# Interpretation of the Proterozoic Kautokeino Greenstone Belt, Finnmark, Norway from combined geophysical and geological data

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Processed images of aeromagnetic, gravimetric and topographical data and geological maps combined with EM helicopter measurements, petrophysical data and digitised geological field observations have been used in a geological interpretation and structural analysis of the Kautokeino Greenstone Belt, KGB. The data were analysed with an image-processing system (geophysical data) and a geographic information system (geological data and interpretations).

The bulk of the mafic volcanic rocks in the Kautokeino Greenstone Belt is situated within a NNW-SSE-trending, 35 km wide and up to 5-6 km deep trough which is thought to represent an Early Proterozoic rift deformed by strike-slip faulting along the Bothnian-Kvænangen Fault Complex, BKFC. The margins of the Alta-Kautokeino Rift, AKR, can be outlined from the geophysical data. The Čiegηaljåkka-Boaganjávri Lineament and the Soadnjujávri-Bajasjávri Fault are the main bordering fault zones and are continuous along the entire greenstone belt. The supracrustals between these two zones are continuous to great depth (5-6 km) and the contacts along these bordering zones are steeply dipping. Gravity interpretations show that the outer amphibolite-facies rocks are just as deep as the central greenschist-facies unit. Results of the present study suggest that the amphibolite-facies volcano-sedimentary rocks situated along the flanks of the KGB should also be included in the rift.

The mudstones and limestones in the Bikkačåkka Formation may have been formed during thermal subsidence as a result of cooling of upwelled asthenosphere after a phase of rifting. The above-lying deep and narrow Čaravarri Formation contains abundant coarse-grained sandstones and conglomerates derived from a granitic source. We believe the Čaravarri Formation to have been the result of late-stage uplift of the margins, subsequent erosion of the exposed basement, and deposition of the sediments in deep internal basins. Strike-slip movements may be incorporated in this model. Large-scale sinistral displacement along the BKFC embraced the AKR which was already a zone of weakness in the Karelian continental block. This strike-slip movement may have allowed the Čaravarri Formation to form in a pull-apart basin within the rift.

The 230 km long Mierujávri-Sværholt Fault Zone, MSFZ, is the main fault zone which separates the flat-lying volcanosedimentary sequences in the Masi area from the Jergol Gneiss Complex to the southeast. The MSFZ extends from Mierujávri 30 km north of Kautokeino in a northeasterly direction through Masi, Iešjávri and Lakselv and then beneath the Caledonian nappes on the Sværholt Peninsula. A system of duplexes can be delineated along the MSFZ from the geophysical images. An extension of the MSFZ can be found to the southwest into northern Sweden. An apparent sinistral offset of the MSFZ can be observed along the margins of the BKFC.

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## Introduction

The purpose of this study has been to compile a geological bedrock map of the Kautokeino Greenstone Belt, KGB (Siedlecka et al. 1985), in Finnmark, northern Norway, and to evaluate areas favourable for prospecting of Bidjovagge-type gold-copper deposits. The geological and geophysical interpretations, with special emphasis on the structural geology, are presented in this paper. Evaluations of promising areas for prospecting have been made by Olesen et al. (1992d) and Sandstad et al. (1992).

The Finnmarksvidda area is heavily covered with glacial drift. Regional geophysical data are therefore a necessary prerequisite to structural analysis and geological interpretation. High-frequency (spatial resolution) and shaded-relief images have proved particularly effective forms of enhancing information from regional data (Henkel et al. 1984, Henkel 1988, Lee et al. 1990). Processed images of aeromagnetic, gravimetric and topographic data combined with EM helicopter measurements, petrophysical data and digitised geological field observations have been used. The data were analysed with an Erdas image-processing system (geophysical data) and an Arc/Info geographic information system (geological data and interpretations). The Erdas system allows data to be swapped in and out of the image buffer, thus permitting easy comparison of data-sets. By the use of the Erdas-Arc/Info Live-link module, the geological information and interpretations are kept in the graphics plane while swapping the geophysical images.

Since the mineralisations at Bidjovagge are assumed to be related to movements along shear zones, it is of great importance to outline the structural geology of the KGB together with the lithological compilation. The main structural elements (Fig. 8), such as the Alta-Kautokeino Rift, AKR (Bergh & Torske 1986), the Baltic-Bothnian megashear (Berthelsen & Marker 1986) which has earlier been renamed the Bothnian-Kvænangen Fault Complex, BKFC (Olesen et al. 1992a) and the Mierujávri-Sværholt Fault Zone, MSFZ (Olesen et al. 1990), will be interpreted in more detail.

The present study is a continuation of the interpretation by Olesen & Solli (1985) utilising improved techniques and more detai-

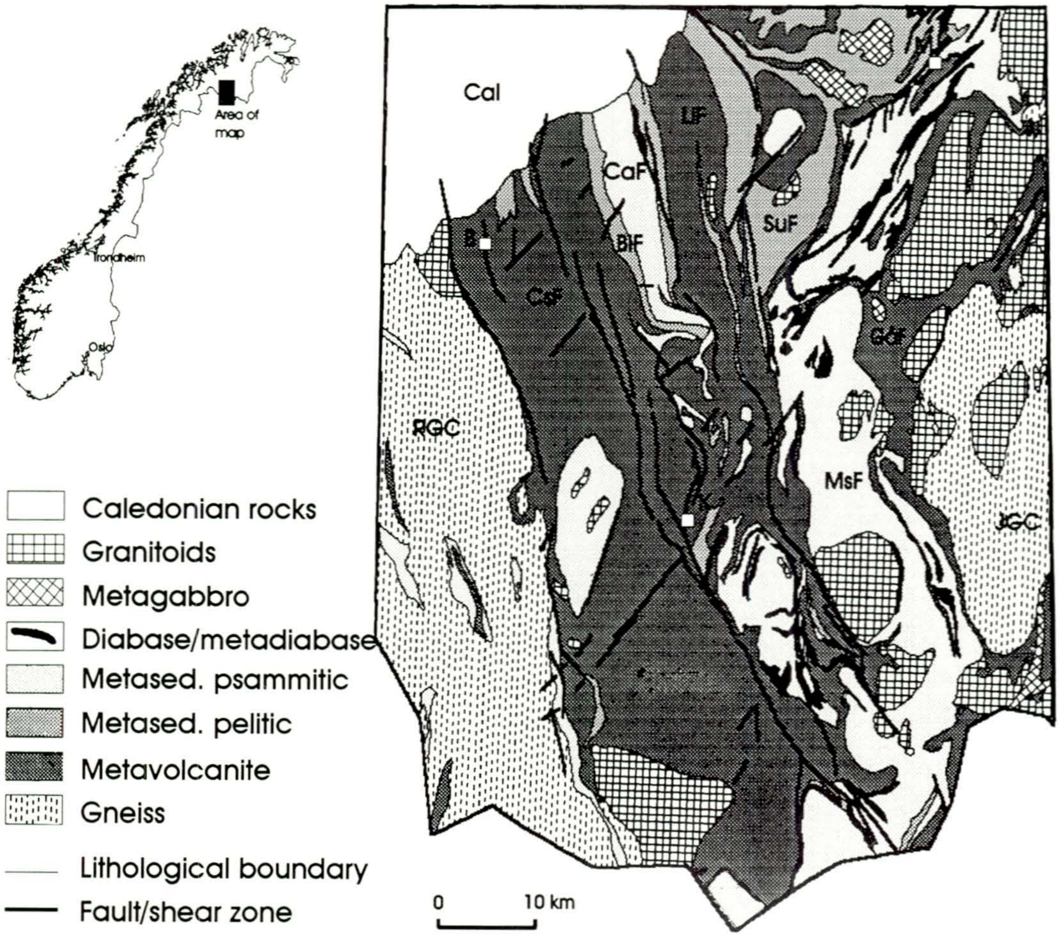

Fig. 1. Simplified bedrock geology map of western Finnmarksvidda. JGC - Jergol Gneiss Complex; RGC - Ráiseatnu Gneiss Complex; GåF - Goldinvarri Formation; MsF - Masi Formation; CsF - Časkijas Formation; SuF - Suolovuopmi Formation; LiF - Likča Formation; BiF - Bikkačåkka Formation; CaF - Čaravarri Formation; Cal - Caledonian nappes and Dividal Group. B - Bidjovagge; K - Kautokeino, M - Masi.

led data-sets. The magnetic dislocation map of Olesen & Solli (1985) has also been transferred to the image-processing system. The images of the more detailed data display, as expected, the previously recognised regional faults of the area (Olesen & Solli 1985). Petrophysical sampling and *in situ* susceptibility measurements have been carried out.

As a consequence of the new interpretation fault-bounded borders of the AKR and duplex structures along the MSFZ have been identified. The present study also helps to resolve the ongoing controversy concerning the formation of the AKR, especially the extent of the rift within the KGB. Another intriguing question is to what extent the faulting is related to rifting or to the subsequent strike-slip deformation. Delineating the fault tectonics in the KGB also has a bearing on our understanding of the formation of gold deposits of the Bidjovagge-type and may be a valuable aid for gold exploration in adjacent areas.

## Geological setting

### *The Kautokeino Greenstone Belt*

The Kautokeino Greenstone Belt (KGB) is the westernmost of three Early Proterozoic greenstone belts within inner Finnmark and is overlain by Caledonian rocks (Fig. 1, Plate 4). The KGB comprises a 40-80 km wide synclinorium of Early Proterozoic volcano-sedimentary rocks (Solli 1983, Siedlecka et al. 1985, Krill et al. 1985, Olesen & Solli 1985, Olsen & Nilsen 1985, Hagen 1987) and is situated between two culminations of gneisses, the Ráiseatnu[1] Gneiss Complex and the Jergol Gneiss Complex to the west and east, respectively (Fig. 1). These gneisses are partly of Archaean age (Olsen & Nilsen 1985) and form the basement to the greenstone belt. However, no clear depositional contact has been found between the gneisses and the supracrustals, presumably since the contacts are either fault-bounded or have been obliterated by younger felsic intrusions. The Ráiseatnu Gneiss Complex may comprise partly remobilised Archaean gneisses (Olsen & Nilsen 1985) or migmatised equivalents of the Kautokeino Greenstone Belt. Opinions differ on the stratigraphy of the greenstone belt: from two cycles (Siedlecka et al. 1985, Solli 1983, Sandstad 1983,1985, Olesen & Solli 1985, Hagen 1987) to four main volcanic cycles (Olsen & Nilsen 1985). We do not think that the evidence for the latter more complex stratigraphy is compelling and will therefore continue to advocate the former interpretation.

