Structure and stratigraphy of the Palaeoproterozoic Karasjok Greenstone Belt, north Norway – regional implications

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The Karasjok Greenstone Belt of the northwestern Baltic/Fennoscandian Shield forms the westernmost unit in a Palaeoproterozoic tectonic belt, recording crustal mobilization, tectonic reworking and metamorphism of the Archaean and Palaeoproterozoic lithosphere during a 2.1–1.7-Ga tectonic episode. In northern Norway, this 100 km-wide tectonic belt consists of linear segments of highly strained rocks that are separated by N–S-striking thrust zones. The lowest unit, the Karasjok Greenstone Belt, consists of low-to medium-grade volcanogenic and sedimentary rocks. Excellent exposures in the northern part of the greenstone belt reveal a continuous lithostratigraphic section towards the core of a major recumbent synform, which is related to the regional D3 deformation episode. This episode is responsible for transposition of primary features and formation of an east-dipping penetrative foliation and banding, with a well-developed east-plunging stretching lineation. Major D3 shear zones, marked by mylonites and blastomylonites, are found (i) locally at the base of the belt, (ii) at high tectonostratigraphic levels, and (iii) at the upper boundary of the greenstone belt. Shear-sense indicators support west-directed displacement along the thrusts. The superimposed D2 episode is evident as east-plunging folds, whereas a major D2 thrust with top-to-the-SSW shear occurs near the base of the greenstone belt. The younger D1 episode is manifested by N-S-trending folds of the former (D3 and D2) structures. All fold systems are truncated by steep NE-SW striking brittle faults of D4 affinity. The polyphase deformation seen in the Karasjok Greenstone Belt supports a model in which the assembly of the Karasjok Greenstone Belt, the Tanaelv Migmatite Complex and the Levajok Granulite Complex occurred from major orogen-normal E-W contraction (collision) during the D2 episode. At this stage the greenstone belt was isoclinally folded and welded to overlying units during west-directed overthrusting of the medium- to high-grade complexes. From then on the greenstone belt acted as a basal detachment zone. The D2 episode of NNE-SSW shortening and SSW-directed thrust emplacement suggest dextral and orogen-oblique movement patterns, prior to continued orogen-perpendicular E-W shortening during the D3 episode. The final faulting (D4) may relate to a post-orogenic, shield-scale strike-slip event.

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Introduction

The Karasjok Greenstone Belt of the northern Baltic/Fennoscandian Shield forms the westernmost and tectonostratigraphically lowest unit of a Palaeoproterozoic tectonic belt, termed the Lapland-Kola Orogen by Marker (1985). In Norway, it consists of the Karasjok Greenstone Belt (KGB), the Tanaelv Migmatite Complex (TMC) and the Levajok Granulite Complex (LGC). This broad belt (nearly 100 km wide) is traceable from northwestern Russia, through northern Finland, into northern Norway (Fig. 1; e.g., Gorbatschew & Bogdanova 1993). It records crustal mobilization, tectonic reworking and stabilization of dominantly juvenile Archaean and Palaeoproterozoic lithosphere during a 2.1–1.7-Ga cycle of rifting, contraction, and subsequent stabilization and uplift (e.g., Barbey et al. 1984; Krill 1985; Marker 1985; Berthelsen & Marker 1986a; Berthelsen 1987; Gaal & Gorbachev 1987; Gorbatschew & Bogdanova 1993). In northern Norway, this orogen consists of linear segments of highly strained rocks that are separated by N–S-striking, east-dipping thrust zones (Fig. 1b), together forming a crustal-scale tectonic boundary (suture?) between the Jer'gul and Baisıvåri gneiss domes of Archaean to Palaeoproterozoic ages (Siedlecka et al. 1985).

A key problem in understanding continental growth is the nature and evolution of convergent strain in a broad zone during accretion (Windley 1993). In northern Norway, as for most of the northern Fennoscandian Shield, there is a lack of detailed data on stratigraphy, metamorphism and deformation, undermining the establishment of sound tectonic models. The KGB, consisting of relatively incompetent supracrustals and intrusive rocks, metamorphosed to medium grade (Crowder 1959; Wennerwirta 1969; Siedlecka et al. 1985), represents the most complexly but also least deformed part of this tectonic belt, making it a well-suited area for studying the polyphase contractional evolution of the Palaeoproterozoic orogenic episode(s).

The aims of this contribution are to describe the lithostratigraphic section of the KGB from the Lakselv area, then to present extensive structural data from two key areas, the Lakselv Valley and Karasjokka River sections. This material is used in discussing the structural archi-
Fig. 1. (A) Regional tectonic map of the northwestern Baltic/Fennoscandian Shield. (B) Bedrock map of main units in the Karasjok Greenstone Belt (KGB) and nearby complexes. Boxes locate the Lakselv and Karasjokka areas. The distribution of units within the KGB represents a highly modified version of the map by Often (1985).
tecture and the polyphase tectonic evolution of the greenstone belt, which has important implications for the proposed regional tectonic models.

