

KARTERING BARENTS 2013

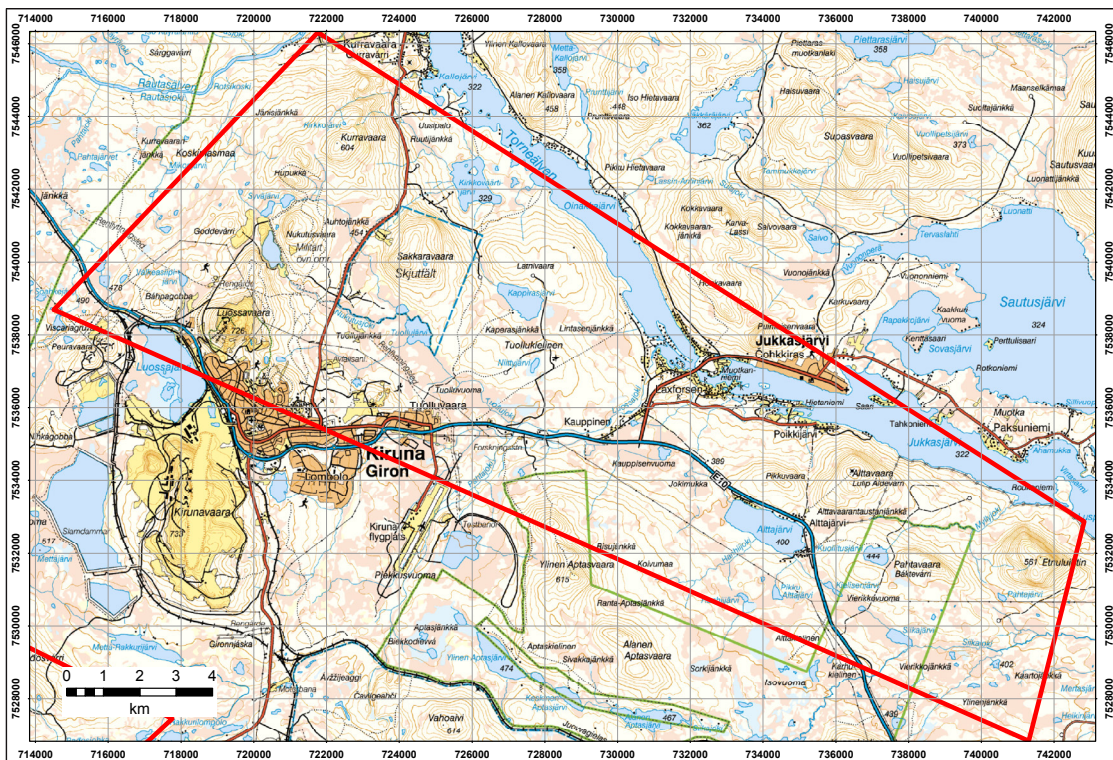
Background information Kiruna–Jukkasjärvi key area

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INTRODUCTION

The rocks of the northern Fennoscandian shield are the bearers of Europe's largest mineral resources. The region Norrbotten in northern Sweden is particularly important for it hosts large deposits of apatite iron ores, copper and gold. Despite its economical importance, the development of the Fennoscandian crust and subsequent geological history is still poorly understood. Reliable field studies are few and far between and age determinations are old, too few and not accurate enough to allow understanding, e.g., the stratigraphic or tectonic development of the Norrbotten area, which in turn is essential for potential further prospecting work.

The Barents project targets 15 small key areas distributed over Norrbotten county which are located at strategic points to resolve regional-scale issues by trying to answer key area-specific questions. The Barents project concentrates on the Paleoproterozoic cover rocks of the region, and in each area aims to understand and characterise the following general points:

- Stratigraphic organisation and development
 - volcanological
 - sedimentological
 - chemical characterisation
 - dating of metavolcanic rocks
 - dating of detrital zircons in sediments
 - structural investigation to understand stratigraphy
- Regional development of the bedrock
 - large fold structures and deformation zones
 - metamorphic parageneses
 - dating of metamorphic events
- Hydrothermal alterations
 - chemical and mineralogical characterisation of alterations
- Mineralisations
 - characterisation
 - description of occurrences

Table 1. SGU reports relevant to the Kiruna–Jukkasjärvi key area.

Code	Title	Year	Author	Location	Relevant content
Ba 56	Regional geological and geophysical maps of Northern Norrbotten (1:250.000)	2001	Bergman, Kübler, Martinsson	Northern Norrbotten	Regional geology, stratigraphy, deformation history
Rm 106	Geochemical classification of plutonic rocks in central and northern Sweden	2001	Ahl, Bergman, Bergström, Eliasson, Ripa, Weihed	Norrbotten	Regional geochemistry of plutonic rocks
Rm 92	The Iron Ore Inventory Programme 1963–1972 in Norrbotten County	1997	Frietsch	Norrbotten, Kiruna, Altavaara	Iron ore deposits sorted by type of mineralisation
C 812	The stratigraphy of the Precambrian rocks of the Kiruna district northern Sweden	1987	Forsell	Kiruna	Stratigraphy, relative age relations, tectonics
C 802	Petrochemistry of the iron ore-bearing metavolcanics in Norrbotten county northern Sweden	1984	Frietsch	Norrbotten, Kiruna	Petrology, geochemistry of metavolcanic rocks; tectonics
C 768	The Precambrian of Sweden	1979	Lundqvist	Sweden, Norrbotten	Regional geology, Summary
C 760	Petrology of the Kurravaara area northeast of Kiruna northern Sweden	1979	Frietsch	Kiruna, Kurravaara	Stratigraphy, petrology, Kurravaara conglomerate
C 709	The origin of the Kiruna iron ores	1975	Parák	Kiruna, Tuolluvaara	Petrology, Tectonics, detailed maps
C 700	The emplacement of the Kiruna iron ores and related deposits	1974	Geijer, Ödman	Kiruna	Detailed description of Kiruna ore bodies
C 629	Problemen kring malm-brottstyckena i Kirunas hängväggsporfyrrer	1968	Geijer	Kiruna	Ore inclusions in hanging wall of Kiruna iron ores
C 625	The relationship between magnetite and hematite in the iron ores of the Kiruna type and some other iron ore types	1967	Frietsch	Kiruna	Metasomatic reactions; discussion on when hematite and when magnetite is formed
C 592	Järnmalmsförekomster inom Norrbottens län	1963	Frietsch	Norrbotten, Kiruna	Regional geology; overview of non-producing iron ore occurrences
C 514	The Rektor ore body at Kiruna	1950	Geijer	Kiruna	Detailed description of Rektor ore body
C 367	The iron ores of the Kiruna type	1931b	Geijer	Kiirunavaara, Luossavaara, Tuolluvaara	Description and comparison of deposits
C 366	Berggrunden inom malmtrakten Kiruna–Gällivare–Pajala	1931a	Geijer	Kiruna–Gällivare–Pajala	Regional geology and stratigraphy
C 288	Recent developments at Kiruna	1919	Geijer	Kiruna	Kiirunavaara ore
C 175	Kiirunavaara och Luossavaara järnmalmsfält	1898	Lundbohm	Kiirunavaara, Luossavaara	Detailed description of ore deposits
C 127	Apatitförekomster i Norrbottens malmberg	1892	Lundbohm	Kiirunavaara, Luossavaara	Regional geology; description of ore deposits

Table 2. SGU map sheets relevant to the Kiruna–Jukkasjärvi key area.

Code	Title	Year	Author	Scale	Descriptions	GIS
Af 13	29K Vittangi NV	1975	Eriksson, Hallgren	1:50000	yes	yes
Af 2	29J Kiruna NO	1967	Offerberg	1:50000	yes	yes
Ba 56	Regional geological and geophysical maps of Northern Norrbotten (east of the Caledonian orogen)	2001	Bergman, Kübler, Martinsson	1:250000	yes	yes

Table 3. Prospecting reports relevant to the Kiruna–Jukkasjärvi key area.

Title	Author	Year	Company	Location	Type	Relevant content
Brap 200030, unpublished report The Paleoproterozoic sedimentary record of northernmost Norrbotten, Sweden	Kumpulainen	2000	SGU	Northern Norrbotten	Stratigraphy	Descriptions and columns of stratigraphic units; detailed section of Kurravaara conglomerate
Mink 95119 Greenstone and porphyry hosted ore deposits in northern Norrbotten	Martinsson	1995	NUTEK	Northern Norrbotten	Stratigraphy, petrography, geochemistry	All
Mink 95118 Greenstone and porphyry hosted ore deposits in northern Norrbotten	Martinsson et al.	1994	NUTEK	Northern Norrbotten	Stratigraphy, petrography, geochemistry	All
Mink 0394 Geofysiska Undersökningar inom Kiruna Statsgruvefält. Bilagor.	Edberg	1994?	SGU	Kiruna	Detailed geophysical mapping	Detailed geophysical maps, geological cross sections through Lappmalmen; map displaying faults
Brap 200030, unpublished report The Paleoproterozoic sedimentary record of northernmost Norrbotten, Sweden	Kumpulainen	2000	SGU	Northern Norrbotten	Stratigraphy	Descriptions and columns of stratigraphic units; detailed section of Kurravaara conglomerate
Mink 95119 Greenstone and porphyry hosted ore deposits in northern Norrbotten	Martinsson	1995	NUTEK	Northern Norrbotten	Stratigraphy, petrography, geochemistry	All
Mink 95118 Greenstone and porphyry hosted ore deposits in northern Norrbotten	Martinsson et al.	1994	NUTEK	Northern Norrbotten	Stratigraphy, petrography, geochemistry	All
Mink 0394 Geofysiska Undersökningar inom Kiruna Statsgruvefält. Bilagor.	Edberg	1994?	SGU	Kiruna	Detailed geophysical mapping	Detailed geophysical maps, geological cross sections through Lappmalmen; map displaying faults

Table 4. Scientific publications relevant to the Kiruna–Jukkasjärvi key area.

Title	Author	Year	Journal	Relevance
Hydrothermal fluid evolution and metal transport in the Kiruna District, Sweden: Contrasting metal behaviour in aqueous and aqueous–carbonic brines	Smith et al.	2013	Geochim., Cosmochim. Acta, v. 102, 89–112	Chemical composition and minimum PT-conditions during trapping of fluid inclusions in veins crosscutting ore deposits at Kiirunavaara, Luossovaara, Nuktus, Henry
Multidisciplinary study of the hanging wall of the Kiirunavaara iron ore deposit, northern Sweden	Jensen et al.	2012	Geophysics, v. 77, no. 6, B269–B285	See title; geophysical study
A correlation of AMS and rock quality in crystalline and sedimentary rocks in the Kiirunavaara hanging wall, Sweden	Jensen and Elming	2012	J. Appl. Geophys., v. 86, 54–69	Simplified geol. overview map Kiruna area; used AMS to derive texture of rocks; AMS contour maps
Metallogenic areas of Sweden	Hallberg et al.	2012	Geol. Surv. Finland, Special Paper 53, 139–206, (edited by Eilu)	Concise summary of metallogenic areas; p. 191–194 address Kiruna area (A. Hallberg)
The sources and evolution of mineralising fluids in iron oxide–copper–gold systems, Norrbotten, Sweden: Constraints from Br/Cl ratios and stable Cl isotopes of fluid inclusion leachates	Gleeson and Smith	2009	Geochim. Cosmochim. Acta, v. 73, 5658–5672	Addresses derivation of Cl in apatite ores and greenstones in Kiruna area vs. Nautanen DZ
In situ U–Pb and trace element analysis of accessory minerals in the Kiruna district, Norrbotten, Sweden: New Constraints on the timing and origin of mineralization	Smith et al.	2009	J. Petr., v. 50, no. 11, 2063–2094	Geochronology of samples from Luossavaara, Kiirunavaara, and Rakkurijärvi
Metallic mineral deposits in the Nordic countries	Weihed et al.	2008	Episodes, v. 31, no. 1, 125–132	List of major ore deposits of Norden;
The Geology of the Rakkurijärvi Cu–(Au) Prospect, Norrbotten: A New Iron Oxide–Copper–Gold Deposit in Northern Sweden	Smith et al.	2007	Econ. Geol., v. 102, 393–414	Geochemistry; description of newly discovered IOCG-deposit south of Kiruna; their Fig. 4: paragenesis of the deposit incl. alterations
In situ LA-ICP-MS U–Pb dating of metavolcanics of Norrbotten, Sweden: Records of extended geological histories in complex titanite grains	Storey et al.	2007	Chem. Geol., v. 240, 163–181	REE analysis and U–Pb dating of zoned titanite in Porphyry group; samples from Kiirunavaara, Luossavaara, Pahtohavare
Geology and metallogeny of the Northern Norrbotten Fe–Cu–Au province	Martinson	2004	Society of economic geologists, Guidebook series, Volume 33, p 131–148	Review on regional geology, stratigraphy, mineralizations and tectonics
Precambrian geodynamics and ore formation: The Fennoscandian Shield	Weihed et al.	2005	Ore geology reviews, Volume 27, p 273–322	Review on geodynamic of Fennoscandian. Cartoons on deformation history and depositional environments.
Tectonic setting and metallogeny of the Kiruna Greenstones	Martinson	1997	PhD-thesis, LTU. ISSN: 1402–1544	Regional geology and stratigraphy (mostly on Viscaria and Pahtohavare)
Rare earth elements in apatite and magnetite in Kiruna-type iron ores and some other iron ore types	Frietsch & Perdahl	1995	Ore Geol. Rev., v. 9, 489–510	See title; REE plots for Kiruna iron ores and other iron ores in Barents region; REE content and pattern shows that apatite iron ores are hydrothermal-exhalative and were fed by same source

Table 4. Continued.

Title	Author	Year	Journal	Relevance
Paleoproterozoic intraplating exposed by resultant gravity overturn near Kiruna, northern Sweden	Talbot & Koyi	1995	Prec. Res., v. 72, 199–225	Tectonic history of Kiruna area re-examined; theory of folded thrust sheets, however, compare to Bergman et al. (2001)!; their Fig. 7: indicating structure lines, mylonites, thrusts, and outline of plutones based on interpretation of geophysical data
Geochronology of the Kiruna iron ores and hydrothermal alterations	Romer et al.	1994	Econ. Geol., v. 89, 1249–1261	See title; contradict 1.5 Ga event by Cliff & Rickard (1992)
Petrochemical and petrological characteristics of 1.9 Ga old volcanics in northern Sweden	Perdahl & Frietsch	1993	Prec. Res., 64, 239–252	See title; reveal differences in tectonic settings of 1.9 Ga old volcanics; samples from Kiruna area
Isotope systematics of the Kiruna magnetite ores, Sweden: Part 2. Evidence for a secondary event 400 m.y. after ore formation	Cliff & Rickard	1992	Econ. Geol., v. 87, 1121–1129	Geochronology of Kiirunavaara magnetite–apatite ores
Early Proterozoic deformational history of the kiruna district, northern Sweden	Wright	1988	PhD-thesis, Univ. of Minnesota	Detailed structural geological investigation and strain analysis of the Kiruna area with detailed structural maps
Aspects of the Proterozoic Geochronology of Northern Sweden	Skiöld	1987	Prec. Res., v. 35, 161–167	Chronological review of Archaean cratonic and cratonic-margin areas (his table 1)
On the age of the Kiruna Greenstones, Northern Sweden	Skiöld	1986	Prec. Res., v. 32, 35–44	U–Pb dating of zircons; minimum age constraint on Kovogroup, north of Kiruna
Sm–Nd and U–Pb dating of early Proterozoic mafic–felsic volcanism in northernmost Sweden	Skiöld & Cliff	1984	Prec. Res., v. 26, 1–13	Geochronology in Kiruna Greenstone group
Early deformation in the Svecokarelian greenstone belt of the Kiruna iron district, Northern Sweden	Vollmer	1984	GFF, Vol. 106 p 109–118	Field study on the deformation patterns in the Kiruna district
The geological and tectonic evolution of the Precambrian of Northern Sweden – a case for basement reactivation?	Witschard	1984	Prec. Res., v.23, 273–315	Discussion of stratigraphy, regional geology, geochronology
Kiruna iron ores are not “Intrusive-Magmatic Ores of the Kiruna-type”	Parák	1975	Econ. Geol., v. 70, 1242–1258	Field observations, chemical analyses, stratigraphy, origin of ore breccias
Malm i Sverige 2 – Norra Sverige	Grip & Frietsch	1973	Almqvist & Wiksell Läromedel AB, Stockholm	All from p. 67 onwards; description of ore deposits around Kiruna; detailed maps; photographs
Igneous rocks and iron ores of Kiirunavaara, Luossavaara and Tuolluvaara	Geijer	1910	Econ. Geol., v. 5, 699–718	Description of ore deposits in Kiruna district; field and thin section photographs

Map databases

Bedrock maps

At a scale of 1:50 000, geological map sheets Af2 (29J Kiruna NO, Offerberg 1967) and Af13 (29K Vittangi NV, Eriksson & Hallgren 1975) contain the western and eastern parts of the key area respectively. These map compilations also contain geological profiles and 3D block sections through parts of the maps giving insight into the interpretation of the underground structures at the time of map creation.

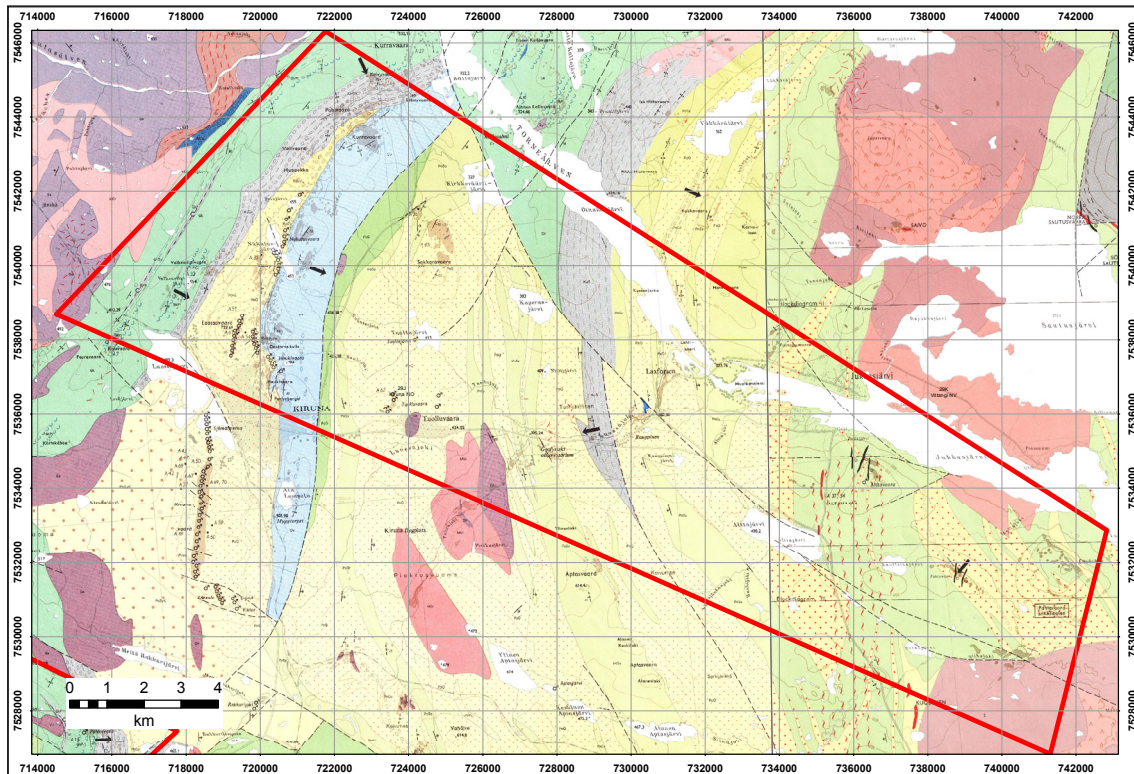


Fig. 1 Scanned geological maps at local scale. Note the abrupt terminations of faults as well as non-matching geological units along the so-called “map faults” between map sheets Af2 and Af13. For the map legend refer to printed version.

