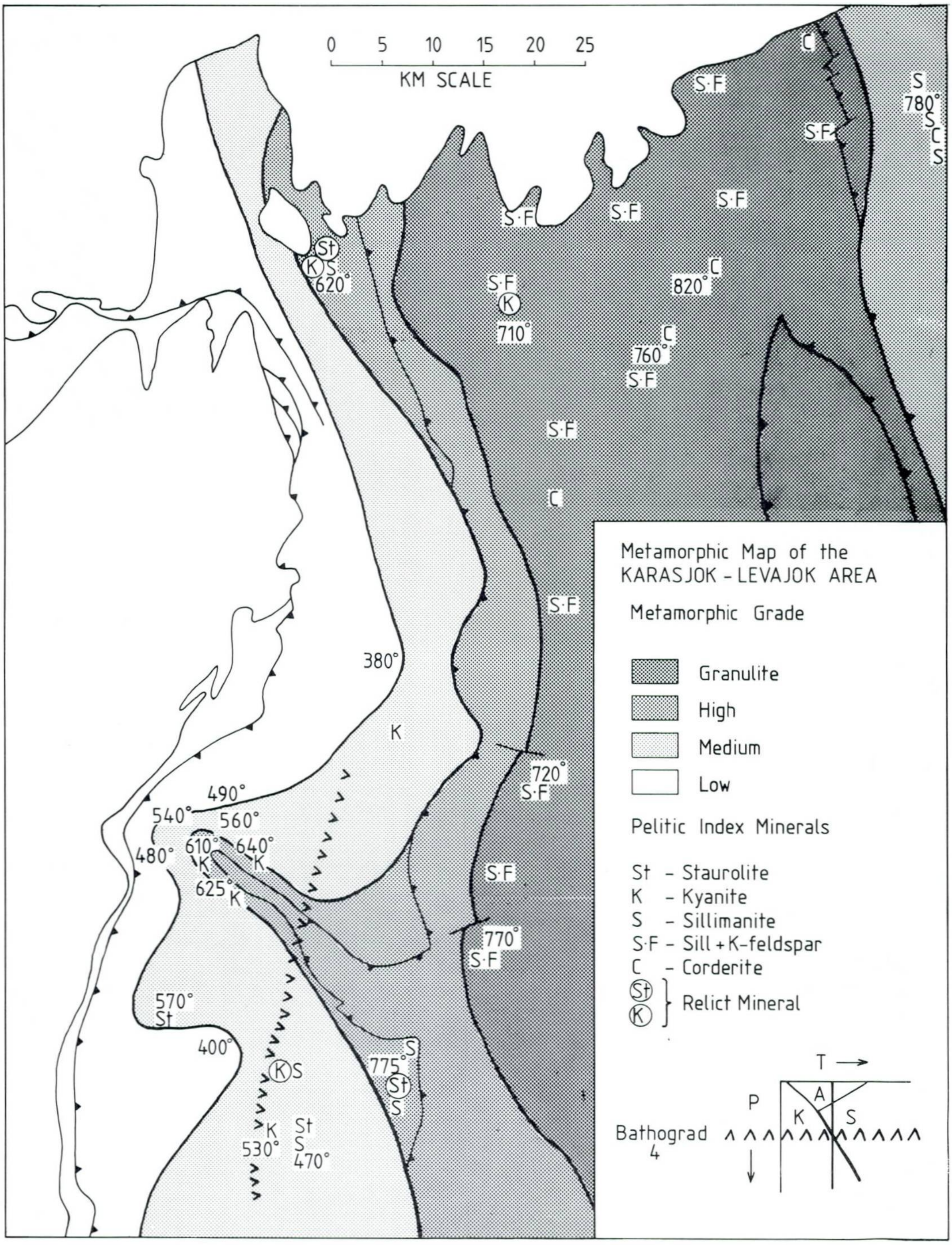


Fig. 4. Metamorphic map of the Karasjok-Levajok area. Zones of metamorphic grade as defined by Winkler (1976). Bathograd 4 as defined by Carmichael (1976). Temperature estimates using the calibration of Thompson (1976).

the granulites themselves indicates that the granulite-facies metamorphism was the result of an initially steep geothermal gradient, possibly from a strongly convective mantle beneath the geosynclinal metasediments. However, if kyanite was stable early, a better interpretation might be that a relatively late addition of heat, perhaps from the crystallization of the syn-metamorphic calc-alkaline magmas, contributed to formation of the granulites. If the magmas represent the development of a magmatic arc on a continental margin (Hörmann et al. 1980) the granulite-facies metamorphism corresponds to the relatively high-temperature metamorphism of a paired metamorphic belt (Miyashiro 1961). In addition to heat, large amounts of CO_2 are necessary to produce granulites from H_2O-rich sediments during a single metamorphic event. Models in which CO_2-rich solutions are derived from subducted rocks or the overlying mantle wedge (Newton et al. 1980, Newton & Hansen 1983) may help to explain the granulite-facies metamorphism.