The Kautokeino Greenstone Belt can be subdivided into a number of formations. The oldest of these are the Goldinvarri Formation (Solli 1983) and the correlative Vuomegielas Formation (Siedlecka 1985), which consists of mafic volcanic rocks metamorphosed in amphibolite facies. They have been found only along the eastern margin of the greenstone belt, to the south and northeast, respectively. The Masi Formation lies above the Goldinvarri Formation with a supposed angular unconformity and consists of quartzitic rocks. The main body of the greenstone belt is occupied by the Časkijas, Likča and Suolovuopmi Formations (Siedlecka et al. 1985) each of which consists mainly of basic metavolcanites (Fig. 1, Plate 4). They can, on a broad scale, be correlated to the Ávži, Stuorajávri and Bahárávdojávri Formations in the southern part of the KGB (Olsen & Nilsen 1985), but the detailed relationships are still controversial. The volcanic rocks are dominated by basic tuffs and tuffites, but basaltic lavas and concordant diabases are also present. In some places, komatiitic metavolcanites are present. Mica schists interpreted as metamorphosed, fine-grained, clastic, terrigenous sedimentary rocks are interbedded with the volcanites, but only in the Suolovuopmi Formation to the northeast do they make up a considerable portion of the rocks. The Suolovuopmi Formation in the Masi area is therefore interpreted to have formed on a platform at the margin of a rift. The youngest rocks of the greenstone belt are found in the central northern parts. Here it can be demonstrated that the volcanism in the Časkijas Formation gradually decreased and that the formation is concordantly overlain by pelites (Bikkačåkka For-

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[1] The official spellings of many Lappish (sami) geographical names, including several used e.g. for lithostratigraphic units, have recently been changed. The old and new forms are listed in an appendix (p.62).

mation) and sandstones (Čaravarri Formation; Sandstad 1985). According to Bergh & Torske (1986, 1988) the Čaravarri Formation and the greenschist-facies volcanosedimentary rocks within the eastern part of the Časkijas Formation were formed within the gradually subsiding Alta-Kautokeino Rift (AKR) along the margin of the Karelian continental block. We argue below that the whole of the Časkijas and Likča Formations should be included in the AKR.

Deformation and metamorphism are of low intensity in the central parts of the KGB and increase towards the gneiss complexes to the west and to the east. As seen from Plates 1 & 4, the general structural trend of the western and southern part of the KGB is NNW-SSE. Within this area both the bedding and the foliation are generally steep. In the northeastern part of the KGB the structural trend is NE-SW and the dip flattens out (Solli 1988).

To the northwest, mudstones of the Upper Proterozoic/Lower Cambrian Dividal Group unconformably overlie the rocks of the greenstone belt. Above this are the Caledonian nappes which, in this area, consist mainly of feldspathic metasandstones (Zwaan 1988).

## *Regional fault zones*

The western area of the KGB is dominated by NNW-SSE trending faults interpreted by Olesen & Solli (1985). Berthelsen & Marker (1986) and Henkel (1988, 1991) include these faults in the regional Baltic-Bothnian megashear and Bothnian-Seiland shear zone, respectively. We think that the name *Bothnian-Kvænangen Fault Complex*, BKFC (Fig. 8), will be a more appropriate name since the zone can be traced from the Bay of Bothnia to Kvænangen; and its continuation to the the Baltic Sea in the south is poorly defined. The BKFC is composed of several fault segments which are well defined from both geological and geophysical data (Holmsen et al. 1957, Olesen & Solli 1985, Geol. Surveys of Finland, Norway and Sweden 1986b, 1987, Berthelsen & Marker 1986, Henkel 1988, 1991, Olesen et al. 1990). In the Kautokeino area, 3-4 regional NNW-SSE fault zones have been delineated (Olesen & Solli 1985, Olesen et al. 1990). Local faulting along these zones has been mapped by Holmsen et al. (1957).

Albite diabases have intruded one section of the BKFC bordering the eastern side of the Čaravarri Formation in the area of mapsheet Čarajávri 1833 I (Solli 1990). The BKFC can be traced on aeromagnetic maps from the Finnmarksvidda area below the Caledonian nappes to the Alta-Kvænangen tectonic window in the north (Olesen et al. 1990). The western and eastern terminations of the Juvri Nappe, which is the lowermost unit within the Caledonian nappe succession in western Finnmark (Sandstad 1985, Zwaan 1988), coincide with extensions of faults within the BKFC. This indicates that the BKFC may have been active during the Caledonian orogeny.

The 230 km long Mierujávri-Sværholt Fault Zone (MSFZ, Fig. 8) extends from Mierujávri 30 km north of Kautokeino in a northeasterly direction through Masi, Iešjávri and Lakselv and then subsurface beneath the Caledonian nappes on the Sværholt Peninsula. In the Masi-Iešjávri area the MSFZ is parallel to the northwestern margin of the Jergol Gneiss Complex and is mostly situated within or at the border of the Masi Formation. Based on interpretation of aeromagnetic and gravity data the MSFZ truncates the Proterozoic Levajok Granulite Belt beneath the Caledonian nappes (Olesen et al. 1990). The Archaean-Lower Proterozoic Goldinvarri Formation and the correlative Vuomegielas Formation (Siedlecka et al. 1985) have been dextrally displaced 20 km along the MSFZ (Olesen et al. 1990). In the Masi area, intrusions of 1815±24 Ma albite diabases (Krill et al. 1985; U-Pb zircon date) are related to the NE-SW trending MSFZ. To the southwest, the MSFZ is truncated by the Proterozoic BKFC. The MSFZ was therefore mainly active before the last major deformation of the Alta-Kautokeino Rift. Brecciation is common along the faults within both the BKFC and the MSFZ.

The postglacial Stuoragurra Fault (Olesen 1988 and Olesen et al. 1992a,b) is situated within the MSFZ and is consequently parallel to the northwestern margin of the Jergol Gneiss Complex. The fault line is shown in Plate 3. It can be traced for 80 km, from south of Biggejávri in a northeasterly direction through Masi. The fault is made up of numerous segments of faults with up to 10 m of reverse displacement. The Stuoragurra Fault is situated mainly within quartzites of the Masi Formation. North of Masi, however, the Stuoragurra Fault cross-cuts amphibolites within the Suolovuopmi Formation and an albite diabase. Brecciation is observed in all the locations where the bedrock is exposed in the fault escarpment (Olesen et al. 1992a) and such brittle deformation is also observed along the entire length of the MSFZ in the Precambrian on Finnmarksvidda. The brittle deformation is consequently believed to have occurred during the formation of the MSFZ and not the younger Stuoragurra Fault.

The earliest detectable displacements along the MSFZ are inferred to be Proterozoic (Olesen et al. 1990) and the latest took place less than 9,000 years ago (Olesen 1988, Olesen et al. 1992b). Along the MSFZ to the northeast of Iešjávri, a syn-sedimentary movement during the deposition of the Cambrian Dividal Group and a post/late-Caledonian displacement which cuts the Gaissa Thrust have been reported (Townsend et al. 1989). Furthermore, the offshore extension of the MSFZ coincides with one of the major basement faults on the continental shelf (Lippard & Roberts 1987). The MSFZ must consequently represent an extremely long-lived fault-zone.

## Data used in the interpretation

### Aeromagnetic data

The aeromagnetic measurements were carried out in two periods. In 1959-62, the area was drape-flown at an altitude of 150 m with a profile spacing of 1 km. Maps in the scale of 1:50,000 have been digitised in a 500 x 500 m grid, from which the Definite Geomagnetic Reference Field 1965 was subsequently removed. A printed map of the medium-altitude data has been published in the scale of 1:500,000 (Olesen et al. 1992c).

During 1979-85 most of the area was reflown at a profile spacing of 200-250 m and a flight altitude of 50 m (Håbrekke 1979, 1980a,b, 1981, 1983, 1984, Dvorak 1982, Mogaard & Skilbrei 1986). These measurements are much more detailed than the former. The low-altitude surveys older than 1985 were compiled, levelled and interpreted by Olesen & Solli (1985), but because of confidentiality only the interpretations were published. Skilbrei (1986) included the survey by Mogaard & Skilbrei (1986) in the compilation and levelled the data-sets using the 'orthognostic' mapping technique of Kihle (1992). In the present study an additional survey flown by Dighem (Dvorak 1982) on the 1:50,000 map-sheet 1833 IV Mållejus has been included, and the total of 29,000 profile-km of low-altitude measurements have been interpolated to a square grid of 100 x 100 m using the minimum curvature method (Swain 1976). The final grid was slightly smoothed using a 3 x 3 point Hanning filter. The data-set has been superimposed on the medium-altitude 500 x 500 m grid to generate the coloured map shown in Plate 1. Because of the different flight altitudes, there are some discrepancies at the border of the medium- and low-altitude data-sets. The final map shown in Plate 1 was produced using the shaded relief technique (Lee et al. 1990, Kihle 1992) with illumination from the east.

### Gravity data

The gravity map in Plate 2 is based on measurements from 2,500 gravity stations. A regional gravity survey was carried out on Finnmarksvidda within the Finnmark Programme during the years 1980-1988 (Olesen & Solli 1985, Olesen et al. 1993), mostly using a snow scooter and helicopter for transportation. Measurements were made at stations located 1 - 4 km apart. The complete Bouguer reduction (Mathisen 1976) of the gravity data has been computed using a rock density of 2,670 kg/m$^3$, the International Gravity Standardization Net 1971 (I.G.S.N. 71) and the Gravity Formula 1980 for normal gravity. A total of 250 measurements from the Norwegian Mapping Authority (Statens kartverk) are included in the survey.

Since the grid was calculated at 500 m intervals the variable areal distribution of the primary observations has been homogenised by extracting stations with a minimum spacing of 300 m from the original data-set. This reduced data-set (ca. 2,200 stations) was gridded using the minimum curvature method, and then smoothed using a 3 x 3 point Hanning filter. The final step in the process was to separate the data into a regional field associated with the mountainous Caledonian area to the northwest, and a residual component using the method by Olesen et al. (1990). The contour interval of the residual field in Plate 2 is 1 mGal, and is believed to be larger than the error in the gravity data. The locations of the gravity stations are shown on the residual map.

## *Electromagnetics*

Electromagnetic data were collected during the helicopter-borne surveys (Håbrekke 1979, 1980a,b, 1981, 1983, 1984, Dvorak 1982, Mogaard & Skilbrei 1986). Discrete electromagnetic responses have been analysed to map conductors using the vertical sheet model. The conductance (i.e. conductivity-thickness product) in ohm$^{-1}$ (mho) of the vertical sheet model was calculated by computer in all of the surveys. This is done regardless of the interpreted geometric shape of the conductor. This was not an unreasonable procedure, because the computed conductance increases as the electrical quality of the conductor increases, regardless of its true shape. Strong conductors are characteristic of graphite or massive sulphides. Conductors with conductance higher than 5 mhos are plotted in Plates 1 - 4.

## *Digital topographical and hydrological data*

The Norwegian Mapping Authority (Statens kartverk) has provided a 100 x 100 m grid of digital topography from the area. This dataset was derived from digitised 1:50,000 scale topographical maps (M711 series), which had an original contour interval of 20 m. The use of digital topography in tectonic studies has been demonstrated by Henkel (1988). Glacial processes will enhance or obliterate pre-glacial tectonic imprints depending mainly on the direction and intensity of ice flow. The map shown in Plate 3 has been produced using the shaded relief technique (Lee et al. 1990, Kihle 1992) with illumination from the east.

Digital topographical and hydrographical data in vector-form delivered by the Norwegian Mapping Authority, series N250-vector, were used in the compilation of the geological map. The data are adapted for use in the scale 1:250,000, but are also suitable for the scale 1:100,000; they consist of automatically and manually generalised and digitised data from 'Norway 1:50,000 (M711)'. Administrative borders, drainage systems, communications, settlements, superficial deposits and elevation contours and points are included.