Geological setting

Investigations by the Geological Survey of Norway in the 1980s obtained extensive map data from the Precambrian province of Finnmark. Some of the results are described in reports on the regional geology (e.g., Krill 1985; Krill et al. 1985; Marker 1985; Often 1985; Siedlecka et al. 1985; Nilsen 1988) that place the various belts and complexes into a tectonic framework.

The Karasjok–Levajok tectonic belt consists of three different, N–S-striking, east-dipping segments, separated by east-dipping thrust zones (Fig. 1). In the following, a brief account of the three units is given as an introduction to the lithostratigraphic description of the Karasjok Greenstone Belt.

**The Levajok Granulite Complex (LGC),** which is part of the extensive Lapland Granulite Belt, consists of granulite facies metasedimentary and subordinate mafic to intermediate igneous rocks (Marker 1985; Berthelsen & Marker 1986a; Krill 1985; Gaåll et al. 1989). Igneous activity and metamorphism took place 2.0–1.9 Ga ago (Bernard-Griffiths et al. 1984; Gaåll et al. 1989; Korja et al. 1996). The western and southwestern parts of the LGC contain sheared, mylonitic rocks, while the eastern parts reveal less strained, migmatitic rocks (Marker 1985). The shearing post-dated the migmatitization (Marker 1985; Krill 1985).

**The Tanaelv Migmatite Complex (TMC)** consists of a high- to medium-grade, banded sequence of partly migmatitic rocks. It includes a variety of assumed Palaeoproterozoic rocks, such as various orthogneisses, amphibolites and lenses of ultramafites (Marker 1985; Krill 1985; Berthelsen & Marker 1986a; Gaåll et al. 1989). The TMC forms a ductile high-strain zone, of age and metamorphism took place 2.0–1.9 Ga ago (Bernard-Griffiths et al. 1984; Gaåll et al. 1989; Korja et al. 1996). The western and southwestern parts of the LGC contain sheared, mylonitic rocks, while the eastern parts reveal less strained, migmatitic rocks (Marker 1985). The shearing post-dated the migmatitization (Marker 1985; Krill 1985).

**The Karasjok Greenstone Belt (KGB)** has a N–S trend with a length of about 160 km, and ranges in width from 20 to 40 km (Crowder 1959; Wennerwirta 1969; Krill 1985; Often 1985; Siedlecka et al. 1985). In Finland, the Kittilä Greenstone Belt constitutes the southern continuation for another 150 km towards the SSE. The KGB is non-conformably overlying and partly thrust over the granitic basement rocks of the Archaean (?) Jer’gul Gneiss Complex to the west. To the east it is bounded by the overthrust TMC (Wennerwirta 1969; Siedlecka et al. 1985).

Lithostratigraphy of the Karasjok Greenstone Belt in the Lakselv area

The stratigraphic complexities encountered in the Karasjokka River section are not evident in the Lakselv area. The Lakselv Valley displays the northernmost extent of the Karasjok Greenstone Belt, surrounded by Caledonian nappes (Fig. 1b). The unique degree of exposure has made it possible to conduct detailed bedrock mapping in the 1:5000 scale, providing detailed knowledge of the field geology (Girard 1989a, b; Roberts & Davidsen 1992; Davidsen 1993a, b, 1994).

In the SSW, the Palaeoproterozoic supracrustal rocks of the Lakselv area are bounded by a thrust zone towards the underlying basement rocks of the Jer’gul Gneiss Complex. Within the Lakselv Valley itself, the folded sequence of
Fig. 2. Bedrock map of the Karasjok Greenstone Belt in the Lakselv Valley.
greenstone belt rocks rest unconformably upon three isolated bodies of granitic basement gneisses, belonging to the Laevdnjavárrí Gneiss Complex (Figs. 2, 3 and 4). Above this, consistent way-up stratigraphic polarity is determined by abundant pillow structures in komatiites, and locally by cross-bedding (Fig. 5).

Nearly all rock boundaries are parallel to the regional D₁ foliation, which is axial-plane parallel to one of the most prominent features of the northernmost KGB, i.e. the large-scale, recumbent Brennelv syncline (Figs. 2 and 3). The stratigraphic section within this structure, which represents the best known and probably one of the most complete sections through the KGB, has been divided into four formations by Davidsen (1994; see Fig. 4). These formations are described as follows, from base to top:

The Lavtevarri Formation is 50–150 m thick. Rocks immediately above the basal unconformity are essentially clastic metasediments, generally comprising mica-schists (locally fuchsite-bearing) with carbonate, and occasionally conglomeratic parts with clasts of granite and granitic gneiss from the basement, in addition to fragments of vein-quartz. Above this the dominant rocks are schistose tholeiitic amphibolites and psammites, subordinate meta-komatiites, high-MgO amphibolites, possible rhylitic metavolcanites ('leprite'), mica-schists and marbles.