The dominant texture of the granulites in the Karasjok-Levajok area is granoblastic to blastomylonitic. Augen of coarse-grained garnet are surrounded by streaks of feldspar and either platy quartz or biotite. Sillimanite needles locally form a lineation, but are mainly randomly oriented in the planes of biotite foliation. Detailed study of the structures of the granulites (Marker 1985) shows that the blastomylonitic folation is most strongly developed within the northern and western parts of the granulite belt.

The western contact of the granulite belt has long been interpreted as a thrust because of the shallow eastern dips and the lower-grade metamorphism of rocks beneath. The blastomylonitic texture of the granulites is parallel to the planar foliation in the Tanaelv Migmatite Belt and suggests that thrusting was syn-metamorphic. The assemblage sillimanite + K-feldspar was stable at the thrust contact during thrusting, and, within the Tanaelv Migmatite Belt near the contact, hypersthene occurs in some quartzo-feldspathic rocks. Similarly, no metamorphic or structural discordance has been recognized along the contact in Finland.

The Tanaelv Migmatite Belt apparently lacks pelitic rocks and no aluminum silicates are found. Some mafic rocks are hypersthene bearing, but more commonly they contain hornblende + garnet + clinopyroxene + plagioclase ± calcite. Detailed temperature and pressure calculations cannot be made, but peak temperatures are estimated to have been only slightly below those of the granulite belt (Hörmann et al. 1980, Raith et al. 1982, Barbey et al. 1984). At one locality in Finland, relics of aluminum silicates indicating very high pressure and intermediate temperature have been found in amphibolites of the Tanaelv Belt (Haapala et al. 1971). Kornerupine and the mineral assemblage gedritesapphirine-corundum may suggest metamorphic pressures on the order of 14 kb at a depth of about 45 km. These rocks may have formed from cooler amphibolites that were thrust or subducted beneath the hotter granites.

Current mapping of the Karasjok Greenstone Belt shows that the grade of metamorphism increases eastward, i.e. structurally upward toward the high-grade rocks of the Tanaelv Migmatite Belt (Fig. 4). The degree of recrystallization also increases upward, as seen from grain-size increases in both metasedimentary and metavolcanic rocks.

Pelitic and semi-pelitic rocks in the west near the Jer'gul Gneiss Complex contain Fe-chlorite + muscovite, showing that they are below the staurolite isograd and within the low-grade zone of Winkler (1976). Indeed, the rocks furthest west are very fine grained and appear to be below the garnet isograd. In the southern part of the Karasjok Greenstone Belt (Fig. 4), the medium grade is recognized by the presence of staurolite. Further east kyanite appears and is replaced in some samples by fibrolite sillimanite. In other samples the assemblage musc + qtz + stt + sil shows that pressures were below 'bathograd-4' of Carmichael (1978). Still further east, a sample of garnet-quartz-sillimanite gneiss with staurolite occurring only as relict inclusions in the garnets (Fig. 5) shows that temperatures were above the reaction line stt + qtz - alm + sil. This assemblage indicates high-grade metamorphic conditions within the rocks of the Karasjok Greenstone Belt near to the migmatitic gneisses of the Tanaelv Migmatite Belt. Other sillimanite-bearing rocks are themselves migmatitic.

Towards the north a large synform (Bourdnavarri synform) folded high-grade quartzo-feldspathic gneisses of the Tanaelv Migmatite Belt into the structrually deeper western parts of the Karasjok Greenstone Belt (Fig. 3). Also here, pelitic rocks nearest the Jer'gul Gneiss Complex are very fine grained and garnet free, while grain size and metamorphic grade increase rapidly toward the Tanaelv gneisses. Pelitic rocks contain kyanite and are anatectic within about 2