## *Petrophysical data*

Olesen & Solli (1985) and Holst (1986) have reported petrophysical data for 1,150 and 114 rock samples, respectively. An additional 1,100 rock samples were collected during geological mapping and the follow up of geophysical anomalies (1986-1989). The rock samples (weighing 0.3 - 1.0 kg) have been measured with respect to density, magnetic susceptibility and remanent magnetisation. The sample locations are shown in Fig. 2. The measuring procedure is described by Torsvik & Olesen (1988). The densities used in the gravity modelling are shown in Table 1. In addition, a large number of *in situ* determinations of magnetic susceptibility have been made in selected areas. These results are presented as histograms in Fig. 3. Measurements of natural remanent magnetisation (NRM) directions on rock samples of reversed magnetised diabase are shown in Fig. 4.

## *Geological data*

Outlines of bedrock exposures, with their lithological information, from 12 preliminary and printed geological maps in the scale

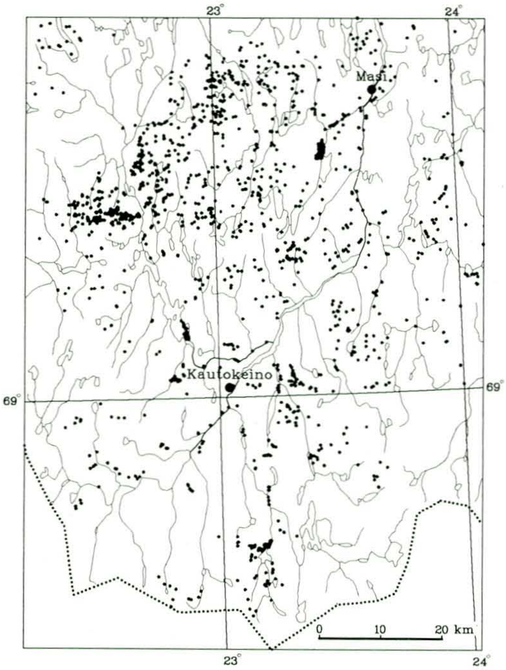


Fig. 2. Sample locations, 2,400 rock samples measured with respect to density, susceptibility and remanence.

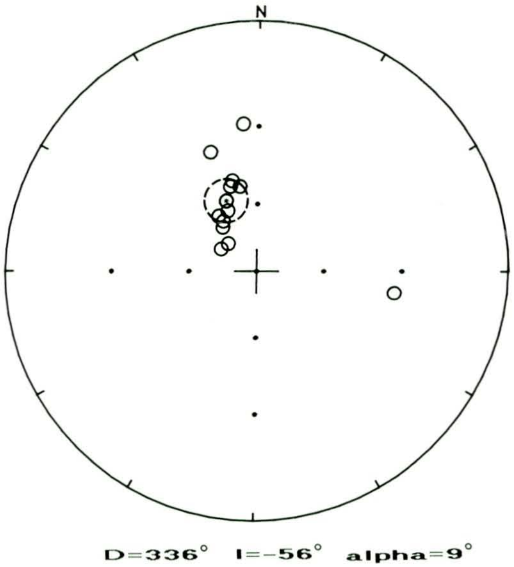


Fig. 4. Plot of natural remanent magnetisation (NRM) directions of a reversed magnetised diabase on a Wulff net (lower hemisphere). Open circles show negative inclination. Dashed line displays the cone of 95 per cent confidence (alpha). The plot shows a condensed distribution except one outlier which is ignored in the calculation of the statistics.

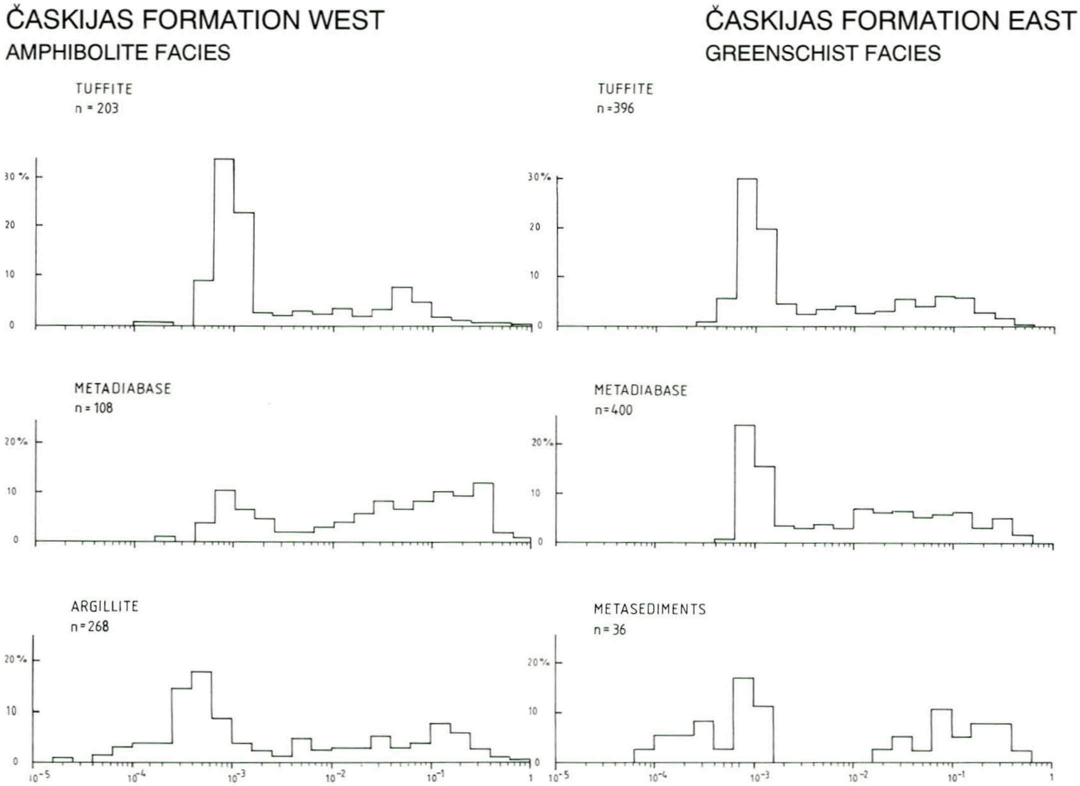


Fig. 3. Susceptibility spectra *of in situ* measurements on amphibolite- and greenschist-facies tuffite, metadiabase and metasediments within the Časkijas Formation.

1:50,000 (Lindahl & Mikalsen 1975, Olsen 1987 a,b,c,d, 1988 a,b,c, Sandstad 1985, Solli 1987,1988,1990) were digitised. Totally, about 6,300 exposures were transmitted to the geographic information system Arc/Info, representing approximately one exposure pr. km$^2$. The area is heavily covered by glacial drift and contains relatively few exposures. The exposures are most numerous in the northern part of the KGB and decrease southwards (Plate 4). A few limited areas in the southern part are well exposed.

## Methods of interpretation

### *Image processing*

The data were analysed with an Erdas image-processing system (Erdas 1990) running on a PC with an Intel 80386 processor and an IMAGRAPH 1024 x 1024 image-processing card. The system can hold three raster images, each with a positive 8-bit range of 0-255 and one 4-bit graphic plane for overlays of vector data. The Erdas system allows data to be swapped in and out of the image buffer and thus allows multiple data-sets to be easily compared. The gridded gravity, aeromagnetic and topographical data-sets were rescaled into the 0-255 range. Histogram-equalised colour, high-frequency filtered and shaded-relief images have been used to enhance the information of the regional data-sets. Shaded-relief presentations, which treat the grid as topography illuminated from a particular direction, have the property of enhancing features which do not trend parallel to the direction of illumination. The interpretation of magnetic dislocations by Olesen & Solli (1985) and preliminary interpretations of aeromagnetic data, the location of VLF ground profiles and VLF anomalies have been digitised and transferred to the Erdas system. These interpretations and the computed electrical conductors from the helicopter-borne electromagnetic measurements are represented as vector data in the image-processing system. Figs. 5 and 6 show shaded relief images of the low-altitude aeromagnetic measurements and digital topography, respectively.

### *Geographic information system*

The geographic information system pcArc/Info, version 3.4D, was used for the interpretation and compilation of the geological map (Plate 4) in combination with the image-processing system Erdas. A detailed description of the compilation and presentation of the map is given by Sandstad (1992).

A uniform legend based on lithology and metamorphic grade was set up for use in the interpretation. The formational legends used in the preliminary and printed bedrock maps were neglected due to the uncertain correlation between different formational units. By this system the screen contains up to 16 different colours and a simplified legend was used during the interpretation (Sandstad 1992). The outlines of the exposures of the lithological units were shown in different colours on the screen.

The Erdas system is driven within the Arc/Info software with the aid of an Erdas Live-link module which allows easy swapping of different images. Processed images of the geophysical data, mainly different processings of the magnetic data, and the electromagnetic indicators were kept in the graphic plane as background for the geological data in the overlay plane. The interpretations of the lithological boundaries and faults are digitised directly on the video monitor using a mouse-controlled cursor within the Arc/Info. The interpretation of the faults was compared with the geophysical interpretations. Once completed, the final geological interpretation map was plotted on a Calcomp electrostatic plotter at the scales of 1:100,000 (Sandstad 1992) and 1:250,000 (Olesen et al. 1992d).

### *Structural interpretation*

The structural interpretation utilising the image-processing technique is similar to the method of Henkel et al. (1984) and Henkel (1988). In Henkel's method, fault zones occurring within magnetic rock units are interpreted from: 1. Linear discordances in the anomaly pattern. 2. Displacement of reference structures. 3. Linear or slightly