The Corgasavzi Formation is 250(?)-700 m thick and interfingers with the Lavtevarri Formation. It is mainly composed of psammitic rocks (Fig. 5c, d), but the upper part includes tholeiitic, amygdaloid lava flows surrounded by mica schists, conglomerates, and layers of marble. Metagabbros and minor metapyroxenitic bodies are common in this formation.

The Brittgáielas Formation is 300–700 m thick, and is dominated by banded amphibolites (volcaniclastic?) of tholeiitic basalt composition. In the lower part, the formation also comprises kyanite-bearing garnet–mica
schists and possible dacitic metavolcanites of calc-alkaline affinity, both units containing layers of graphite–schist. An extensive marble unit (calcite–dolomite–tremolite) marks the basal contact towards the underlying Corgasavzi Formation. Distinct for the formation is the presence of metakomatiites, which have been recognized as four

250–300 m and consists of metakomatiitic and coarse-grained mafic rocks. Two thick-pilowed lava flows constitute the lower part, above which agglomerates/volcaniclastic deposits and possible lava flows dominate.

No significant tectonic breaks have been observed between any of the above-mentioned formations, which are presented tentatively as a lithostratigraphy. On the whole, the sequence was deposited under sub-aquatic conditions, as suggested by the pillow lavas and graphite-bearing schists. An intracratonic paleotectonic setting is likely for the northernmost KGB, as there are several indications of a continental basement. According to Davidsen (1994), geochemical indications are tholeiitic metabasites showing negative Nd anomalies that can be caused by crustal contamination, and the presence of siliceous high-MgO metabasalts thought to be formed by crustal contamination of komatiitic melts. Most important is, of course, the preserved depositional contacts against granitic basement gneisses. In addition, extensive metasedimentary units occurring in the sequence are dominated by material from granitoid sources (Davidsen 1994), suggesting the presence of cratonic source areas.

Structural phases

The KGB reveals three ductile deformational stages/phases (Pharaoh 1981, 1984; Nilsen 1988; Girard 1989b; Braathen 1991; Andreassen 1993; Davidsen 1994), which, based on overprinting relationships, are designated D1, D2, and D3. The latest event, the D4 phase, is seen as brittle faults and joints. These events are summarized in the sections below, and function as a guide to the following description of the deformation patterns seen in the Lakselv and Karasjokka areas.

D1 phase.— The D1 phase, evident in the entire province, is characterized by a penetrative east-dipping foliation and mineral banding, which is subparallel with lithological contacts (e.g., cross-section X-X′, Fig. 3). The most prominent feature of the D1 phase is the macroscopic recumbent synform/syncline of the greenstone belt (see above). Zones of highly sheared rocks (D2), such as mylonites and porphyroblastic gneiss/blastmylonites (Wise et al. 1984) define the top and partly the base of the greenstone belt, and mark the contact between the two overlying complexes. These zones are interpreted as regional thrust faults (Fig. 1; Krill 1985; Marker 1985).

Elongated minerals within the D1 foliation are subparallel, showing similar orientations to stretched volcanioclastic fragments, volcanic pillows and conglomerate clasts, and also with quartz-ribbons in the high-strain zones (Pharaoh 1981; Girard 1989b; Braathen 1991; Andreassen 1993). The east-dipping lineation is therefore interpreted as a stretching lineation, designated L1 (Fig. 6). This is further supported by the orientation of mesoscopic F1 folds that are isoclinal, recumbent and transposed, plunging variably from N–S to east, the latter orientation similar to the L1 stretching lineation. The spread of fold axes and observations of lobe-shaped folds show these to be non-cylindrical (e.g., Ramsay & Sturt 1973), and suggest a generation as sheath-folds (Bell & Hammond 1984; Hamner & Passchier 1991).

Stable mineral assemblages in metasediments (e.g., kyanite, garnet, biotite) and amphibolites (e.g., garnet, hornblende) show that the D1 phase occurred during
amphibolite facies conditions (Fig. 7a; for details on metamorphic textures and parageneses, see Davidsen 1994 and Braathen 1991). Migmatitization of metasediments in the KGB immediately below the TMC indicate upper amphibolite facies at high tectonostratigraphic levels (Krill 1985), whereas kyanite, evident in pelites of the entire greenstone belt, suggest that Kyanite Zone (e.g., Yardley 1989) conditions affected the whole rock column. Based on stability fields for various mineral assemblages, Davidsen (1994) estimated temperatures between 625
and 750°C, and pressures in the range of 7–11 kbar for the D1 fabric generation.