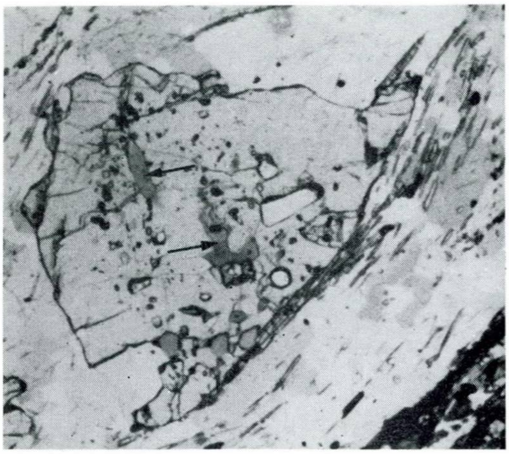


Fig. 5. Two inclusions of staurolite in garnet, with sillimanite needles in gneiss matrix. All large garnets in this sample contain staurolite, whereas no staurolite is present in matrix. Diameter of garnet is c. 3 mm. Sample location UTM: 434671.

map-kilometers of the Tanaelv gneisses, or about 1 km structurally beneath the contact. Garnets are homogeneous and unzoned, and temperatures estimated from $K_D = (Fe/Mg\ gar)/(Fe/Mg\ biot)$ (Fig. 4) using the calibration of Thompson (1976) show a metamorphic field gradient from 490° to 640° over a map distance of 5 km. If the metamorphic isograds were parallel to the foliation, as they appear to be from the map pattern, the inverted metamorphic field gradient is about 60°/km.

During the mapping of this synform, it was apparent from the assemblage kya + biot + gar in the migmatites that pressures here were above 'bathograd-4' of Carmichael (1978). Pressures were not above bathograd-5, as muscovite and not K-feldspar, is present in the migmatites. Preliminary estimates of pressure using the plag-gar-Al_2SiO_5-qtz geobarometer of Ghent (1976, Ghent et al. 1979) confirm the decrease in pressure eastward within the Karasjok Greenstone Belt. Pressure estimates from the western part of the Buordnavarri synform are 6 - 6.3 Kb (625 - 640°C) and in the eastern part of the greenstone belt a pressure estimate of 4.9 Kb (775°C) was obtained.

In the migmatitic pelites in the western part of the Bourdnavarri synform, the large kyanite blades are oriented both within the foliation and parallel to axes of small-scale folds in the migmatites. These folds appear to be parasitic to the large-scale synform, showing that the metamorphism was coeval with folding. There is no evidence suggesting that the inverted metamorphic zonation in the Karasjok Greenstone Belt was due to metamorphic stacking of previously metamorphosed nappes. Rather, the high-grade gneissic contact of the Tanaelv Migmatite Belt suggests that these gneisses were thrust-emplaced and folded at high metamorphic grade, while the Karasjok rocks were metamorphosed beneath. The higher pressure metamorphic rocks are appropriate at structurally deeper levels in the greenstone belt, and provide independent petrologic evidence that the metamorphism was *in situ*.

Garnets analyzed from the Karasjok-Levajok area are generally unzoned, and temperature estimates (Thompson 1976) from coexisting garnet-biotite pairs (Fig. 4) are consistent within samples. Garnet compositions within the pelitic rocks of the Karasjok Greenstone Belt vary from almandine in the low-grade rocks, to almandine-pyrope in the high-grade rocks. The most pyrope-rich garnets are in the granulites, but no compositional jump can be recognized between the garnets of the Karasjok Greenstone Belt and those of the granulites (Fig. 6).

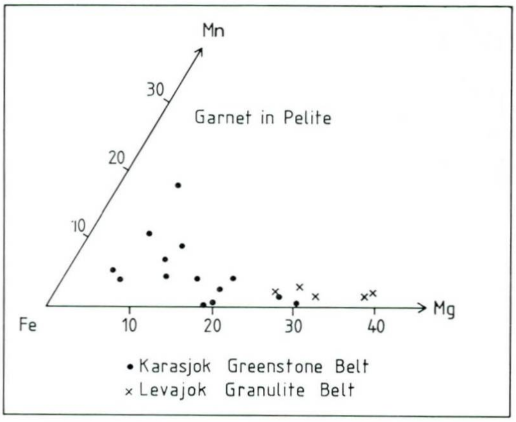
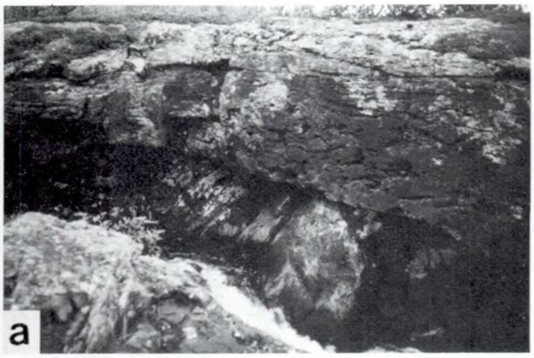


Fig. 6. Composition of garnets from the Karasjok-Levajok area, based on microprobe analyses, normalized to Wt. % FeO + MgO + MnO = 100.