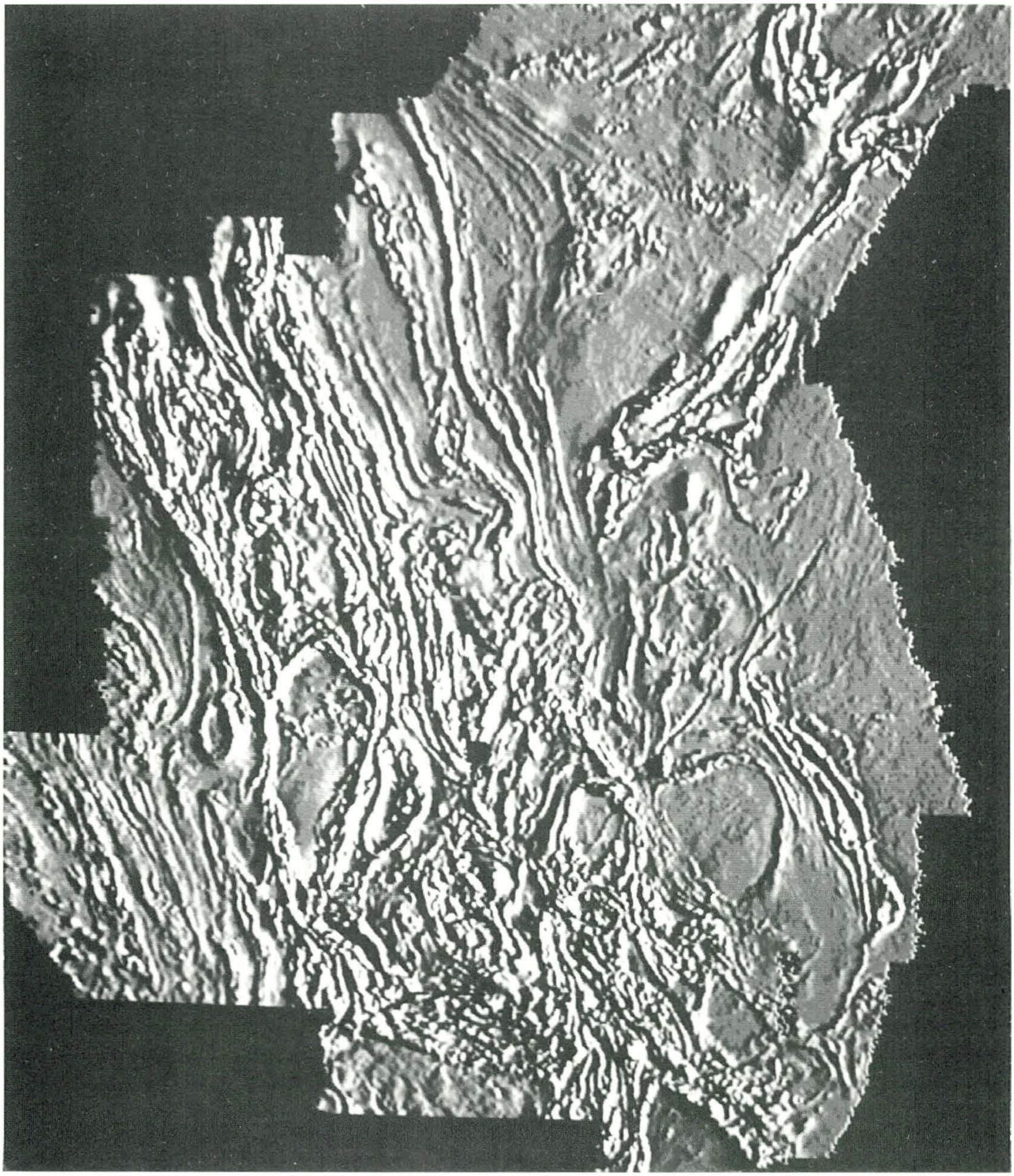


Fig. 5. Shaded relief image of the low-altitude aeromagnetic measurements from the Kautokeino Greenstone Belt ('illumination' from the east). For scale and location of the image; see Plate 1.

curved magnetic gradients. 4. Discordant linear or curved minima (Henkel & Guzmán 1977). The digital elevation data can be used to corroborate the interpretation of the magnetic data since fault zones commonly coincide with linear depressions in the topography. Regional fault zones will, furthermore, emerge as intermittent linear gradients in the gravity image.

Ground VLF and magnetic profiles with lengths varying from 400 m to 4 km have been measured on 28 selected locations across fault zones in the Masi area (Olesen

Fig. 6. Shaded relief image of the digital topography from the Kautokeino Greenstone Belt ('illumination' from the east). For scale and location of the image; see Plate 3.

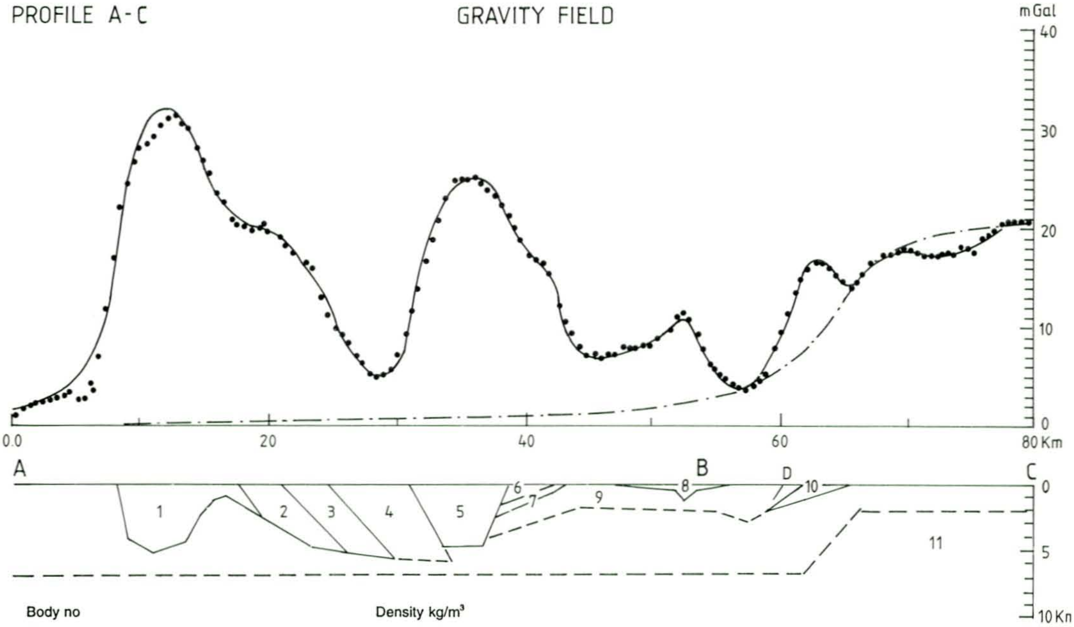
et al. 1992a). The purpose of these measurements was to check and correct the interpretations based on the method just outlined. In regions of resistive soil and bedrock the VLF method can be used to detect large water-containing fracture zones in the bedrock (Eriksson 1980, Henkel & Eriksson 1980).

The magnetic banding within the KGB is generally found to represent the primary layering of the volcano-sedimentary sequences and metadiabase sills which now mostly show up with steep dips. The dip of albite diabases in the Masi area has been modelled using the aeromagnetic data recorded along helicopter-profiles and the measured magnetic properties of the bedrock (Olesen et al. 1992a).

We have used the computer programme by Torsvik (1992) to compute the gravity response of a model along one profile across the Kautokeino Greenstone Belt (Plate 2). The basic model in the programme comprises bodies of polygonal cross-section with limited extension in the strike direction. The interpretation is shown in Profile A-C in Fig. 7. This profile is an extension of the profile interpreted by Olesen & Solli (1985) and is continuous across the whole of the greenstone belt. The densities used in the gravity modelling are shown in Table 1.

Table 1. Rock densities employed in the gravity modelling, Kautokeino Greenstone Belt.

| Rock unit | No. | Density ($10^3$ kg/m$^3$) Mean | st.dev. |
|---|---|---|---|
| Rai'sædno Gneiss Complex | 86 | 2.69 | .14 |
| Jer'gul Gneiss Complex | 457 | 2.69 | .11 |
| Gål'denvarri Formation | 80 | 2.96 | .11 |
| Masi Formation | 117 | 2.65 | .07 |
| Čas'kejas Formation (Amphibolite facies) | 198 | 2.96 | .10 |
| Čas'kejas Formation (Greenschist facies) | 65 | 2.88 | .12 |
| Suoluvuobmi Formation Metavolcanics | 144 | 2.97 | .10 |
| Suoluvuobmi Formation Metasediments | 72 | 2.73 | .06 |
| Lik'ča Formation | 182 | 2.85 | .19 |
| Čaravarri Formation | 52 | 2.66 | .06 |
| Albite diabase | 55 | 2.91 | .10 |



| Body no |  | Density kg/m$^3$ |
|---|---|---|
| 1 | Časkijas Formation (amphibolite facies) | 2960 |
| 2 | Časkijas Formation (greenschist facies) | 2860 |
| 3 | Bikkačåkka Formation | 2760 |
| 4 | Čaravarri Formation | 2660 |
| 5 | Likča Formation | 2850 |
| 6 | Suolovuopmi Formation, micaschist | 2730 |
| 7 | Suolovuopmi Formation, amphibolite | 2970 |
| 8 | Suolovuopmi Formation, amphibolite | 2970 |
| 9 | Masi Formation | 2650 |
| 10 | Goldinvarri Formation | 2960 |
| 11 | Intermediate gneiss | 2800 |
| D | Albite diabase | 2910 |

Ambient density 2690 kg/m$^3$

— — — Inferred model boundary

• Observed Bouguer anomaly

—·— Regional gravity field from body no. 11

⌒ Calculated gravity effect

Fig. 7. Gravity section across the Kautokeino Greenstone Belt. Location of the profile shown in Plate 2.

# Results

## *Lithological compilation*

The western and eastern gneiss complexes were readily distinguished during the interpretation. Most characteristic is the different magnetic patterns of the complexes. While the Ráiseatnu Gneiss Complex (RGC) has a weak, but pronounced banded magnetic appearance similar to the supracrustals of the greenstone belt, the magnetic signature of the Jergol Gneiss Complex (JGC) is more irregular (Plate 1). Bodies of supracrustal rocks are mapped within the RGC, while intrusive granitoids are more common within the eastern complex (Plate 4). We suggest that the RGC mainly consists of migmatised parts of the greenstone belt and that the JGC represents an older and probably Archaean basement. This interpretation agrees with Olsen (in press) who claims that only the southern part of the RGC can be correlated with the JGC. Grant (1985) has also shown that migmatisation is likely to reduce the susceptibility of the bedrock and this may explain why the amplitude of the banded anomalies in the RGC is reduced when compared with the anomalies representing the greenstone belt.

One of the major controversies bearing on our understanding of the geology of the Kautokeino Greenstone Belt relates to the number of major volcanic cycles and hence the stratigraphy of the belt. During this combined interpretation we were able to use the more simple model with two major volcanic cycles. The oldest volcanic unit is the Goldinvarri Formation (Solli 1983) and the correlative Vuomegielas Formation (Siedlecka 1985) northeast of Plate 4. We have correlated these formations with the Sotnabeaijávrit Formation (and partly the Bahárávdojávri Formation) in the south (Olsen & Nilsen 1985). They occur along the eastern margin of the KGB and represent the '*Sedimentary and volcanic rocks of probable Late Archaean age*' on Plate 4. The dominating amphibolite-facies metavolcanites are basaltic and have relatively high MgO and low $TiO_2$ contents (Solli 1983). Minor occurrences of ultramafic metavolcanites, and psammitic and pelitic metasediments exist. Geophysically the formations are characterised by a lack of electromagnetic indicators and low magnetic field.

The '*Sedimentary and volcanic rocks of supposed Early Proterozoic age*' are divided into medium- and higher-grade metamorphic rocks and low- and very-low grade metamorphic rocks (Plate 4). The amphibolite-facies supracrustals constitute the most abundant rock-type within the map area (Plate 4). The stratigraphically lowermost Masi Formation consists mainly of quartzites and feldspathic quartzites and minor conglomerates (Siedlecka et al. 1985). The psammitic metasediments which are believed to constitute the lowermost part of the overlying metavolcanic formations (Olsen & Nilsen 1985) are also included. The metasediments commonly define dome-shaped structures. These dome structures have a low and smooth magnetic pattern compared to similar structures caused by granitic intrusions which give a low but irregular magnetic pattern. The quartzites are intruded by several diabases/metadiabases which commonly occur as sills surrounding the dome structures.