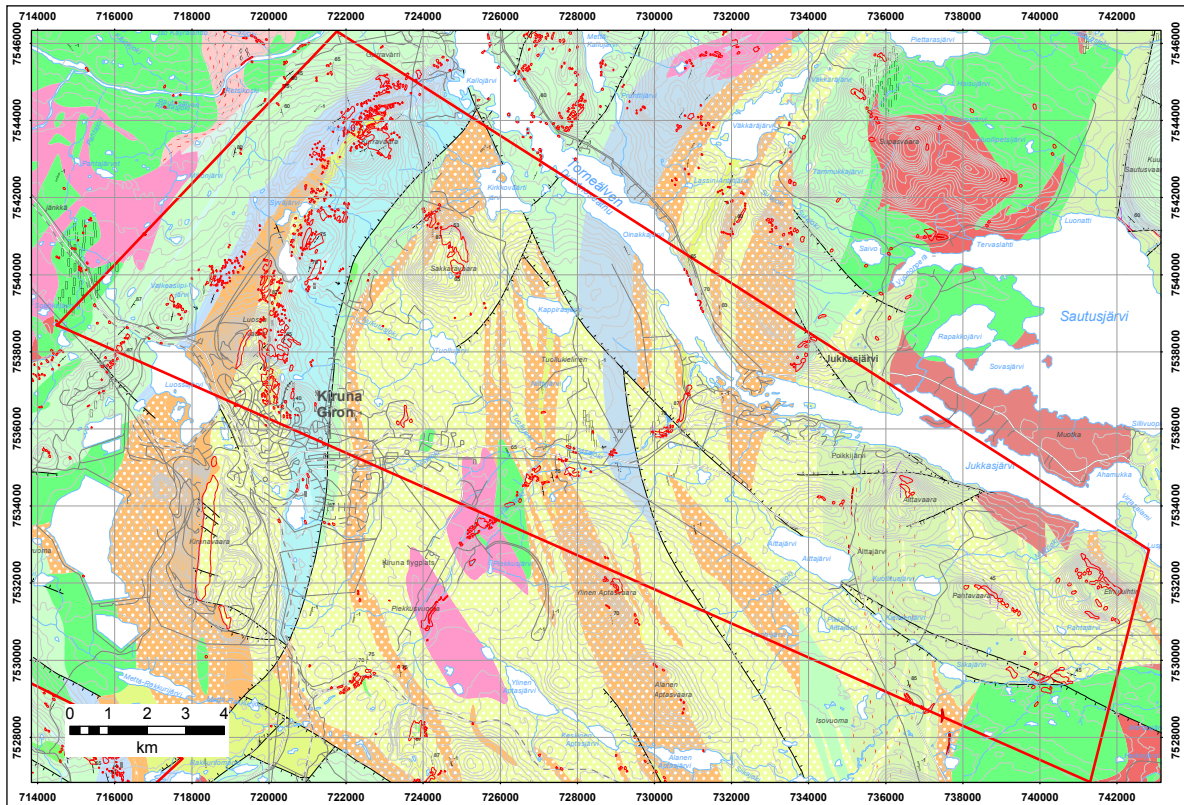
The above mentioned older map sheets have been scanned (Fig. 1) and used as a basis of the digitally available local (1:50,000) and regional (1:250,000) SGU vector-based map database (Fig. 2 & 3). No difference between the printed and the digitised versions of the maps could be found.

The map compilations by Offerberg (1967) and Eriksson & Hallgren (1975) also contain printed geomagnetic maps. The magnetic data was derived from airborne measurements that were recorded at a flight altitude of 30 m, a line spacing of 200 m, and a sampling interval of ~40 m.

In the late 1980's, T. Sjöstrand and H. Henkel summarised a digital map of the bedrock of northern Sweden called NBDig. This database contains simplified stratigraphic units, more detailed structural measurements, as well as an updated structural interpretation of the Kiruna area. NBDig also contains information on outcrop locations as well as on the rock types exposed in these outcrops.

Drill sites

SGU's database counts 78 drill holes that are completely within the Kiruna–Jukkasjärvi key area. Information about their location, references, and ownership is summarised in Fig. 4. Core logs in pdf format are available for the following drill sites: Altavaara, Sakkaravaara, Kallosalmi, Kirkkoväertijärvi, Kurravaara, Nukutusjärvi, Sakkaravaara, Viscaria. All of the drill cores are stored at the SGU archive in Malå and further information about them can be found in the SGU database.



Tolkade strukturer, lokal

- ↑ Uppåtstruktur
- ┆ Lagring, med gradtal för stupning
- ┆ Lagring, vertikal stupning
- ┆ Lagring, okänd stupning
- ┆ Foliation, med gradtal för stupning
- ┆ Foliation, vertikal stupning
- ┆ Foliation, okänd stupning
- ┆ Geofysiskt indikerad struktur, med gradtal för stupning
- ┆ Geofysiskt indikerad struktur, vertikal

Textur, lokal

- ↗ Ådrad (metatexit)

Strukturlinjer, lokal

- ┆ Spröd deformationszon, symbolerna ligger i det sänkta blocket; Spröd deformationszon (förkastning, spricka, sprickzon)

Berggrundslinjer, lokal

- Ultrabasisk, basisk och intermediär intrusivbergart (gabbro, diorit, diabas m.m.)
- Sur vulkanisk bergart (ryolit, dacit m.m.)
- Ultrabasisk, basisk och intermediär vulkanisk bergart (basalt, andesit m.m.)
- Kvarter-fältpatrik sedimentär bergart (sandsten, grävacka m.m.)
- Glimmerrik omvandlad bergart (fyllit, skiffer, paragneis m.m.)

Berggrundspunkter, lokal

- Porfyrisk
- (bergart x), <50 m bred gång
- Lins eller inlagring
- ◇ Xenolit, kantig

Berggrundsytor, lokal (överbeteckningar)

- Porfyrisk eller ögonförande

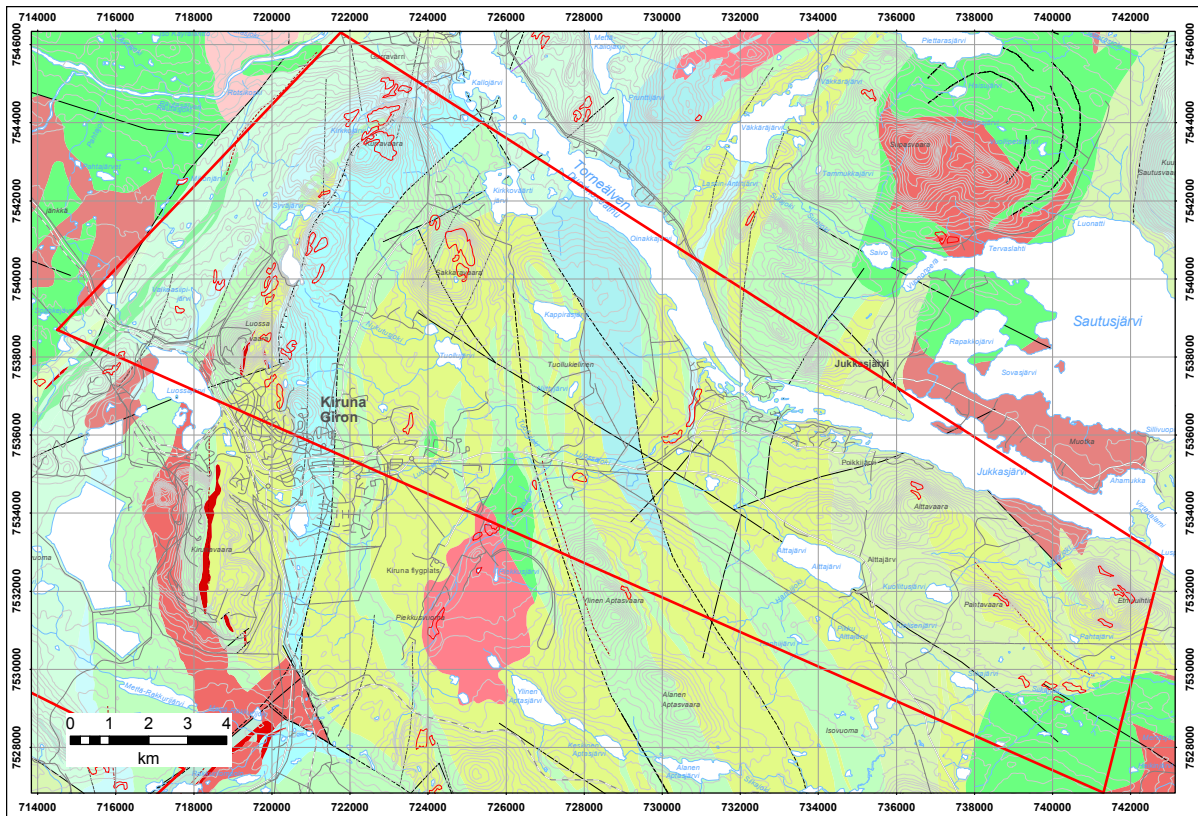
Berggrundsytor, lokal

- Vulkanisk bergart; Svekokarelska orogenen, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år

- Ryolit; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år
- Dacit-ryolit; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år
- Traktytoid-ryolit; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år
- Basalt-andesit; Svekokarelska orogenen, metamorf ytbergart 2,30-2,05 miljarder år
- Basalt-andesit; Svekokarelska orogenen, metamorf ytbergart 2,05-1,96 miljarder år
- Basalt-andesit; Svekokarelska orogenen, metamorf ytbergart 2,40-1,96 miljarder år
- Basalt-andesit; Svekokarelska orogenen, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år
- Basalt-andesit; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år
- Granit; Svekokarelska orogenen, metamorf arkeisk bergart >2,50 miljarder år
- Granit; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år
- Granit; Svekokarelska orogenen, intrusivbergart (GP), ställvis metamorf, 1,87-1,74 miljarder år
- Syenitoid-granit; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år
- Gabbroid-dioritoid; Svekokarelska orogenen, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år
- Gabbroid-dioritoid; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år
- Sedimentär bergart; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år
- Konglomerat; Svekokarelska orogenen, metamorf ytbergart 2,40-1,96 miljarder år
- Konglomerat; Svekokarelska orogenen, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år
- Konglomerat; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år
- Kvarterarenit; Svekokarelska orogenen, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år

- Kalksten; Svekokarelska orogenen, metamorf ytbergart 2,40-1,96 miljarder år
- Fyllit; Svekokarelska orogenen, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år
- Glimmerskiffer; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år
- Grafitisk skiffer; Svekokarelska orogenen, metamorf ytbergart 2,40-1,96 miljarder år
- Järmineralisering; Svekokarelska orogenen, metamorf ytbergart 2,40-1,96 miljarder år
- Järmineralisering; Svekokarelska orogenen, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år

Fig. 2 Local bedrock map (1:50,000) of the Kiruna–Jukkasjärvi area. The digitised vector-based maps are stored in SGU's databases.



Strukturlinjer, regional

- Geofysiskt tolkad magmatisk bandning
- Spröd deformationszon (förkastning, spricka, sprickzon)
- Plastisk skjuvzon
- Plastisk skjuvzon, symbolerna ligger i det sänkta blocket
- Strukturell formlinje, plastisk skjuvdeformation; Strukturell formlinje, plastisk deformation
- Strukturell formlinje, lagring

Berggrundslinjer, regional

- Ultrabasisk, basisk och intermediär intrusivbergart (gabbro, diorit, diabas m.m.)
- Glimmerrik omvandlad bergart (fyllit, skiffer, paragnejs m.m.)

Berggrundsytor, regional

- Dacit-ryolit; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år
- Basalt-andesit; Svekokarelska orogenen, metamorf ytbergart 2,40-2,30 miljarder år

- Basalt-andesit; Svekokarelska orogenen, metamorf ytbergart 2,30-2,05 miljarder år
- Basalt-andesit; Svekokarelska orogenen, metamorf ytbergart 2,05-1,96 miljarder år
- Basalt-andesit; Svekokarelska orogenen, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år
- Basalt-andesit; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år
- Granit; Svekokarelska orogenen, metamorf arkeisk bergart >2,50 miljarder år
- Granit; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år
- Granit; Svekokarelska orogenen, intrusivbergart (GP), ställvis metamorf, och migmatit 1,82-1,74 miljarder år
- Syenitoid-granit; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år
- Gabbroid-dioritoid; Svekokarelska orogenen, metamorf ytbergart 2,40-1,96 miljarder år
- Gabbroid-dioritoid; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år

- Ultrabasisk intrusivbergart; Svekokarelska orogenen, metamorf ytbergart 2,40-1,96 miljarder år
- Sedimentär bergart; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,87-1,84 miljarder år
- Konglomerat; Svekokarelska orogenen, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år
- Konglomerat; Svekokarelska orogenen, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,87-1,84 miljarder år
- Arenit; Svekokarelska orogenen, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år
- Vacka; Svekokarelska orogenen, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år
- Skiffer; Svekokarelska orogenen, metamorf ytbergart 2,40-1,96 miljarder år
- Järnmineralisering; Svekokarelska orogenen, metamorf ytbergart 2,40-1,96 miljarder år
- Järnmineralisering; Svekokarelska orogenen, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år

Fig. 3 Regional bedrock map (1:250,000) of the Kiruna–Jukkasjärvi area. The digitised vector-based maps are stored in SGU's databases. Note that in comparison to the local bedrock map some faults seem to be missing, and some lithologies have been combined into one unit.

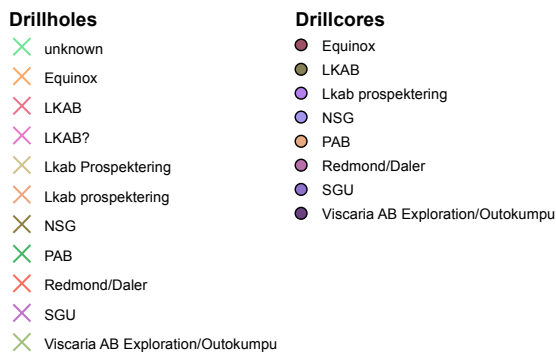
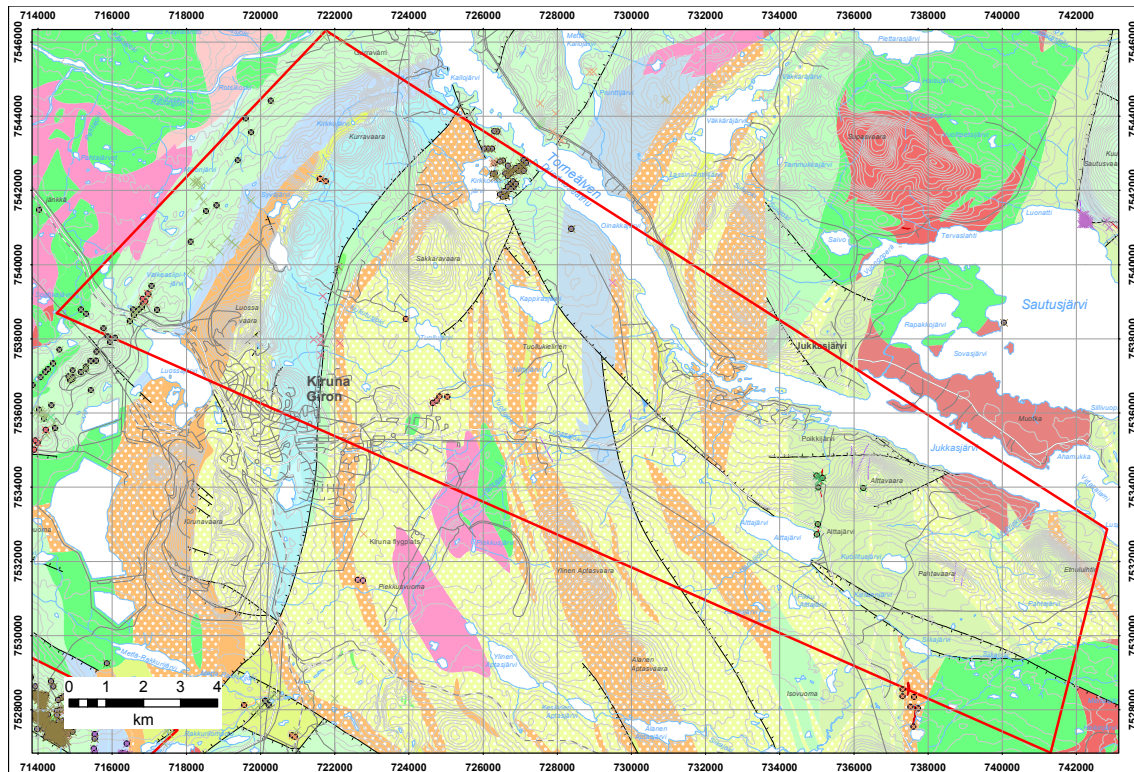
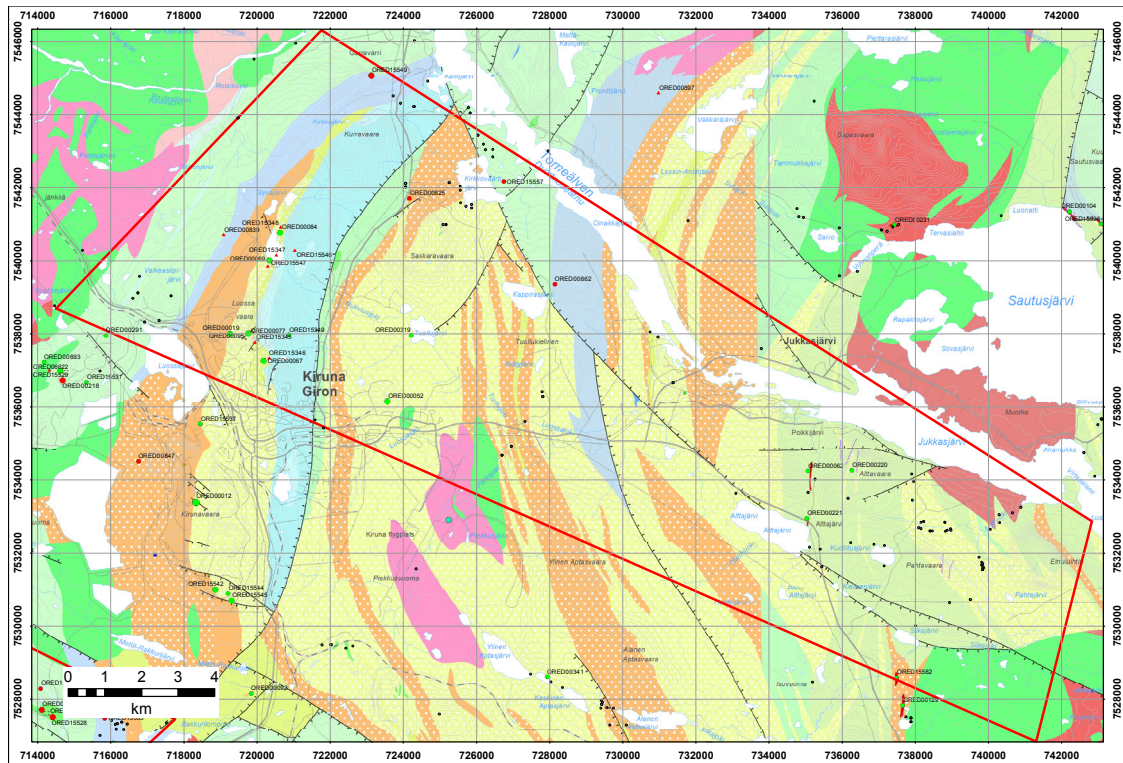


Fig. 4 Drill sites in the Kiruna area coloured after prospecting company. All of these cores are available at the SGU Malå archive.