Thrusts beneath the Levajok Granulite Belt and the Tanaelv Migmatite Belt (Fig. 3) are recognized from the patterns of inverted metamorphic zonation, together with distinct lithologic breaks and intensely foliated rocks near the contacts. Near the base of the Karasjok Greenstone Belt and within the Jer'gul Gneiss Complex, thrusts developed at low metamorphic grade. Part of the main thrust zone is easily accessible south of Skoganvarre. This locality is



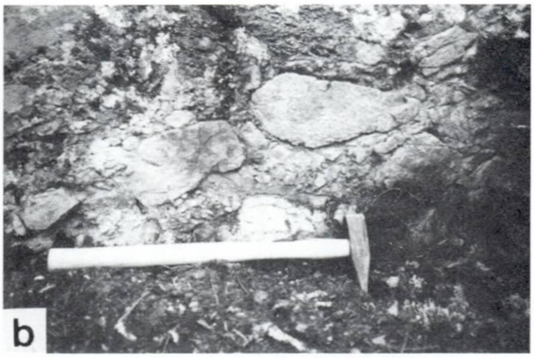
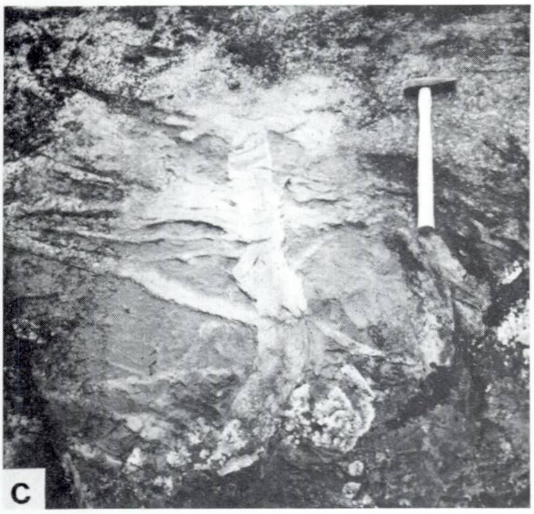


Fig. 7a. Flat-lying basal conglomerate of the Karasjok Greenstone Belt unconformably overlying SE-dipping gneiss of Jer'gul Gneiss Complex. Photo location UTM: 288407.

Fig. 7b. Well preserved basal conglomerate. Hammer handle c. 75 cm. UTM: 288407.



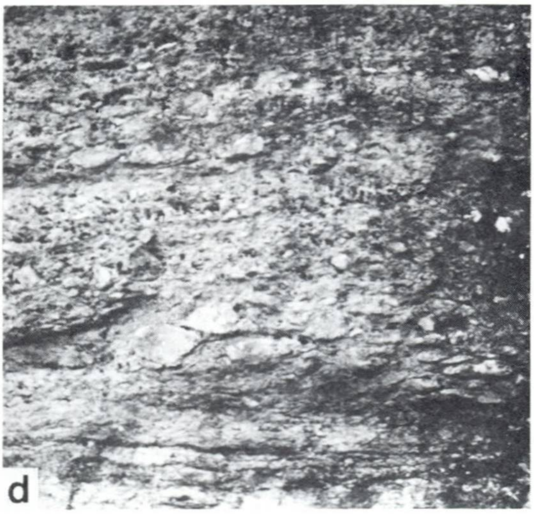


Fig. 7c. Jer'gul gneiss with granitic dikes. Gneiss lies directly above basal conglomerate of Fig. 7a, 7b, with apparent tectonic contact. UTM: 288407.

Fig. 7d. Strongly deformed conglomerate within mylonitic quartzo-feldspathic sequence well above basal unconformity. UTM: 289414.

well known (Skålvoll 1978) for the remarkably well preserved basal conglomerate discordantly overlying steeply dipping Jer'gul gneisses (Figs. 7a, b). However, the conglomerate is only a few meters thick, and is immediately overlain by a tectonic slice of Jer'gul gneiss (Fig. 7c). Further upward in the exposed profile, are quartzo-feldspathic mylonites tens of meters thick, which contain lenses of strongly deformed Jer'gul gneiss and conglomerate (Fig. 7d). An ENE cobble stretching lineation, noted in one outcrop of sheared conglomerate, is probably parallel to the thrust direction. The mylonitic foliation is also folded by open, west-verging folds with gentle north-plunging axes.