The contact between the metasediments and the overlying metavolcanites is usually a primary depositional contact (Siedlecka et al. 1985). The lowermost parts of the metavolcanic formations consist of carbonates, mica schists and graphite schists. The metamorphic boundaries between the amphibolites and greenstones on Plate 4 are arbitrary and mark the transititional zones. In most places gradually changes in metamorphic grade are observed. The lack of abrupt breaks in metamorphic grade, and similar chemical compositions and magnetic susceptibilities are among the major arguments why we favour one major volcanic cycle overlying the Masi Formation within the Alta-Kautokeino Rift (AKR). The metavolcanites are characterised by a banded magnetic pattern. The basaltic amphibolites consist mainly of metatuffs and metatuffites. In addition there are metamorphosed lavas and diabases and metasediments; mica schists, marbles and graphite schists. The low-grade metamorphic metabasalts along Stuorajávri and agglomeratic layers west of Kautokeino are strongly magnetic and readily distinguished. Only in the northeastern part of the KGB, within the Suolovuopmi Formation, and centrally in the KGB do the pelitic metasediments make up a considerable portion of the rocks. The graphite schists are outlined by the EM conductors, especially within the AKR where the rocks are steeply dipping. The numerous EM indicators in the northeastern part of the map-area are partly due to weakly folded and almost flat-lying rocks. Komatiitic metavolcanites, partly consisting of pillow lavas (Olsen & Nielsen 1985), occur at different stratigraphic levels along the eastern margin of the AKR and within the Masi area.

A gradual decrease in volcanic activity with accompanying deposition of pelitic sediments has been mapped in the north-central part of the AKR (Sandstad 1985, Siedlecka et al. 1985). The border between pelites with layers of graphite schist (Časkijas Formation) and pelites with layers of siltstone (Bikkačåkka Formation, Sandstad 1985) is mapped with the use of the EM conductors. Above these rocks are situated feldspathic sandstones constituting the youngest supracrustal unit within the KGB (Čaravarri Formation, Siedlecka et al. 1985).

Albite felsites and albite-carbonate altered rocks occur locally within the greenstone belt (e.g. Holmsen et al. 1955, Gjelsvik 1958, Padget 1959). They often constitute thin layers or irregular zones associated with tectonic activity, and just a few major areas dominated by albite-rich rocks are shown on the map (Plate 4). Very fine-grained albite felsites representing altered pelitic metasediments and metatuffites occur primarily in the lower or upper part of the basaltic metavolcanic sequences. They are assumed to be formed in association with the intrusion of diabase sills in the unconsolidated sedimentary sequence (Vik 1985, Bjørlykke et al. 1993) and are commonly associated with copper-gold mineralisations as observed in the Bidjovagge Mine. Medium- to coarse-grained albite-carbonate rocks are common in the central part of the AKR, surrounding Kautokeino, in areas where brittle faulting is most intensive (Sandstad et al. 1992).

The '*Intrusive rocks of supposed Early Proterozoic age*' have retained the classifications used in the preliminary and printed bedrock maps in the scale 1:50,000. The major granites are located mainly in the eastern part of the map area (Plate 4), within both the Jergol Gneiss Complex and the greenstone belt. The granites are occasionally highly differentiated and weakly deformed to undeformed. They have intruded the supracrustals and are assumed to represent post-orogenic intrusions. In areas where a mixture of exposures of granites and other non-magnetic felsic rocks occur, the borders are arbitrary. A similar simplification is also shown for granodiorites within the JGC. The granodiorites are weakly to moderately foliated and represent syn- to post-orogenic intrusions. Xenoliths of gneisses and supracrustal rocks of the KGB are found within the larger granodioritic massif east and south of Masi (Solli 1988). The large Riednjajávri quartz monzonite occurring in the extreme southwest of the greenstone belt is massive to weakly foliated and has a minor angular discordance against the metavolcanites. Major bodies of gabbro/metagabbro are assumed to represent subvolcanic intrusions and are mapped mainly along the eastern part of the greenstone belt. In the northeast they cover large areas partly due to the presence of concordant intrusions within the flat-lying supracrustals. A minor peridotite is spatially associated with regional faults east of the Čaravarri Formation. It is the only ultrabasic intrusion known within the KGB, but similar intrusives are found within correlative rocks within the Alta-Kvænangen tectonic window (Vik 1985).

The basaltic dykes are subdivided into several groups (Plate 4). The clearly most distinctive of these are the diabases with reverse magnetisation. They are the youngest rocks within the greenstone belt and paleomagnetic studies indicate an age of around 900-950 mill. years (Mertanen et al. 1990). They have retained an ophitic texture and are orientated NE-SW parallel to the

Mierujávri-Sværholt Fault Zone (MSFZ). Most of the albite diabases which occur frequently along the MSFZ have a similar orientation. They have a high content of magnetite (up to 10 %, Solli 1983) giving a charcteristic anomaly pattern on the aeromagnetic map (Plate 1). They are supposed to represent intrusive rocks with a high albite content (Solli 1983, Olsen in press). However, it is likely that some of the other mapped diabases/metadiabases may be classified as albite diabase. Olsen (in press) describes gradual transititions from ordinary diabase to reddish albite-bearing diabase. More detailed mapping shows that NE-SW orientated albite diabases occur just north of Kautokeino (Sandstad et al. 1992). Most of the albite diabases have this NE-SW orientation, but such intrusions are also found along N-S trending faults, e.g. south of Čarajávri. The further classification of the basaltic dykes based on deformation follows the mapping of Olsen (in press) in the southern part of KGB. Olsen considers

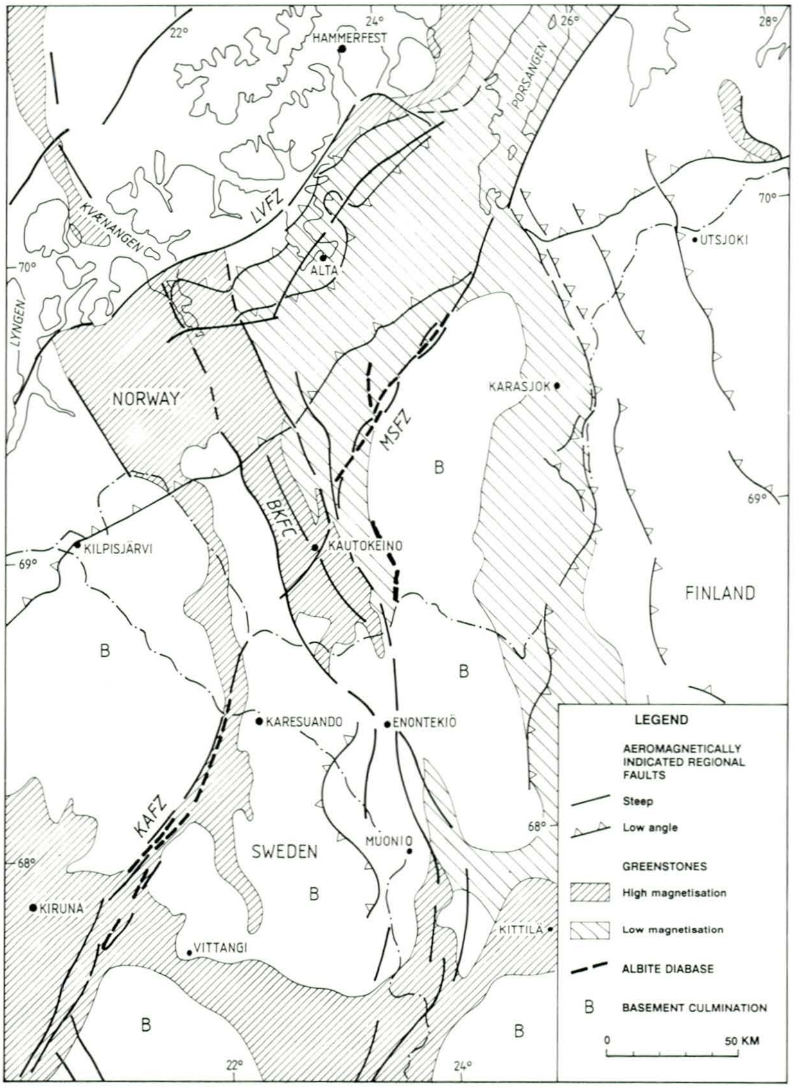


Fig. 8. Sketch map of regional structural elements interpreted from aeromagnetic and gravity data in Finnmark and adjacent areas in northern Finland and northern Sweden (Modified from Geological Surveys of Finland, Norway and Sweden 1986b, Olesen et al. 1990, Henkel 1991). BKFC - Bothnian-Kvænangen Fault Complex; KAFZ - Karesuando-Arjeplog Fault Zone; MSFZ - Mierujávri-Sværholt Fault Zone; LVFZ - Langfjord-Vargsund Fault Zone.

that the different dykes are associated with different volcanic cycles. In disagreement with this interpretation, as discussed in the previous section, we have, however, chosen to map diabases with preserved ophitic texture in the southern part of the KGB. Both low- and high-magnetic basaltic dykes occur independently of the degree of deformation. In general they are assumed to be associated with the basaltic volcanism and commonly occur as sills.

## *The Bothnian-Kvænangen Fault Complex*

The NNW-SSE trending Alta-Kautokeino Rift is bounded to the west and east by steeply dipping fractures, the Čiegŋaljåkka-Boaganjávri Lineament, CBL, to the west and the Soadnjujávri-Bajasjávri Fault, SBF, to the east (Plate 3). These structures are continuous along the entire greenstone belt and constitute part of the BKFC. Especially along the eastern fault, the SBF, cross-cutting relationships to magnetic reference structures can be observed. A striking feature seen in Plate 1 is the change in the magnetic pattern from NE-SW-trending structures 5 km north of Mierujávri to the NNW-SSE-trending structures at the margin of the AKR. This indicates that the NE-SW structures are apparently transected by sinistral displacement along the SBF. Immediately to the south of the Caledonian front north of Soadnjujávri there is a similar discordance between the E-W-trending structures within the Suolovuopmi Formation and the N-S-trending structures in the Likča Formation. Holmsen et al. (1957) reported N-S-trending faults with brecciation and mylonitisation of the rocks at both locations. Further to the south, Olsen (in press) has reported shearing along this zone. A reversed magnetised dyke (Plates 1 - 4) has an apparent sinistral offset of 1 km along the SBF. Measurements of natural remanent magnetisation on samples from the dyke are shown in Fig. 4. Modelling of aeromagnetic profiles across this dyke shows that it dips 60-70° to the southeast. The true movement along the SBF after the intrusion of the dyke is therefore either (a) 1 km sinistral or (b) 2-3 km dip-slip with the eastern block being downthrown or (c) an oblique movement consisting of both sinistral and dip-slip movement.

