

KARTERING BARENTS 2013

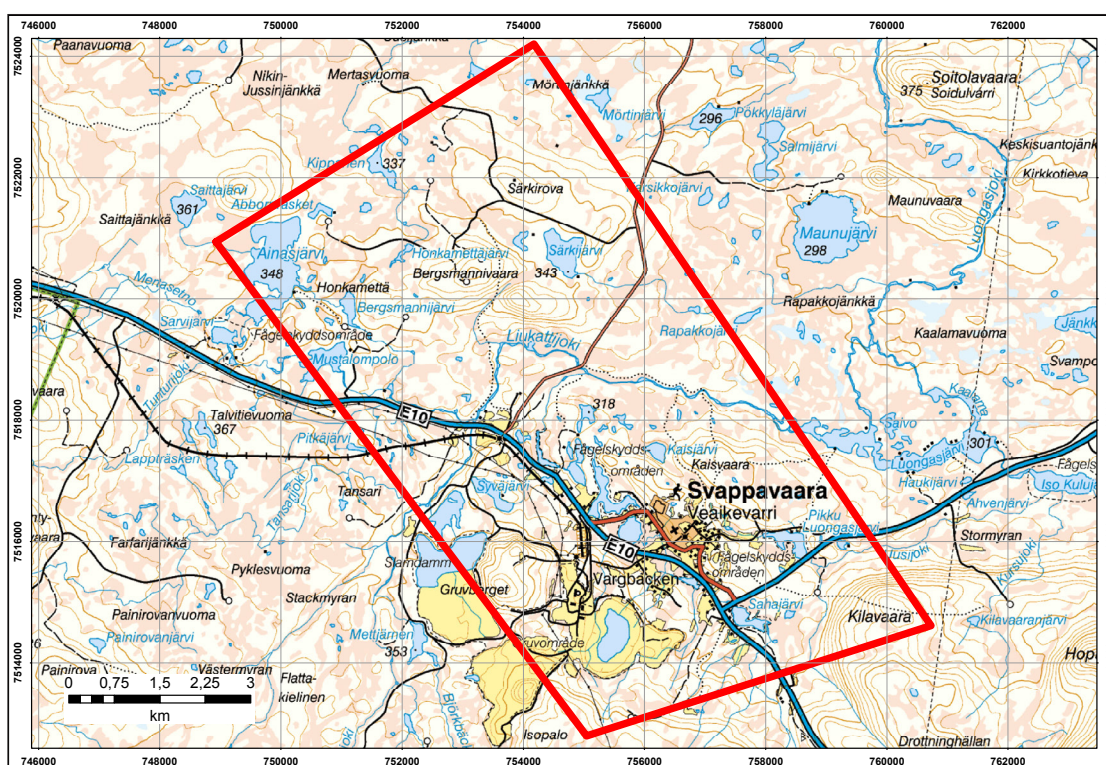
Background information Svappavaara key area

Susanne Grigull & Johan Jönberger

October 2013



SGU-rapport 2013:9



SGU

Sveriges geologiska undersökning
Geological Survey of Sweden

Sveriges geologiska undersökning
Box 670, 751 28 Uppsala
tel: 018-179000
fax: 018-179210
e-post: sgu@sgu.se
www.sgu.se

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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 and tectonic development of the Norrbotten area, which in turn is essential for potential further prospecting work.

The Barents project (Kartering Barents) targets 15 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

AVAILABLE DATA FOR THE SVAPPAVAARA KEY AREA (SVKA)

Published material

Table 1. SGU reports relevant to the Svappavaara 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, deposits around Svappavaara	Iron ore deposits sorted by type of mineralisation
C 802	Petrochemistry of the iron ore-bearing metavolcanics in Norrbotten county northern Sweden	1984	Frietsch	Norrbotten, Svappavaara	Petrology, geochemistry of metavolcanic rocks; tectonic control of apatite iron ore deposits
C 768	The Precambrian of Sweden	1979	Lundqvist	Sweden, Norrbotten	Regional geology, Summary
C 625	The relationship between magnetite and hematite in the iron ores of the Kiruna type and some other iron ore types	1967	Frietsch	Norrbotten, world	Metasomatic reactions; discussion on when hematite and when magnetite is formed
C 604	Berggrund och malmer i Svappavaarafältet, norra Sverige	1966	Frietsch	Svappavaara, Gruvberget	Detailed maps of the Svappavaara ore fields
C 592	Järnmalmsförekomster inom Norrbottens län	1963	Frietsch	Norrbotten, Gruvberget, Leveänemi, Tansari	Regional geology; overview of non-producing iron ore occurrences
C 284	Det grafit- och järnmalmsförande området vid Vittangi	1918	Geijer	Vittangi, Svappavaara	Description of graphite and iron ore deposits
C 127	Apatitförekomster i Norrbottens malmberg	1892	Lundbohm	Svappavaara	Regional geology; description of ore deposits

Table 2. SGU map sheets relevant to the Svappavaara key area

Code	Title	Year	Author	Scale	Descriptions	GIS
Af 15, 16	29K Vittangi SV, SO	1975	Eriksson, Hallgren	1:50,000	yes	yes
Ba 56	Regional geological and geophysical maps of Northern Norrbotten (east of the Caledonian orogen)	2001	Bergman, Kübler, Martinsson	1:250,000	yes	yes

Table 3. Prospecting reports relevant to the Svappavaara 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 stratigraphic columns of stratigraphic units; Kiilavaara part
Mink 95119 Greenstone and porphyry hosted ore deposits in northern Norrbotten	Martinsson	1995	NUTEK	Northern Norrbotten	Regional stratigraphy, petrography, geochemistry	All, regional maps of ore deposits
Mink 95118 Greenstone and porphyry hosted ore deposits in northern Norrbotten	Martinsson et al.	1994	NUTEK	Northern Norrbotten	Stratigraphy, petrography, geochemistry	All

Title	Author	Year	Company	Location	Type	Relevant content
NSG93003 The Swedish Norrbotten Greenstone Belt	Gustafsson	1993	Sveriges Geologiska AB	Norrbotten	Stratigraphy, lithogeochemistry	Stratigraphic variations in the Greenstone belt
NSG91510 Basmetaller i Norrbotten	Lilljequist	1991	NSG	Norrbotten, Gruvberget	Description of basic metals in Norrbotten	Map of faults and deformation zones in Norrbotten
Brap 881 Berggrunden inom det centrala Vittangifältet dess petrografi, stratigrafi och tektonik	Eriksson	1969	SGU	Vittangi, Nunasvaara	See title	Detailed study of folds in the Vittangi/ Nunasvaara area
Brap 853 Gruvbergets järnmalmförekomst	Espersen & Frietsch	1964	SGU	Gruvberget	Stratigraphy, tectonics, ore geology	Description of Gruvberget ore deposit
Brap 841 Mängdberäkning av malmen i Gruvberget	Frietsch	1962	SGU	Gruvberget	Calculation of tonnage	
Brap 832 P.M. rörande de geologiska undersökningarna av Tansari	Frietsch	1961	SGU	Tansari	Ore geology	Description of Tansari ore deposit
Brap 814 Om spräckesystemet i Svappavaara, Gruvberget, Kiruna	Henriksen	1958	SGU	Svappavaara, Gruvberget, Kiruna	Fault systems	Stereographic projection with fault-related mineralisations

Table 4. Scientific publications relevant to the Svappavaara key area

Title	Author	Year	Journal	Relevant content
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, Luosovaara, Nuktus, Henry
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. 196–197 address Vittangi area (J. Gonzales)
Strukturgeologin i Gruvberget i Svappavaara	Klemo	2012	LTU, examensarbete, 48 p.	Mapping of Gruvberget quarry; attitude measurement plus stereoplots
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 and Gruvberget
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 Gruvberget
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;
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 Gruvberget

Table 4. Continued.

Title	Author	Year	Journal	Relevant content
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.
Geology and metallogeny of the Northern Norrbotten Fe-Cu-Au province	Martinsson	2004	Society of economic geologists, Guidebook series, Volume 33, p 131–148	Review on regional geology, stratigraphy, mineralisations and tectonics
Some aspects on the subdivision of the Haparanda and Jörn intrusive suites in northern Sweden	Mellqvist et al.	2003	GFF, 125, 77–85	Description of Haparanda suite; U–Pb dating; geochemistry
Tectonic setting and metallogeny of the Kiruna Greenstones	Martinsson	1997	PhD-thesis, LTU. ISSN: 1402–1544	Regional geology and stratigraphy
Contrasting 1.8 Ga potassic granitoids in northern Sweden; the Edefors and Lina suites	Öhlander & Skiöld	1996	GFF, 118, p. A22	Abstract about Lina type granite
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 Mertainen, Gruvberget, Leveäniemi; REE content and pattern shows that apatite iron ores are hydrothermal-exhalative and were fed by same source
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)
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
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
Granite types in Sweden	Wilson	1980	GFF, 102:2, 167–176	See title; Lina suite sample from Norrbotten; geochronology
Malm i Sverige 2 – Norra Sverige	Grip & Frietsch	1973	Almqvist & Wiksell Lärmedel AB, Stockholm	All from p. 97 onwards; description of ore deposits; detailed maps; photographs

Map databases

Bedrock maps

At a scale of 1:50,000, geological map sheets Af 15 and Af 16 (29K Vittangi SV, SO, Eriksson & Hallgren 1975) contain the key area. This map compilation also contains 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. Blockdiagram V by Eriksson & Hallgren (1975) is oriented SW–NE, extends across the entire key area and contains the Leveäniemi iron ore deposit.

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

In 1966, R. Frietsch published detailed geological maps of the Svappavaara ore field (Fig. 3). Frietsch (1966) presents one map at 1:20,000, including, amongst others, the most prominent ore fields Tansari, Gruvberget and Leveäniemi. A detailed map of the Gruvberget deposit is included at a scale of 1:2000 (Fig. 4). Both maps are available as scanned and georef-

erenced layers in the SGU databases. It is important to notice, however, that the stratigraphy in these maps is upside-down. The so-called Svappavaara group corresponds to the upper Vittangi greenstone group (uVGG) and should stratigraphically be placed underneath the Porphyry group.

The area is also covered at the SGU regional map scale (1:250,000, Fig. 5).

The map compilation by Eriksson & Hallgren (1975) also contains 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 1980s, 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 Svappavaara 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 45 drill sites within the SVKA and in its vicinity. The drill sites are summarised by ownership and displayed in the map in Fig. 6. All of the drill cores are stored in the SGU archive in Malå.

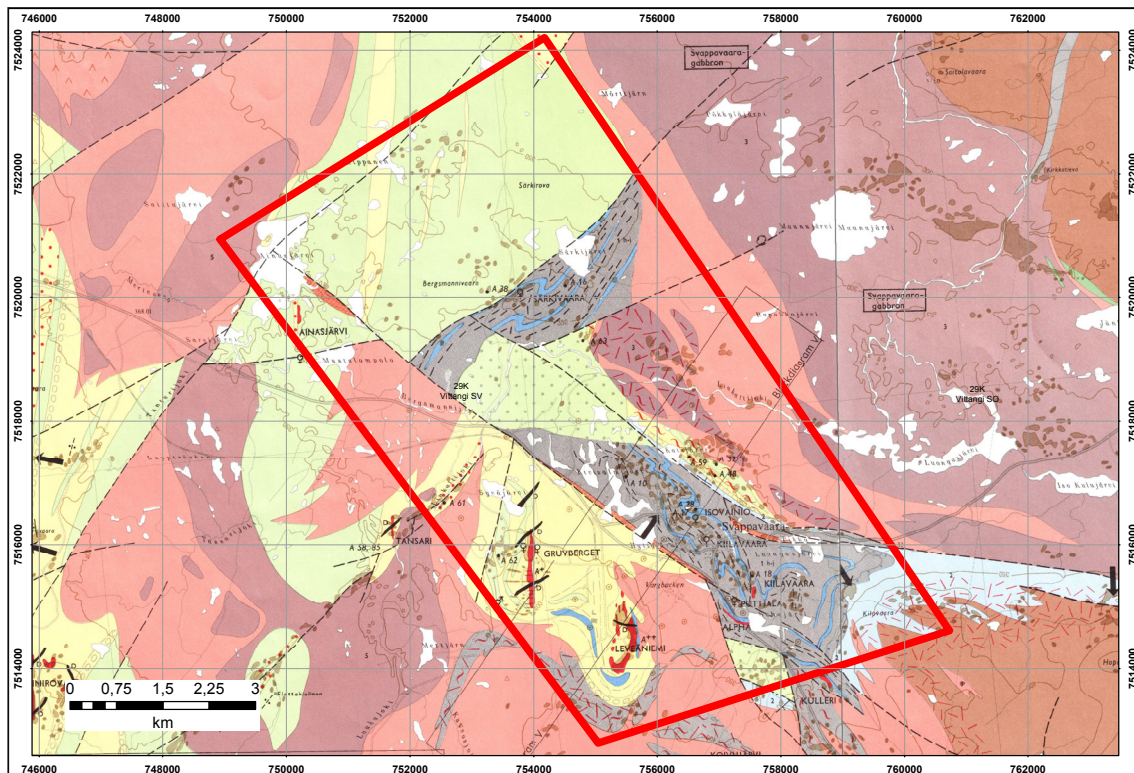
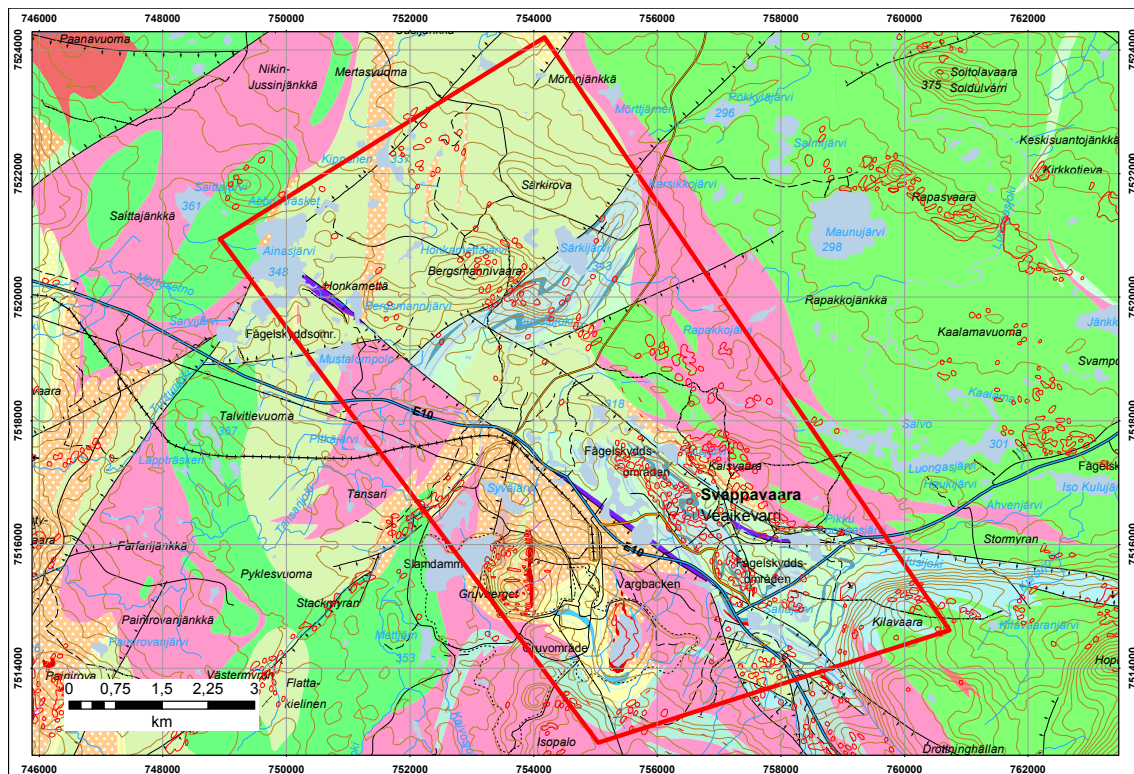