Mineralisations and alterations

Several economically valuable mineral deposits exist within the key area, contributing to the development of the Kiruna mining district. Iron ore and sulfide deposits hosting Cu are the most common mineral deposits in the area (Fig. 5). The most important deposits are the apatite iron ores in Kiirunavaara, Luossavaara, the so-called Per Geijer ores, and the Viscaria Cu deposit. Information on the distribution and types of mineral deposits can be found in SGU's databases. Mineralised boulders are also present (Fig. 5).

Host rock and mineral alteration are wide-spread in the KJKA (Fig. 6). Most alterations occur along tectonic lineaments such as faults and wider deformation zones. In the KJKA, scapolitisation is the most common alteration, followed by epidote alteration and albitisation.



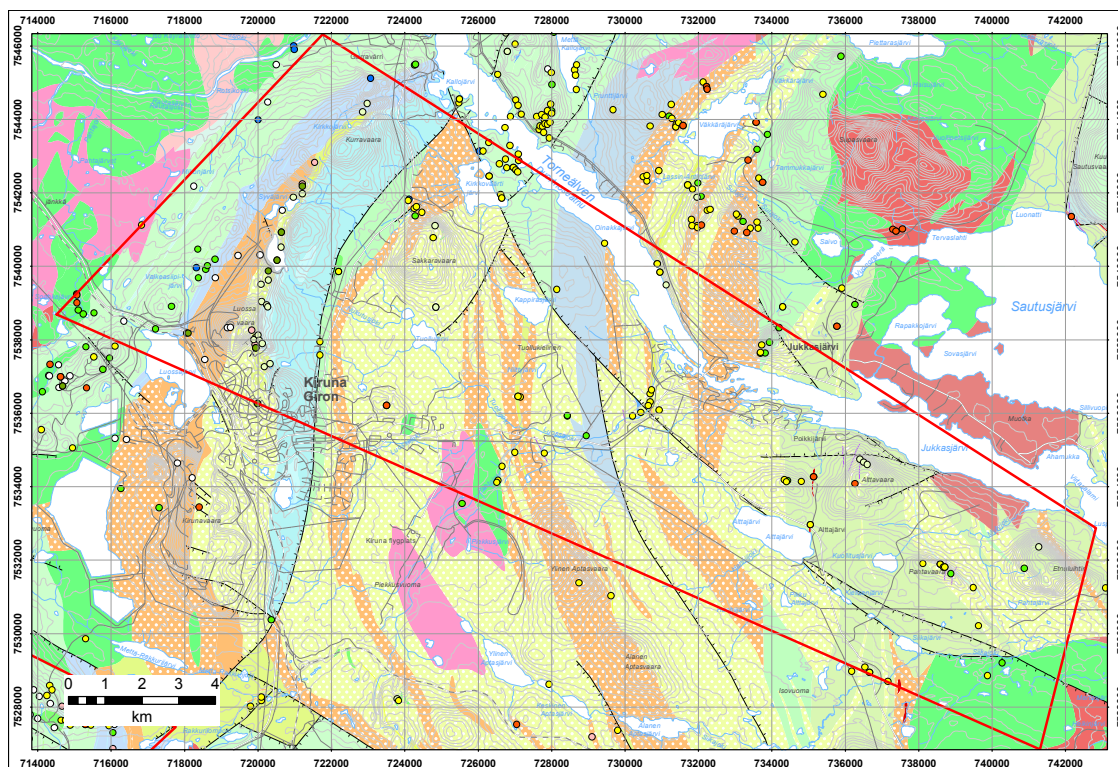
- | Mineralised boulders | | Mineral Resources | |
|----------------------|---|--|--|
| ● unknown | □ Average point for mining field or production area | ● Iron mine, in operation | |
| ● Bornite | | ● Iron mine, abandoned | |
| ● Chalcocite | | ● Iron ore, trial pit or prospect | |
| ● Chalcopyrite | | ● Sulphide mine, abandoned | |
| ● Chromite | | ● Sulphide mineralization, trial pit or prospect | |
| ● Gold | | ▲ Quarry, industrial mineral, abandoned | |
| ● Graphite | | Naturgrustäkter (produktion i ton per år) | |
| ● Hematite | | ● > 100 000 | |
| ● Magnetite | | | |
| ● Malakite | | | |
| ● Molybdenite | | | |
| ● Pyrite | | | |
| ● Pyrrhotite | | | |
| ● Total sulphide | | | |

Fig. 5 Kiruna–Jukkasjärvi key area showing distribution and type of mineral deposits north of the Kiirunavaara apatite iron ore deposit. Mineralised boulders are also shown.

Litho- and till geochemistry

Twenty-four litho-geochemical analyses are available within the key area. Most of the whole-rock litho-geochemical data is derived from the map description to map sheets Af 1–4 (Kiruna) by Offerberg (1967) as well as Af 13–16 (Vittangi) by Eriksson and Hallgren (1975). Eight samples of 1.9 Ga year old volcanic rocks in the area were analysed by Per Dahl & Frietsch (1993). Information on the type and distribution of samples taken for litho-geochemical analyses are found in the geochemical database (Fig. 7).

Additionally, information on till geochemistry is available. New till samples have been taken by SGU within the Kiruna–Jukkasjärvi key area during the summer of 2012. The results have been published by Ladenberger et al. (2012).



Mineral alterations

- TOURMALINE
- SKARN
- SCAPOLITE
- WHITE MICA
- CARBONATE
- ALKALI FELDSPAR
- EPIDOTE
- ALBITE

Fig. 6 Kiruna–Jukkasjärvi key area showing distribution and type of mineral alterations north of the Kiirunavaara apatite iron ore deposit.

Geochronology

Within the Kiruna–Jukkasjärvi area only three sites have been sampled for age dating. However, there are several other dates available for samples from rocks around the Kiirunavaara deposit in the SW of the key area (Fig. 8). Nonetheless, collecting rock samples suitable for dating of (a) protolith ages and (b) metamorphic or deformational ages is a high priority in this area.

Table 5 refers to the analysis ID numbers in Fig. 8, since different types of ages have been retrieved at the same location.

Topographic maps

Topographic and infrastructural maps from Lantmäteriet are available in the SGU database in both raster- and vector formats (Fig. 9).

- Mineral alterations**
- TOURMALINE
 - SKARN
 - SCAPOLITE
 - WHITE MICA
 - CARBONATE
 - ALKALI FELDSPAR
 - EPIDOTE
 - ALBITE

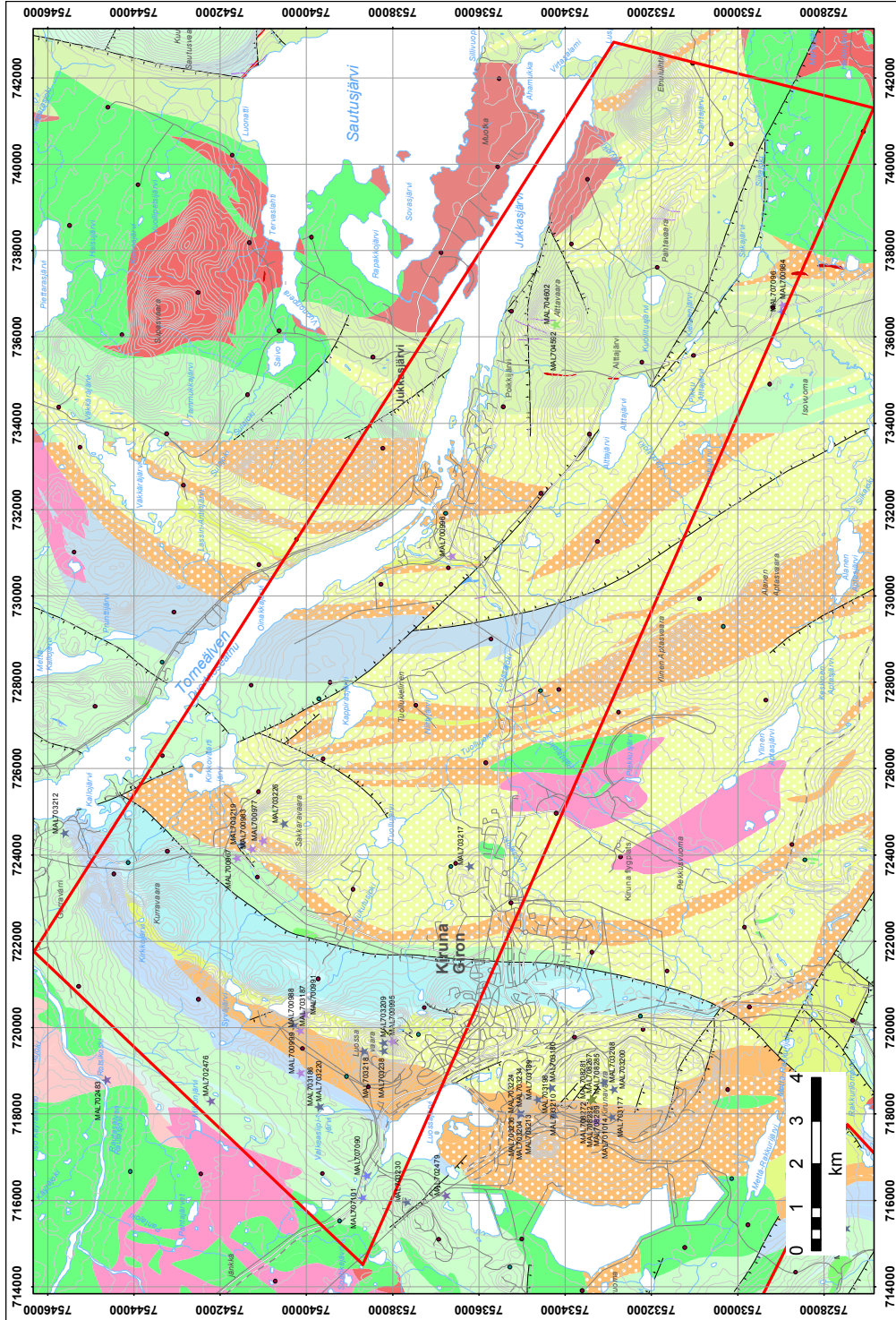


Fig. 7 Sample locations for both litho geochemistry (stars) and till geochemistry (filled circles). The colours indicate the source from which the geochemical data was derived.

Table 5. Reference ID of dated samples (cf. Fig. 8). STDEV: standard deviation.

ID	Lithology	Age	STDEV	Isotope system	Material	Publ. Year	Reference	Locality	Stratigraphic unit
154	Syenite	2000	0	K-Ar	not known	1970	Magnusson N.H.: Atlas över Sverige 5-6, AB Kartografiska Institutet, Esselte AB, Stockholm	Kiruna	
1767	Trachyandesite	1870	24	U-Pb	Titanite	2007	Storey, Smith and Jeffries: Chemical Geology 240, 163-181	Lous-savaara	Porphyrite Group
1387	Basaltic andesitic tuff	2687	3	U-Pb	Zircon	1998	Skiöld and Page: Nordic Geological Winter Meeting, Aarhus, abstract 273	Viscaria	Kovo Group
1768	Trachyandesite	2058	47	U-Pb	Titanite	2007	Storey, Smith and Jeffries: Chemical Geology 240, 163-181	Lous-savaara	Porphyrite Group
716	Basalt	1932	45	Sm-Nd	Multi mineral	1984	Skiöld and Cliff: Precambrian Research, 26, 1-13	Viscaria	Kiruna greenstone
1349	Granophyric dyke	1880	3	U-Pb	Zircon	1990	Cliff, Rickard and Blake: Economic Geology, 85, 1770-1776	Kiruna	
1052	Syenite	1876	9	U-Pb	Titanite	1994	Romer, Martinsson and Perdahl: Abs. vol. 21:a NGV, 16	Kiruna	
1383	Greenstone	2702	7	U-Pb	Zircon	1993	Skiöld 1993, PIM report	Kiruna	
986	Granophyre dyke	1890	90	Sm-Nd	not known	1990	Cliff, Rickard and Blake: Economic Geology 85, 1770-1776	Kiruna	
323	Apatite-iron ore	486	95	Fission track	Apatite	1978	Koark, Märk, Pahl, Purtscheller and Vartanien: Bull Geol Inst Uppsala 7, 103-108	Tuolluvaara	
746	Rhyolite	1882	24	U-Pb	Zircon	1987	Welin E: Precambrian Research 35, 95-113	Kiruna	
1400	Granophyric dyke	1890	90	U-Pb	Whole rock	1990	Cliff, Rickard and Blake: Economic Geology, 85, 1770-1776	Kiruna	Magnetite-apatite ore body
1088	Magnetite-titanite vein	1888	6	U-Pb	Titanite	1994	Romer, Martinsson and Perdahl: Economic Geology 89, 1249-1261	Luos-savaara	
1384	Felsite	2020	0	U-Pb	Zircon	1993	Skiöld 1993, PIM report	Viscaria	
1089	Syenite	1876	9	U-Pb	Titanite	1994	Romer, Martinsson and Perdahl: Economic Geology 89, 1249-1261	Kiruna	
163	Porphyry	1570	65	Rb-Sr	Whole rock	1980	Welin: Geologiska Föreningens i Stockholm Förhandlingar (GFF) 101, 209-320	Kiruna	
985	Granophyre dyke	1880	35	U-Pb	Zircon	1990	Cliff, Rickard and Blake: Economic Geology 85, 1770-1776	Kiruna	
1389	Intermediate volcanite	1881	5	U-Pb	Zircon	1994	Skiöld 1994, PIM report	Kiruna	

Geochronology

Fission track

K-Ar

Rb-Sr

Sm-Nd

U-Pb

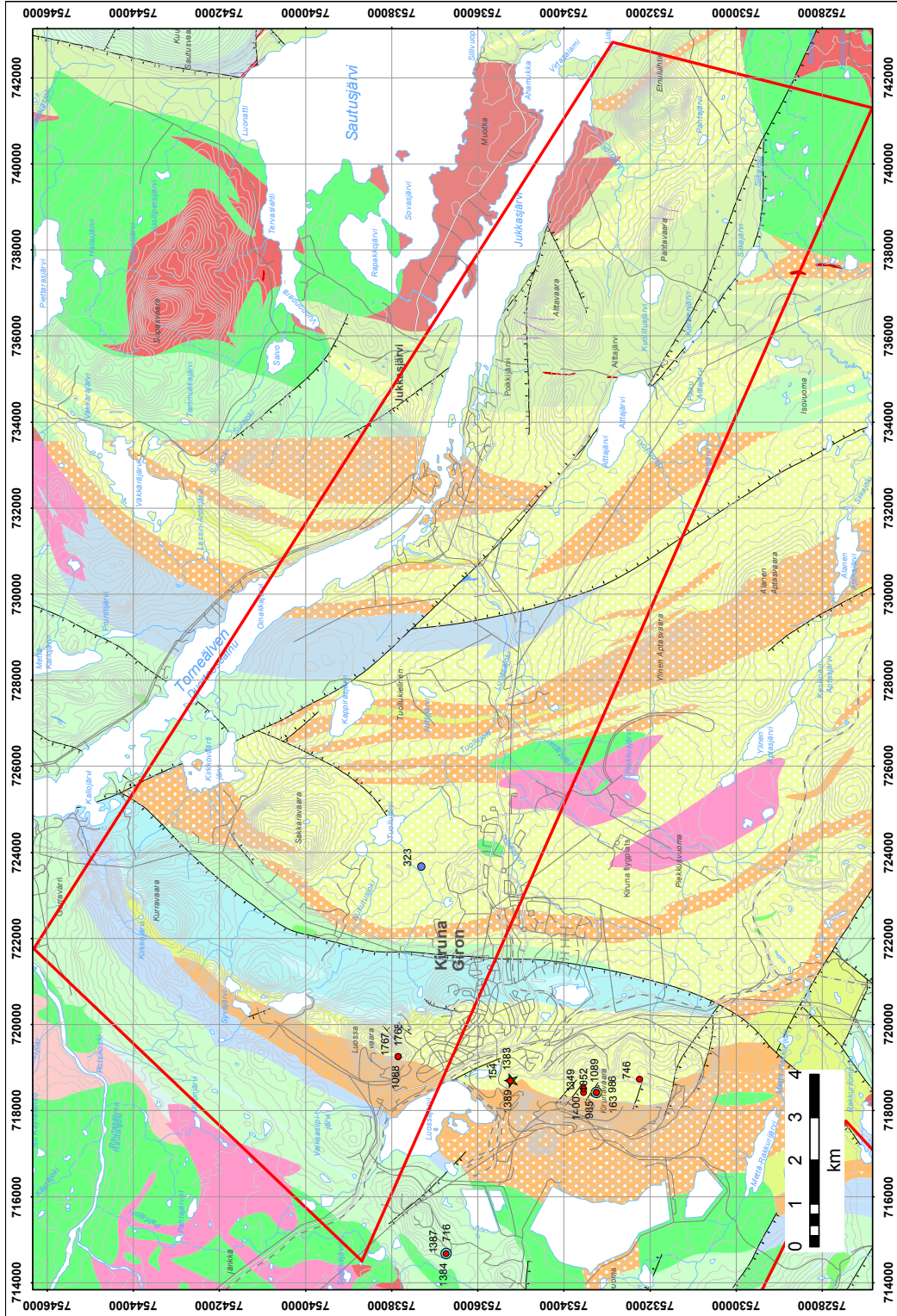


Fig. 8 Locations and ID numbers (cf. table 5) of available isotopic age data.