Toward the south, thrusting near the base of the Karasjok Greenstone Belt is characterized by zones of shearing with carbonate-chlorite alteration and development of secondary quartz lenses. Small drag folds in the sheared rocks generally verge westward. In one set of outcrops the west-verging folds plunge both NE and SW. When plotted on an equal-area net (Fig. 3 inset) using a method of Hansen (1971), the folds define a SE-dipping plane indicating reverse or thrust displacement toward the northwest during the folding.

Syn-orogenic intrusions appear to follow the common pattern of increasing K_2O-content with time (Hietanen 1975). Granodiorites (Fig. 2)

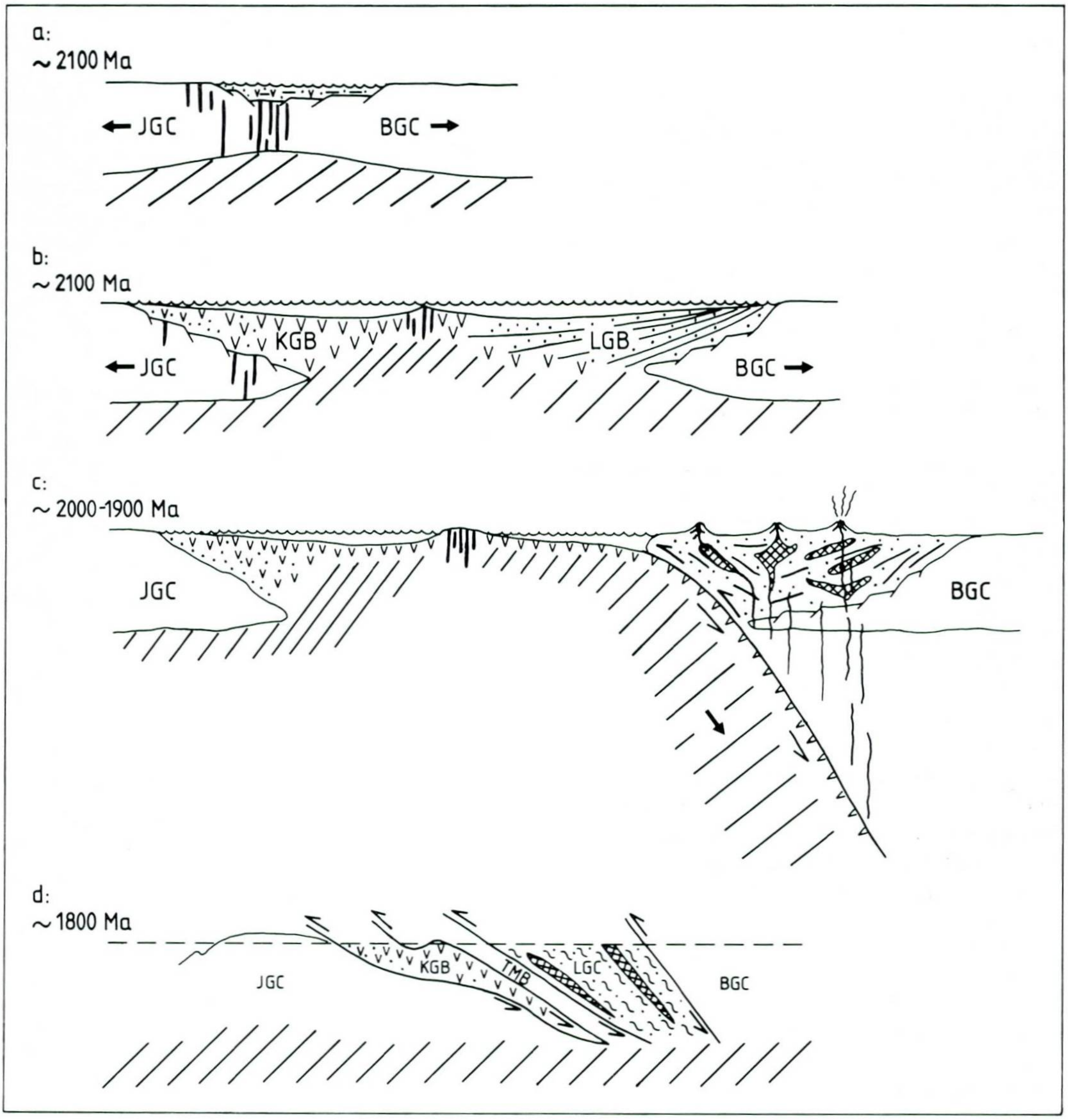


Fig. 8. Proposed tectonic development of the Karasjok-Levajok area.