Fig. 1. Scanned geological maps Af 15 and Af 16 at local scale (1:50,000).



Tolkade strukturer, lokal

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

Textur, lokal

- ▬ Adrad (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.)
- ▬ Kvarts-fällspatrit sedimentär bergart (sandsten, grävacka m.m.)
- ▬ Glimmerrik omvandlad bergart (fyllit, skiffer, paragnejs m.m.)

Berggrundsytor, lokal (överbeteckningar)

- ▬ Porfyrisk eller ögonförande

Berggrundsytor, lokal

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

- ▬ Ryyolit; Svekokarelska orogena, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år

- ▬ Ryyolit; Svekokarelska orogena, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år

- ▬ Traktytoid-ryyolit; Svekokarelska orogena, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år

- ▬ Ryyolit; Svekokarelska orogena, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år

- ▬ Basalt-andesit; Svekokarelska orogena, metamorf ytbergart 2,05-1,96 miljarder år

- ▬ Basalt-andesit; Svekokarelska orogena, metamorf ytbergart 2,40-1,96 miljarder år

- ▬ Basalt-andesit; Svekokarelska orogena, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år

- ▬ Basalt-andesit; Svekokarelska orogena, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år

- ▬ Granitoid-syenitoid; Svekokarelska orogena, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år

- ▬ Granit; Svekokarelska orogena, intrusivbergart (GP), ställvis metamorf, och migmatit 1,82-1,74 miljarder år

- ▬ Granit; Svekokarelska orogena, intrusivbergart (GP), ställvis metamorf, 1,87-1,74 miljarder år

- ▬ Syenitoid-granit; Svekokarelska orogena, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år

- ▬ Gabbroid-dioritoid; Svekokarelska orogena, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år

- ▬ Gabbroid-dioritoid; Svekokarelska orogena, intrusivbergart (GSDG-GDG) och svekofennisk ytbergart, ställvis metamorf, 1,88-1,84 miljarder år

- ▬ Kvartsarenit; Svekokarelska orogena, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år

- ▬ Karbonatsten, marmor; Svekokarelska orogena, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år

- ▬ Kalksilikatbergart; Svekokarelska orogena, metamorf ytbergart 2,40-1,96 miljarder år

- ▬ Skiffer (schist); Svekokarelska orogena, metamorf ytbergart 2,40-1,96 miljarder år

- ▬ Grafitisk skiffer; Svekokarelska orogena, metamorf ytbergart 2,40-1,96 miljarder år

- ▬ Paragnejs; Svekokarelska orogena, metamorf ytbergart 2,40-1,96 miljarder år

- ▬ Paragnejs; Svekokarelska orogena, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år

- ▬ Järnmineralisering; Svekokarelska orogena, metamorf ytbergart 2,40-1,96 miljarder år

- ▬ Järnmineralisering; Svekokarelska orogena, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år

- ▬ Leukodiabas; Svekokarelska orogena, bergart med ospecificerad ålder

Fig. 2. Local vector-based bedrock map (1:50,000) of the Svappavaara area.

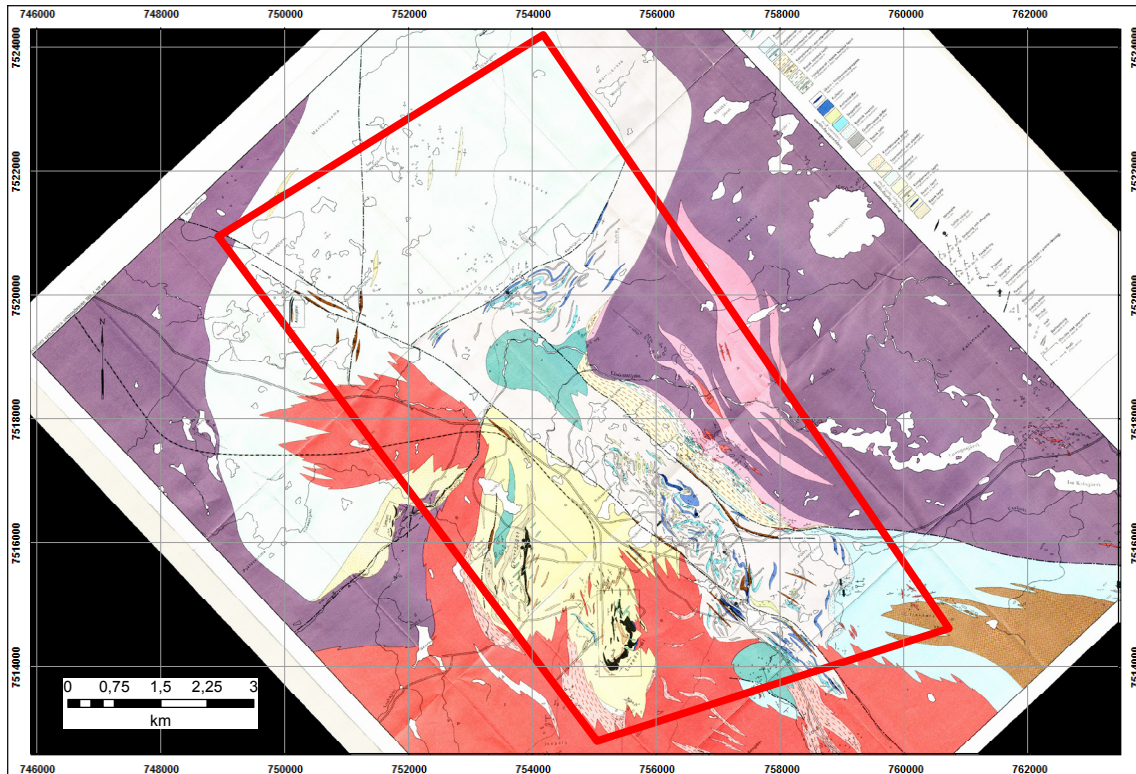


Fig. 3. Rectified and georeferenced scanned geological map by Frietsch (1966) at 1:20,000 scale, depicting the geological context of the Svappavaara ore district.

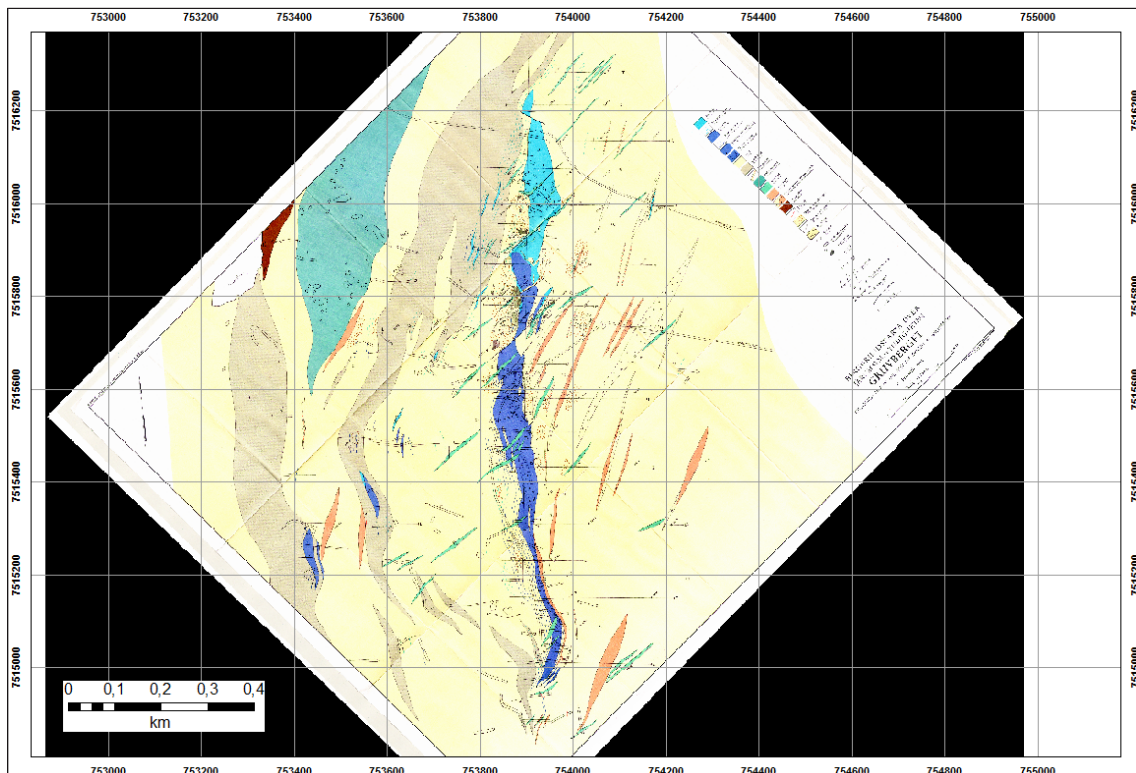
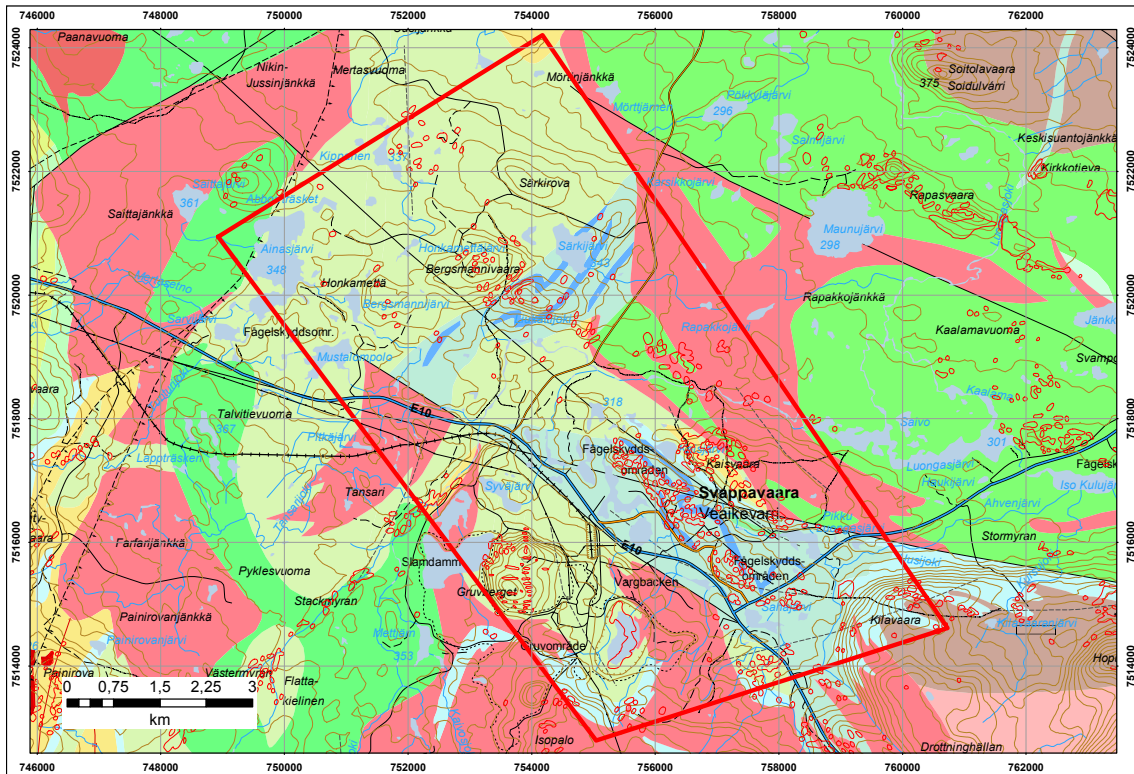


Fig. 4. Rectified and georeferenced scanned geological map by Frietsch (1966), depicting the geological context of the Gruvberget (Svappavaara) ore deposit.