- | | | |
|---|---|--|
| ○ Vändplan | — Enskild bättre bilväg | — Militärt skjutfält och skjutområde |
| ✈ Trafikflygplats | — Enskild bilväg/gata, större - Matarväg | — Militärt skjutfält, sammanfallande med annan gräns |
| ✈ Elljusspår | — Enskild bilväg | — Militärt övningsområde |
| □ Station | — Enskild sämre bilväg | ■ Större byggnad |
| × Mast | — Enskild uppfartsväg | □ Flyg bana |
| · Hus, storleksklass 1 | — Allmän väg > 7m, klass 1, riksväg | — Gångstig |
| · Hus, storleksklass 2 | — Allmän väg > 7m, klass 1, ej riksväg | — Vattendrag 1 |
| ✚ Kyrka | — Allmän väg 5-7m, klass 2, riksväg | — Vattendrag 2 |
| ✚ Kyrka, mindre | — Allmän väg 5-7m, klass 2, ej riksväg | — Vattendrag 3 |
| ⚡ Vindkraftverk | — Allmän väg < 5m, klass 3, ej riksväg | — Vattendrag under markyta |
| × Torn | — På- och Avfartsväg, riksväg | — Strandlinje |
| ⊕ Begravningsplats | — Gata | — Bebyggelsebegränsning |
| ⊕ Idrottsplats | — Enskild bättre bilväg | ■ Vatten |
| ↑ Skjutbana | — Enskild bilväg/gata, större - Matarväg | ■ Vatten |
| ♨ Bad, tempererat | — Enskild bilväg | ■ Bebyggelseområde |
| ⌂ Golfbana | — Enskild sämre bilväg | ■ Skog |
| ⌂ Vandrarhem | — Enskild uppfartsväg | ■ Öppen mark |
| ⌂ Sjukhus | — Allmän väg > 7m, klass 1, riksväg, underfart/tunnel | ■ Kalfjäll/fjällhed |
| ⌂ Biologiskt naturminne | — Allmän väg 5-7m, klass 2, riksväg, underfart/tunnel | ■ Fjällbjörskog |
| ⌂ Fornlämning | — Gata, underfart/tunnel | ■ Sankmark, svårframkomlig (blåmyr) |
| · Höjdpunkt | — Enskild bilväg, underfart/tunnel | ■ Sankmark, normal, skogklädd (brunmyr) |
| ⋯ Traktgräns | — Enskild sämre bilväg, underfart/tunnel | ■ Sankmark, normal, öppen (brunmyr) |
| — Höjdkurva | — Anläggningsområde, streckad linje | |
| — Kraftledning, region | — Anläggningsområde, heldragen linje | |
| — Kraftledning, fördelning | — Linbana | |
| — Järnväg med enkelspår, elektrifierad | — Viadukt | |
| — Järnväg med enkelspår, elektrifierad, i underfart | — Renstängsel | |
| — Allmän väg > 7m, klass 1, riksväg | — Dammyggnad, större, kantlinje | |
| — Allmän väg > 7m, klass 1, ej riksväg | — Rengärde | |
| — Allmän väg 5-7m, klass 2, riksväg | — Naturresevat | |
| — Allmän väg 5-7m, klass 2, ej riksväg | — Naturresevat, sammanfallande | |
| — Allmän väg < 5m, klass 3, ej riksväg | — Övriga resevat | |
| — På- och Avfartsväg, riksväg | — Övriga resevat, sammanfallande | |
| — Gata | — Militärt övningsområde, sammanfall. m. annan gräns | |

Fig. 9 Topographic and infrastructural map of the KJKA.

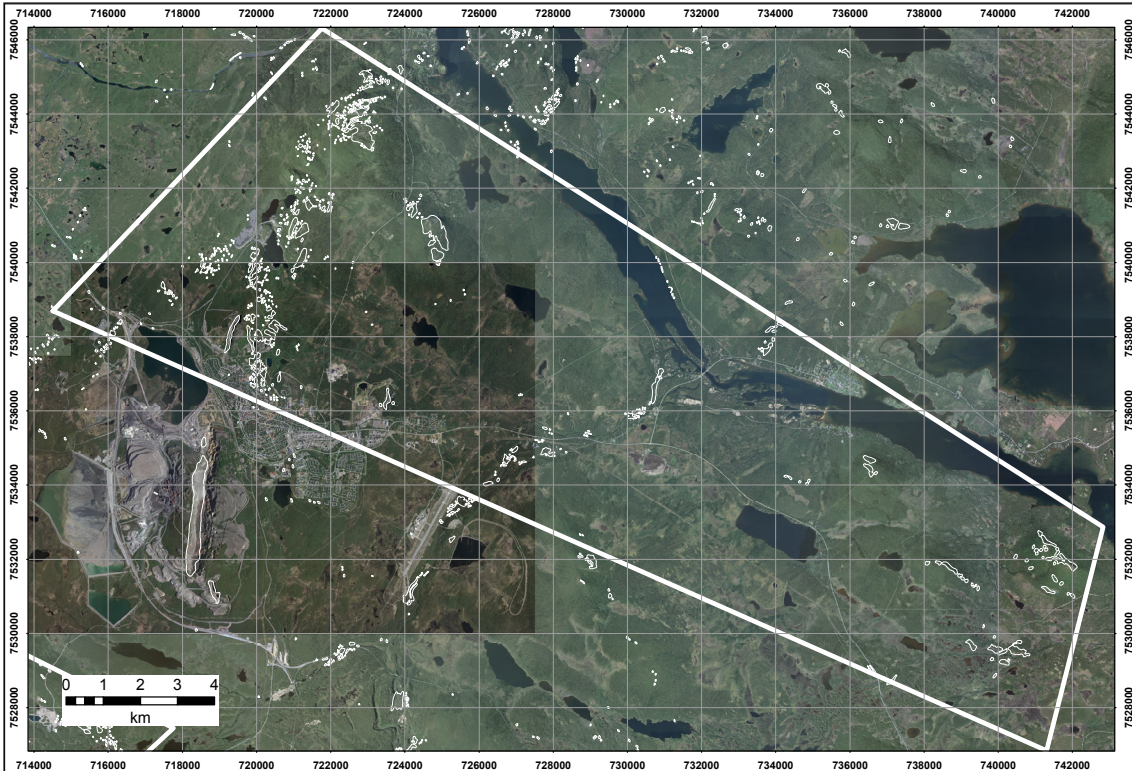


Fig. 10 Aerial photograph of the KJKA.

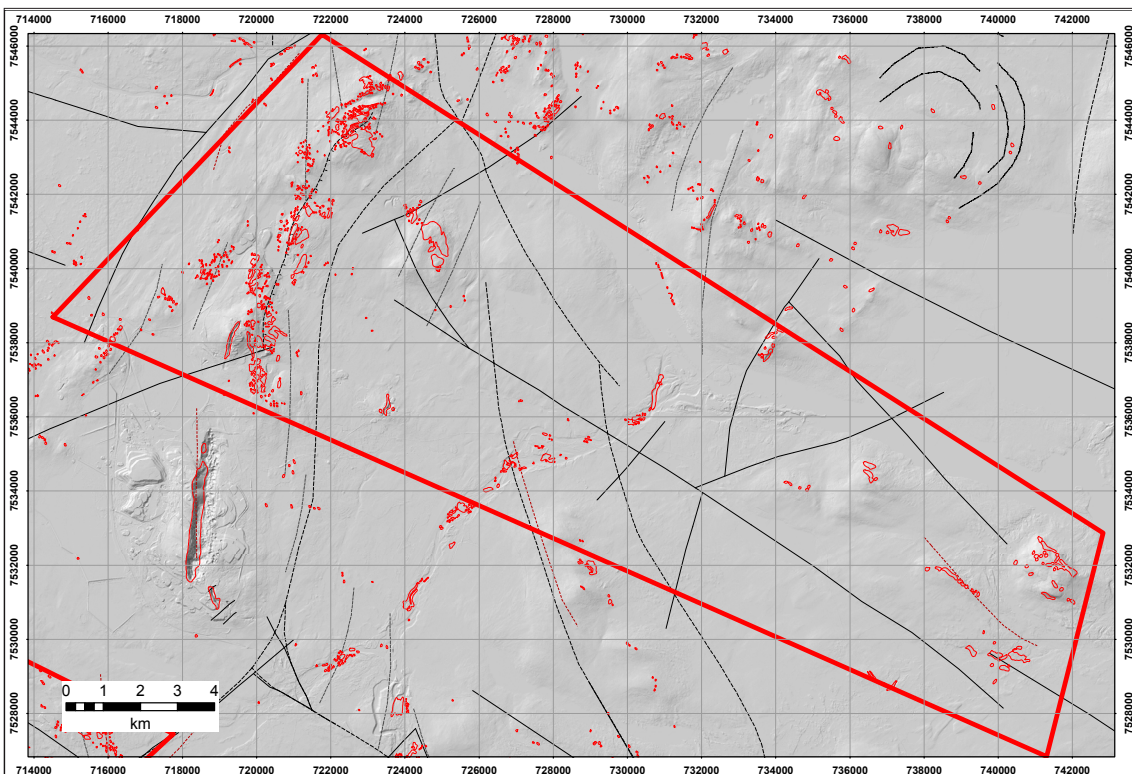


Fig. 11 Digital elevation model (DEM) overlain by major structural lines .

Aerial photographs

Aerial orthophotographs are available as digitised raster images in the SGU database. They can be viewed in natural colours (Fig. 10) as well as in infrared spectrum.

LiDAR data, Digital Elevation Model (DEM)

High resolution (2m × 2m) LiDAR data is available for the Kiruna–Jukkasjärvi area. Some linear structural features can be recognised in the digital elevation model (Fig. 11).

Outcrop situation and access

One of the challenges in this key area is the poor outcrop situation southeast of the Kiruna mining area. The soil map (Fig. 12) and the soil depth map (Fig. 13) show that the majority of the area is covered under Quaternary sediments including glacial deposits as well as peat. However, the infrastructural situation is good, due to the long mining history of the area.

Geophysical databases

Airborne data

Airborne geophysical measurements in the area were carried out by the Geological Survey of Sweden (SGU) during 1960–1964. The magnetic field was measured by SGU as a part of the iron inventory program. Loussavaara–Kiirunavaara AB (LKAB) collected airborne data during 1973 to 1985. LKAB measured the magnetic field, the electromagnetic field, both with VLF- and Slingram methods and gamma ray radiation. The survey direction was east–west. The VLF measurements collected by LKAB in the 1980's were made with two different transmitters, which means that the peaker and apparent resistivity maps can be transformed. (Pedersen et al, 1994). All airborne surveys in the area were made with a line separation of 200 m, a point distance of 40 m and a ground clearance of 30 m.

The magnetic anomaly map over the area is shown in Fig. 14. Four key areas, Harrijärvi, Vit-tangivaara, Kiruna–Jukkasjärvi and Saarijärvi, which will be studied in the Barents project are superimposed on the magnetic field. The most prominent magnetic anomaly in the area is caused by the Kiruna iron ores. Both iron and sulphide mineralisations, appear in areas with patterns of banded magnetic anomalies mostly caused by supracrustal rocks. The intrusive rocks appear mostly as circular, more homogenous patterns with lower magnetisation.

Electromagnetic (VLF- peaker and Slingram) data are shown in Figs. 15 and 16. Highly conductive horizons clearly appear in both VLF (Fig. 15) and slingram data (Fig. 16). Sedimentary rocks (black shales) can be identified in the Viscaria area, northwest of Kiruna and in the area northeast of Kurravaara. The VLF data contains more details than slingram data, for example in addition to the conductive horizons even brittle deformation zones can be identified using the VLF information. Resistivity and current density over the area can also be estimated from VLF data.

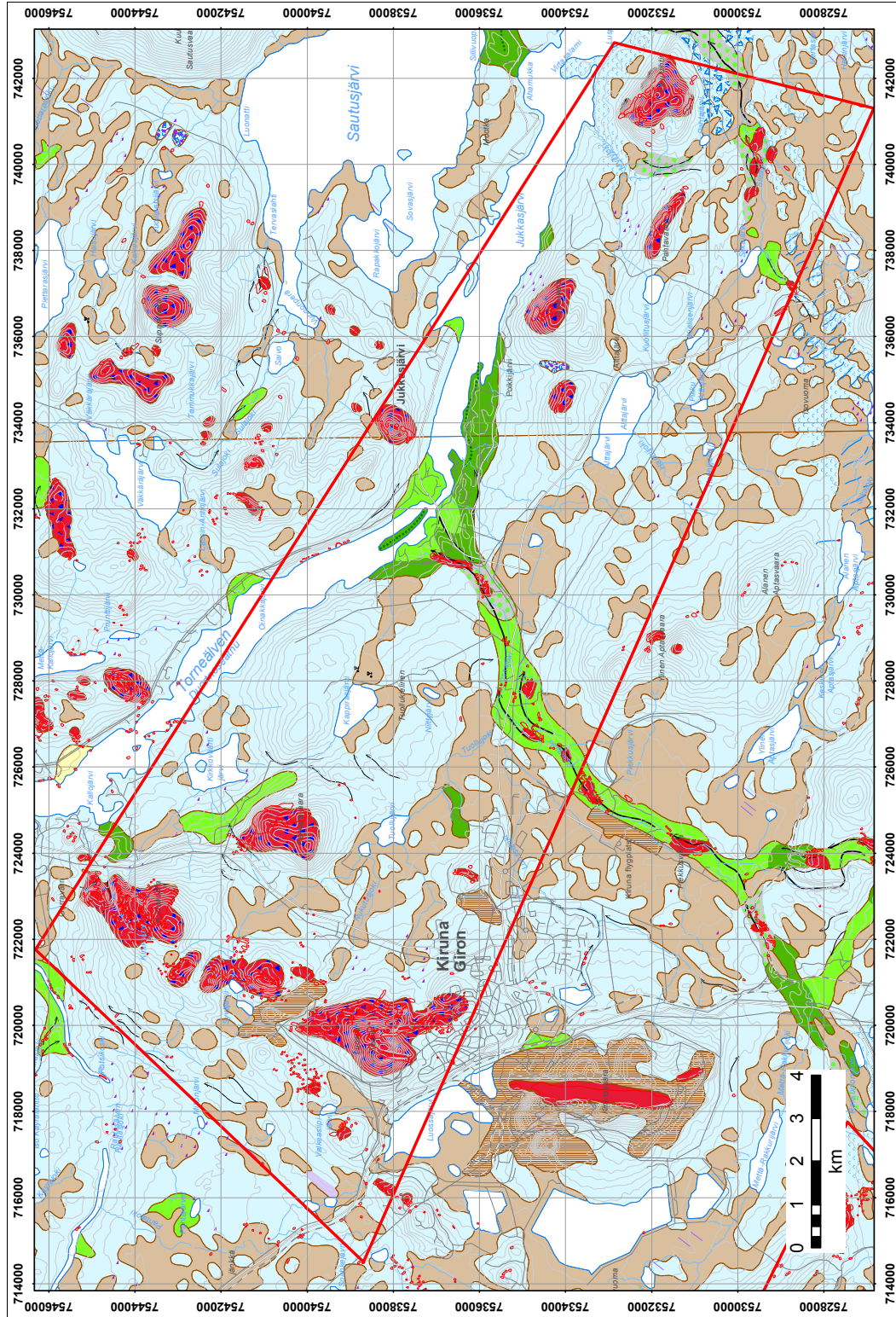


Fig. 12 Soil map of the Kiruna-Lukkasjärvi region.

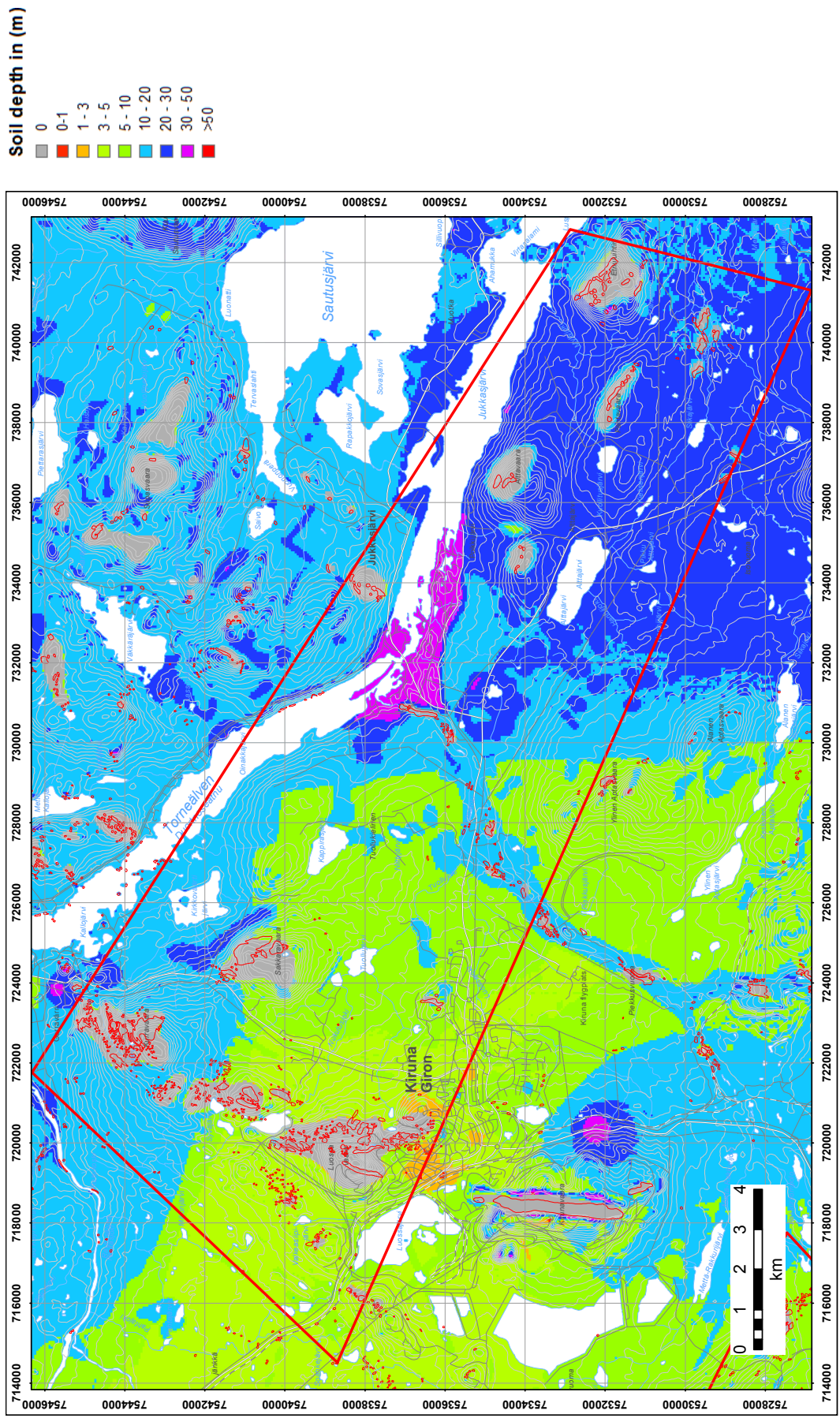


Fig. 13 Map of soil depth indicating where it is reasonable to search for outcropping bedrock.