The western zone, the CBL, appears on the aeromagnetic image as the border between the high-amplitude, banded magnetic pattern to the east and the low-amplitude, banded pattern to the west. The CBL coincides with the eastern margin of the migmatised Ráiseatnu Gneiss Complex. This border is intruded by granites and pegmatites (Holmsen et al. 1957, Sandstad 1983, Olsen in press). However, faulting along the northern part of this lineament has been observed by Holmsen et al. (1957), and Sandstad (1983) reported strong deformation along the zone. Shear deformation has been observed by A. Bjørlykke (pers. comm. 1990) to the west of the Bidjovagge Mine. Shear-heating at greater depth along strike-slip faults can enhance crustal anatexis (Michard-Vitrac et al. 1980, Sylvester 1988), and the original fault rock along the rift-fault may therefore not be recognisable. From the geophysical images, we conclude that the CBL represents the most distinct dislocation along the western border of the AKR. We interpret this lineament as a continuous fault zone from the better exposed area north of Ráisjávri to the south. In this southern area, which is to a great extent covered by glacial drift, a steep fault bordering the Ráiseatnu Gneiss Complex has also been described by Holmsen et al. (1957, Fig. 16). Several large fault zones also occur within the rift (Plate 4). These, however, are not continuous along the entire rift. One interesting result is that the electrical conductors representing mainly graphite schists (Plate 4) seem to coincide with some of the fault zones which are interpreted from the aeromagnetic and topographical data. Note that the VLF-EM method could not be used to control the location of these faults. These zones may represent the same type of shear zones as those appearing in the Bidjovagge Mine, which to a great extent control the gold mineralisations within this mine (Bjørlykke et al. 1993).

The gravity field in Plate 2 is composed of anomalies of different wavelengths. The central area, the Kautokeino Greenstone Belt, consists of alternating high and low, short-wavelength (5-10 km) anomalies. The local lows correspond to basement rocks, felsic intrusions and quartzites in antiforms, and sandstones within the basinal Čaravarri Formation. The gravity highs correspond to the basic metavolcanites. Within the rift, both bedding and schistosity are generally steeply dipping. Flat-lying structures occur where the underlying basement forms dome structures (Olesen & Solli 1985). Four antiformal structures in the Mierujávri area have been defined in addition to those previously identified by Holmsen et al. (1957) and Olesen & Solli (1985). These structures (Plates 2 & 3) can be interpreted either as gravity-driven diapirs (Olesen & Solli 1985), as fold-interference phenomena (Olsen in prep.) or as folds within shear-induced strike-slip duplexes (flower structures). The largest gravity highs are interpreted as accumulations of strongly folded and/or faulted amphibolites with depths of up to 6 km (Olesen & Solli 1985).

The western part of Profile A - C in Fig. 7 is dominated by a synclinorium of amphibolites from the Časkijas Formation. The volume of these rocks is significantly larger than that of the Goldinvarri Formation. There is a prominent gravity low related to the Čaravarri Formation. The mudstone underlying the Čaravarri Formation is interpreted to have a depth of 5-6 km. Since the Čaravarri Formation is deposited on top of the mudstone, the depth of these sandstones is likely to be similar. The depth of the Čaravarri Formation, however, cannot be determined from the gravity data because of a lack of density contrast with the underlying basement. The gravity data do not allow the presence of any greenstones below the Čaravarri Formation.

From the aeromagnetic and gravity data, the AKR and the BKFC can be traced beneath the Caledonian nappes to the Alta-Kvænangen window, where they were deformed during the Caledonian orogeny (Zwaan & Gautier 1980, Olesen et al. 1990). From the aeromagnetic and gravity maps of Olesen et al. (1990) there is also evidence that the AKR continues further NNW onto the continental shelf of the Norwegian Sea.

Fig. 3 shows the frequency distributions of *in situ* susceptibility measurements of the main lithologies of the Časkijas Formation in the area of 1:50,000 map-sheet 1833 IV Mållejus. As described above, the eastern part of this map area contains mostly greenschist-facies rocks while the western part contains their amphibolite-facies equivalents (Sandstad 1983,1985). It has long been a matter of dispute whether or not these two units represent one and the same formation as stated by Sandstad (1983,1985) and Siedlecka et al. (1985), or two different units with regard to time of formation and depositional environment (Olsen & Nilsen 1985, Bergh & Torske 1988). The histograms in Fig. 3 show a very similar pattern for the correlative rock-types in the two areas. The bimodal distribution of the susceptibility is responsible for the typical banded anomaly pattern which can be seen within the greenstone belt on the aeromagnetic map in Plate 1. There is no difference with regard to major element chemistry between the low-magnetic and the high-magnetic volcanites (Sandstad 1983). The difference in magnetite content must therefore be a result of different oxidation states inherited from the pre-metamorphic state (Grant 1985). The source of the volcanic rocks and the depositional environment is therefore likely to be similar in the two areas. In this context it should be pointed out that the Časkijas Formation and correlative units in the southern part of the KGB are unique among the volcanosedimentary formations in the Proterozoic on Finnmarksvidda in terms of high magnetite content. The aeromagnetic anomalies caused by the Časkijas Formation resemble those of the Kiruna and Kittilä greenstones in northern Sweden and northern Finland, respectively, with regard to amplitude and wavelength (Geological Surveys of Finland, Norway and Sweden 1986a).

## *The Mierujávri-Sværholt Fault Zone*

The prominent, NE-SW-trending, characteristic high-magnetic anomalies in the Masi area are due to Proterozoic albite diabases that have intruded along faults within the MSFZ (see Plates 1 & 4). Outside this fault zone the albite diabases have intruded regionally as sills along layering and foliation surfaces. Locally, deformation of these diabases can be observed, for instance along the main road between Masi and Kautokeino (UTM coord. 602400-7698500) where the diabase has been transformed to amphibolite. From the aeromagnetic and topographical images, a complex system of duplexes (Woodcock & Fischer 1986) can be delineated along the MSFZ from Mierujávri to Iešjav′ri (Plates 1 & 3). Local, weak, magnetic anomalies are caused by small amounts of magnetite in quartzite beds within the Masi Formation. The interpretations have been followed up in the till-covered area with electromagnetic, VLF, ground profiles (Olesen et al. 1992a).

Magnetic model calculations along aeromagnetic profiles indicate that the albite diabase has either intruded into a positive flower structure (Wilcox et al. 1973) or has been involved in the deformation along a similar structure (Olesen et al. 1992a). The wedge-shaped structure bordered by faults along Fidnajåkka, Biggejávri, Mazejåkka and the Kautokeino River has been interpreted as a duplex which Olesen et al. (1992a) proposed to name the Biggevarri Duplex. In the eastern part of the gravity Profile A-C (Fig. 7) there is an increase in the regional field towards the Jergol Gneiss Complex. This long-wavelength anomaly is interpreted to be caused by a layered basement consisting of an upper felsic unit and a lower intermediate unit. On Finnmarksvidda, this layered basement is interpreted to form two large culminations with amplitudes of 5-7 km in the Ráiseatnu and Jergol Gneiss Complexes, as demonstrated by Olesen & Solli (1985). The western flank of the latter is visible on the profile. The gradient of the regional field is larger in the Masi area than in the Kautokeino area further to the south (Plate 2). The gravity anomaly caused by the Goldinvarri Formation is situated on the flank of the regional anomaly.

According to the gravity modelling of Profile A-C in Fig. 7, the thickness of the Suolovuopmi Formation increases continuously to the west of the Masi Formation. The Biggevarri Duplex to the east of Biggejávri (Plates 3 & 4) is therefore interpreted to continue beneath the amphibolites to the north of the Mazejåkka river. The albite-carbonate alteration along the Mazejåkka is thought to represent a gently northward-dipping roof of the Biggevarri Duplex structure mainly located within the quartzite. The Biggejávri REE-Sc mineralisation (Olerud 1988, Sandstad 1989) located within an albitite is situated in the amphibolites shortly above this duplex interface and the mineralisation may be related to faulting along the MSFZ.

The gravity low in Plate 2 to the northwest of Biggejávri is caused by the absence of amphibolites in an anticlinal structure of quartzites of the Masi Formation. A magnetic anomaly (Plate 1), which is composed of short- and long-wavelength components, is related to the same structure and is interpreted as sill-like intrusions of albite diabase, a relation that is generally valid in the Masi area (Olesen & Solli 1985). When interpreting the negative gravity anomaly in this area it was necessary to take into account the gravity effect of the amphibolites in the Suolovuopmi Formation located 2 km to the north of Profile A-B (Plate 2).

## Discussion and conclusions

The bulk of the mafic volcanites in the Kautokeino Greenstone Belt is located within a NNW-SSE-trending, 35 km wide and up to 5-6 km deep structure which is thought to represent the AKR modified by later folding, faulting and shearing along the BKFC. The borders of this sheared rift can be outlined from the geophysical images. The CBL and SBF in Plate 3 are the main bordering faults and are continuous along the entire length of the greenstone belt. As can be seen from the three northernmost gravity profiles by Olesen & Solli (1985), the supracrustals between these two zones are continuous to great depth and the contacts along these bordering zones are generally steeply dipping. The southernmost profile in Olesen & Solli (1985) does not reveal a steep contact and is interpreted as the southern termination of the rift at the Finnish border. The quartzites within the Masi Formation along the Finnish border are characterised by their high metamorphic grade and migmatisation (Olsen & Nilsen 1985). The high metamorphic grade is also characteristic further north at the western and eastern margins of the rift. We therefore favour the interpretation by Bergh & Torske (1984, 1988) of a southward-propagating rift into the Karelian continental block. Olsen & Nilsen (1985) and Bergh & Torske (1988) prefer to exclusively incorporate the low-grade volcanic rocks of the Časkijas Formation in the AKR. From the geophysical images there is no evidence of these low-grade rocks of the Časkijas Formation representing a separate fault-bounded rift. On the contrary, gravity interpretations by Olesen & Solli (1985) and Fig. 7 show that the outer amphibolite-facies rocks are just as deep as the central greenschist-facies unit. The present study consequently suggests that the amphibolite-facies volcanosedimentary rocks along the flanks of the Kautokeino Greenstone Belt should also be included in the rift. Detailed mapping in the map area 1833 IV Mållejus by Sandstad (1983) shows that the two units represent the same stratigraphic succession with a gradual change in metamorphic facies from one unit to the other. Sandstad (1983) could not detect any abrupt break with regard to lithology, chemistry, metamorphism or tectonic style between the two units.

Bergh & Torske (1987) include the Bergmark area in the western part of the Alta-Kvænangen Window in the rift. The stratigraphy in this area (Vik 1981) is similar to the stratigraphy described by Sandstad (1983) for the westernmost part of the Časkijas Formation on the map-sheet Mållejus. This observation also supports our interpretation that the whole of the Časkijas Formation should be included in the rift.

The model for the development of the KGB must explain why the formation of the deep and narrow Čaravarri Formation contains abundant coarse-grained sandstones and conglomerates derived from a granitic source (Holmsen et al. 1957, Siedlecka et al. 1985). This is most likely caused by late-stage uplift of the margins, subsequent erosion of the exposed basement and deposition of the sediments in deep internal basins. One model for the formation of the KGB was proposed by Olesen & Solli (1985); to re-establish gravitational equilibrium after the deposition of the dense volcanic rocks, the layered crust culminated on both sides of the belt and formed the Ráiseatnu and Jergol Gneiss Complexes. In this late stage the uplifted basement was exposed to erosion and the sediments were deposited in basins within the greenstone belt. A similar model was proposed in northeastern Sweden by Lindroos & Henkel (1978). However, in this they incorporated marginal sedimentary basins and not a central basin.