**D2 phase.** – The D2 phase is characterized by deformation under ductile conditions. Major structures are present as map-scale folds of the bedding and S1 foliation, and as discrete shear zones. F2 folds are upright and open to tight, showing an elliptical to chevron geometry. They plunge subhorizontally-to-moderately to the east, whereas the axial surfaces are subvertical-to-steeply inclined to the NNE (Fig. 6). Fold-hinges of mesoscopic F2 folds, found as parasitic folds to map-scale structures, commonly show a well-developed crenulation cleavage in mica-rich units. This cleavage together with the S1 foliation defines an intersection lineation (L2) that is subparallel with the F2 axes.

D2 shear zones are commonly located near the base of ultramafic rocks, i.e. as chlorite–actinolite phyllonites. Retrograde alteration of kyanite, garnet and amphibole into mica, chlorite and quartz in fold-related cleavages and shear zones (Fig. 7a, b) suggests that greenschist facies metamorphic conditions prevailed during the D2 phase (Pharaoh 1981; Braathen 1991; Andreassen 1993).

**D3 phase.** – The D3 phase is seen as deformation under ductile to semiductile conditions which, both in deformation character and metamorphic conditions, appear similar to those of the D2 episode. However, the D3 structures show different orientations, and are superimposed onto the D2 structures.

Map-scale F3 folds of the S1 foliation are present within most of the KGB and the lower part of the TMC. They are upright and open, elliptical- to chevron-shaped, and plunge variously to the north and south, with steep eastward-dipping axial surfaces (Fig. 6). Mesoscopic fold-hinges commonly display a mica- and chlorite-bearing crenulation cleavage (S3) with an S1-S3 intersection lineation (L3) that is subparallel with mesoscopic F3 fold axes. Minor discrete shear zones locally modify the fold-limbs. Similar structures are found near the base of the TMC, where narrow (~10 m-thick) thrust-zones reactivate, or locally are subparallel to, the D1 foliation (Braathen 1991).

**D4 phase.** – The D4 phase is characterized by brittle, steeply dipping faults and joints (Fig. 6) that truncate all foliations and folds in the greenstone belt, as well as the foliation of the overlying complexes. NW–SE-striking faults, the most prominent structures of this episode, displace fold-hinges and vertical bedding in the greenstone belt, but do not truncate the overlying Caledonian nappes (Davidsen 1994). This indicates that they relate to a Palaeoproterozoic deformational event. The orientation of these faults partly coincides with the regional fracture pattern, seen as subvertical NW–SE- and NE–SW-striking joints (Braathen 1991) and magnetic dislocations (Midtun 1988).

**The Lakselv area**

The main structure of the Lakselv area is the macroscopic isoclinal recumbent F1 syncline, the Brennelva syncline (Crowder 1959; Pharaoh 1981; Davidsen 1994). The lower limb of this structure starts in the basement gneiss dome to the west, whereas the inverted, upper fold-limb has its roof in the TMC (Fig. 2 and Fig. 3 cross-section X–X'), the latter located on top of the greenstone belt with an east-dipping thrust contact. The S1 foliation, evident as an axial plane-parallel cleavage to the macroscopic fold, has a general east dip (Fig. 8a). Plots of the S1 foliation and bedding reveal a spread of the poles that plot along two great circles. These circles define two possible regional fold axes, plunging moderately to the ENE, and SE to SSE, respectively. These directions partly coincide with orientations of lineations (Fig. 8b). The composite lineation plot shows mainly axes plunging moderately SE to SSE. However, the lineations cluster along two great circles as well, one striking E–W with a subvertical orientation, the
other striking NNW–SSE and dipping steeply to the ENE. These great circles are similar in orientation to axial surfaces of mesoscopic $F_2$ and $F_3$ folds, respectively (see below).

The $F_1$ macrofold changes from a tight elliptical shape in the northwest (Figs. 9 and 10), where primary volcanic features are preserved in the hinge-zone, to parallel limbs further southeast and east, where bedding is entirely transposed to become parallel with the $S_1$ foliation. Further southeast the fold-hinge is revealed from stratigraphic repetition. The Brennelva $F_1$ syncline folds bedding, as well as an amphibolite–facies metamorphic foliation, which, at this locality, is preserved in the fold-hinge zone. This implies that an older (than $D_1$?) metamorphic episode may be present in the greenstone belt. However, this episode is almost entirely overprinted, and therefore not regionally preserved (see discussion).