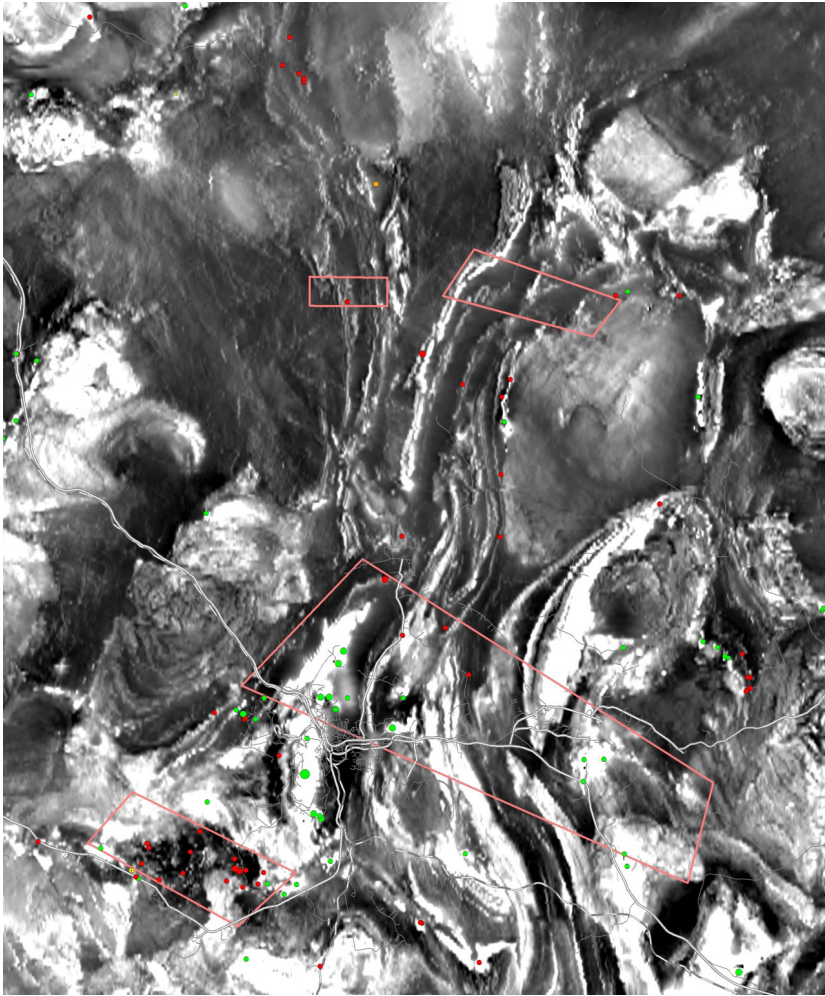


Fig. 14 Airborne magnetic map over the area. Green dots show iron ores and mineralisations, red dots show sulphide mineralisations. The red polygons show four of fifteen key areas to be studied in the Barents project.

Ground based data

Regional gravity measurements have been carried out during 1960 and 1989. The point separation for the measurements varies considerably in the area, a good regional coverage is available in the KJKA. Unfortunately the point density is very sparse in the northern part of the area (Fig. 17).

During the past 60 years, various geophysical ground measurements were made by different companies in the area. An overview of historical ground geophysical data stored at SGU is given in this report. Geophysical measurements of the magnetic-, and electromagnetic field with different methods and induced polarisation were carried out between 1963 and 1987. The data were collected with a line separation of 50 or 100 m and at a point distance of 10 or 20 m. In certain areas the measurements was done with a line separation of 40 m. Detailed gravity measurements were collected earlier by LKAB. Some of those measurements are still confidential. The distribution of the detailed gravity measurements are shown in Fig. 18 and ground magnetic and electromagnetic measurements in the area in Fig. 19.

However, there are several exploration permits in the area and new geophysical data with new methods added all the time. Companies with today permits can be found at SGU's webpage (www.sgu.se).

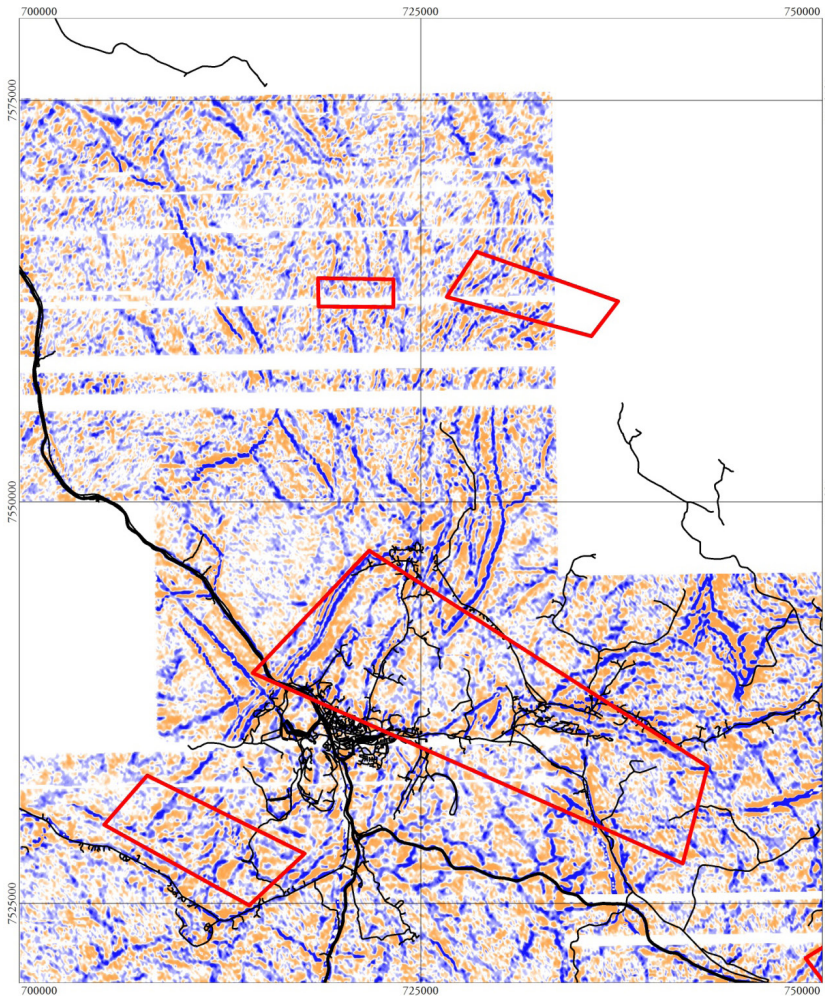


Fig. 15 Peaker VLF map over the area. Blue colour indicates conductive structures. The red polygons show four of fifteen key areas to be studied in the Barents project.

Examples of the magnetic and the electromagnetic (slingram) field measurements in the KJKA and north thereof are shown in Figs. 20 and 21. A fold structure can clearly be seen in both the magnetic and electromagnetic maps. The high magnetic anomalies, caused by volcanic rocks in the fold structure, do not coincide with the slingram anomalies caused by sedimentary rocks in the area (Fig. 22). A combination of the magnetic and the electromagnetic data results in a good overview of the spatial distribution of the highly magnetic volcanic rocks and highly conductive sedimentary rocks in the area.

Petrophysics

Petrophysical samples were collected in earlier projects, such as regional mapping activities and prospecting campaigns since the 1960's. Susceptibility, remanent magnetisation and density were measured. Compilation of the petrophysical data over northern Norrbotten was done for example during the Nordkalott Projekt by Granar et al. (1986), and by Bergman et al. (2001). The sample sites can be seen in Fig. 23 together with the magnetic anomaly map and the four key areas.

There are 1706 petrophysical samples stored in the SGUs database in the area. The distribution of the susceptibility and density is shown in Fig 24.

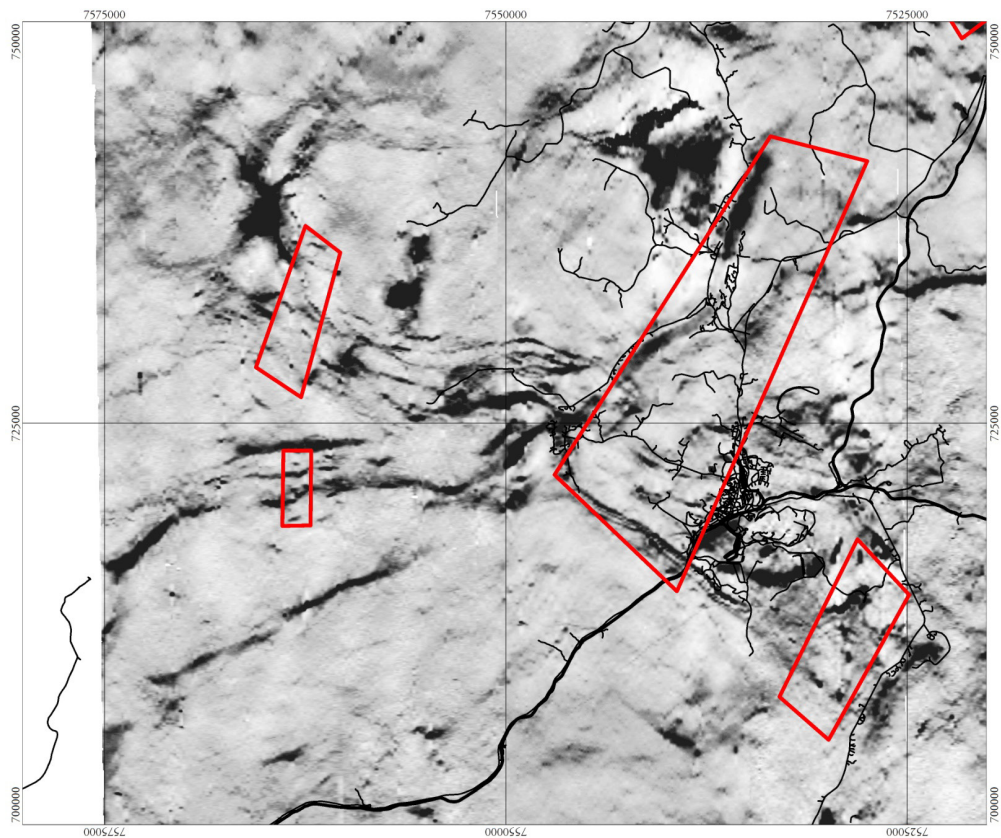


Fig. 16 Electromagnetic (slingram, imaginary part, 3720 Hz) map over the area. Black colour indicates conductive structures. The red polygons show four of fifteen key areas to be studied in the Barents project.

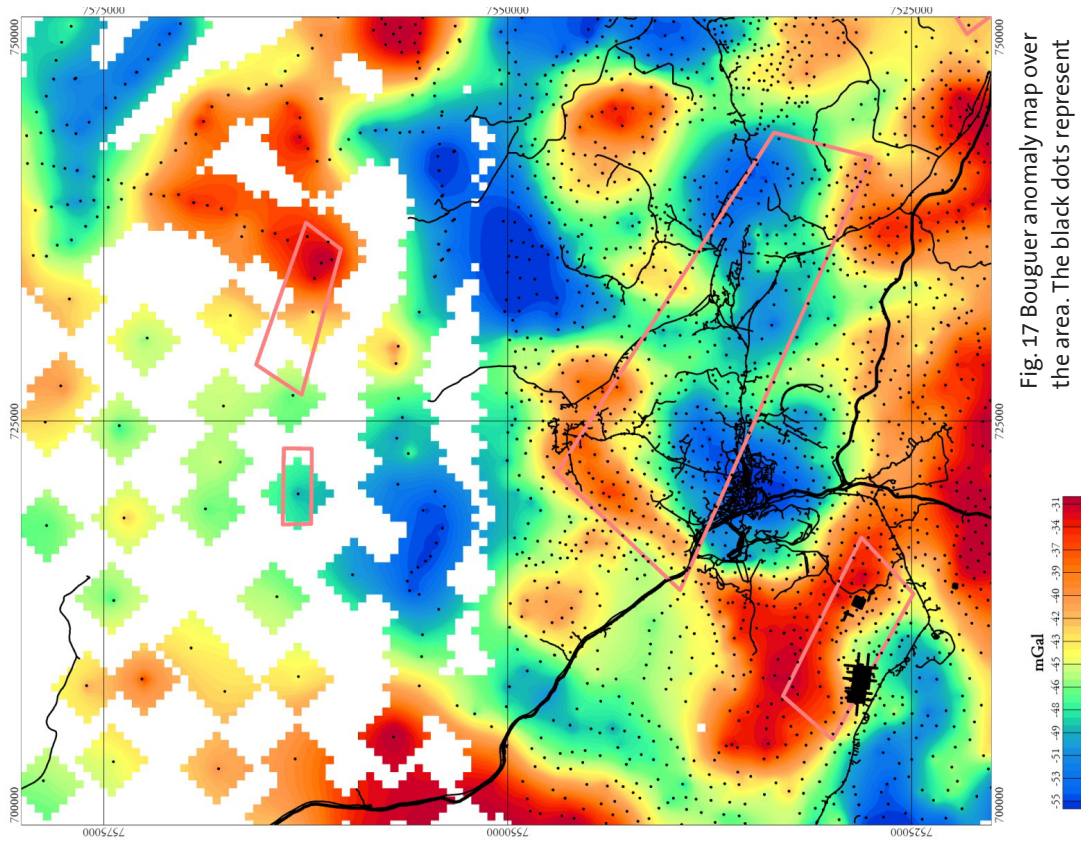


Fig. 17 Bouguer anomaly map over the area. The black dots represent gravity data points. The red polygons show four of fifteen key areas to be studied in the Barents project.

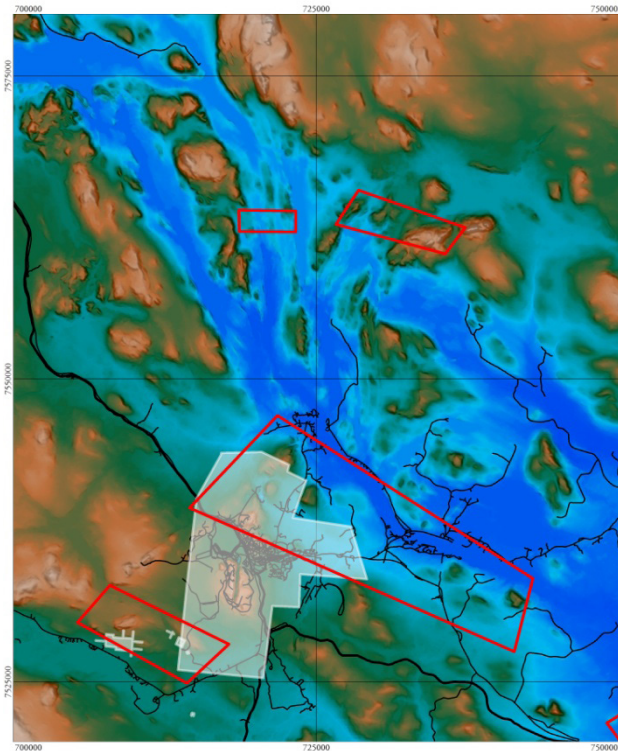


Fig. 18 White polygons show the detailed gravity measurements in the area superimposed on the topography map. Data are still confidential.

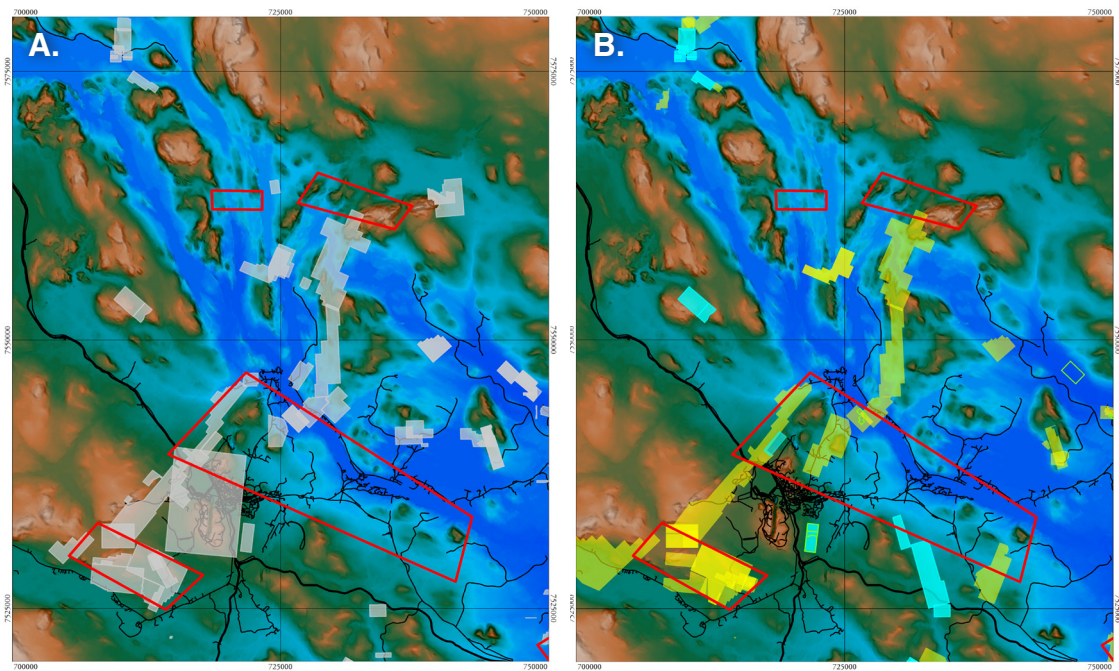


Fig. 19. A.) White polygons indicate ground magnetic surveys superimposed on the topography map. B.) Yellow polygons indicate slingram measurements. Blue polygons show the locations of VLF-measurements. Key areas in red.