Diverse punkter, regional

- ♂ Gruva, nedlagd
- * 134

135

- ▽ Uppslag

Strukturlinjer, regional

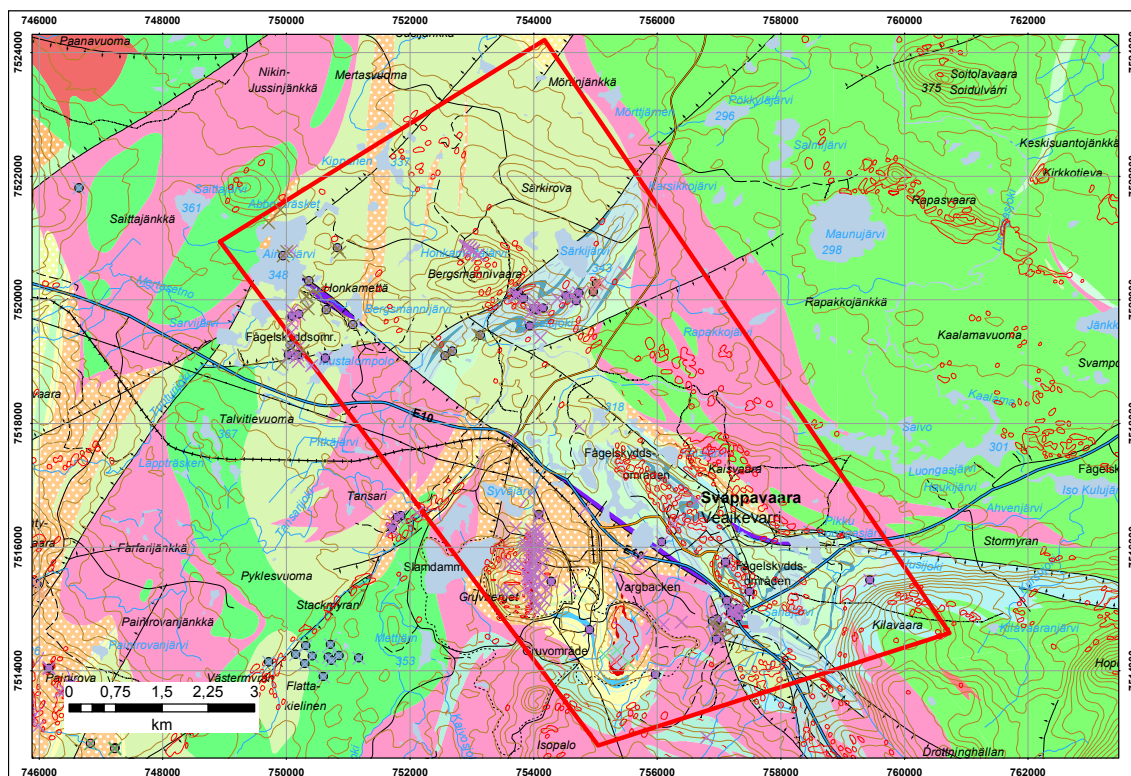
- Spröd deformationszon (förkastning, spricka, sprickzon)
- Plastisk skjuvzon
- ▮ Plastisk skjuvzon, symbolerna ligger i det sänkta blocket
- Synform
- Strukturell förmilnig, plastisk skjuvdeformation; Strukturell förmilnig, plastisk deformation
- Antiform

Berggrundsytor, regional

- Dacit-ryolit; Svekokarelska orogenen, intrusivbergart 1,92-1,87 miljarder år
- Dacit-ryolit; Svekokarelska orogenen, intrusivbergart (GSDG-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
- Basalt-andesit; Svekokarelska orogenen, intrusivbergart 2,05-1,96 miljarder år
- Basalt-andesit; Svekokarelska orogenen, 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 intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 miljarder år
- Granit; Svekokarelska orogenen, intrusivbergart (GP), ställvis metamorf, och migmatit 1,82-1,74 miljarder år
- Tonalit-granodiorit; Svekokarelska orogenen, metamorf intrusivbergart (GDG-GSDG) och svekofennisk ytbergart 1,92-1,87 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
- Diabas; 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
- Arenit; 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
- Karbonatsten, marmor; 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. 5. Regional bedrock map (1:250,000) of the Svappavaara area. Note that in comparison to the local bedrock map, especially the SW-NE striking faults seem to be missing, and some lithologies have been simplified.



Drillholes	Drillcores
✕ unknown	● LKAB
✕ LKAB	● Lkab prospektering
✕ Lkab prospektering	● NSG
✕ NSG	● Phelps Dodge Sweden AB
✕ Phelps Dodge Sweden AB	● Phelps Dodge Sweden AB/RTZ
✕ Phelps Dodge Sweden AB/RTZ	● Phelps dodge
✕ Phelps dodge	● SGU
✕ SGU	

Fig. 6. Drill sites in the Svappavaara area coloured after prospecting company. All of the cores within the key area are available at the SGU archive in Malå.

Mineralisations and alterations

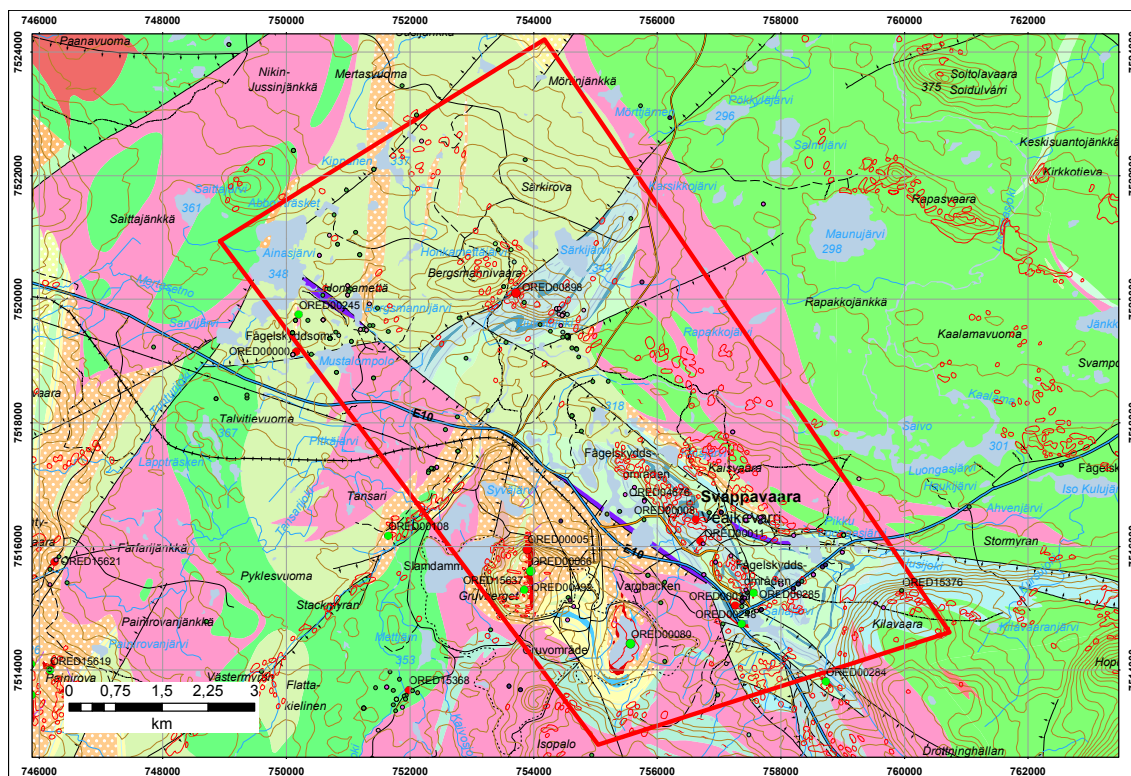
Several economically valuable mineral deposits exist within the key area, contributing to the development of the Svappavaara mining district. Iron ore and Cu-hosting sulphide deposits are the most common mineral deposits in the area (Fig. 7). The most important iron ore deposits are the Tansari, Gruvberget, and Leveäniemi deposits, Leveäniemi being the third largest apatite iron ore deposit in Norrbotten (Bergman et al., 2001). Information on the distribution and types of mineral deposits can be found in the SGU databases.

Mineralised boulders are also present (Fig. 7). The location of blocks is stored in the SGU databases.

Host rock alterations are wide-spread in the SVKA. Scapolitisation, skarn formation, as well as albitisation are the most frequent types of alterations (Fig. 8).

Litho- and till geochemistry

135 litho-geochemical analyses are available within the key area (Fig. 9). About one half of the whole-rock litho-geochemical data is derived from the map description to map sheets Af 13–16 (Vittangi) by Eriksson and Hallgren (1975) and the other half from the map de-



- | Mineralised boulders | Mineral Resources |
|----------------------|--|
| ● unknown | ● Iron mine, abandoned |
| ○ Bornite | ● Iron ore, trial pit or prospect |
| ● Chalcocite | ● Sulphide mine, abandoned |
| ● Chalcopyrite | ● Sulphide mineralization, trial pit or prospect |
| ● Galena | ▲ Quarry, industrial mineral, abandoned |
| ● Gold | □ Quarry, abandoned |
| ● Hematite | |
| ● Magnetite | |
| ● Molybdenite | |
| ● Nickel | |
| ● Pyrite | |
| ● Pyrrhotite | |
| ● Total sulphide | |

Fig. 7. Map showing mineral resources in the SVKA. Mineralised boulders are also shown.

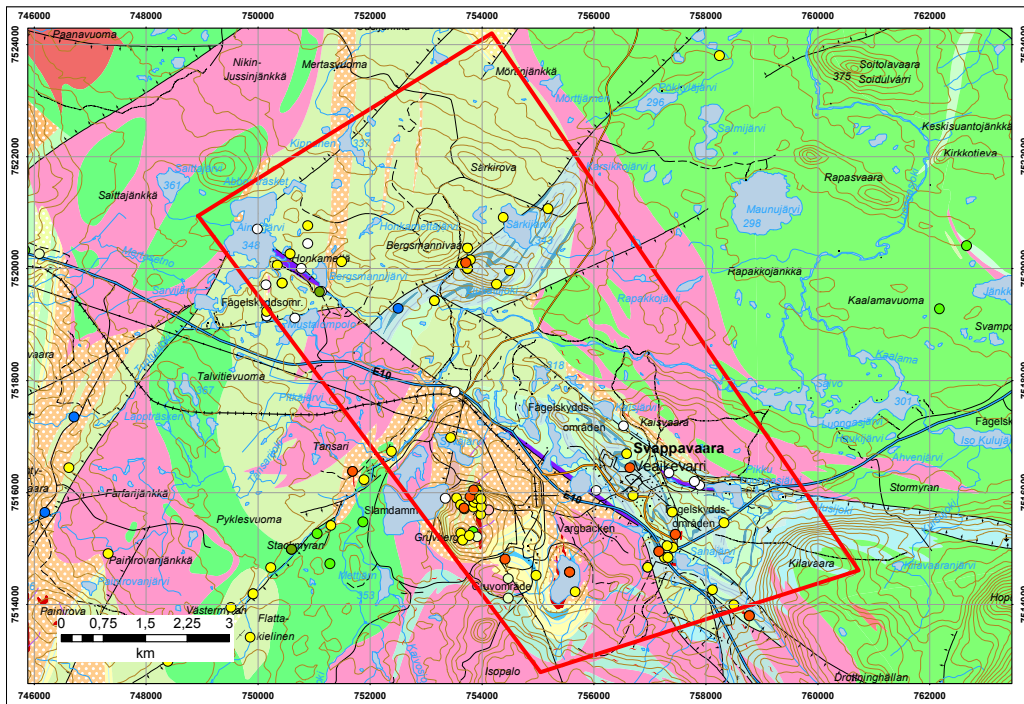
scription Ca 41 by Ödman (1957). Four samples from the Porphyry group were analysed by Perdahl & Frietsch (1993). Information on the type and distribution of samples taken for litho-geochemical analyses are found in SGU's databases.

No till geochemistry was undertaken in the key area.

Geochronology

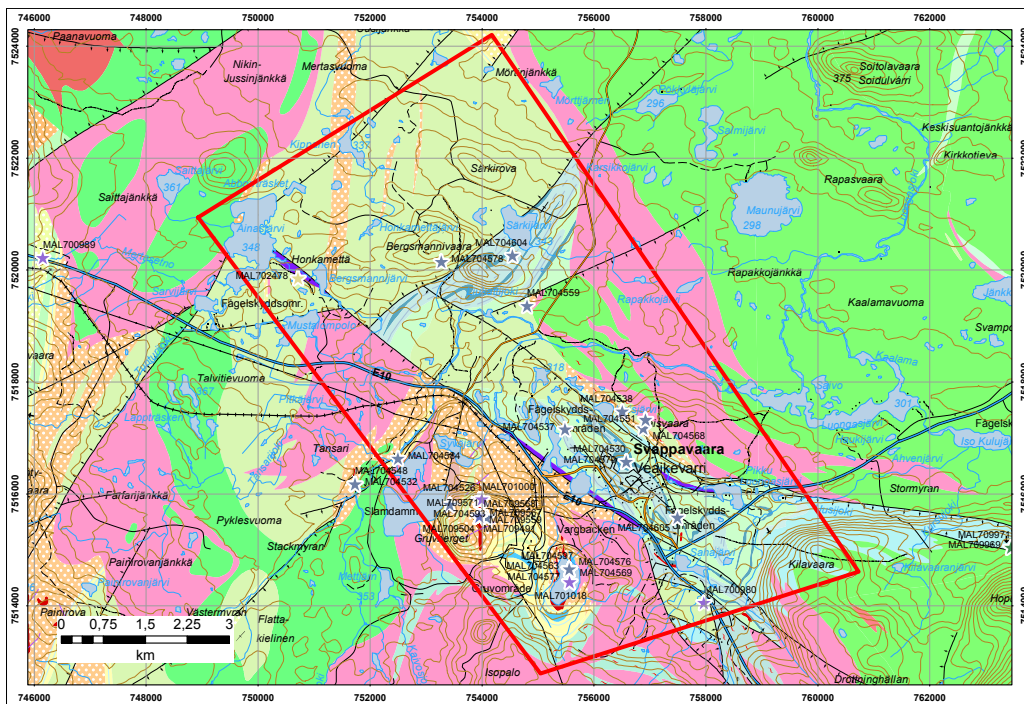
Protolith ages

Seven age determinations are available for the SVKA in the SGU databases (Fig. 10 and corresponding table 5). These include the ages derived by Storey et al. (2007) who have performed in situ U–Pb analyses of complex titanite in a potassic (ep-act-Kfsp) altered meta-volcanic rock from the Porphyry group at Gruvberget and have found that the titanite core



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

Fig. 8. Map showing the distribution of available data on mineral alterations.