Two sets of folds are superimposed on the Brennelva syncline. Eastward-plunging map-scale $F_2$ folds are present within the entire area, as illustrated in stereoplots of bedding/$S_1$ from various subareas (plots B, C, D, E and F in Fig. 9). These folds are generally upright and open with subvertical axial surfaces, as seen in the southwest and west in Fig. 9 (see also Fig. 3, cross-sections \(X-X'\) and \(Z-Z'\)), where basement is unfolded in the core of an $F_2$ anticline. Further northeast the $F_2$ folds tend to be tighter and overturned to the south.
Fig. 9. Structural map of the Lakselv area (cf. Fig. 2). Contoured stereoplots (lower hemisphere, equal area) show orientation of poles to the S$_1$ foliation in various subareas that are located on the map. The box locates Fig. 10.
Fig. 10. Detailed bedrock map of the Brennelva area, locating the Brennelva F1 syncline, superimposed F2 and F3 folds, and late brittle faults. Contoured stereoplots (lower hemisphere, equal area) show orientation of bedding/S1 foliation for various subareas that are located in the inset map. Plot A3 presents a plane and the associated fold axis (star) constructed with basis in the two average poles of foliations in plots A1 and A2.
The youngest fold set, F₃, trends N–S (plots A and F, Fig. 9). They are present within two areas, in the east and in the northwest, where they show an open to tight elliptical geometry with steep east-dipping axial surfaces, i.e. they verge to the west (cross-section Y–Y', Fig. 3).

Several NW–SE-striking, subvertical D₄ faults truncate and offset the various fold sets (Figs. 8 and 9). Subvertical bedding of some fold-limbs and subvertical axial surfaces are displaced up to 500 m right-laterally, suggesting that the structures represent dextral strike-slip faults. Fault-offsets terminate eastward in a NE–SW-striking, bedding-parallel fracture zone with no visible displacement.

The Brennelva area (Fig. 10) is ideal for studying and documenting map-scale and mesoscopic superimposed folding of three generations of folds (F₁, F₂ and F₃). The Brennelva F₁ syncline, in its least deformed core to the northwest, shows an inter-limb angle of approximately 20°, as revealed from stereo-plots of bedding/banding in the upper and lower fold-limbs (plots A1 and A2, Fig. 10). These fold-flanks define a moderately SE-plunging fold axis (plot A3) that represents the best estimate for the original orientation of the major F₁ axis in the greenstone belt.

The Brennelva F₁ syncline is clearly folded around E–W- and N–S-trending folds (Fig. 10). The E–W-oriented F₂ fold system, present as an antiform–synform pair, folds the F₁ syncline into two NE- and SE-trending domains in the western area. Eastward, the F₁ trace is folded into several N–S-trending F₃ anti- and synforms.

The western area reveals a moderately east-plunging F₂ fold axis (plot B, Fig. 10). Further eastwards, approaching the D₃ tectonized area, the fold axes of the F₂ folds change to southeast plunges (plots C and D, Fig. 10) and, in the intensely F₃ folded domain, to west and southeast plunges (plot E). In the same domain F₃ folds, which are parasitic to a major antiform to the east, plunge to the northeast and southeast (plots F and G, Fig. 10). These two plunge orientations are related to the north and south limbs of an E–W-trending F₂ synform. The F₃ fold axes plot along the general F₃ axial surface, dipping steeply to the east, demonstrating that the NE and SE plunges of the F₃ folds are controlled by inherited orientations of the S₀/S₁.

The Karasjokka area

The Karasjokka River profile (Fig. 1b; Often 1985) displays a section from the basal Jer'gul Gneiss Complex, through the greenstone belt, to the lower part of the TM C. The main outcrop-scale structure is the penetrative S₁ foliation, which strikes approximately N–S and dips moderately east (plots A and B, Fig. 11). An eastward plunge is clear for the mineral and stretching lineation, L₁, whereas mesoscopic intrafolial F₁ folds spread from north to east plunges (plot A).

Later deformation is divided into the D₂ and D₃ phases, as for the rest of the greenstone belt. Mesoscopic F₂ folds plunge moderately to the ESE, having WNW–ESE-striking and steeply NNE-dipping axial surfaces (plots C and D, Fig. 11). F₃ folds plunge subhorizontal to the north and south, displaying axial surfaces that dip steeply to the east (plots E and F).

Map-scale structures of the Karasjokka area include (1) the Storfossen Thrust (ST of Figs. 12 and 13) near the base of the greenstone belt, (2) an overlying isoclinal F₁ synform (Noaidatjåkka synform, NIS) that is terminated by (3) the Luossajavri thrust (LT) in the upper limb, and (4) the Bourdnnavari synform (BS). The Noaidatjåkka synform (NIS) is an isoclinal, recumbent F₁ synform with subparallel fold-limbs that has been located by stratigraphic repetition, S- and Z-shaped folds, and locally, by a distinct angle between bedding and the S₁ axial plane parallel foliation in the fold-hinge (Fig. 14a). This fold, which is strikingly similar to the Brennelva F₁ syncline of the Lakselv area, repeats the lower part of the stratigraphic section. In the upper fold-limb the structure is truncated by a shear zone, identified by protomylonitic to mylonitic granitoid rocks, that is interpreted as a D₁ thrust (= LT; Fig.
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Fig. 12. Simplified bedrock map of the Karasjokka area. The stereoplots (lower hemisphere, equal area) present data for various subareas that are located in the map. BS = Bourdnavarri synform; LT = Luossajavri Thrust; NIS = Noaidatjåkka F1 synform; NOAS = Noaidatjavri synform; NT = Noaidatjavri thrust; RA = Raitevarri antiform; RT = Raitejåkka thrust; ST = Storfossen thrust zone.
Further indications for a major tectonic boundary at this level are shown as a break in both the rock composition and the apparent metamorphic grade, i.e. the difference between supracrustal rocks below the shear zone and overlying large, granodioritic gneissic bodies situated in migmatitic supracrustal rocks.