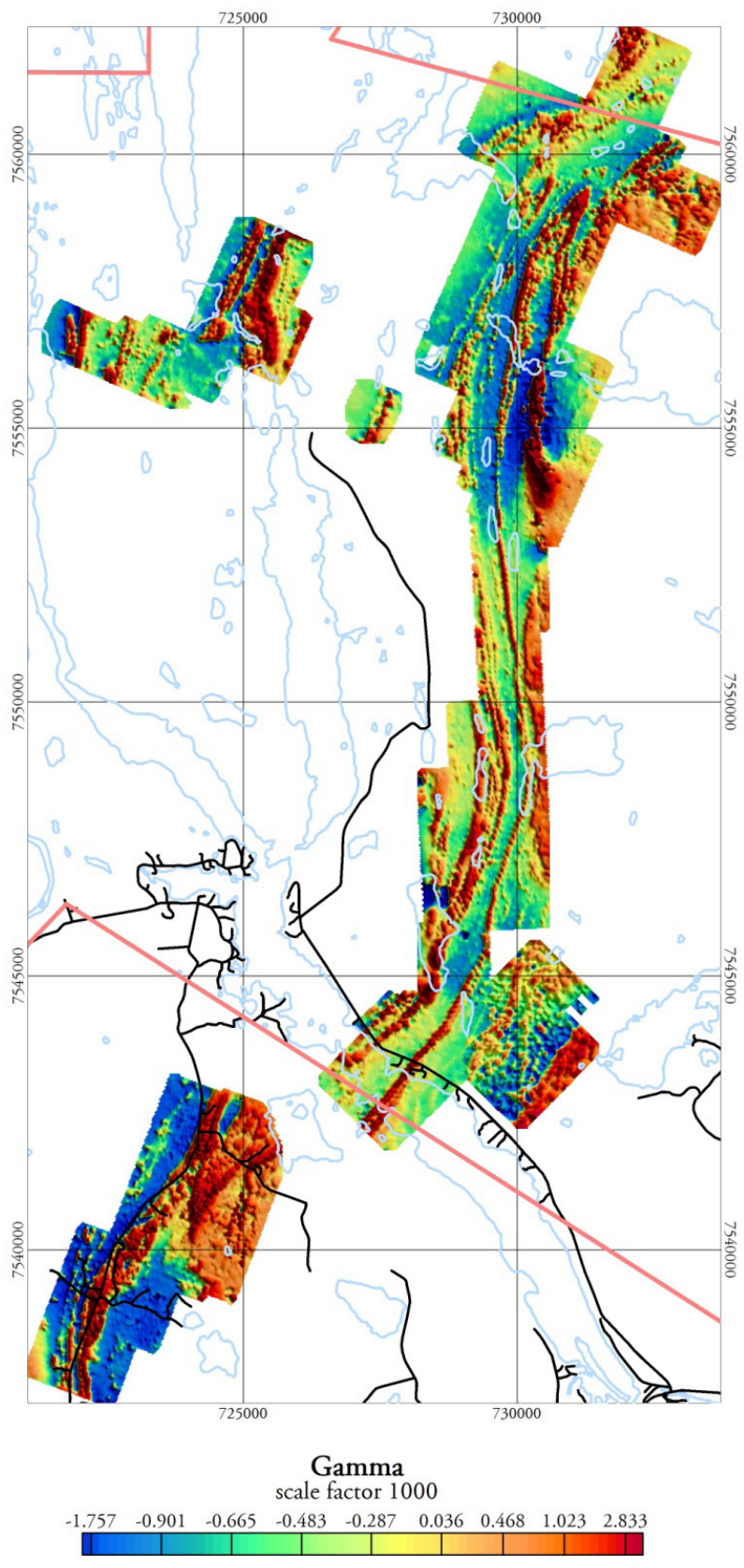


Fig 20. Ground magnetic measurements within and north of the KJKA. Parts of the key areas shown in light red colour.

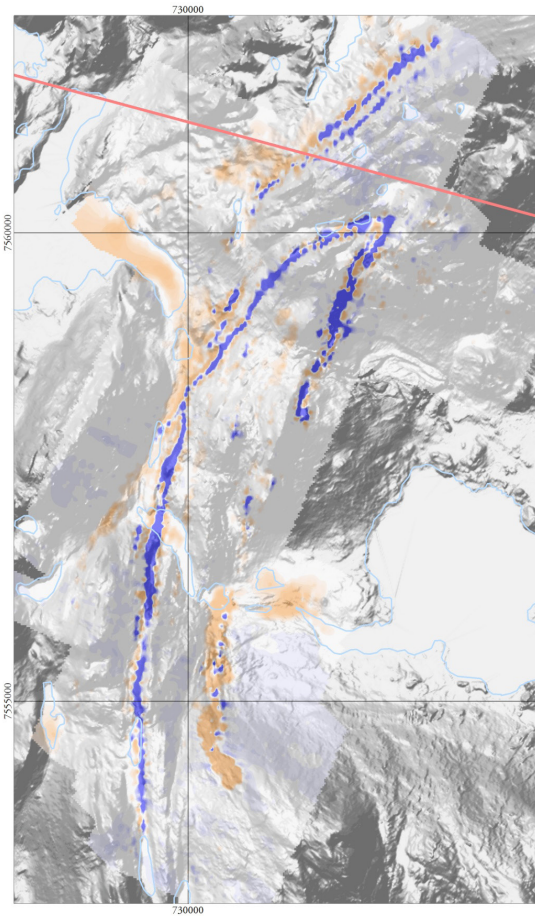


Fig. 21. Ground electromagnetic (slingram) measurements superimposed on topography data from Lantmäteriet, over parts of the Vakkola area north of the KJKA. Blue colour shows electrically conductive layers.

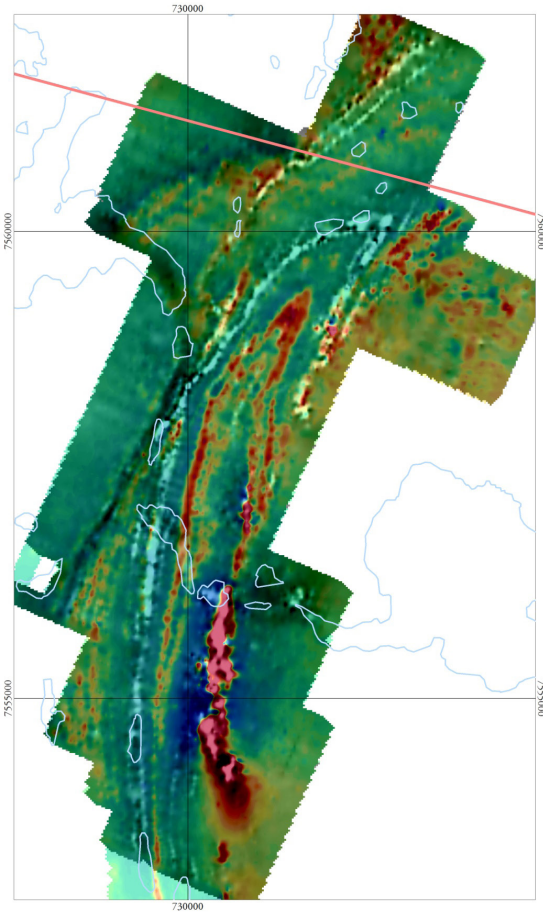


Fig. 22. Ground magnetic measurements in colour, superimposed ground on electromagnetic (slingram) measurements in grey. High magnetic anomalies in red, electrically conductive structures in white.

SUMMARY

Lithology and Stratigraphy of the supracrustal rocks in the KJKA

The stratigraphy of the Kiruna–Jukkasjärvi key area (Fig. 25) has been studied and discussed extensively (see previous tables). The following description of the stratigraphy and lithology is mainly based on Martinsson (2004), Bergman et al. (2001), Martinsson (1997), Offerberg (1967) and Eriksson & Hallgren (1975). The key area contains rocks from the Kovo group (KOG) in the very western corner, overlain by the Kiruna Greenstone Group (KGG) along the western area margin. The KGG is followed by rocks of the Kurravaara conglomerate (KCO) and stratigraphically equivalent Porphyrite group (PTG) occurring in the western and middle parts of the area. The KCO is overlain by the Kiirunavaara group (KIIG), which covers most of the key area to the east of Kiruna. A strip of sedimentary rocks belonging to the Hauki quartzite group (HQG) overlies the KIIG in the west. Fig. 26 shows the distribution of the various units in the Kiruna area.

Whilst they do not crop out directly in the KJKA, Archean basement rocks occur to the north of Kurravaara, and most probably continue southwards under the Paleoproterozoic

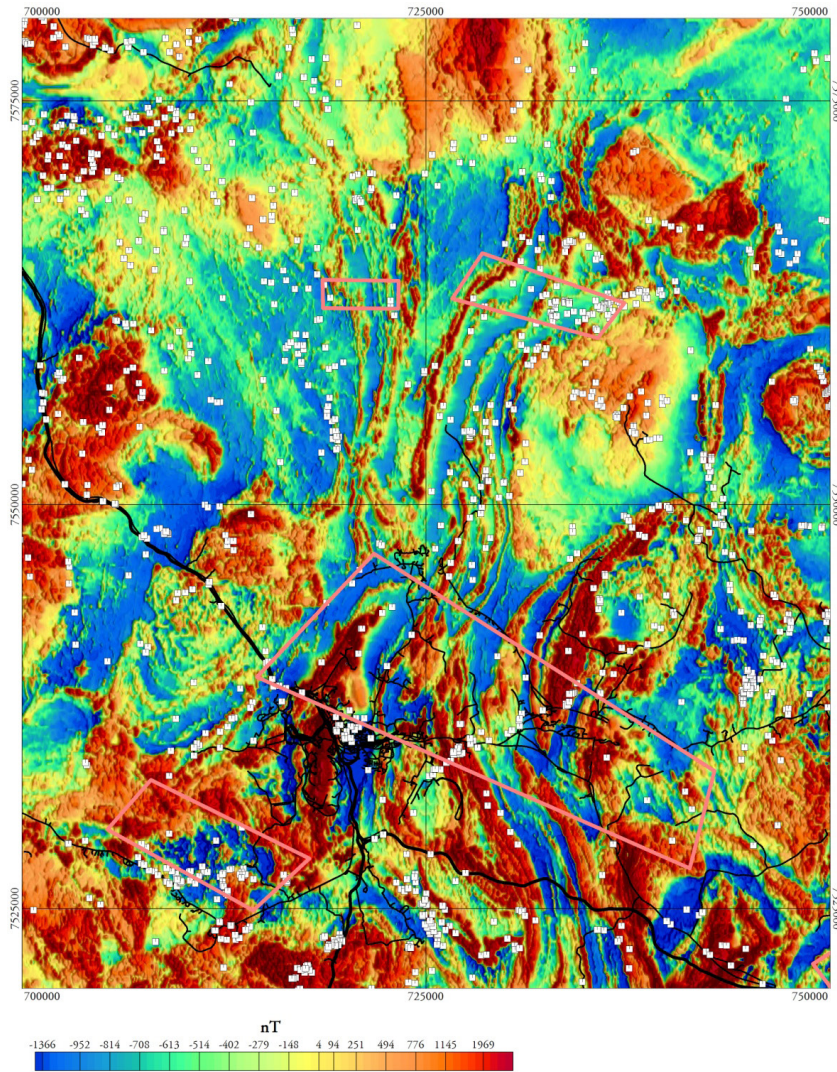


Fig. 23. Magnetic anomaly map over the area, reduced to the pole. White symbols show the petrophysical sample locations.

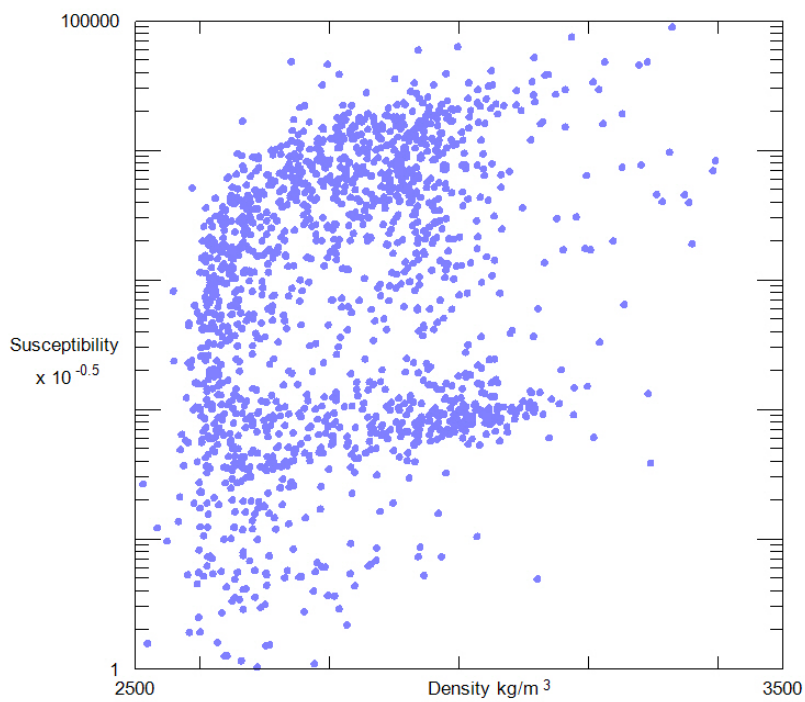


Fig. 24. Magnetic susceptibility (SI) vs. density in semi-logarithmic diagram. Total population.

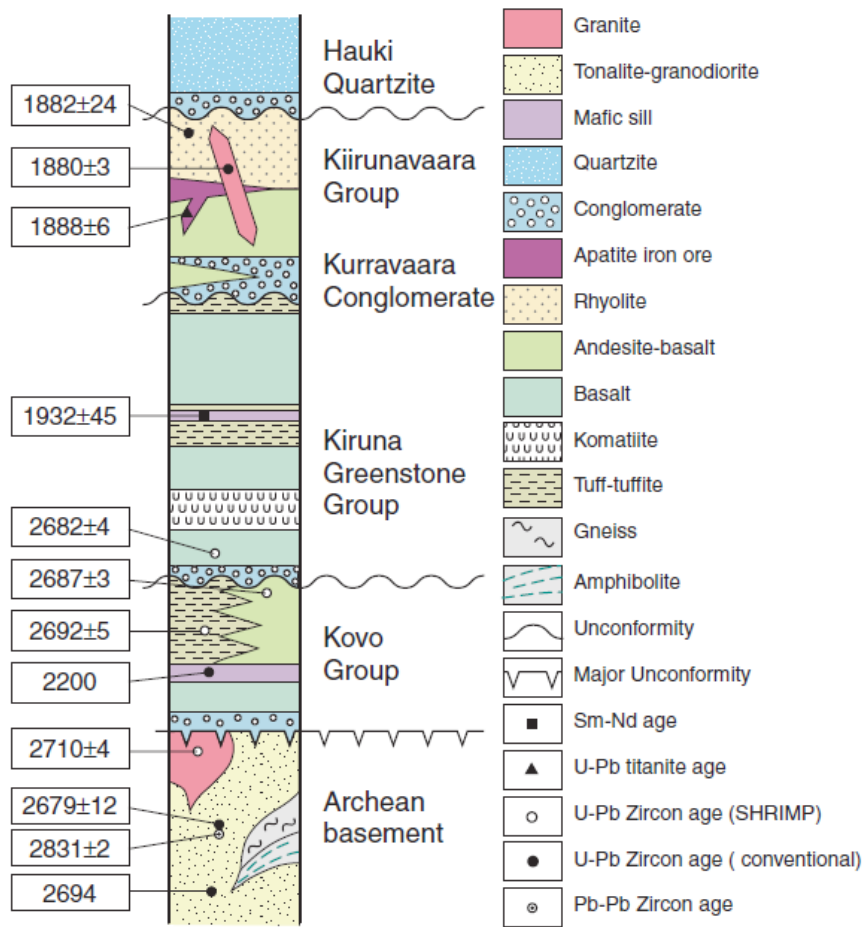


Fig. 25. Stratigraphy and geochronology of the Kiruna area, taken from Martinsson (2004). Chronological data from Skiöld (1979, 1986), Skiöld & Cliff (1984), Welin (1987), Cliff et al. (1990), Romer et al. (1994), Skiöld & Page (1998) and Martinsson et al. (1999).

supracrustal rocks that make up the key area. The basement rocks primarily consist of moderately foliated, tonalitic granodiorites, which have protolith ages of ~2.8 Ga (Welin et al. 1971, Skiöld 1979, and Martinsson et al. 1999). Other abundant rock types are biotite gneiss, reddish granite, and even metavolcanic rocks and quartzite. The distribution and ages of those varying lithologies are poorly constrained.

The Kovogroup (KOG) is exposed in the very western corner and outside of the KJKA. It consists of a basal conglomerate, tholeiitic lava, calcalkaline mafic to intermediate volcanic rocks and volcanoclastic sediments (Martinsson 1997). Kumpulainen (2000) suggests deposition of the KOG sediments in an alluvial fan along the coast line of a marine rift basin.