Litho-geochemistry

- ★ Frietsch, Perdahl, 1993
- ★ Frietsch & Perdahl, 1989
- ★ Martinsson, unpublished
- ★ SGU Af 13,14,15,16
- ★ SGU Ca 41

Fig. 9. Sample locations for litho-geochemistry (stars). The colours indicate the source from which the geochemical data was derived.

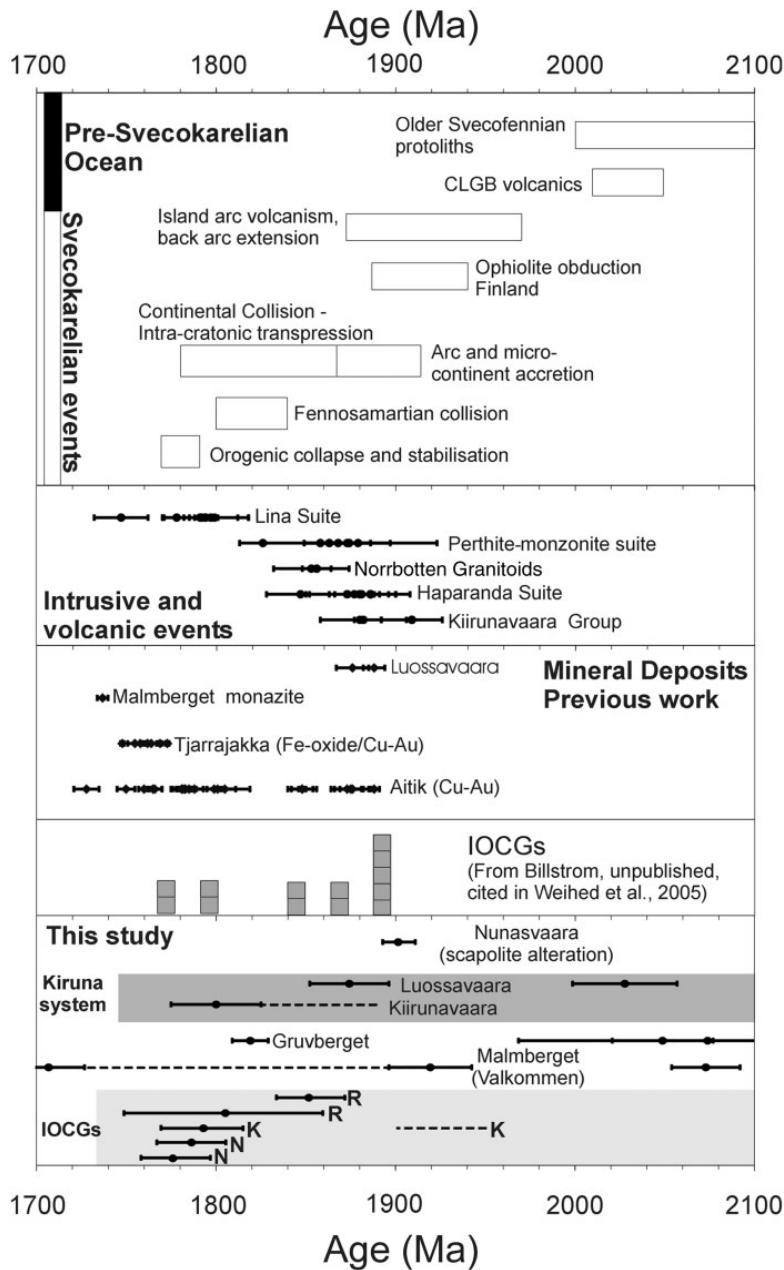
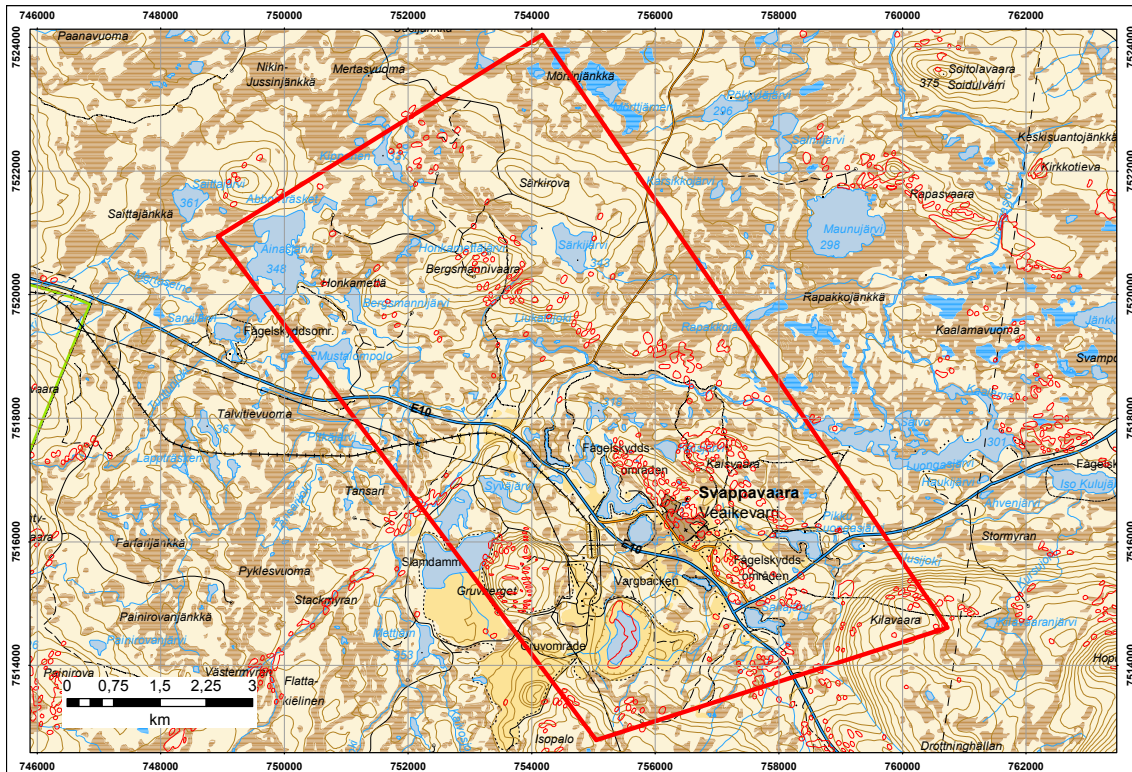


Fig. 11. From Smith et al. (2009): their Fig. 17 and their figure caption: Summary of key events in the evolution of the Fennoscandian Shield compared with previous geochronological data from the Norrbotten region and this study. Data from the reviews of Nironen (1997), Bergman et al. (2001) and Weihed et al. (2005). Other data from Romer et al. (1994) (Luossavaara); Romer et al. (1996) (Valkommen); Lahtinen et al. (2002) (older Svecofennian protoliths); Edfelt et al. (2005) (Tjarrajakka); Wanhainen et al. (2005) (Aitik). Data for other IOCGs are unpublished data from K. Billström cited by Weihed et al. (2005). K, Kallosalmi; R, Rakkurijärvi; N, Nautanen. Points indicate weighted mean ages from this study, except in the case of Malmberget where limiting single analyses are shown. Dashed lines indicate either single analyses or ranges inferred from the spread of data along concordia and cumulative probability plots.



- | | |
|--|--|
| ○ Vändplan | — Allmän väg 5-7m, klass 2, ej riksväg |
| ✕ Elljusspår | — Gata |
| ✕ Mast | — Enskild bättre bilväg |
| • Hus, storleksklass 1 | — Enskild bilväg/gata, större - Matarväg |
| • Hus, storleksklass 2 | — Enskild bilväg |
| + Kyrka, mindre | — Enskild sämre bilväg |
| ⊕ Biologiskt naturminne | — Enskild uppfartsväg |
| • Höjdpunkt | ·· Anläggningsområde, streckad linje |
| — Odlingsgräns | — Naturreservat |
| — Höjdkurva | — Djurskyddsområde |
| — Skärning | --- Gångstig |
| — Gropkurva | — Vattendrag 1 |
| — Kraftledning, region | — Vattendrag 3 |
| + Järnväg med enkelspår, elektrifierad | — Strandlinje |
| — Allmän väg > 7m, klass 1, riksväg | — Bebyggelsebegränsning |
| — Allmän väg 5-7m, klass 2, ej riksväg | ■ Vatten |
| — Gata | ■ Vatten |
| — Enskild bättre bilväg | ■ Bebyggelseområde |
| — Enskild bilväg/gata, större - Matarväg | ■ Skog |
| — Enskild bilväg | ■ Öppen mark |
| — Enskild sämre bilväg | ■ Sankmark, svårframkomlig (blåmyr) |
| — Enskild uppfartsväg | ■ Sankmark, normal, skogklädd (brunmyr) |
| — Allmän väg > 7m, klass 1, riksväg | ■ Sankmark, normal, öppen (brunmyr) |

Fig. 12. Exemplary topographic map.

Topographic maps

Topographic and infrastructural maps (Fig. 12) from Lantmäteriet are available in the SGU database in both raster- and vector formats.

Aerial photographs

Aerial photographs (Fig. 13) are available in digital format. Aerial photographs can also be viewed in infrared spectral colours.

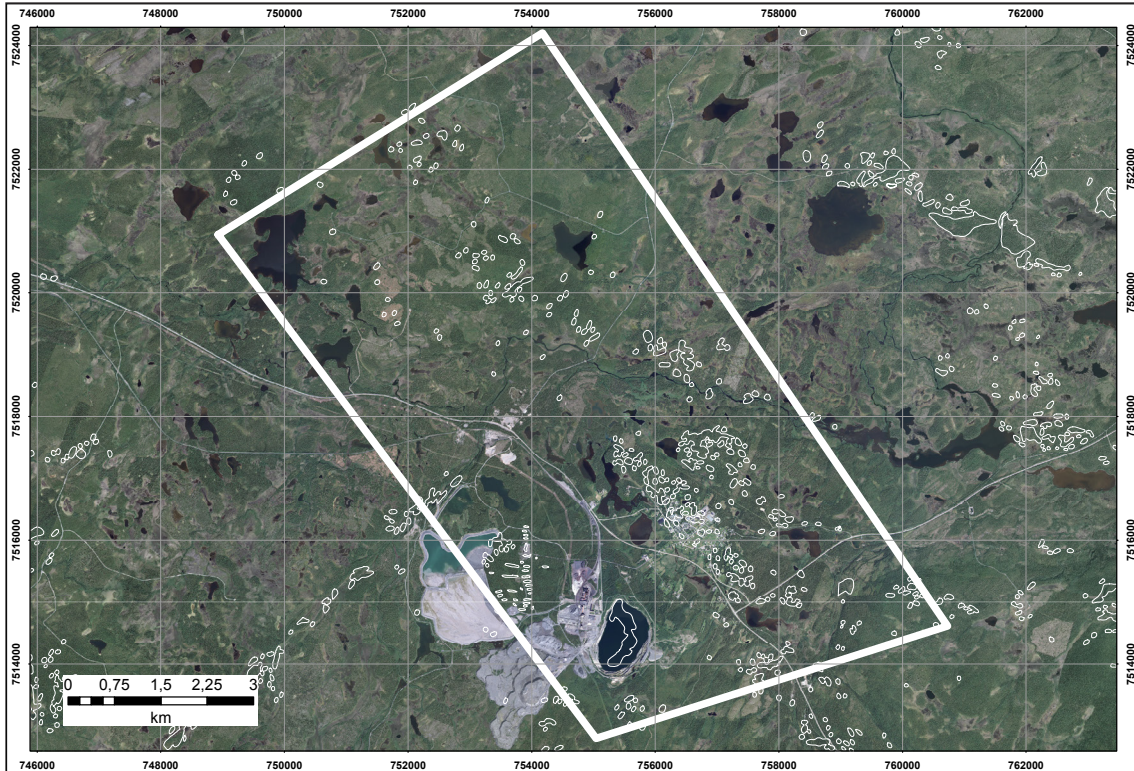


Fig. 13. Aerial photograph of the SVKA. The areas affected by mining are easily recognisable. Red polygons are sites of outcropping bedrock.