The $D_1$ synform and thrust (NIS and LT) are folded into an E–W- to WNW–ESE-trending, open and upright $F_2$ antiform–synform pair (RA and NOAS, Fig. 12) that verges moderately to the south. Two N–S- to NW–SE-striking $F_3$ synforms, the most prominent being the Buordnavarri synform (BS, Figs. 12 and 13), are superimposed on the $D_1$ and $D_2$ structures. This synform downfolds the TMC gneisses (Krill 1985; Osten 1985), establishing a regional NW-directed tongue of the migmatite complex into the greenstone belt (see Fig. 1b).

The $F_2$ folds are rooted in the gently ENE-dipping Storfossen thrust (ST, Figs. 12 and 13). This thrust zone shows a tectonic mixture of slivers of the basement gneiss, locally with overlying basal conglomerate of the Skuvvanvarri Formation, the basal Skuvvanvári Formation psammites, and the Iddjajavri Group metasediments and metavolcanites (Fig. 14a, b). A well-developed $S_2$ foliation in the zone, characterized by a general grain size reduction and local proto- to orthomylonitic fabric, overprints the $S_1$ foliation, which in most cases is totally erased.

Common deformation structures of the Storfossen thrust zone indicating the sense-of-shear are: the vergence and asymmetrical shearing of folds (Fig. 14b), composite shear fabrics (Fig. 14c) (Lister & Snoke 1984; Simpson & Schmidt 1983; Dennis & Secor 1987, 1990), asymmetrically winged porphyroclasts and conglomerate clasts (Passchier & Simpson 1986; Hanmer & Passchier 1991), and outcrop-scale, stacked units and foliation duplexes (Fig. 14d). Together, the $D_2$ structures suggest non-coaxial flow and top-to-the-SSW movement in the Storfossen thrust zone. Orientation of mesoscopic folds within the zone (plot ST1, Fig. 12), having gently east- to NE-dipping axial surfaces and eastward-plunging fold axes, are in accordance with the shear sense. However, variation in the fold-trend and locally curved hinge-zones suggest that progressive deformation and rotation (non-cylindrical/ sheath folds) and superimposed folding may have modified some folds.

The Storfossen thrust was apparently reactivated during the $D_3$ episode. The $S_2$ foliation is affected by mesoscopic folds, having N–S-trending axes (plot ST2, Fig. 12) and axial surfaces dipping moderately to the east or, less commonly, to the west. These folds are in general confined to discrete shear zones, where the $S_2$ foliation is transposed into a new, $S_3$ mylonitic/phyllonitic fabric, or erased by cataclasis in more competent rocks (Fig. 14d). Structures indicating sense-of-shear, i.e. similar to the ones assigned to the $D_2$ episode, are present within the $D_3$ tectonic zones as well, indicating non-coaxial flow and top-to-the-west movement.

Structural evolution and kinematics

Overprinting structural relationships, such as those described for the Lakselv area (Fig. 10), document that a four-phase deformation sequence applies to the KGB. Variation in the tectonometamorphic conditions are in accordance with such a sequence, rising to upper amphi-
bolite to amphibolite facies conditions during the $D_1$ episode, followed by greenschist facies metamorphism during the $D_2$ and $D_3$ phases, and finally sub-greenschist facies and brittle deformation during the $D_4$ episode (Fig. 7).

Orientation of the $D_1$ structures, present as an east-dipping, penetrative foliation that contains an east-plunging stretching lineation, variously oriented intrafolial folds, and shear sense indicators, indicate westward-directed thrusting (Krill 1985; Marker 1985) during the $D_1$ phase. Thrusts with a $D_1$ signature are located at the base of the TMC along the length of the province (Krill 1985), at the base of the Rai'tegår'zi nappe of the Karasjokka area, as well as near the base of the greenstone belt south of the Lakselv Valley (Figs. 1; Pharaoh 1984; Krill 1985; Andreassen 1993). A similar $D_1$ thrust located near the base of the greenstone belt in the Karasjokka area cannot be ruled out, since the Storfossen thrust of $D_2$ and $D_3$ affinity overprints earlier formed structures. Thus, the extent of the $D_1$ phase indicates that most of the KGB was allochthonous at this stage of deformation.