To the east, the Kovogroup is unconformably overlain by the Paleoproterozoic Kiruna greenstone group (KGG), which is described in detail in the Kiruna region by e.g. Martinsson (1997). The dominant rock types are mafic to ultramafic metavolcanic rocks. Martinsson (1997) divides the Kiruna greenstone group into six formations, primarily based on differences in their lithology and/or geochemistry. The formations as well as their main characteristics and depositional setting are listed in table 6. For a more detailed description refer to Martinsson (1997, 2004). The Viscaria formation hosts the economically important strati-

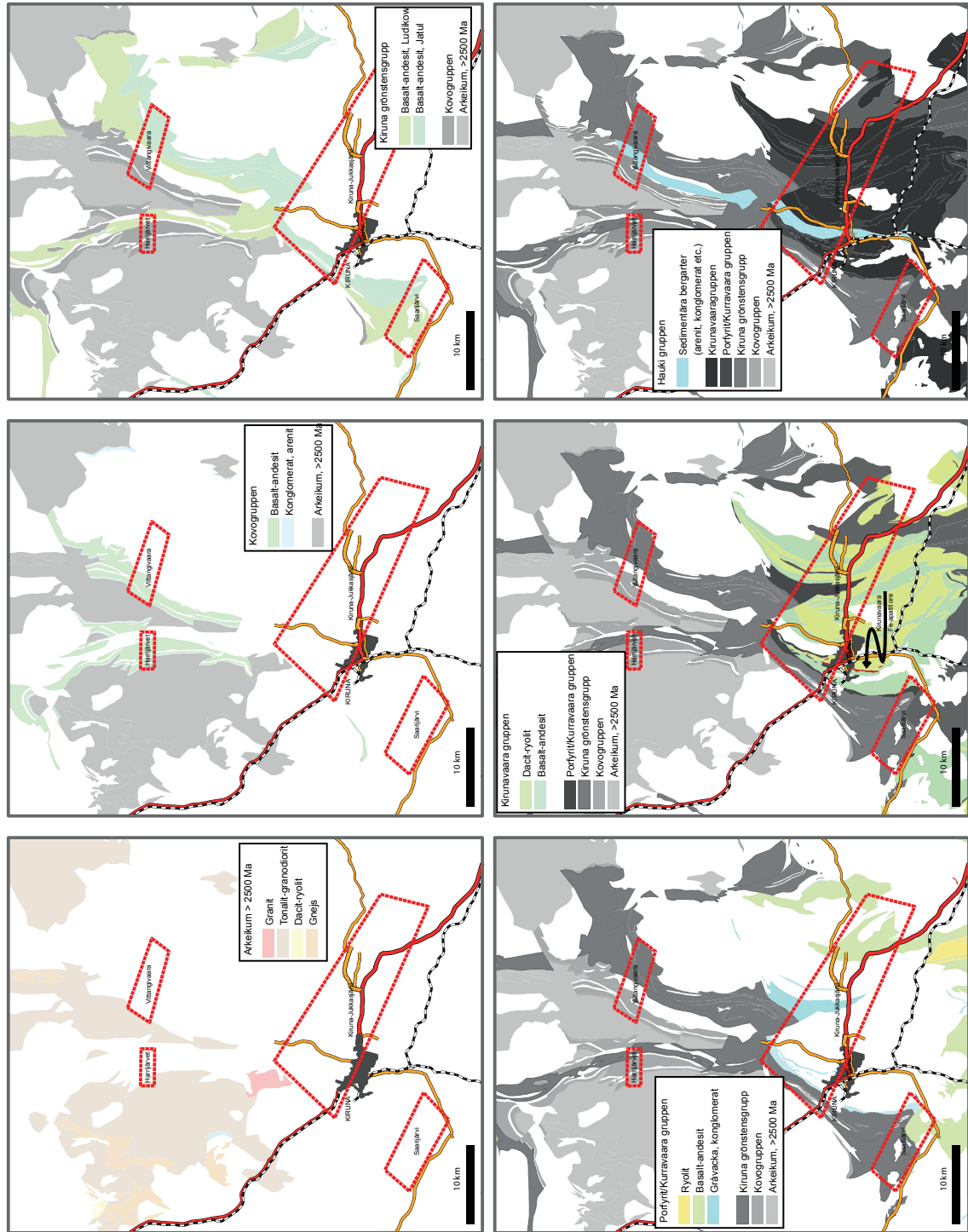


Fig. 26 Spatial extent of stratigraphic units and subunits. Maps created by A. Hallberg.

Table 6. Subdivision of the Kiruna Greenstone Group from oldest to youngest after Martinsson (1997). MOR: Mid Ocean Ridge; LKT: Low-K tholeiite

Formation	Dominant lithologies	Thickness	Depositional/tectonic setting
Linkaluoppal	Tholeiitic volcanoclastics, with layers of graphite schists, magnetite, skarn, and dolomite	>700 m	Rapid basin shallowing; uplift; erosion; WPB-type volcanism in upper parts
Peuravaara	Tholeiitic pillow basalts	~1000 m	MORB-preceding rapid basin subsidence
Viscaria	Volcanoclastics; basaltic tuff and thin layers of graphite schist; MORB-type magma; minor andesitic to dacitic volcanic rocks	~400 m	Change from terrestrial/shallow water to prevailing subaqueous conditions; large basin; bimodal, pyroclastic volcanism
Pikse	Tholeiitic basalts	~350-400 m	Terrestrial to shallow water amygdaloidal lava flows form extensive lavaplain; MOR, LKT
Ädnamvare	Peridotitic komatiites Basaltic komatiites in upper parts	~400 m	Mantle melting
Säkevaratjah	Basaltic lava with WPB-character Dolomite Locally conglomerates containing pebbles of KOG	~250 m	Clastic sedimentation; possibly evaporite deposition; WPB-type volcanism; small fault-controlled basins

Table 7. Subdivision of the Kiirunavaara group from oldest to youngest after Martinsson (2004 and references therein).

Formation	Dominant lithologies	Thickness	Depositional/tectonic setting
Hoppuka	Intermediate volcanic rocks; amygdaloidal andesite and trachyandesite	300-1400 m	Mainly lava flows
Luossavaara	Rhyodacitic composition; dominated by porphyritic tuff-lapillituff; intercalated conglomerates	Up to 800 m	Pyroclastic origin
Matojärvi	Mixed volcanic-sedimentary unit; basalt/rhyolite at the base; clastic and siliceous hematite ore; basaltic volcanic and clastic rocks	>500 m (?)	Explosive hydrothermal activity

form–stratabound Viscaria Cu deposits (e.g. Martinsson 1997, Bergman et al. 2001). Since the Kiruna greenstone belt continues towards the north of the Kiruna district, it might be possible that more Cu-sulphide deposits of the Viscaria type may be found further north.

The volcanosedimentary rocks of the KGG are unconformably overlain by the so-called Kurravaara conglomerate (KCO). This unit is dominated by clastic sediments and contains mostly clasts derived from the KGG at its basal parts whereas the top parts are dominated by well-rounded pebbles with a calc-alkaline composition suggesting the stratigraphically equivalent Porphyrite group (PTG) as a source (Martinsson & Perdahl 1995). South of the Torneälven river, the KOC is represented by a mica schist. Kumpulainen (2000) suggests a fan delta setting for the deposition of the KCO.

The KCO and PTG underlie the Kiirunavaara group (KIIG). In the central Kiruna area, the KIIG is dominated by intermediate to felsic volcanic rocks that are overlain by epiclastic sediments (Martinsson, 2004). The KIIG is divided into three subunits based on their lithology and chemical composition and is summarised in table 7. The ‘famous’ and economically important apatite iron ore deposits Kiirunavaara and Luossavaara are hosted by the Kiiruna-

vaara group between the trachyandesitic Hoppuka formation and the rhyodacitic rocks of the Luossavaara formation. The so-called Per Geijer Ores (Nukutus, Henry, Rektorn, and Lappmalmen) are situated between the Luossavaara and the Matojärvi formation. A detailed description of the KIIG subunits as well as the metallogeny of the Kiruna area can be found in Martinsson (2004).

The youngest sedimentary rock unit exposed in the KJKA are the rocks of the Hauki quartzite group (HQG), which consist of cross-bedded feldspar arenite, intercalations of sedimentary breccia and conglomerates mostly at the base of the unit. An erosional unconformity separates the HQG from the underlying KIIG. Witschard (1984) proposes deposition of the Hauki sediments in small, tectonically active grabens so that the contact with the underlying rocks is often tectonically controlled (Martinsson 2004).

Paleoproterozoic magmatism

The volcanosedimentary supracrustal rocks in the field area are intruded by several suites of magmatic rocks. Their names, lithologies, magmatic character, ages, and inferred tectonic setting are summarised here from Ahl et al. (2001) and Bergman et al. (2007) and presented in table 8.

In the KJKA, no rocks of the Haparanda suite (HPS) seem to be exposed, however, the contemporary Perthite–Monzonite suite (PMS) intruded the Archean basement rocks as well as the Kiruna greenstones. Compared to the Haparanda suite, the PMS seems less deformed, especially at the contact with the Haparanda intrusives (Bergman et al. 2001). In the key area, the youngest magmatic intrusions are granites and adamellites of the Granite–Pegmatite (GPA) or Lina suite (LS). Fig. 27 shows the distribution of the Precambrian magmatic rocks around the key area.

Deformation and metamorphism in the KJKA

Although the area between Kiruna and Kurravaara hosts several of the biggest ore deposits, structural geological studies are rare. Probably the most detailed structural study of the Kiruna mining district is presented in Wright (1988) and much of the information in this section is taken from his work as well as from structures and attitudes indicated on the geological maps.

The supracrustal rock units in the KJKA generally strike N–S to NW–SE. In the very western part, between Kiruna and Kurravaara the complete stratigraphic sequence can be seen from the KGG through to the Hauki quartzite with all units dipping subvertically or relatively steeply to the east (Fig. 28). One single cleavage is present in the rocks and dips even steeper than the foliation (Wright 1988) and usually in the same direction, indicating that the western part of the key area may represent the eastern limb of a west-vergent, south-closing anticline. This would also be consistent with the model by Forsell (1987). The rock sequence is cut to the east by a reverse fault placing rocks of the HQG next to the lower parts of the Kiirunavaara group or even against the KGG.

Further to the east, the rocks seem to have been folded in tight to isoclinal folds that trend more or less NNW–SSE but seemingly show strong deflections around the PMS intrusions.

Table 8. Subdivision of Precambrian magmatic suites according to Ahl et al. (2001) and Bergman et al. (2007).

Suite	Age (Ga)	Geochemical character	Lithologies	Tectonic setting	References
Haparanda suite (HPS)	1.90-1.86	Calc-alkaline	Granite, granodiorite, tonalite, diorite, gabbro	Volcanic-arc; Co-magmatic with extrusive phases of early Svecofennian arc magmatism (Porphyrite group?)	Ödman (1957); Skiöld (1988); Bergman et al. (2001); Mellqvist et al. (2003)
Perthite-Monzonite suite (PMS)	1.88-1.86	Alkaline	Granite, monzonite, diorite, gabbro, peridotite	Co-magmatic with Kiirunavaara group volcanic rocks; intra-plate setting; mantle-plume origin	Skiöld (1981); Skiöld & Öhlander (1989); Martinsson et al. (1999)
Granite-Pegmatite association (GPA) OR Lina suite (LS)	1.81-1.78	Calcic(?)	Monzogranite, syenogranite, adamellite	Continent-continent collision OR contemporaneous to TIB 1 magmatism	Skiöld et al. (1988); Öhlander & Skiöld (1994); Bergman et al. (2001)
A-, I-type intrusions	1.80-1.77	Alkaline	Granite, monzonite, granodiorite, diorite, gabbro	Part of TIB; TIB inferred to have formed in an extensional phase in subduction setting; OR may be related to final orogenic collapse	Romer et al. (1994); Bergman et al. (2001); Lahtinen (2003, 2005)

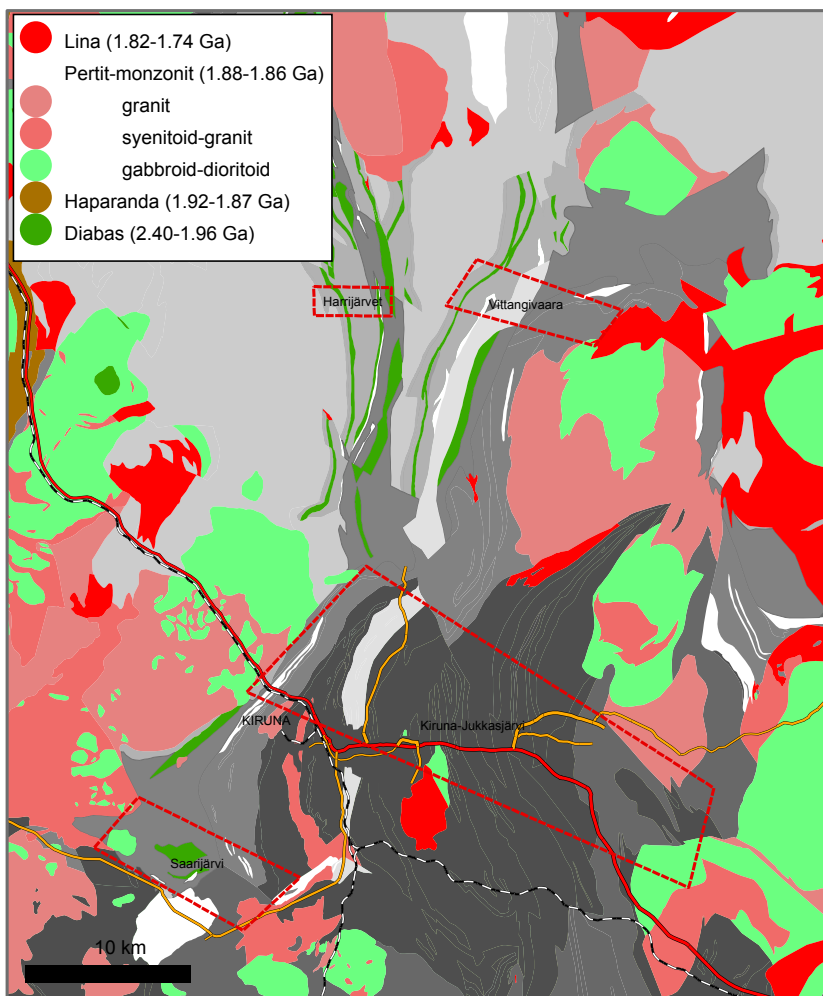


Fig. 27. Distribution of Paleoproterozoic magmatic rocks in and around the KJKA. Map created by A. Hallberg.

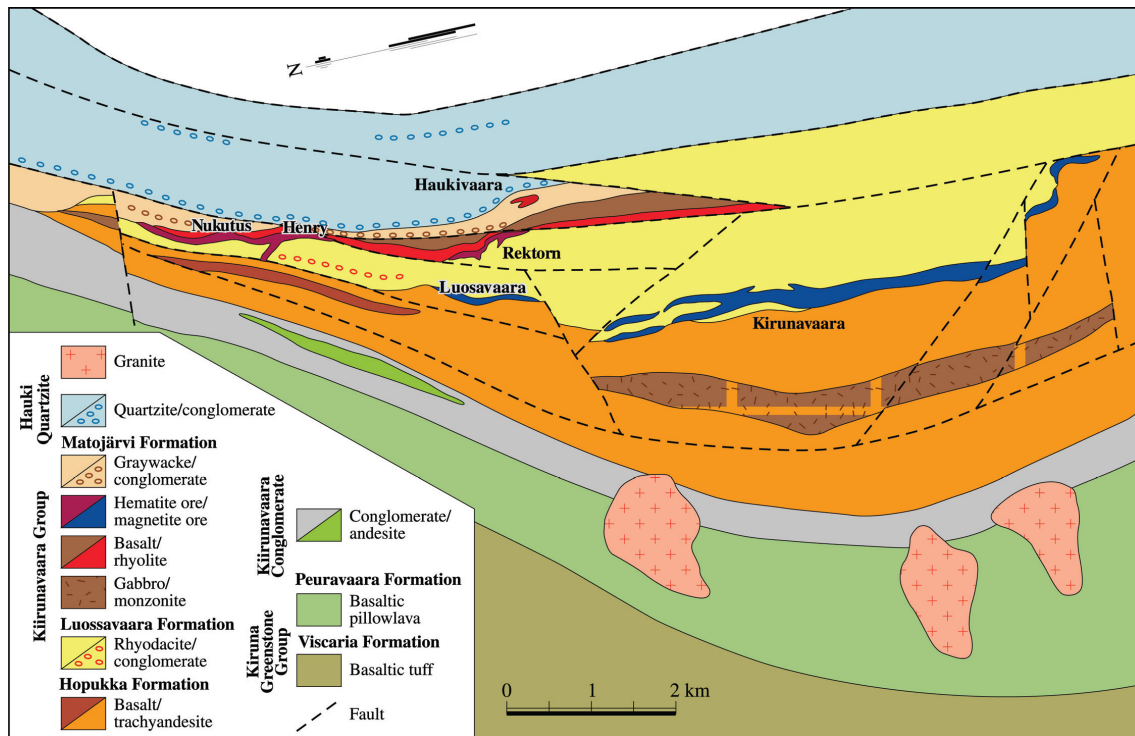


Fig. 28. Detail from the regional map around the Luossavaara and Kirunavaara apatite iron ore deposits. Taken from Martinsson & Hansson (2004).

One tip of these tight folds within the KGG points into the key area near Kallosalmi to the east of Kurravaara. Here, it is not clear if the adjacent KCO and KIIG rocks underwent the same deformation as the Kovo group and the KGG. Prospecting reports by Gustafsson (1991) displays several maps and cross sections from a drilling project in the Kallosalmi area. Their results indicate that there must have been at least two folding events in this area. One approximately WNW–ESE striking event was followed by refolding about NNE–SSW trending, S-plunging fold axes. Since some of the horizons in the KGG to the north are ore bearing, it is essential to understand the continuation of these layers underneath the rocks of the Kiirunavaara group. The region between Kurravaara and Kallosalmi will therefore have a high priority in this project.

If compared to geomagnetic and other geophysical data, several tight folds with steeply dipping limbs can be recognised (Fig. 29). These folds may correspond to the D2-folds of Wright (1988). Fig. 29 also shows, that the granite intrusions of the PMS (perthite monzonite suite) seem largely unaffected by the deformation. Either the intrusion of the PMS rocks ‘squeezed’ the rock units apart and lead to the meandering pattern of the fold axes or the PMS intrusions acted as almost rigid blocks ‘swimming’ in the less competent volcanoclastic supracrustal rocks of the KGG and the Kiirunavaara group (KIIG). The supracrustals seem to have taken up the bulk of the deformation along collision zones. During a compressive event, the PMS rocks to the west may have acted as an indenter, leading to the high strain belt in the supracrustal rocks.

Later, the rocks in the Kiruna–Jukkasjärvi area were also affected by the NNE–SSW extending Kiruna–Naimakka deformation zone (KNDZ) which runs parallel to the Ka-

resuando–Arjeplog deformation zone (KADZ). Bergman et al. (2001) reports a W-side up movement along this shear zone whereas Wright (1988) suggests the opposite shear sense. According to Bergman et al. (2001), these shear zones were active at 1.8 Ga.

In general, the timing between the folding events, magmatic intrusions, metamorphism, and the effect of the KNDZ on the rocks is not well understood and requires further studies.

The metamorphic grade in the KJKA varies between low to medium grade metamorphism (upper greenschist to lower amphibolite facies) and it seems as if the metamorphic grade increases towards the east. No reliable P–T–t estimates exist for the KJKA and will be tried to improve upon during this project.

Mineralisations and alterations

Frietsch et al. (1997) report, that albitisation and scapolitisation are common in the Kiruna area (cf. Fig. 6). Martinsson (2004) divides the most important metallic mineral occurrences into four groups: stratiform–stratabound base metal mineralisations, iron formations, apatite iron ores and epigenetic sulfide mineralisations. Maps showing the different types and localities of mineralisations can be found in Bergman et al. (2001).