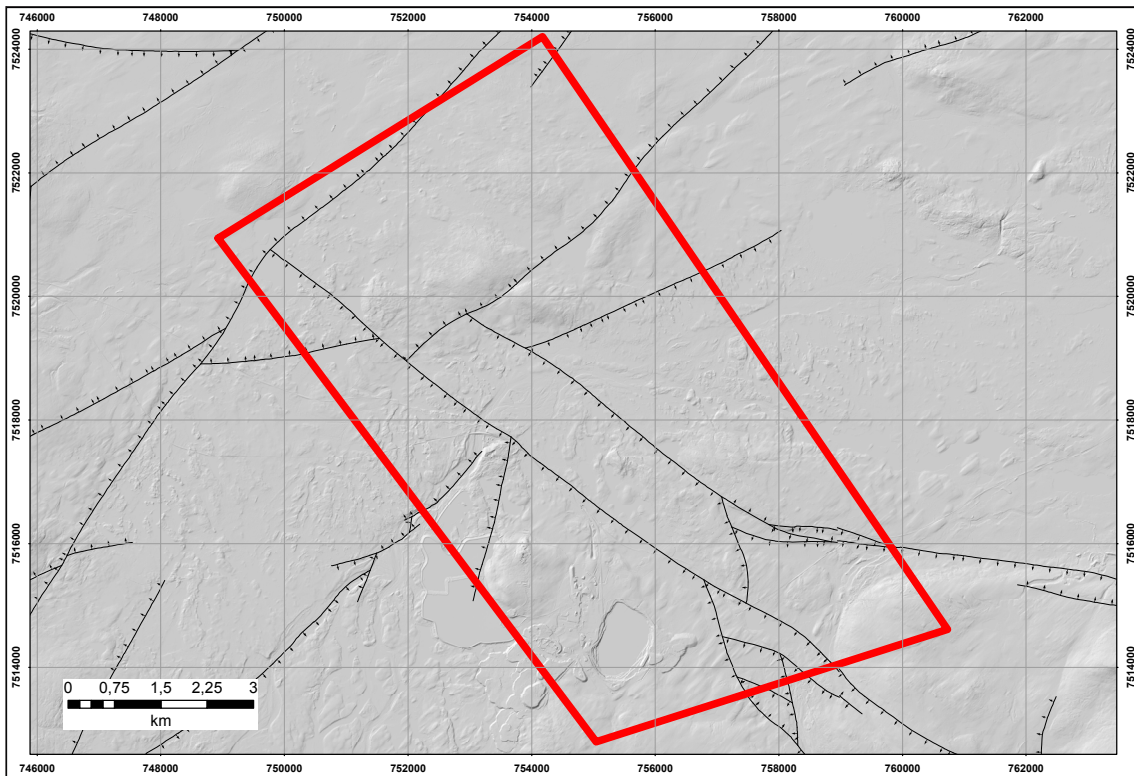
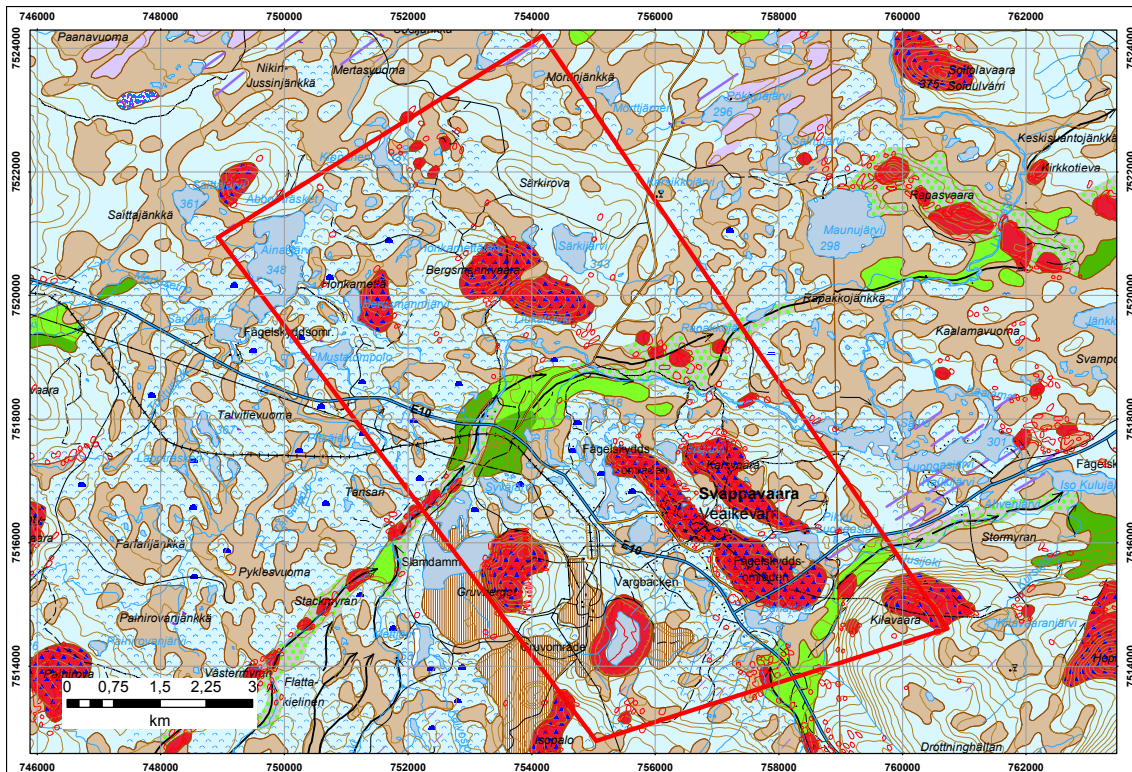


Fig. 14. Digital elevation model of the SVKA. Some of the faults are expressed in the geomorphology of the area. Resolution 2 metres.



Punkter	Landform
— Blocksänka	— Blocksänka
— Dyn	— Moränbacklandskap
— Moränformer, starkt brutna	— Drumlin, mindre utpräglad
— Källa	— Starkt brutna positiva former
Linjer	— Isälvsroderat område
— Räfflad morän	Grundlager
— Drumlinisering	— Torv (kärr eller ospec.)
— Isälvsrännna, > 50 m bred	— Isälvs sediment, sand-block
— Isälvsrännna, < 50 m bred	— Morän, sandig eller morän ospec.
Gränser	— Blockjord
— Gränser	— Berg, urberg eller ospec.
Blockighet	— Fyllning
— Blockrik moränyta eller blockjord	— Vatten
Ytlager 1	
— Isälvs sediment, sand-block	

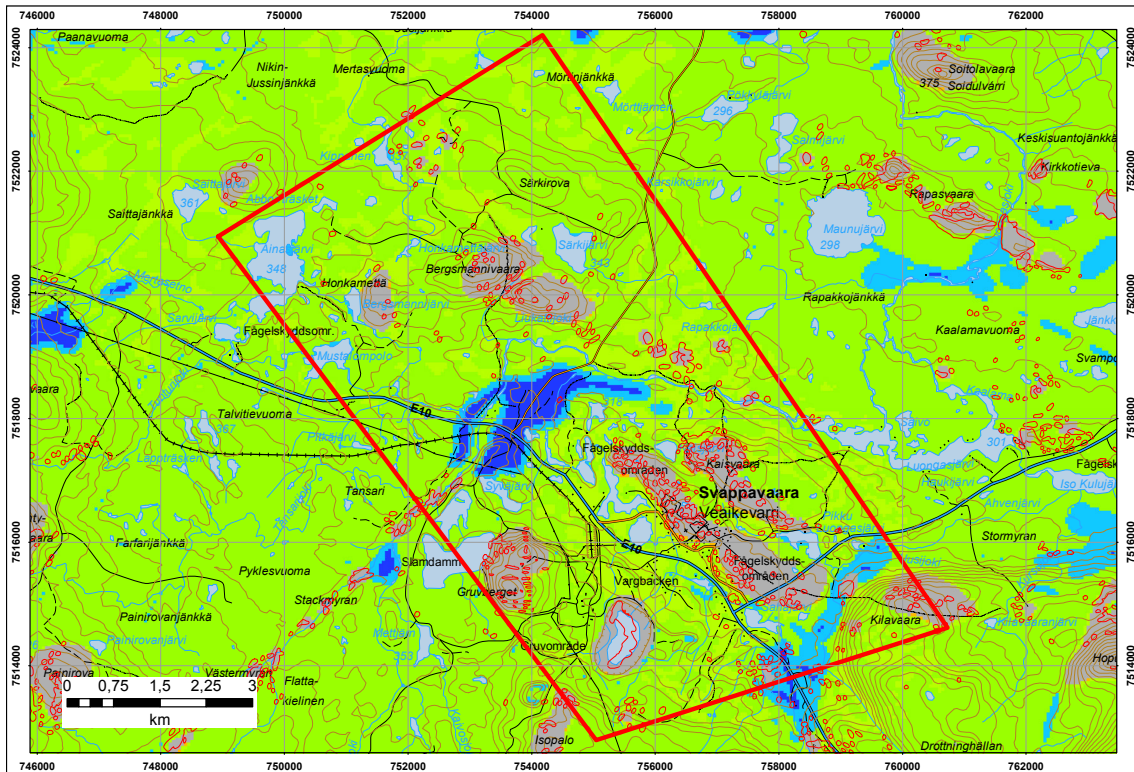
Fig. 15. Soil map with red areas indicating potential exposure of bedrock.

LiDAR data, Digital Elevation Model (DEM)

The Svappavaara region is covered by raster LiDAR data with a resolution of 2 metres. Notice how several of the SW–NE and NW–SE striking faults can be recognised directly in the DEM model (Fig. 14).

Outcrop situation and access

Due to mining activities, there are numerous paved and unpaved roads which allow access to most parts of the key area. The frequency of outcrops seems to be reasonably high (Figs. 15, 16). However, it is possible that some deep weathering of the rocks may obliterate primary geological structures and mineral composition in that area. In order to characterise the volcanic and sedimentary rocks it is probably most sensible to perform core logging on chosen



Soil depth in (m)

- m**
- 0
 - 0-1
 - 1-3
 - 3-5
 - 5-10
 - 10-20
 - 20-30

Fig. 16. Map of soil depth. May be used to determine more bedrock outcrops.

Table 6: A complete list over the airborne geophysical surveys that have been made over the SVKA.

Year	Company	Geophysical methods used	Area	Flight direction	Flight line separation (m)	Flight altitude (m)
1962	SGU	Magnetics	29K SV & 29K SO	E-W	200	30
1972	SGU	Magnetics, gamma spectrometry	Entire 29K	E-W	200	30
1975	SGU	Magnetics, gamma spectrometry, VLF (1-transmitter)	Part of 29K SV	E-W	200	30
1976	SGU	Magnetics, gamma spectrometry, VLF (1-transmitter)	Almost entire 29K	E-W	200	30
1983	LKAB	Magnetics, gamma spectrometry, VLF (2-transmitters), slingram	29K SV & 29K SO (projekt R7)	E-W	200	30

drill cores. It is questionable whether folding structures can be recognised in the field. This could potentially be solved by using a combination of ground geophysical measurements and structural mapping.

Geophysics

Airborne data

Several airborne geophysical surveys have been made over the SVKA. A comprehensive list over these measurements can be found in table 6. During 1962, SGU made airborne surveys over the southern part of map sheet 29K. Their geophysical instrumentation consisted of a fluxgate magnetometer. In 1972, SGU made a new airborne survey over the entire map sheet 29K. The fluxgate magnetometer had been replaced with a trums and a gamma spec-

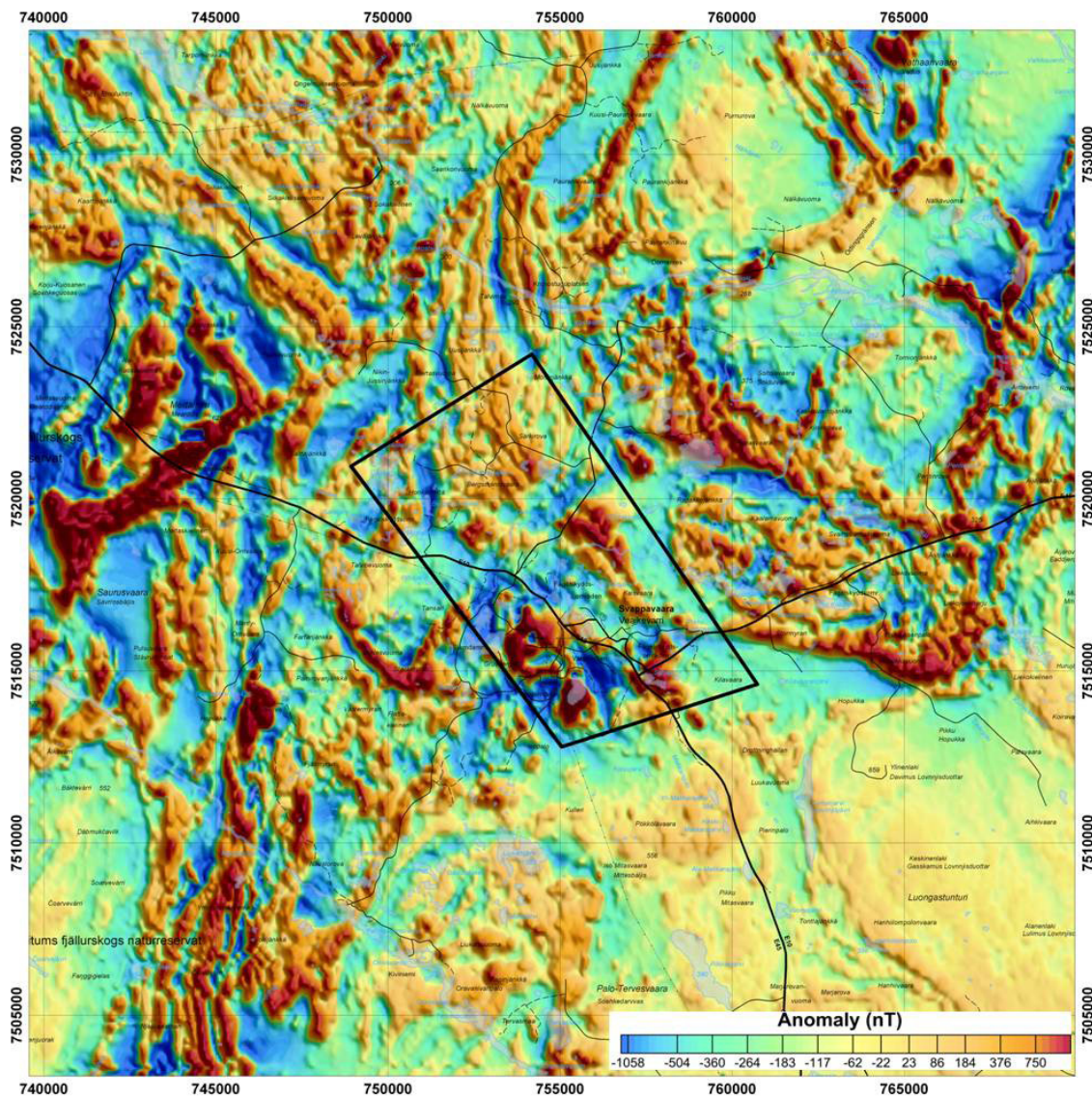


Fig. 17. The magnetic anomaly map within the SVKA (shown as a black polygon in the middle of the map) and its surroundings. The map is derived from the newest airborne magnetic data and has been filtered in order to enhance the magnetic response from more shallow seated lithologies. The iron ore deposits Leveäniemi and Gruvberget are easily recognisable as the high magnetic anomalies in the SW-corner of the area.

trometer had been added to the geophysical equipment. The next two airborne surveys over the SVKA, made in 1975 and 1976, was equipped with a trums magnetometer, gamma spectrometer and a VLF-receiver, capable of acquiring electromagnetic data from one transmitter. In 1983, LKAB made an airborne survey over the southern part of map sheet 29K. Among their geophysical equipment was a VLF-receiver capable of acquiring electromagnetic data from two independent transmitters, thus making it possible to map conductive features in the ground independent of their strike direction with respect to the VLF-transmitter.