The well-preserved stratigraphic succession in the Lakselv Valley diverts from this strain pattern. There, domes of basement (Jer'gul Gneiss Complex?) and a continuous stratigraphic cover section suggest that the basement and overlying cover was transported on a basal $D_1$ thrust. Thus, the basement domes were detached from the underlying Jer'gul Gneiss Complex, and later uplifted during the $D_2$ phase (see below).

The $D_2$ phase shortened the greenstone belt in a N–S to NE–SW direction, as suggested from the fold-trends and vergences. Shear sense indicators in thrust zones like the Storfossen thrust support southward movement along $D_2$ shear zones near the base of the belt. Folds in the overlying greenstone belt, rooted in the Storfossen thrust (Fig. 12), suggest that the $D_2$ deformation was detached from the underlying basement. A similar situation is evident south of the Lakselv Valley, where several small shear zones, locally reactivating $D_1$ structures, indicate that the greenstone belt was partly detached from the Jer'gul Gneiss Complex in this area as well (Andreassen 1993). These shear zones may form the base for the $F_2$ uplifted basement domes of the Lakselv Valley.

Most of the $D_2$ thrusts strike N–S to NW–SE, i.e. oblique to the indicated SSW direction of tectonic transport. This indicates that the $D_2$ shear zones represent top-to-the-SSW dextral–oblique thrusts, which likely rejuvenated the $D_1$ foliation.
The $D_3$ phase is characterized by N–S-trending, west-verging folds that affect distinct areas of the greenstone belt, as seen in the Lakselv Valley (Fig. 10). Shear zones of this stage are generally insignificant and located to the $F_3$ fold-limbs, with exception of several 10 m-thick thrust zones located near the base of the TMC. These zones show retrograde alteration of the migmatitic, banded gneisses, and locally modify the map pattern (Braathen 1991). Similar retrograde shear-zones have reactivated many of the thrusts in the western part of the Karasjok–Levajok tectonic belt (Marker & Braathen, pers. comm. 1991), indicating that these $D_3$ structures are of regional extent.

The Storfossen thrust is an example of a significant $D_3$ shear zone that has reactivated a $D_2$ thrust. Shear sense indicators from this structure indicate top-to-the-west $D_3$ thrusting. Because similar structures are not known from other areas of the greenstone belt, the $D_3$ reactivation of the Storfossen thrust may be a local feature.

$D_4$ faulting and fracturing affected the entire region; however, significant faults have not been detected in the south. In the Lakselv area, NW–SE faults showing dextral separation of markers terminate in a NE–SW-oriented, foliation-parallel fracture zone. Movement within this fracture zone, if any, opens for a conjugate fault configuration, which may relate to a N–S-shortening axis. Alternatively, a regional dextral shear event may explain the dextral faulting (see below).

**Tectonic model for the Karasjok Greenstone Belt**

The structural evolution of the KGB can be summarized in a four-phase tectonic model, as presented in Fig. 15. This illustration of the orientation and genesis of various structures during the polyphase deformation history, which may well reflect a progressive sequence, places all deformation within a bulk crustal shear system. The regional, E-W-oriented, orogen-normal shortening axis is directly reflected by the orientation of $D_1$ and $D_3$ structures. For the $D_2$ phase, a counter-clockwise rotation of the regional shortening axis into a N-S to NE-SW orientation is suggested. Such a change to an orogen-oblique, contractual setting may have triggered right-lateral thrust movement near the base of the greenstone belt, and generated shear-related folds in the overlying units. The $D_4$ structures, constituting a minor part of the bulk strain in the area, deviate from the deformation style and orientation of the earlier formed structures. This distinction may point to a younger, separate event, where strike-slip faults formed during N–S to NE–SW shortening (Fig. 15).

**Discussion**

Two important questions arise from the above description
and discussion: First, does the lithostratigraphic section of the Lakselv area correlate with the tectonostratigraphy southward in the greenstone belt? Secondly, how does the polyphase structural evolution and the proposed model correspond to other tectonic models for the region? In the following we address these questions.

Stratigraphic correlation. – An attempt to correlate the continuous lithostratigraphic section of the Brennelya area (Lakselv) with the tectonostratigraphy of Osten (1985) and Siedlecka et al. (1985), which is based mainly on the Karasjokka area, is presented in Fig. 1b. In order for the correlation to be meaningful, we assume that some units can be traced for the length of the KGB.