An alternative model, following the thermal model for basin evolution proposed by McKenzie (1978), involves the formation of the mudstones and limestones in the Bikkačåkka Formation during thermal subsidence as a result of cooling of upwelled asthenosphere after a phase of rifting. Specifically, horizontal heat flow could cause additional cooling within the rift and uplift of its shoulders (Ingersoll 1988). Strike-slip movements may be incorporated in the model. The large-scale sinistral displacement reported by Berthelsen & Marker (1986) and Henkel (1988) along the 1.9-1.8 Ga-old Bothnian-Kvænangen Fault Complex embraced the 2.2-1.9 Ga Alta-Kautokeino Rift which was already a zone of weakness in the Karelian continental block. This strike-slip movement may have produced pull-apart basins within the rift. The Čaravarri Formation has been interpreted to be the youngest unit within the greenstone belt. The strike-slip movements could also have triggered the formation of the gravity-induced diapirs which were delineated by Olesen & Solli (1985).

The flat-lying, thin (up to 2 km) sequences to the west of Masi (Plate 4) are interpreted as having been deposited on a platform at the margins of the deep rift. This is supported by the increased volume of sediments in this area (Olesen & Solli 1985). The amphibolites occur adjacent to the AKR. The

MSFZ constitutes the border between this flat-lying sequence to the northwest and the more deformed Goldinvarri Formation and Jergol Gneiss Complex to the southeast (Plate 4). Holmsen et al. (1957) and Solli (1983) reported that the Masi Formation has locally been inverted and thrusted above the Suolovuopmi Formation to the west. In the present model of the MSFZ we interpret the thrusting and imbrication of the Masi Formation to have occurred internally within the formation, as a result of dextral strike-slip movements along the MSFZ. The thrusting of the quartzite consequently developed mainly underneath and along the border of the Suolovuopmi Formation.

In the area of map-sheet 1933 IV Masi (Solli 1988), foliation and layering steepen towards the Kautokeino River; from the geophysical data this river valley area is interpreted to represent the central part of the MSFZ (Plates 3 & 4). A palm tree structure (Sylvester & Smith 1976) slightly tilted to the northwest, can be inferred along the MSFZ by combining the geophysical interpretation and the geological observations. This type of structure typically occurs along strike-slip faults (Sylvester 1988). Two minor, fault-bounded blocks representing the Suolovuopmi Formation on Årvušvarri and Håigadančåkka (Solli 1988), immediately east of Masi and 15 km south of Masi respectively, are situated close to the centre of the MSFZ. These blocks are interpreted to be emplaced by normal faulting, which may represent extension across the top of the uplifted and laterally spreading blocks (Sylvester 1988). The S-shaped MSFZ, representing a restraining bend, is consistent with the observed accumulated dextral displacement of 20 km along the fault zone. The wedge-shaped positive Biggevarri Duplex, interpreted from geophysical images, may have been formed as a consequence of this dextral strike-slip component. Internal thrusting of the Masi Formation within this structure was reported by Holmsen et al. (1957).

Based on the interpretation of aeromagnetic and gravimetric data the MSFZ truncates the Proterozoic Levajok Granulite Belt beneath the Caledonian nappes (Olesen et al. 1990). On the Kola Peninsula a similar large-scale fault, the Mokhtozerckaya Fault Zone, MFZ (Barzhitzky 1988), has been reported to terminate the eastern end of the Lapland Granulite Complex which is the continuation of the Levajok Granulite Belt through Finland into Russia. During or after the emplacement of the Levajok Granulite Belt in the continent-continent collision (Krill 1985), the MSFZ and the MFZ may have acted as dextral and sinistral transform faults, respectively. 'Indentor tectonics' (e.g. Tapponier et al. 1986) may also explain these large-scale strike-slip faults adjacent to continent-continent collision zones. Watterson (1978) suggested that indent-linked faults may be the main cause of the pervasive lineament networks in Precambrian continental crust.

Proterozoic albite diabases have intruded the MSFZ in the Masi area. Locally, deformation features can be observed in these diabases. In the Masi area, Olesen (1988) reported that the Stuoragurra Fault follows one old fracture zone and then cuts across to follow another. Interpretations of more detailed geophysical images have resulted in the delineation of a system of duplexes along the MSFZ from Mierujávri to Skoganvarre. Albite-carbonate alteration occurs along the borders of the Biggevarri Duplex. Slight tilting of the MSFZ towards the northwest may have been caused by the doming of the Jergol Gneiss Complex. Since the deformation increases towards the MSFZ, the folding and imbrication in this area may be associated with movement along the MSFZ.

To the southwest into northern Sweden, an extension of the MSFZ can be found; the Karesuando-Arjeplog Fault Zone, KAFZ (Fig. 8), reported by Henkel (1991). This fault zone occurs in the Tjärrå Formation which is correlated with the Masi Formation (Geological Surveys of Finland, Norway and Sweden 1987) and is intruded by highly magnetic albite diabases. The MSFZ and KAFZ have an apparent sinistral offset of 10-15 km along the BKFC (Fig. 8).

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# Appendix

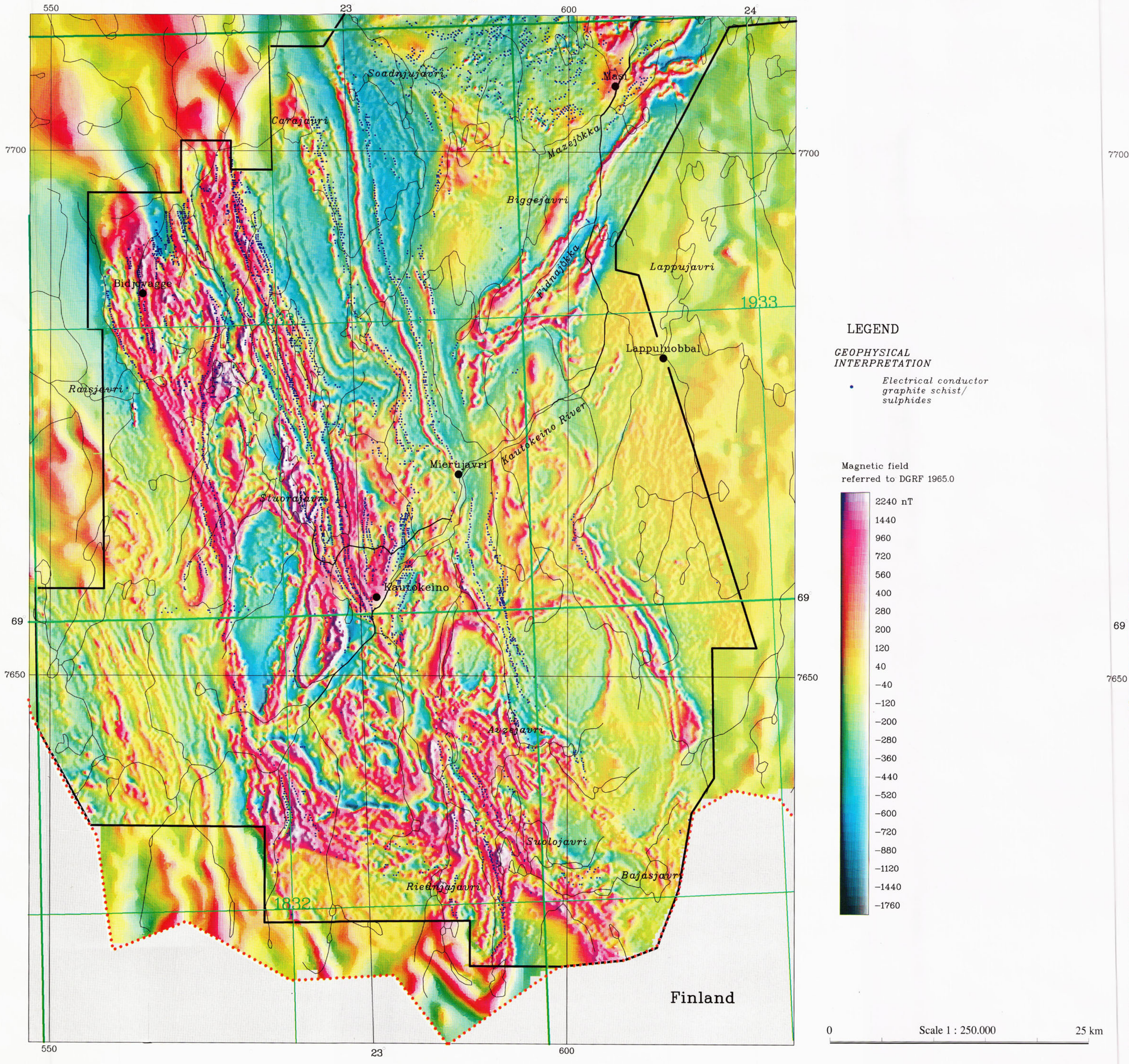
Many Lappish geographical names have been used in stratigraphic nomenclature, especially for formations, groups, complexes, etc., in the Proterozoic and Archaean of Finnmarksvidda: Following the recommendations of the Norwegian Committee for Stratigraphy, we have adopted the revised spellings decided by the 'Navnekonsulenttjenesten for samiske navn'. The old and new names are here listed alphabetically.

| Old spelling | New spelling |
|---|---|
| Baharavdujav´ri Formation | Bahárávdojávri Formation |
| Čas´kejas Formation | Časkijas Formation |
| Gål´denvarri Formation | Goldinvarri Formation |
| Jer´gul Gneiss Complex | Jergol Gneiss Complex |
| Rai´sædno Gneiss Complex | Ráiseatnu Gneiss Complex |
| Suoluvuobmi Formation | Suolovuopmi Formation |
| Sådnabei Formation | Sotnabeaijávarit Formation |