All of the airborne geophysical surveys made over SVKA have been executed at 30 m above ground level, with 200 m flight line separation and along east–west flight lines, which pin-points magnetic structures trending north–south more accurate than those trending east–west. A magnetic anomaly map over the SVKA and its surroundings is shown in Fig. 17.

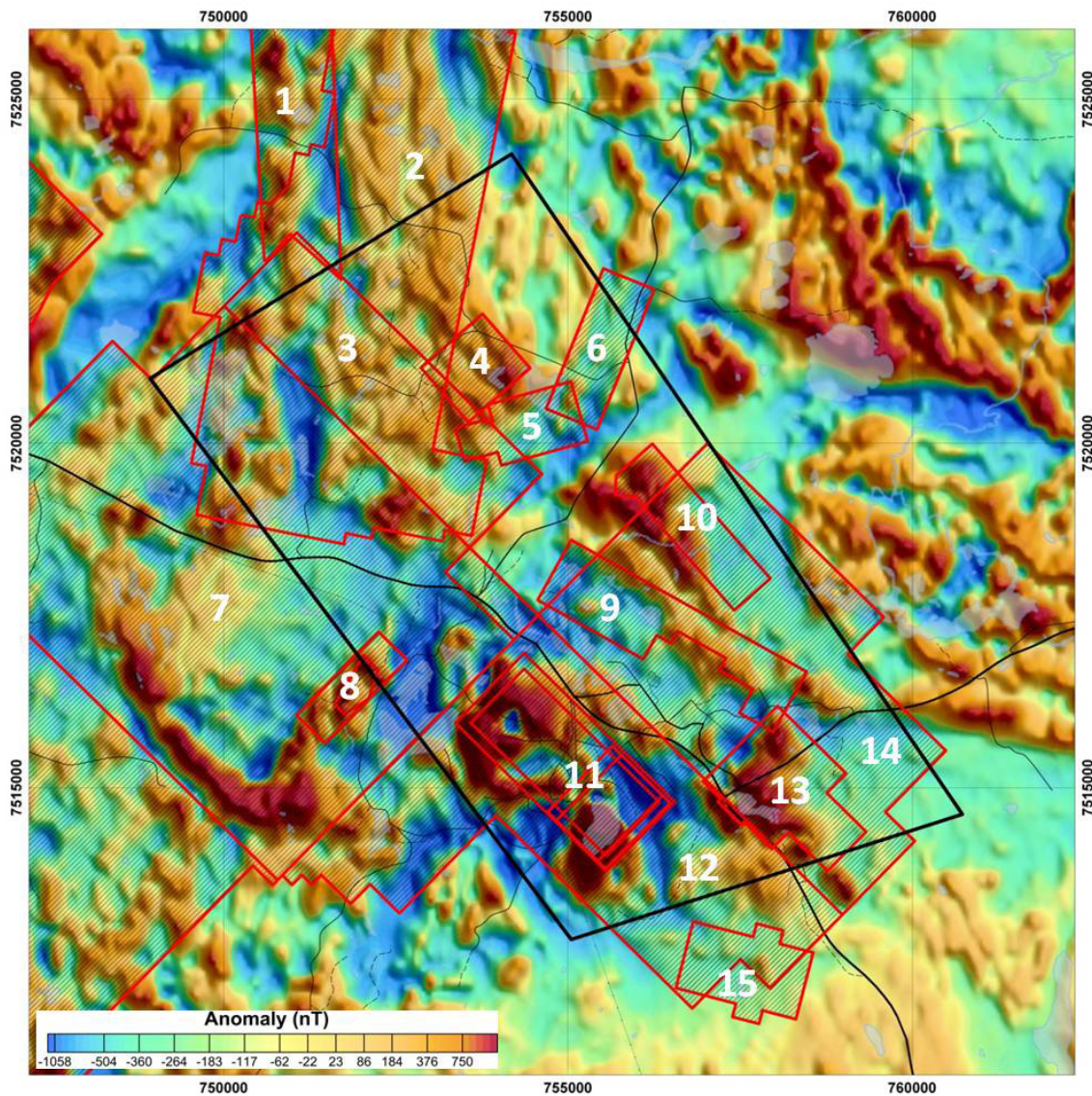


Fig. 18. The magnetic anomaly map within the SVKA and its closest surroundings. The red polygons represent the distribution of ground magnetic surveys. Explanations for the numbered polygons can be seen in table 7.

Table 7. A list over the magnetic ground surveys within the Svappavaara key area and its closest surrounding. The numbers in column "Polygon nr" refer to those found in figure 18.

Polygon nr	Name	Method	Operator	Year of measurement
1	Puonajokki	Magnetometer	SGU	1961-1962
2	Ainasjärvi	Magnetometer Z-anomaly	SGU	1976
2	Ainasjärvi	Mag-Askania	No information	1979
3	Särkirova	Magnetometer	SGU	1959-1962
4	Hopukka	Magnetometer	LKAB	1978
5	Särkijärvi 2	Magnetometer T-anomaly	LKAB Prosp. AB	1980
6	Särkijärvi	Magnetometer T-anomaly	LKAB Prosp. AB	1979
7	Tansari	Magnetometer	SGU	1957-1962
8	Tansari	Magnetometer tibergrsvåg	W Thisell	1902
8	Tansari	Magnetometer	SGU	1958
9	Svappavaara	Magnetometer Z-anomaly	SGU	1979
9	Magsvapp	Magnetometer	No information	1979
10	Jokijänkkä	Magnetometer	LKAB	1978
11	Gruvberget	Magnetometer 2:deriv	SGU	1957?
11	Gruvberget	Magnetometer 1:deriv	SGU	1957?
11	Leveäniemi	Magnetometer	SGU	1957-1958
11	Leveäniemi	Magnetometer	SGU	1957-1958
12	Gruvberget	Magnetometer	SGU	1957?
13	Sahajärvi	Magnetometer	SGU	1959
14	Kiilavaara	Magnetometer	SGU	1959-1960
15	Koivujärvi	Magnetometer T-anomaly	LKAB Prosp. AB	1978

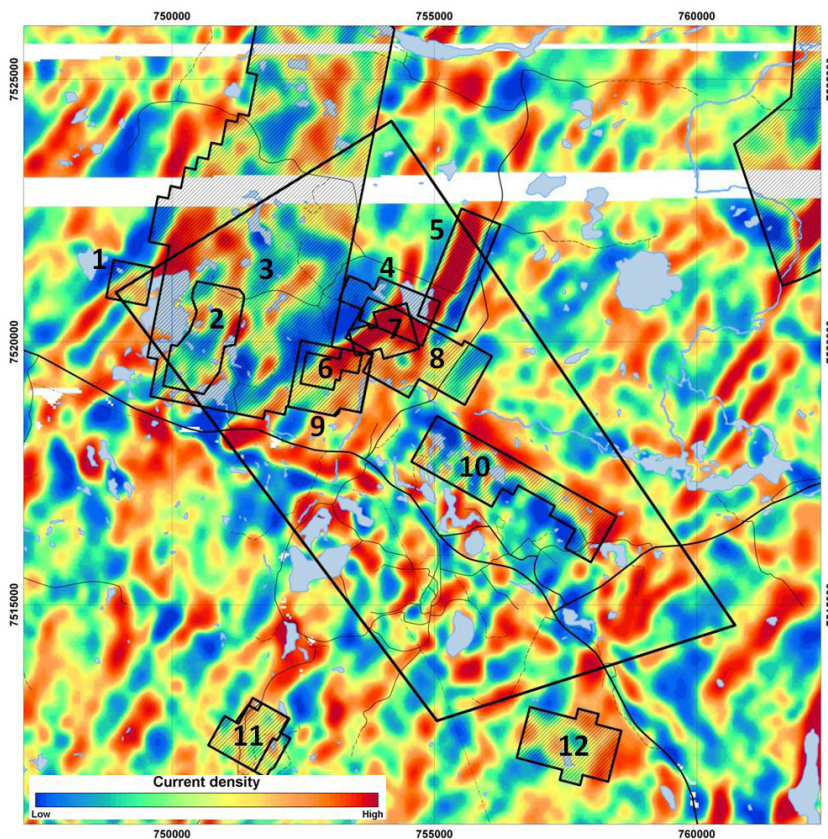


Fig. 19. Map over the current density within the SVKA and its closest surroundings. The map is based on airborne VLF-data from two transmitters. The black polygons with hatches represent locations where ground geoelectric and/or electromagnetic surveys have been made. Explanations for the numbered polygons can be seen in table 8.

Table 8. Summary of the geoelectric and electromagnetic ground surveys within the SVKA and its closest surrounding. The numbers in column “Polygon nr” refer to those found in figure 20.

Polygon nr	Name	Method	Operator	Year of measurement
1	Ainasjärvi	IP, SP, kond.	SGU	1968
2	Ainasjärvi	IP, R, SP	SGU	1976
3	Ainasjärvi	Slingram	SGU	1977
3	Ainasjärvi	Slingram	No information	1994
4	Särkijärvi 1	Slingram	LKAB	1979
5	Särkijärvi	Slingram	LKAB Prosp. AB	1979
6	Ainasjärvi	Slingram	SGU	1978
7	Särkijärvi 2	Slingram	LKAB Prosp. AB	1980
8	Ainasjärvi	Slingram	SGU	1968
9	Ainasjärvi	IP, R, SP	SGU	1978
10	Svappavaara	Slingram	SGU	1979
10	Svappavaara	Slingram	No information	1979
11	Puttjala	IP	SGU	1969
11	Puttjala	IP, SP, kond.	SGU	1969
12	Koivujärvi	Resistivity	LKAB Prosp. AB	1978
12	Koivujärvi	VLF	LKAB Prosp. AB	1978

Ground-based data

Magnetics

There have been extensive measurements within the Svappavaara key area where detailed, ground based magnetometer surveys have been made (Fig. 18). Almost the entire area is covered by these measurements and a comprehensive list can be found in table 7.

Electromagnetics

The newest airborne geophysical survey over the SVKA was made in 1983. In that survey, VLF-information from two transmitters was acquired. The information can then be used to produce maps which show how the electrical conductivity varies in the ground (Fig. 19) independent of their strike direction with respect to the VLF-transmitter. Red areas in Fig. 19 represent features with higher electrical conductivity compared to those shown in blue.

There are several areas within the SVKA where detailed ground geoelectric or electromagnetic measurements have been made. A comprehensive list over these surveys can be found in table 8.

Gravity

The regional gravity measurements at the SVKA have been made with station spacing of approximately 1 km (Fig. 20). Lithologies with higher densities give rise to positive gravity anomalies compared to more felsic bedrock units which can be seen as negative anomalies in the gravity map. There are areas within the southern part of SVKA where dense gravity measurements have been made. A comprehensive list over these measurements can be found in table 9.

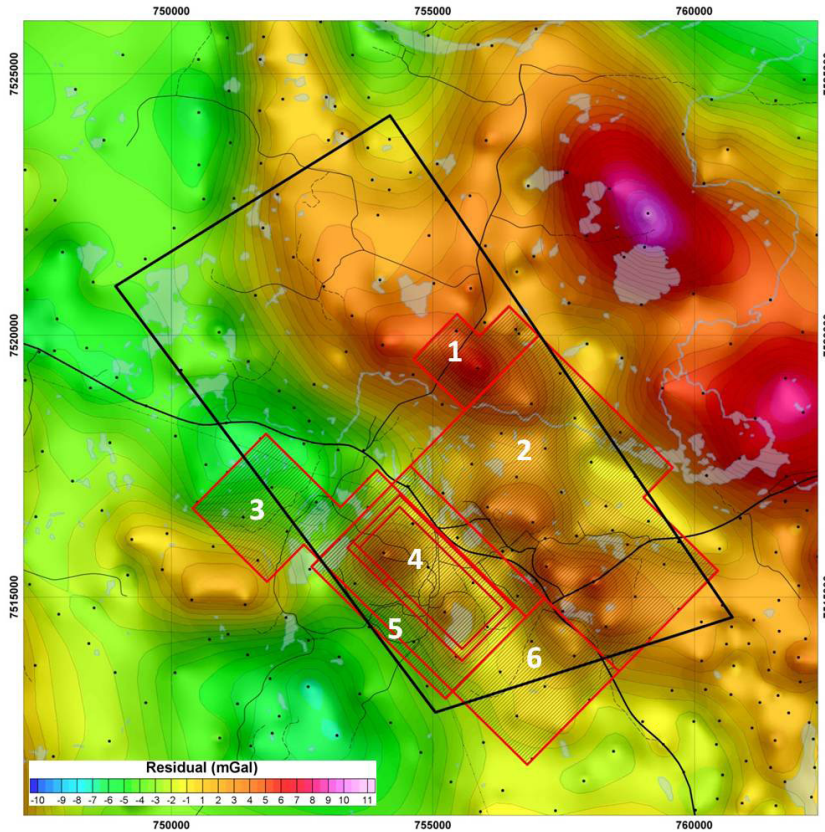


Fig. 20. The residual gravity field within the SVKA and its closest surroundings. The gravity data has been filtered to enhance more shallow seated density variations in the bedrock. Black dots represent regional gravity measurements. The red polygons represent areas where more detailed measurements have been made. Explanations for the numbered polygons can be seen in table 9.