There are some regional similarities, especially for the base of the belt. The Corgasavzi Formation of the Lakselv area most likely overlaps with the Skuvvavari Formation, and perhaps also lower parts of the Gål-lebake Formation; the former rest non-conformably on basement, and contain a basal conglomerate and overlying psammites. Osten (1985) places the boundary between the Skuvvavari and Gål-lebaikke formations to the first appearance of meta-volcanites/intrusives which, on a regional scale, are discontinuous or missing. In the Lakselv area, volcanic rocks appear near the base of the belt and interfinger with the psammites.

The overlying section, tectonically dismembered in the Karasjokka area, may be divided into two general parts: sedimentary rocks underneath volcanic rocks. In the Lakselv area, this subdivision applies to the Corgasavzi and Briittagielas–Fossestranda formations, respectively, which may equal the Gål-lebaibke and Bakkilvarri formations in the Karasjokka area. The overlying Rai-tegær’zi nappe (Rai-tegär’zi Formation of Osten 1985) in the Karasjokka area seems to be restricted to the southern part of the belt, or alternatively, it may have been incorporated in the TMC east of Lakselv. The map presented in Fig. 1b is based on these correlations.

Regional models. – Models for the Karasjok–Levajok Mobile Belt (Krill 1985; Marker 1985; Berthelsen & Marker 1986a) place the KGB as a passive margin basin, which is in accordance with the continental influx in sediments of the belt and possible continental magma contamination (see above; Davidsen 1994). The units overlying the KGB were located to the western margin of a collision zone, which involved several Archaean continents and Palaeoproterozoic volcanic arcs and basins. They were assembled during a ca. 2.0–1.8-Ga cycle of continental growth. The main collision phase emplaced the hot LGC, yielding the heat for the metamorphism (Krill 1985), over the TMC, which was thrust on top of the KGB.

This tectonic scenario is consistent with our D1 phase, showing extensive deformation and infolding of the greenstone belt (Fig. 15). However, amphibolite–facies metamorphism probably affected the greenstone belt before thrusting, as indicated by the early (pre-D1; from subduction?) metamorphic banding in the hinge-zone of the Brennelya F1 syncline of the Lakselv area, and also from consistent D1 mineral parageneses for the entire width of the belt. Thrust emplacement of the TMC probably occurred at a late stage of the D2 episode, during ultimate collision, before uplift (from thrusting?) and cooling.

An E–W-inverted metamorphic gradient, as proposed by Krill (1985), is clear for the Karasjok–Levajok tectonic belt as a whole, if the Jer’gul Gneiss Complex represents the base of the tectonostratigraphic section, and the S1 foliation defines the general dip of the Karasjok Greenstone Belt. However, stratigraphically, the greenstone belt is isoclinal folded, with an inverted upper fold-limb that is truncated by a regional thrust. Thus, the TMC is in a position which, without thrusting, would be the position of the basement gneisses of the Jer’gul Gneiss Complex in the upper fold-limb. This structural architecture allows for an interpretation of the highly strained TMC, at least partly, as a zone of sheared basement. In this case the metamorphic grade present in the TMC may reflect earlier tectonocontact metamorphic episodes that were partly overprinted during Palaeoproterozoic reworking.

During the following D2 phase the greenstone belt was shortened and transported on a basal thrust toward the SSW under retrograde, greenschist–facies conditions. The SSW transport direction suggests dextral, orogen-oblique movement for the greenstone belt and the attached (during D1) overlying complexes (Fig. 15), i.e. at this stage the KGB acted as a basal detachment zone. Such a transcurrent phase may, for example, be related to somewhat later (than D1) approximately N–S collision in the Lapland-Kola Orogen in the south (e.g., Barby et al. 1984; Gaal & Gorbatschev 1985; Gorbatschev & Bogdanova 1993). According to Nironen (1997), the D1–D2 collision occurred during 1.90–1.87 Ga, when NE–SW shortening in the northern part of the Svecofennian Orogen resulted in initial orogen-normal shortening and subsequent clockwise rotation, the latter leading to dextral transpression.

The following D3 phase could reflect a regional episode of E–W shortening, modifying the position of belts and complexes, as indicated by the numerous D3 thrusts that reactivated the foliation of the Karasjok–Levajok tectonic belt. Other indications for this regional extent are found as, for example, the N–S folds in the Po1mak–Pavik–Pechenga belt further east (e.g., Marker 1985; Melezhik & Sturt 1994), strikingly similar to those in the KGB (Brathen 1996). In the shield-scale model of Nironen (1997), no E–W event is proposed. The timing of this event is uncertain, but could correlate with the major 1.90–1.87 Ga event mentioned above.

A possible explanation for the D4 faults may be found in a shield-scale, strike-slip shearing phase that has been proposed for the Baltic Shield by Berthelsen & Marker (1986b) and Kärki et al. (1993). In this model, the D4 faulting of the KGB occurred in a fairly stable block (assembled during the D1, D2 and D3 phases) that was slightly influenced by the regional shearing event.

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