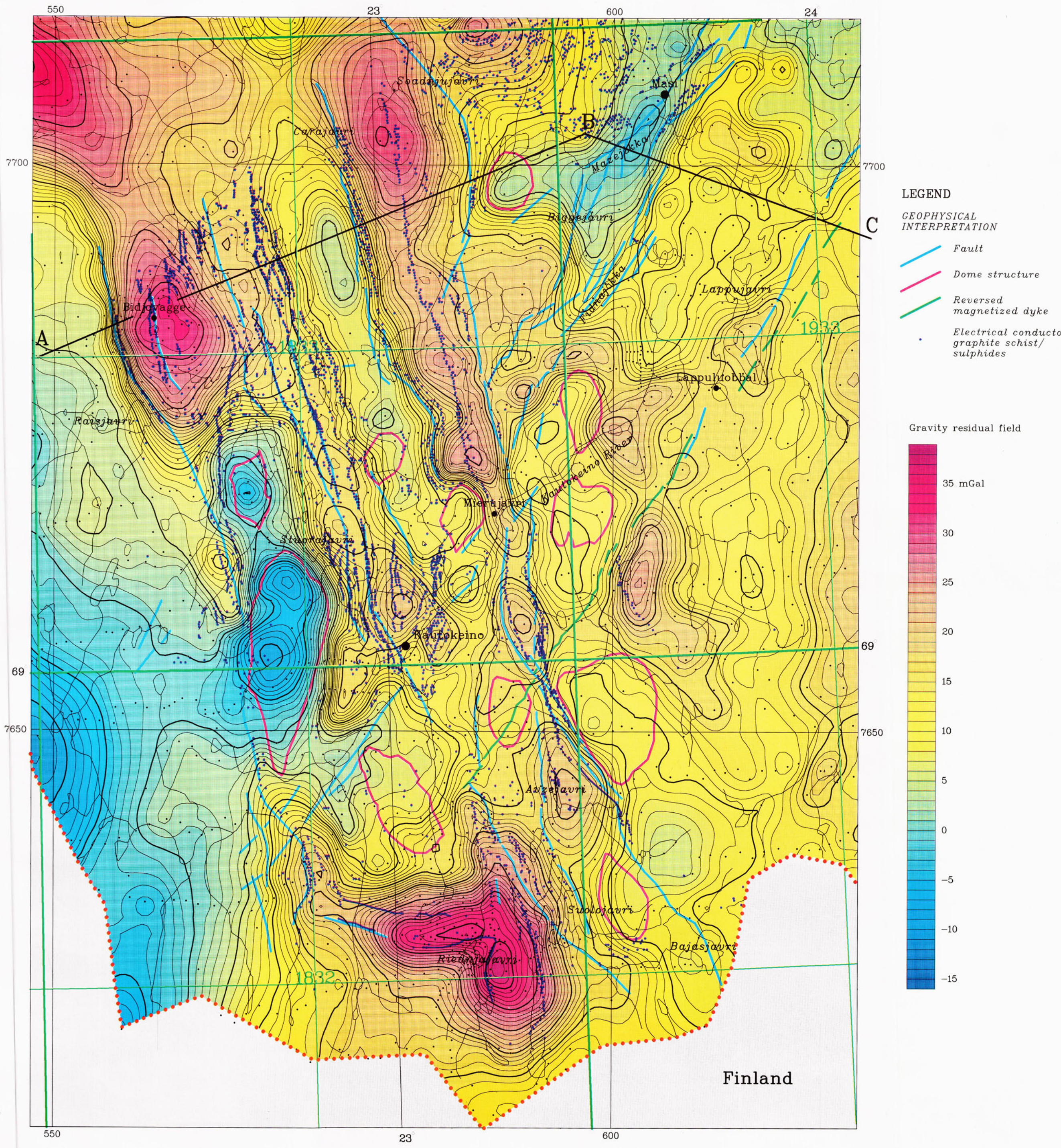
# KAUTOKEINO GREENSTONE BELT

## GEOPHYSICAL AND GEOLOGICAL MAPS

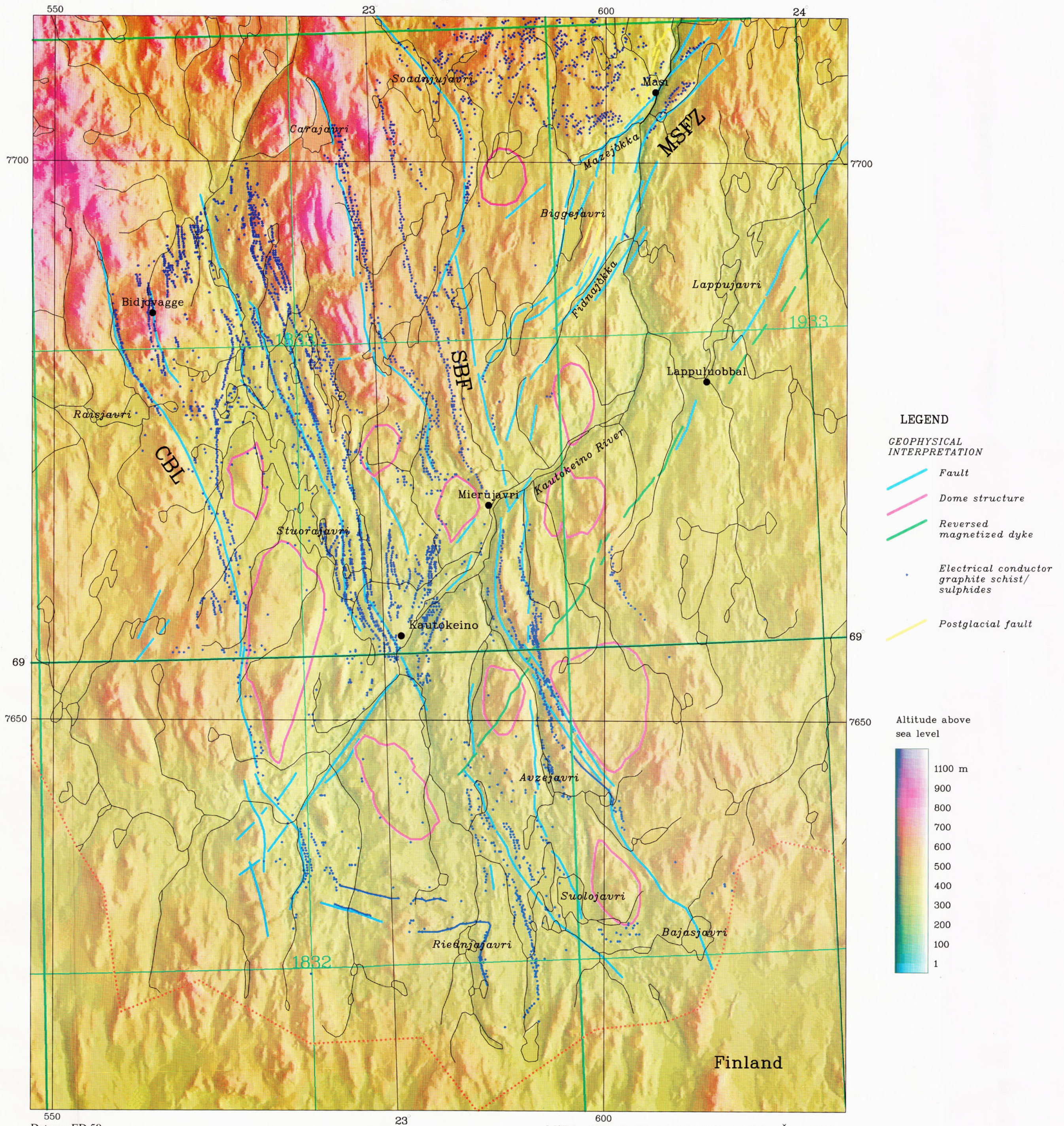
### Plate 1: Aeromagnetic residual map, shaded relief presentation



### Plate 2: Residual Bouguer gravity anomaly map



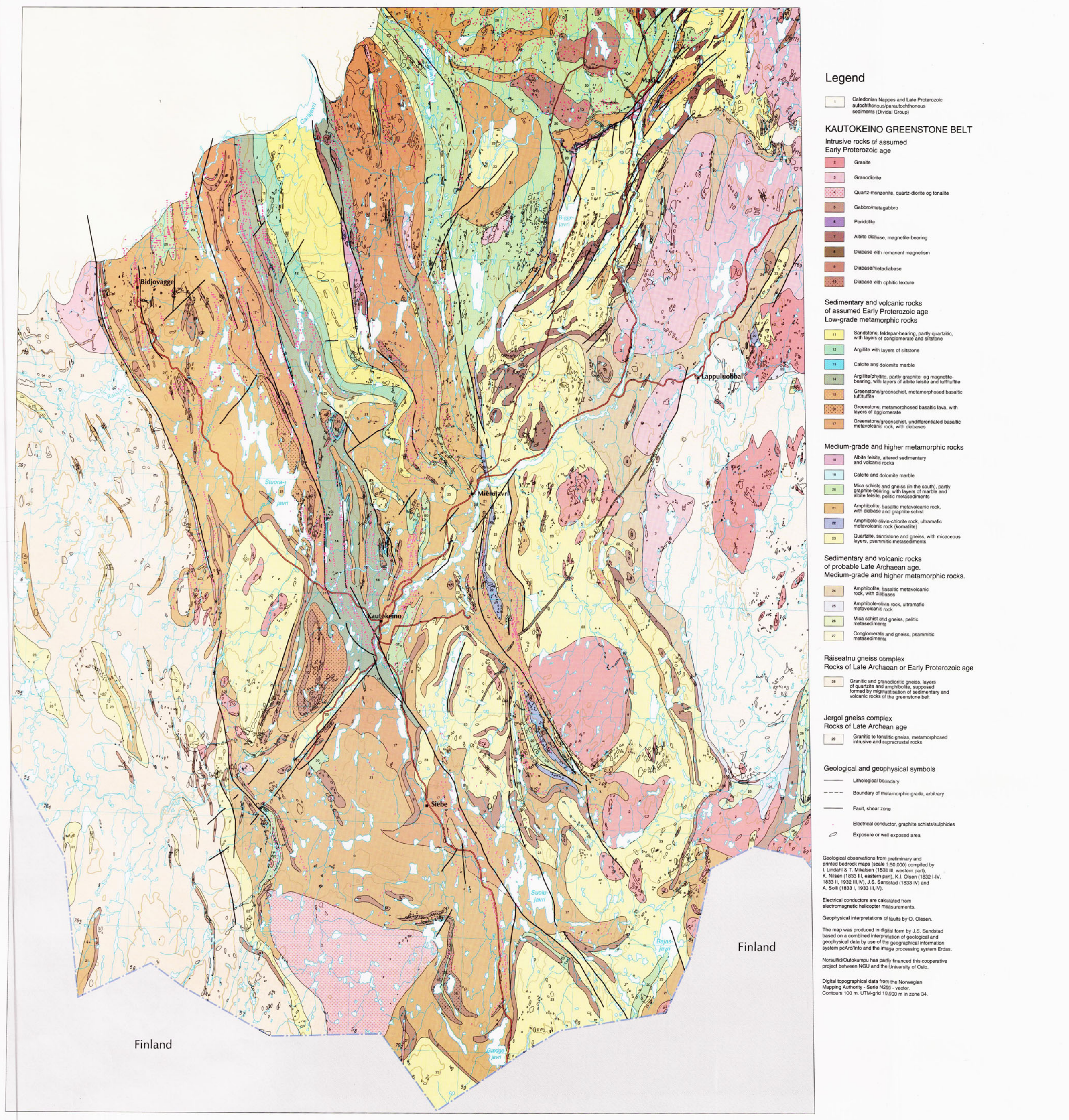
### Plate 3: Digital terrain model, shaded relief presentation



Datum : ED 50
Map projection: Universal Transverse Mercator,
mid meridian 21° E. Gr.

MSFZ = Mierujávri-Sværholt Fault Zone; CBL = Čiegnaljåkka-Boaganjávri Lineament; SBF = Soadnjujávri-Bajasjávri Fault.

### Plate 4: Bedrock map



Geological observations from preliminary and printed bedrock maps (scale 1:50,000) compiled by I. Lindahl & T. Mikalsen (1833 III, western part), K. Nilsen (1833 III, eastern part), K.I. Olsen (1832 I-IV, 1833 II, 1932 III,IV), J.S. Sandstad (1833 IV) and A. Solli (1833 I, 1933 III,IV).

Electrical conductors are calculated from electromagnetic helicopter measurements.

Geophysical interpretations of faults by O. Olesen.

The map was produced in digital form by J.S. Sandstad based on a combined interpretation of geological and geophysical data by use of the geographical information system pcArc/Info and the image processing system Erdas.

Norsulfid/Outokumpu has partly financed this cooperative project between NGU and the University of Oslo.

Digital topographical data from the Norwegian Mapping Authority - Serie N250 - vector.
Contours 100 m. UTM-grid 10,000 m in zone 34.

Base map : N1mill/N250, Norwegian Mapping Authority, Hønefoss
Cartography : NGU and Cartographica, Trondheim
Printing : Emil Moestue a.s., Oslo

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