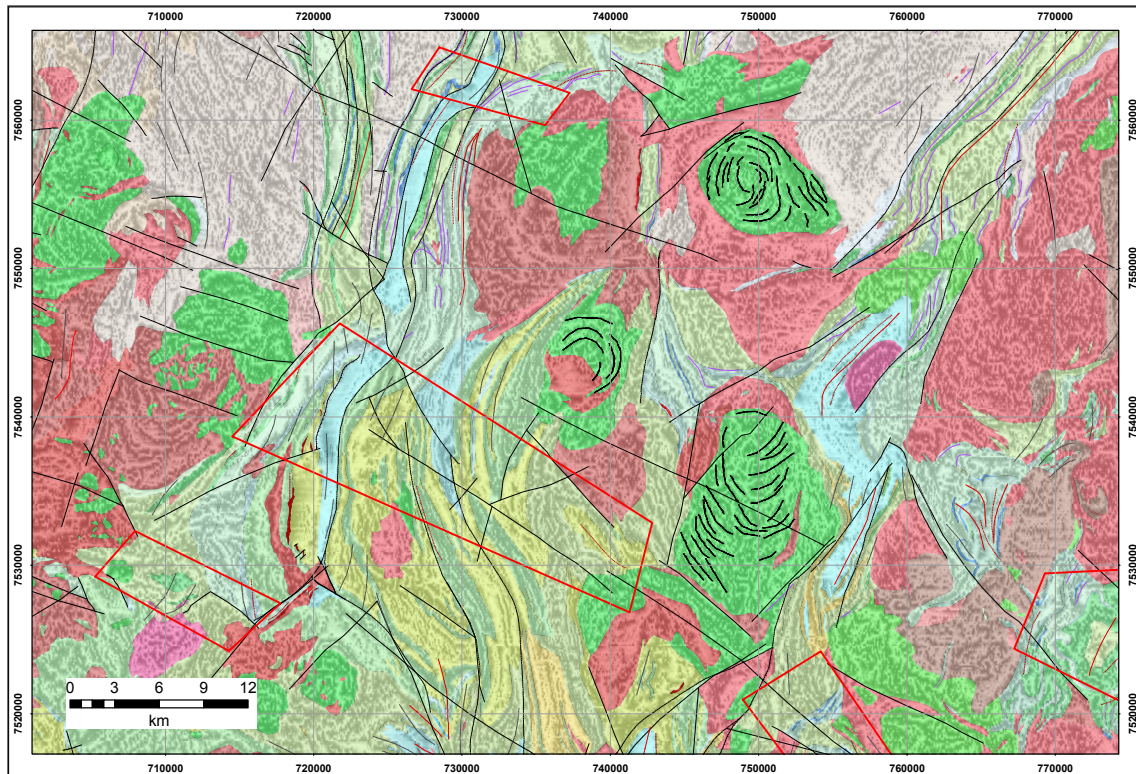


Fig. 29. Regional geological map (1:250,000) underlain by magnetic field data (TDR). The narrow meandering more or less N-S striking folds can easily be detected. Note how the PMS intrusions have withstood the deformation whereas the rocks of the KGG and KIIG seem to 'flow' around them.

Stratiform and stratabound iron formations and sulfide occurrences

The volcanoclastic rocks of the Kiruna greenstone group (KGG) in association with graphite schists and carbonate rocks host stratiform deposits of iron ore and base metals of which only the Viscaria-Cu deposit north of Kiruna is economically important (Martinsson 2004). The Viscaria deposits are interpreted to be of an exhalative origin, related to the dissolution of evaporites at the bottom of the greenstone pile (Martinsson 1997, Martinsson 2004). However, until now, no direct evidence of the existence of evaporites in the greenstone group has been found. Lense-shaped skarn rich iron formations occur in e.g. Altavaara, south of Jukkasjärvi.

Apatite iron ores

The type locality for apatite iron ores is Kiruna. The apatite iron ores either occur in breccias or stratiform–stratabound or as a mixture between these two types of deposits (Bergman et al. 2001, Martinsson 2004). The breccia–type occurs in stratigraphically lower parts of the Kiirunavaara group (KIIG) and the stratabound version occurs in the higher parts of the KIIG. Host rock alterations with sericite, biotite, tourmaline, and carbonate are common around the stratabound deposits, whereas they are insignificant around the breccias. The Nukutus, Henry, Rektorn, and Lappmalmen deposits are of the breccia type whereas the Kiirunavaara (and Luossavaara?) deposits belong to the mixed stratiform-brecciated group (Martinsson 2004).

Epigenetic sulfide mineralisations

Epigenetic sulfide deposits can be hosted by the KGG, Svecofennian volcanic and volcanoclastic rocks, and sometimes even by intermediate and felsic intrusions. The majority of these deposits is spatially related to major shear zones (Martinsson 2004). The Cu–Au deposit in Pahtohavare SW of Kiruna is the only economically significant deposit. In general, the Cu–Au deposits are related to the intrusion of the paleoproterozoic suites. Cu–Au mineralisation is due to the intrusion of the Haparanda suite, Cu-mineralisation may be related to the PMS intrusions, whereas Cu–Au–Mo deposits are reported in relation to the Lina suite (Martinsson 2004, Billström & Martinsson 2000).

DISCUSSION

A general lack of reliable age data for all rocks in the western part of the KJKA, as well as insufficient understanding of the sequence of deformational events make it necessary to undertake more targeted field studies and sampling of the KJKA. One of the ultimate goals will be to create formline maps tracing the bedding, foliation(s) and fold axial planes in the area. The area will be under renewed investigation keeping the following questions and issues in mind:

- Some faults on the local databases do not make sense when compared to the magnetic data.
- Are all the faults really faults? Or are there also brittle–ductile or purely ductile deformation zones? What is the interplay between brittle and ductile deformation?
- Are some parts of the rocks in the east really migmatized or are these metasomatic alterations?

- What are the ages of the faults and how are they related to the plutons in the area (age wise and kinematic wise)? Are there different fault generations?
- How are the mineralisations/ alterations related to the deformation (folding/faulting) in the area?
- How many folding phases are there?
- What is the significance of the fault near Kirkkoväärtijärvi?
- What is the significance of the two kink folds around Mt Kurravaara in the W?
- Were there originally evaporites in the Greenstone group?
- Has the top of the Greenstone group been eroded, and what does that mean?
- Which unit does the rock type east of the Hauki quartzite belong to?
- Can the Kurravaara conglomerate really be a facies variant of the porphyrite group?
- Which events represent the Matojärvi formation?

Some potential methods to address these questions are:

- Detailed mapping along profiles, by using GPS, DEM, geophysical measurements and interpretations.
- Sampling in order to confirm the age, chemistry, and degree of metamorphism as well as the protolith ages of the different stratigraphic units.
- Mapping and dating dikes or sills cross-cutting the foliation to further constrain the age of deformation.
- Creating relative timing constraints through a distinction between fractures showing scapolitisation and/or other hydrothermal alterations, and unaffected fractures.
- Structural modelling (numerical and analogue) to understand the mechanisms behind the observed deformation pattern.
- Making use of the enormous amount of core logs in creating 3D models of the area around Kallosalmi.
- Making use of the new seismic profile extending from Kiruna 70 km to the east to understand the deeper parts of the folded rock sequence.

PLANNED WORK

One of the main goals for this area is to produce a formline map for bedding and cleavage(s) using a combination of structural geological observations and measurements where possible with supporting geophysical ground measurements. The field work that is planned for summer 2013 was divided into 5 sectors presented in table 9 and Fig. 30.

Table 9. Description of planned field work in sectors indicated in Fig. 26.

Sector	Planned work / sampling / aim	Time estimate
Red	Detailed structural investigation if possible from KGG through KCO, KIIG, and HQ along profiles; potentially ground geophysics; try to identify the folding pattern; make use of drill cores in the Kallosalmi area; is there really only one cleavage present? Also, try to understand the faulting pattern	5 days; plus some days at the Malå archive
Grey	Sampling mainly for geochronology of KGG, KCO, and KIIG rocks; if possible, detailed structural geological measurements.	2 days
Orange	Sampling mainly for geochronology and geochemistry of KIIG rocks; if possible, detailed structural geological measurements.	3 days
Purple	Structural investigations in “migmatites”; sampling for thin section preparation in order to determine whether these are really migmatites or rather alterations; retrieve more structural measurements in the so-called Pahtavaara anticline	2 days
Blue	Sampling of Paleoproterozoic intrusives for later U–Pb dating of protolith and potentially metamorphic ages	1 day
Green	Detailed structural geological profile(s) in order to understand the folding patterns in this region; sampling for lithochemical analyses	4 days

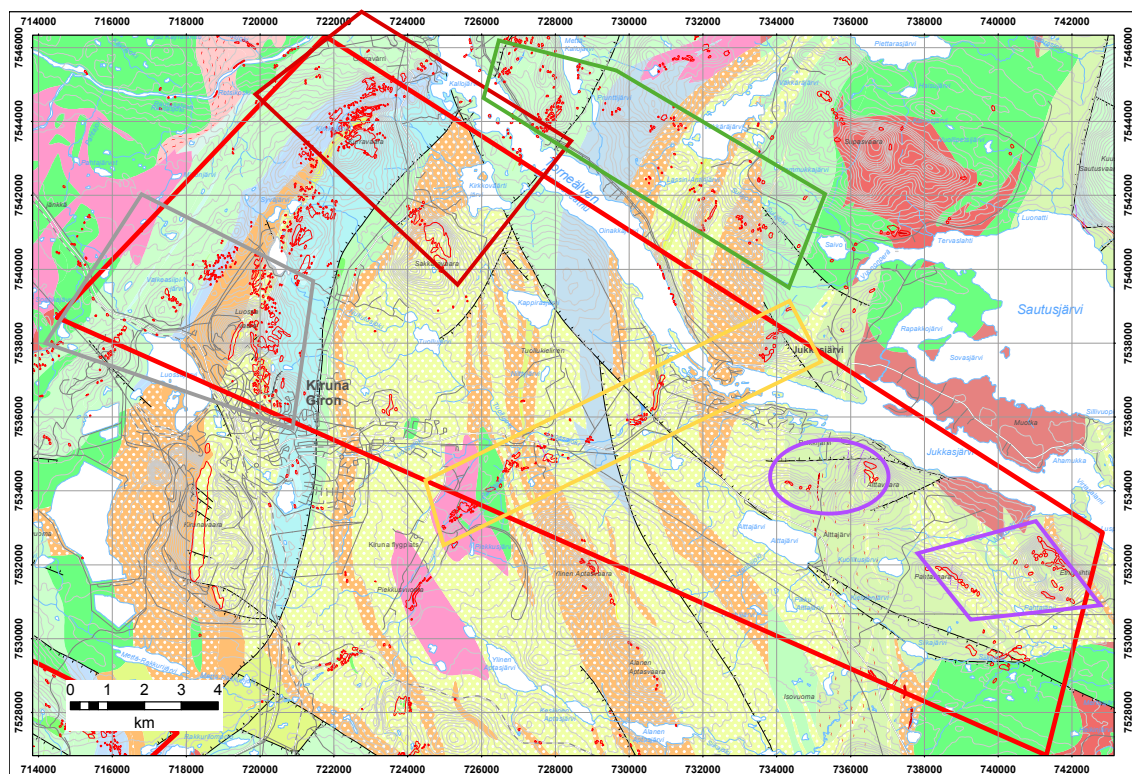


Fig. 30 Proposed areas for structural mapping and sampling within the KKA. Coloured polygons refer to table 9.

REFERENCES

- Ahl, M., Bergman, S., Bergström, U., Eliasson, T., Ripa, M. & Weihed, P., 2001: Geochemical classification of plutonic rocks in central and northern Sweden. *Sveriges geologiska undersökning R&M 106*, 82 pp.
- Bergman, S., Kübler, L. & Martinsson, O., 2001: Description of regional geological and geophysical maps of northern Norrbotten County (east of the Caledonian orogen). *Sveriges geologiska undersökning Ba 56*, 110 pp.
- Bergman, S., Weihed, P., Martinsson, O., Eilu, P. & Iljina, M. 2007: Geological and tectonic evolution of the northern part of the Fennoscandian Shield. In V.J. Ojala, P. Weihed, P. Eilu & Iljina, M. (eds.): Metallogeny and tectonic evolution of the Northern Fennoscandian Shield: Field trip guidebook. *Geologian Tutkimuskeskus 54*, 6–15.
- Billström, K. & Martinsson, O., 2000: Links between epigenetic Cu–Au mineralizations and magmatism/deformation in the Norrbotten county, Sweden. In Weihed, P. & Martinsson, O. (eds.): 2nd Annual GEODE-Fennoscandian Shield workshop on Palaeoproterozoic and Archaean greenstone belts and VMS districts in the Fennoscandian Shield: Gällivare–Kiruna, Sweden. Luleå University of Technology, *Research Report 2000:6*, 6.
- Cliff, R.A., Rickard, D. & Blake, K., 1990: Isotope systematics of the Kiruna magnetite ores, Sweden. I. Age of the ores. *Economic geology 85*, 1770–1776.
- Eriksson, B. & Hallgren, U., 1975: Beskrivning till Berggrundskartbladen Vittangi NV, NO, SV, SO. *Sveriges geologiska undersökning Af 13–16*, 203 pp.
- Forsell, P., 1987: The stratigraphy of the Precambrian rocks of the Kiruna district, Northern Sweden. *Sveriges geologiska undersökning C 812*, 36 pp.
- Frietsch, R., Tuisku, P., Martinsson, O. & Perdahl, J.-A., 1997: Early Proterozoic Cu–(Au) and Fe ore deposits associated with regional Na–Cl metasomatism in northern Fennoscandia. *Ore Geology Reviews 12*, 1–34.
- Granar, L., Henkel, H. & Lind, J., 1986: The Nordkalott Project, Report of petrophysical rock samples. *Sveriges geologiska undersökning BRAP 86408*, 54 pp.
- Gustafsson, B., 1991: Kallosalmi diamantborrning VT 1991. *Sveriges Geologiska AB Prospekteringsrapport PRAP 91020*, 146 pp.
- Kumpulainen, R., 2000: The Palaeoproterozoic sedimentary record of northernmost Norrbotten, Sweden. Unpublished report. *Sveriges geologiska undersökning BRAP 200030*, 45 pp.
- Ladenberger, A., Andersson, M., Gonzalez, J., Lax, K., Carlsson, M., Olsson, S.-Å. & Jelinek, C., 2012: Markgeokemiska kartan. Morängeokemi i norra Norrbotten. *Sveriges geologiska undersökning K 410*, 112 pp.
- Martinsson, O., 1997: Tectonic Setting and Metallogeny of the Kiruna Greenstones. Unpublished PhD thesis 1997:19, Luleå University of Technology.

- Martinsson, O., 2004: Geology and Metallogeny of the Northern Norrbotten Fe–Cu–Au Province. In R.L. Allen, O. Martinsson & P. Weihed (eds.): Svecofennian ore-forming environments. Volcanic–Associated Zn–Cu–Au–Ag, Intrusion-Associated Cu–Au, Sediment-Hosted Pb–Zn, and Magnetite–Apatite Deposits of Northern Sweden. *Society of Economic Geologists Guidebook Series 33*, 131–148.
- Martinsson, O. & Perdahl, J.-A., 1995: Paleoproterozoic extensional and compressional magmatism in northern Sweden. In J.-A. Perdahl: Svecofennian volcanism in northern Sweden, Doctoral thesis 1995:169D, Paper II, 1–13. Luleå University of Technology.
- Martinsson, O. & Hansson, K.-E., 2004: Apatite Iron Ores in the Kiruna Area. In R.L. Allen, O. Martinsson & P. Weihed (eds.): Svecofennian ore-forming environments. Volcanic-Associated Zn–Cu–Au–Ag, Intrusion-Associated Cu–Au, Sediment-Hosted Pb–Zn, and Magnetite–Apatite Deposits of Northern Sweden. *Society of Economic Geologists Guidebook Series 33*, 173–175.
- Martinsson, O., Vaasjoki, M. & Persson, P.-O., 1999: U–Pb zircon ages of Archaean to Paleoproterozoic granitoids in the Torneträsk–Råstojaure area, northern Sweden. In Bergman, S. (ed.): Radiometric dating results 4. *Sveriges geologiska undersökning C 831*, 70–90.
- Offerberg, J., 1967: Beskrivning till Berggrundskartbladen Kiruna NV, NO, SV, SO. *Sveriges geologiska undersökning Af 1–4*, 147 pp.
- Pedersen, L.B., Qian, W., Dynesius, L. & Zhang, P., 1994: An airborne tensor VLF system. From concept to realization. *Geophysical Prospecting 42*, 863–883.
- Perdahl, J.-A. & Frietsch, R., 1993: Petrochemical and petrological characteristics of 1.9 Ga old volcanics in northern Sweden. *Precambrian Research 64*, 239–252.
- Romer, R.L., Martinsson, O. & Perdahl, J.-A., 1994: Geochronology of the Kiruna Iron Ores and Hydrothermal Alterations. *Economic Geology 89*, 1249–1261.
- Skiöld, T., 1979: U–Pb zircon and Rb–Sr whole-rock and mineral ages of Proterozoic intrusives on mapsheet Lannavaara, north–eastern Sweden. *Geologiska Föreningens i Stockholm Förhandlingar 101*, 131–137.
- Skiöld, T., 1986: On the age of the Kiruna Greenstones, northern Sweden. *Precambrian Research 32*, 35–44.
- Skiöld, T. & Cliff, R.A., 1984: Sm–Nd and U–Pb dating of Early Proterozoic mafic–felsic volcanism in northernmost Sweden. *Precambrian Research 26*, 1–13.
- Skiöld, T. & Page, R.W., 1998: SHRIMP and isotope dilution zircon ages on Archaean basement-cover rocks in north Sweden. 23. *Nordiske Geologiske Vintermöde, Abstract volume Århus 1998*, 273.
- Welin, E., 1987: The depositional evolution of the Svecofennian supracrustal sequence in Finland and Sweden. *Precambrian Research 35*, 95–114.
- Welin, E., Christiansson, K. & Nilsson, Ö., 1971: Rb–Sr Radiometric ages of extrusive and intrusive rocks in northern Sweden 1. *Sveriges geologiska undersökning C 666*, 1–38.

Witschard, F., 1984: The geological and tectonic evolution of the Precambrian of northern Sweden – a case for basement reactivation? *Precambrian Research* 23, 273–315.

Wright, S.F., 1988: Early Proterozoic deformational history of the Kiruna district, northern Sweden. Unpublished PhD thesis, University of Minnesota, 170 pp.