Table 9. A list over the dense gravity surveys within the SVKA and its closest surrounding. The numbers in column "Polygon nr" refer to those found in figure 21

Polygon nr	Name	Method	Operator	Year of measurement
1	Särkirova	Gravimeter	SGU	1961
2	Kiilavaara	Gravimeter terrain corrected Bouguer anomaly	SGU	1959-1961
3	Tansari	Gravimeter terr corr + Bouguer anom + 1 derv	SGU	1957-1959
4	Gruvberget	Gravimeter terrain corrected Wzzz	SGU	1957?
4	Gruvberget	Gravimeter 2:deriv	SGU	1957?
4	Gruvberget	Gravimeter 1:deriv Bouguer anomaly	SGU	1957?
5	Gruvberget	Gravimeter regional	SGU	1957-1958
5	Gruvberget	Gravimeter terrain corrected	SGU	1957?
5	Gruvberget	Gravimeter local anomaly	SGU	1957-1958
5	Gruvberget	Gravimeter Bouguer anomaly	SGU	1957-1958
6	Gruvberget	Gravimeter terrain corrected Bouguer anomaly	SGU	1957-1958

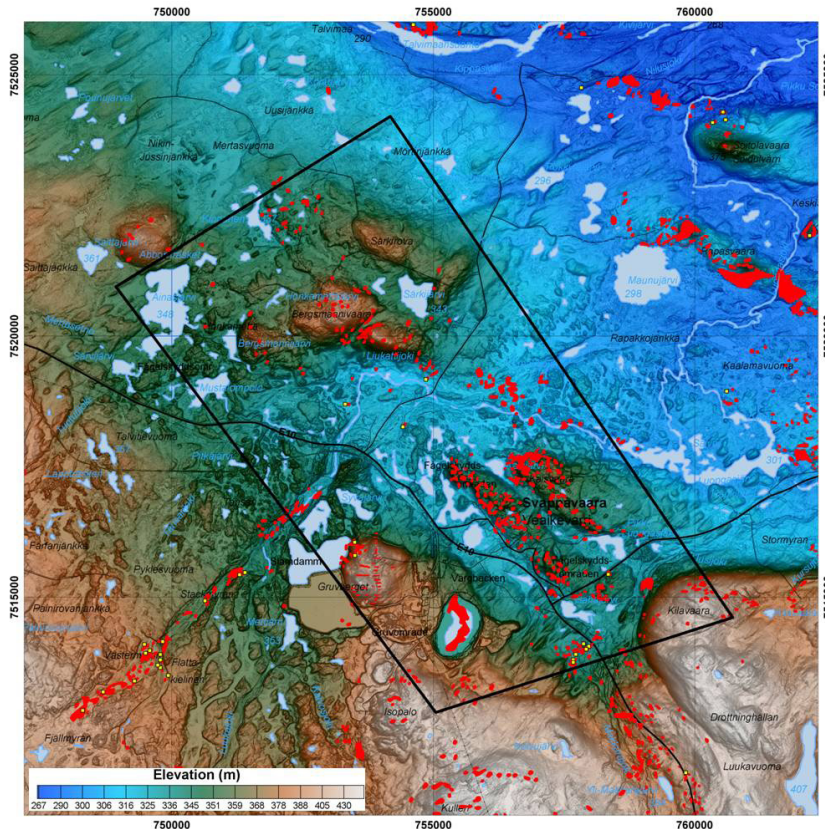


Fig. 21. The topography within the SVKA and its closest surroundings. The variations in topography are based on LiDAR data (2x2 m DEM). The red polygons represent outcrops and yellow dots show the location for existing petrophysical samples.

Petrophysics

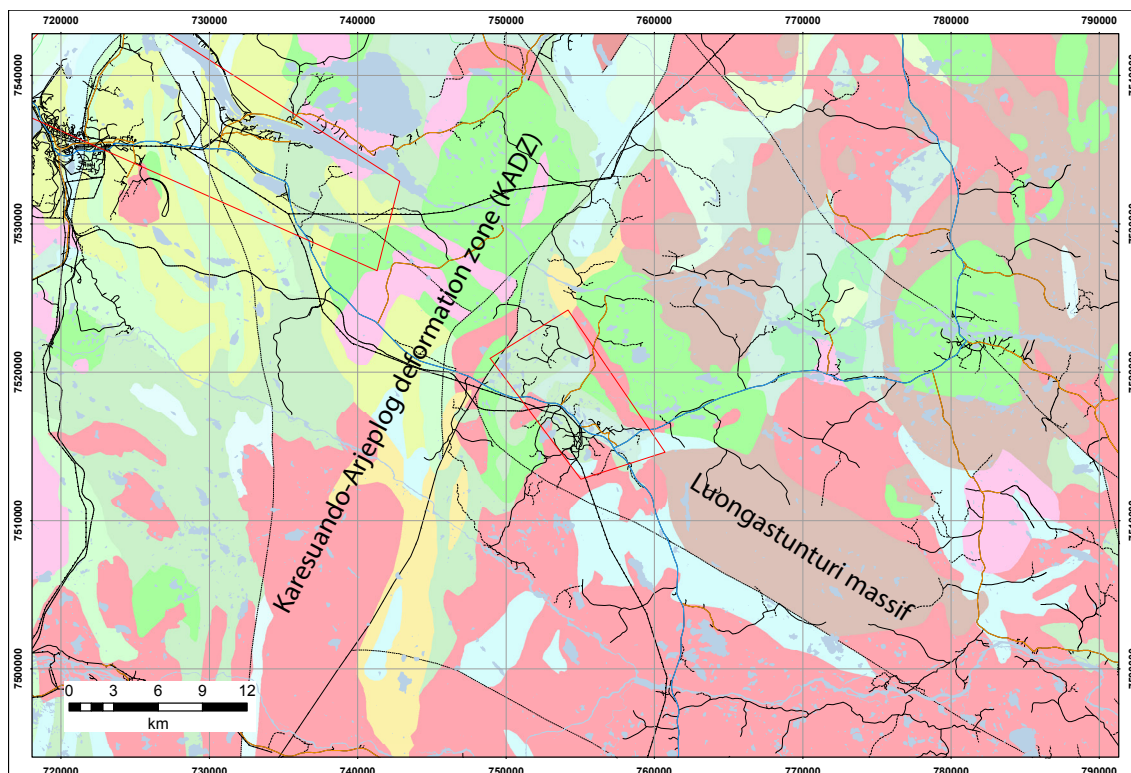
There are currently only 12 petrophysical bedrock samples registered in SGU's database from the SVKA and they are mainly gathered from basalt–andesite (Porphyry group) in the southernmost part of the SVKA. The geographical distribution of these samples can be seen in Fig. 21 along with the outcrops and topographic variations. All of the samples have data regarding density, magnetic susceptibility and Königsberger ratio. The majority of samples is oriented, thus making it possible to determine which direction their remanent magnetisation has with respect to the Earth's magnetic field.

SUMMARY

Stratigraphy and lithology of the supracrustal rocks of the SVKA

The Svappavaara key area (SVKA) extends between the major SW–NE trending, locally dextral Karesuando–Arjeplog deformation zone (KADZ) to the NW and the intrusive rocks of the NW–SE oriented Luongastunturi massif to the SE (Fig. 22). To the SW, it is bound by a nameless deformation zone striking NW–SE, paralleling the Nautanen deformation zone (NDZ) some 60 km further southwest.

All rocks occurring in the key area are Paleoproterozoic in age. The stratigraphic succession in the Vittangi/Svappavaara area has been extensively discussed and described in several publications (e.g., Bergman et al., 2001; Martinsson 1997; Martinsson 1993; Gustafsson 1993; Eriksson & Hallgren 1975; Frietsch 1966). It is summarised in Fig. 23 and put in a



Deformationszoner, 1:1M

- Spröd till plastisk deformationszon, högervriden (dextral) horisontell rörelsekomponent
- Spröd till plastisk deformationszon, ospecificerad rörelse

Berggrundslinjer, 1:1M

- 634; Gabbro, diabas (ca 2,3-2,0 miljarder år), metamorfa; Svekokarelska orogener; Paleoproterozoiska bergarter 2,44-1,96 miljarder år

Berggrundsytor, 1:1M

- 624; Rylvit, dacit (ca 1,91-1,88 miljarder år), metamorfa; Svekokarelska orogener; Paleoproterozoiska bergarter 1,96-1,75 miljarder år
- 617; Rylvit, dacit och metamorfa ekvivalenter (ca 1,88-1,86 miljarder år); Svekokarelska orogener; Paleoproterozoiska bergarter 1,96-1,75 miljarder år
- 636; Basalt, komatiit (ca 2,3-2,05 miljarder år), metamorfa; Svekokarelska orogener; Paleoproterozoiska bergarter 2,44-1,96 miljarder år
- 633; Basalt, andesit (ca 2,05-1,96 miljarder år), metamorfa; Svekokarelska orogener; Paleoproterozoiska bergarter 2,44-1,96 miljarder år

- 616; Basalt, trakandesit, andesit, komatiit och metamorfa ekvivalenter (ca 1,88-1,86 miljarder år); Svekokarelska orogener; Paleoproterozoiska bergarter 1,96-1,75 miljarder år

- 615; Granit, syenitoid och metamorfa ekvivalenter (ca 1,88-1,87 miljarder år); Svekokarelska orogener; Paleoproterozoiska bergarter 1,96-1,75 miljarder år

- 607; Granit, pegmatit (1,85-1,75 miljarder år); Svekokarelska orogener; Paleoproterozoiska bergarter 1,96-1,75 miljarder år

- 619; Granitoid och underordnad syenitoid (ca 1,91-1,87 miljarder år), metamorfa; Svekokarelska orogener; Paleoproterozoiska bergarter 1,96-1,75 miljarder år

- 601; Granit, granodiorit, syenitoid, kvartsmonzodiorit och metamorfa ekvivalenter (1,8 miljarder år); Svekokarelska orogener; Paleoproterozoiska bergarter 1,96-1,75 miljarder år

- 623; Basalt, andesit och underordnad dacit (ca 1,91-1,88 miljarder år), metamorfa; Svekokarelska orogener; Paleoproterozoiska bergarter 1,96-1,75 miljarder år

- 634; Gabbro, diabas (ca 2,3-2,0 miljarder år), metamorfa; Svekokarelska orogener; Paleoproterozoiska bergarter 2,44-1,96 miljarder år

- 620; Gabbro, dioritoid, diabas, ultrabasisk bergart och metamorfa ekvivalenter (ca 1,91-1,87 miljarder år); Svekokarelska orogener; Paleoproterozoiska bergarter 1,96-1,75 miljarder år

- 625; Metagrävacka, glimmerskiffer, grafit- och/eller sulfidförande skiffer, paragnejs, migmatit, kvartsit, amfibolit (ca 1,96-1,87 miljarder år); Svekokarelska orogener; Paleoproterozoiska bergarter 1,96-1,75 miljarder år

- 621; Sandsten, slamsten, konglomerat, vulkanisk bergart (ca 1,91-1,87 miljarder år och möjligen yngre), metamorfa; Svekokarelska orogener; Paleoproterozoiska bergarter 1,96-1,75 miljarder år

- 632; Lerskiffer, dolomit, basalt, sandsten (ca 2,05-1,96 miljarder år), metamorfa; Svekokarelska orogener; Paleoproterozoiska bergarter 2,44-1,96 miljarder år

Fig. 22. Overview map showing location of SVKA with respect to the KADZ and Haparanda suite intrusions.

regional context in Fig. 24. The rocks in the key area can essentially be assigned to four major units within this stratigraphic column: the upper part of the Vittangi greenstone group (uVGG), the Kilavaara quartzite group (KQ), the Porphyry group (PG), and younger intrusive rocks.

It should be noted that in the more recent regional map by Bergman et al. (2001), the Porphyry group (PG) in the SVKA has been assigned to the so-called Porphyrite group (PTG). However, for simplicity, here it will continuously be referred to as Porphyry group (PG) in the sense of Eriksson & Hallgren (1975). The affiliation of the PG of the SVKA to the PTG will be tested in the upcoming field work.