are relatively early-kinematic, and are restricted to the middle- and high-grade metamorphic zones of the Karasjok Greenstone Belt. They have an older age and lower initial Sr ratio (c. 1980 Ma, .703). Microcline granites (Fig. 2) are less deformed and late-kinematic. They occur both near the margin of the Jer'gul Gneiss Complex and within the Tanaelv Migmatite Belt. They have relatively high initial Sr ratios (.713, 1750 Ma; .715, 1730 Ma), and may be interpreted as anatectic magmas derived from crustal material or terrigenous sediments (Krill et al. 1985).

Tectonic Synthesis

If plate tectonic processes occurred anywhere in early and middle Precambrian time, they have not left the same characteristic tectonic signatures known from Phanerozoic mountain belts. Features such as ophiolites, and high P, low T metamorphic belts have not been identified in older Precambrian terrains, and there is relatively little evidence indicating major low-angle thrusting, inverted metamorphic zonation or subduction-related volcanism. The Levajok Granulite Belt and the Tanaelv Migmatite Belt have drawn some attention as providing evidence for relatively old plate tectonic activity. Hörmann et al. (1980) suggested that the igneous rocks represent inner and outer parts of a volcanic arc. Barbey et al. (1984) interpreted the granulite metasediments as recording a geosynclinal flysch sequence. They proposed a model for the Proterozoic Belomorian Geosyncline, which was defined to include the Tanaelv Belt and Levajok Granulite Belt. However, the Karasjok Greenstones were considered to be part of the Archean basement. The present tectonic model incorporates the new isotopic results and metamorphic and structural observations from the Karasjok-Levajok area, and provides additional support to the plate tectonic interpretation.

A Svecokarelian Wilson cycle was probably initiated around 2.1 Ga ago with crustal thinning and depression, and deposition of clastic sediments upon the Jer'gul/Baišvarri basement complex (Fig. 8a). Some of the mafic and ultramafic dikes in the Jer'gul Gneiss Complex presumably indicate the beginnings of Karasjok volcanism. While Karasjok volcanics developed mainly toward the west (Fig. 8b), tubidites of the present granulite belt were deposited toward the east. The tremendous volume of metasedimentary granulites suggests that the turbidites formed along a passive continental margin, and that a true oceanic basin had developed. Characteristic chemical trends from the Tanaelv Migmatite Belt and Levajok Granulite Belt suggest that they represent outer and inner magmatic arcs derived from east-dipping subduction of basaltic rocks (Hörmann et al. 1980) (Fig. 8c). This suggests that the rocks of the Karasjok Greenstone Belt may record only a fraction of the actual volcanism, which presumably formed along a north-south spreading center. Heat from the subduction-generated magmas, and CO_2 released from carbonates among the subducted rocks or from the mantle, helped to produce the granulite-facies conditions of the Levajok Granulite Belt (Fig. 8c). With closing of the Svecokarelian Karasjok-Levajok ocean, both the postulated spreading ridge and the bulk of the Karasjok volcanic rocks were subducted beneath the granulites. Eeast-dipping thrust faults developed sub-parallel to the original subduction zone (Fig. 8d). The granulites were thrust above the Tanaelv Migmatite Belt, which was metamorphosed at high grade and thrust above the Karasjok Greenstone Belt. The greenstones, probably already at low metamorphic grade from the heat of the intital volcanism, were further metamorphosed to medium and high grade by the inverted thermal gradient. Thrusts developed also within the lower parts of the Karasjok Greenstone Belt and in the Jer'gul Gneiss Complex, but if the thrusting brought up rocks from great depths, they were later recrystallized at intermediate pressure conditions. Although a few high-pressure rocks have been found in the Tanaelv Belt in Finland, there is no preserved record of a high P, low T metamorphic belt.

Acknowledgements

Mogens Marker, Kjell Nilsen, and Morten Often contributed greatly by sharing their data and ideas during field work and discussions. In addition, I thank my many colleagues in the Finnmark Program and Nordkalott Project for helpful cooperation.

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