The eastern and southeastern parts of the key area are dominated by rocks of the uVGG in the form of basaltic tuffites, schists, graphite schists, and lime-skarn-rich rocks. Skarn-banded magnetite ores exist for example at Kulleri, Alpha, and Kiilavaara, whereas

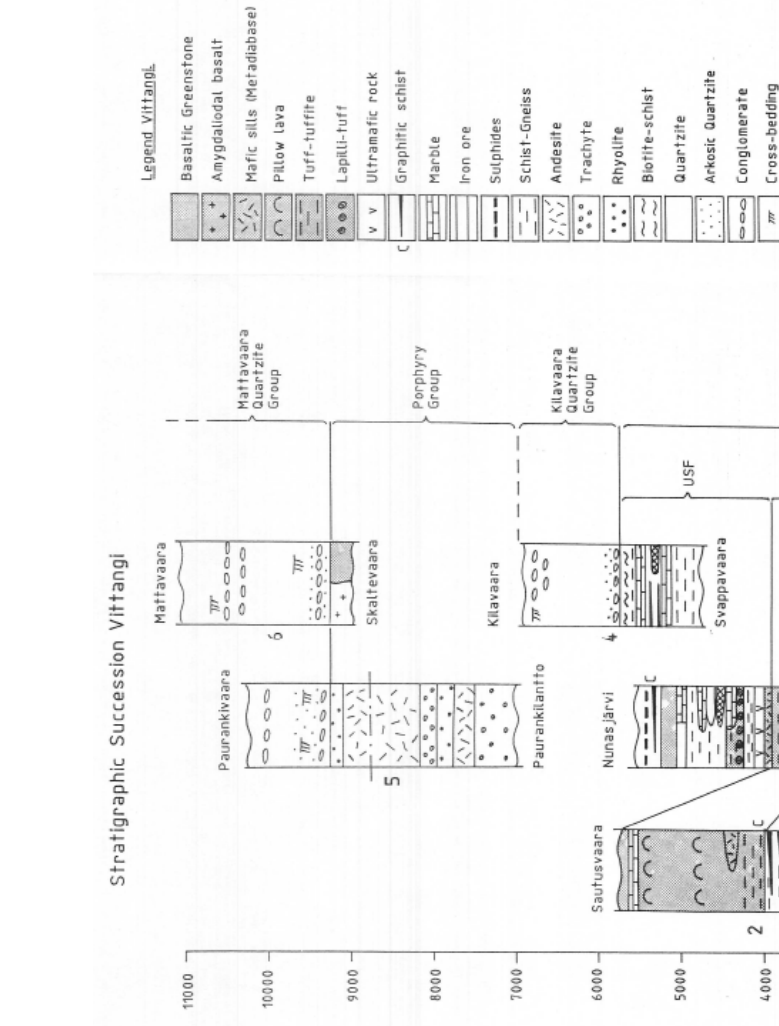
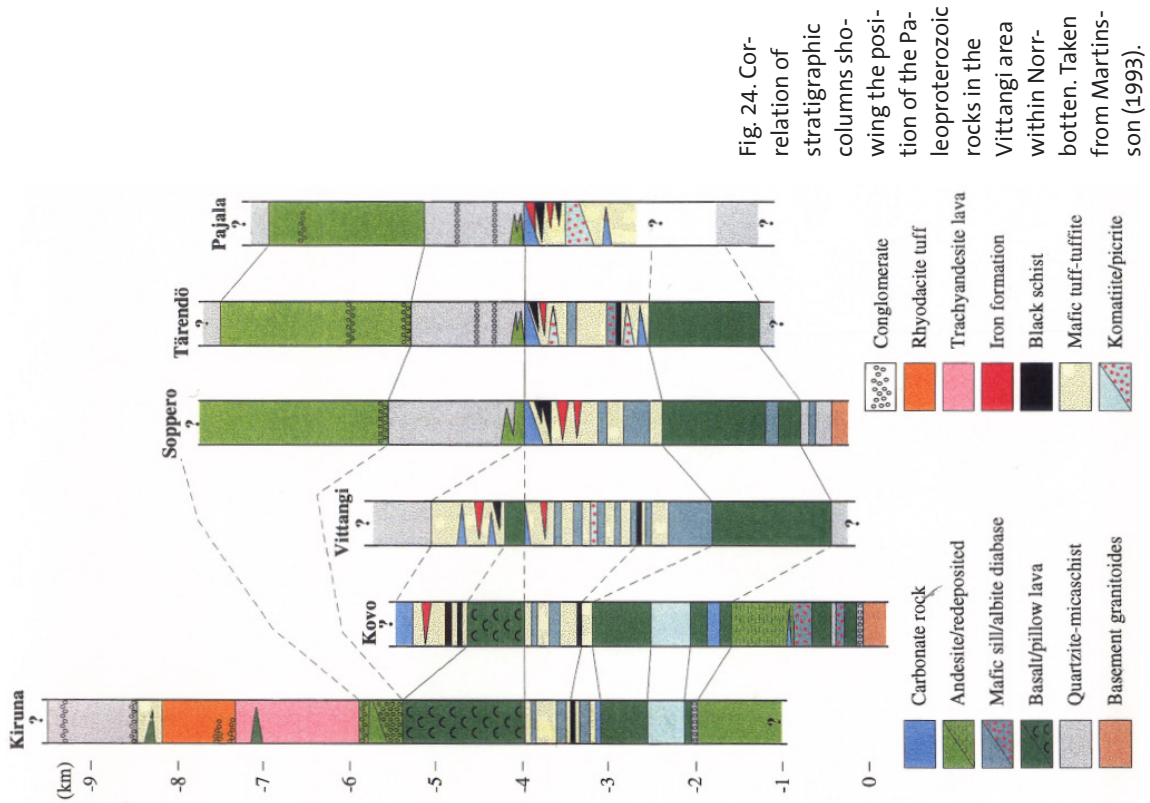


Fig. 23. Stratigraphic succession in Vittangi area. TQF: Tjärro quartzite, LGF: lower greenstone formation, LSF: lower sedimentary formation, UGF: upper greenstone formation, USF: upper sedimentary formation. Taken from Gustafsson (1993).



Isovainio, Kilavaara and Puttjala are locations of sulfide-mineralisations (Gustafsson 1993, Frietsch 1966). The lower parts of the Vittangi greenstone group (incl. Tjärro quartzite) are absent in the study area.

Biotite schists, quartzites and arkoses of the Kilavaara quartzite group unconformably overlie the Vittangi greenstones in the southeastern corner of the target area. The Kilavaara group is correlated with the Pahakurkio group in the Tändö area, and with the Kurravaara conglomerate in the Kiruna region and is interpreted to have been deposited under shallow marine conditions (Kumpulainen 2000). The NW and SW parts of the key area are dominated by rocks of the Porphyry group. The PG is composed of basalts, andesites, trachytes, and rhyolites. South of the Leveäniemi mine, and southeast of Kaisjärvi, the PG also contains some basal conglomerate layers with porphyritic clasts (which Eriksson & Hallgren (1975) also correlate with the Kurravaara conglomerate in the Kiruna area). Several apatite iron ores are hosted by the PG in the key area: from NW to SE these are Tansari, Gruvberget, and Leveäniemi. Additionally, at Gruvberget, a Cu-bearing sulfide deposit is present. Martinsson (2004) interprets the Gruvberget sulfide deposit in the ordinarily sulfide-poor apatite iron ores as due to a coincidence where the apatite iron ores may have acted as a trap to the Cu mineralisation.

In the maps by Frietsch (1966), and by Eriksson & Hallgren (1975), it seems that dikes and a more massive body of a “andesine–porphyrite” have intruded the rocks of the uVGG (west of lake Särkijärvi and west of lake Sahajärvi) as well as rocks of the PG (near Gruvberget). However, Bergman et al. (2001) affiliated these porphyrite intrusions also to the so-called Porphyrite group (PTG). They may thus represent the latest stages during PTG formation.

As shown in Fig. 23, the Porphyry group is usually unconformably overlain by the predominantly clastic sediments of the Maatavaara quartzite group. These rocks are not reported within the SVKA, but occur to the west and north of the area. They are interpreted to be the equivalent to the Hauki quartzite in the Kiruna area and are thought to have been deposited in small tectonic grabens (Witschard 1984).

Table 10. Characteristics of paleoproterozoic intrusives in the SVKA.

Suite	Age (Ga)	Geochem. character	Lithologies	Tectonic setting	References
Haparanda (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 et al. (1988); Bergman et al. (2001); Mellqvist et al. (2003)
Perthite-Monzonite (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)

Paleoproterozoic magmatism

The volcanosedimentary cover rocks in the field area are intruded by several suites of magmatic rocks. Their names, lithologies, magmatic character, ages, and inferred tectonic setting as well as relevant references are summarised here from Ahl et al. (2001) and Bergman et al. (2007) and presented in table 10.

To the SE of the SVKA, the rocks of the Vittangi and Kilavaara groups are intruded by quartz diorite bodies of the *Haparanda suite* (1.90–1.86 Ga, Bergman et al. 2007). The Svappavaara gabbro to the NE of the area also belongs to the Haparanda suite. According to Eriksson and Hallgren (1975), the relationship between the Porphyry group and the Haparanda suite is unclear. Almost contemporarily, the Perthite–Monzonite suite intruded. Compared to the Haparanda suite, this series 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).

Deformation and metamorphism in the SVKA

Following the division of northern Norrbotten into “structural domains” by Bergman et al. (2001), the key area is situated in structural domain I.

The fold interference patterns in the carbonate–tuffite–graphite rocks of the upper VGG in the Svappavaara vicinity (Figs. 3 and 25) indicate that these rocks must have been affected by at least two (if not three or more) folding events. One folding event is here interpreted to have occurred under E–W compression, resulting in narrow probably N–S trending fold axes (F1). The following event (F2) has so far only been observed in between the two NW–SE trending faults enclosing the upper VGG. The F2-event is characterised by E–W trend-

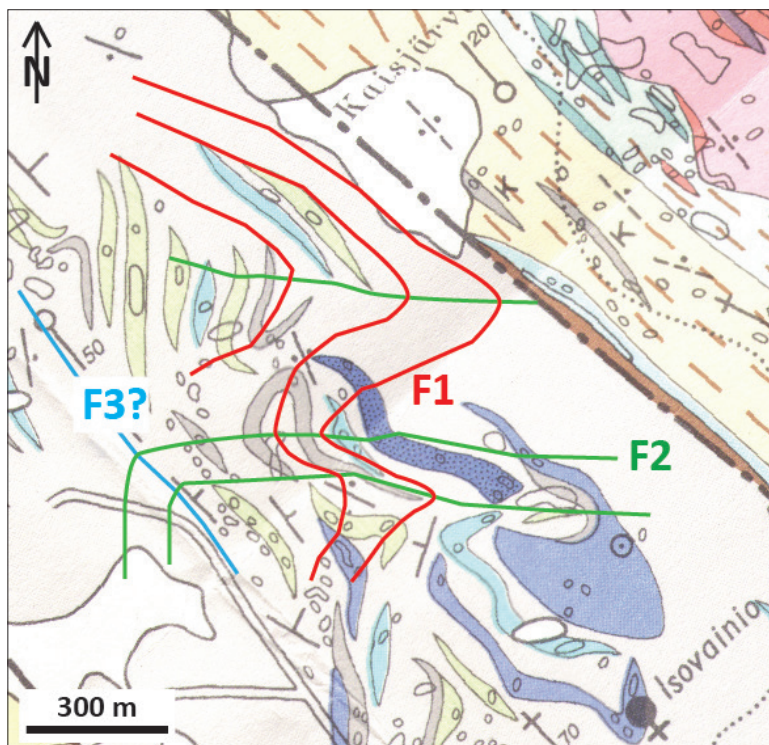


Fig. 25. Detail from geological map by Frietsch (1966) showing polyphase folding of graphite, scapolite, amphibolite, and limestone layers in the uVGG. F1, F2, F3 are the inferred folding phases referred to in the main text.

ing fold axes that refold the F1-folds. The trace of the refolded F1-fold axial plane seems to form a “Z-pattern”, indicating that there could have been dextral oblique compressive shearing along the fault/shear zone walls during D2. Additionally, Frietsch (1966) reports moderately to steeply SE plunging fold axes. From the available maps, it is not clear whether these fold axes represent a third folding event (F3). If F3 is a true folding event, the inferred fold axis trends for F1 and F2 would need to be reconsidered. Aside from the fact that the rocks of the uVGG host several iron ore and copper deposits, it is also essential to understand the sequence of folding in this area in order to unveil the deformational history prior to the formation of the Karesuando–Arjeplog deformation zone (KADZ) and to determine whether the rocks on the eastern and western sides of the KADZ have undergone the same type of deformation (cf. report on Kiruna–Jukkasjärvi key area). Further detailed structural mapping in combination with geoelectric, VLF, or IP-measurements could help to unravel the folding pattern.

The volcanic rocks of the Porphyry group, including the apatite iron ores at Leveäniemi, Gruvberget, and Tansari are folded about fold axes plunging $\sim 50^\circ$ towards the North. This folding direction is matched by larger scale N–S trending folds to the west and northwest. It is questionable whether this N–S folding event is contemporaneous to the above mentioned folding in the VGG rocks. Since the PG rocks are younger than the VGG rocks, this would imply that the PG rocks have not undergone the E–W folding that has affected the VGG rocks. In the Leveäniemi area, a change in strike of the schistosity was noted which could point to a second folding event (Frietsch, 1966). Also, the near-closure of the synclinally folded iron ore body towards the north suspiciously points at a second folding event with a more or less E–W trending fold axis. The potentially larger fold wavelengths in the PG rocks may be due to rheological differences between the less viscous, easily deformable uVGG rocks and the somewhat stiffer PG rocks. Further structural geological work is necessary here in order to constrain the number of folding events having affected the different geological units.

The rocks in the SVKA seem largely unaffected by the high strain deformation zone to the west (KADZ). A new seismic profile starting at Kiruna and continuing eastwards towards north of Svappavaara indicates, that the KADZ dips towards the east and becomes listric at depth (Juhojuntti, pers. comm.). In a compressional regime, this would be inconsistent with the postulated W-side up movement of the KADZ. One way to explain this could be that the KADZ was reactivated as a brittle structure. However, further thorough processing of the newly gathered seismic data is necessary in order to retrieve a reliable geophysical model of the KADZ.

Several brittle faults cut the area into distinct blocks. The two major fault trends are NW–SE and SW–NE, which is consistent with the orientation of brittle deformation zones throughout Norrbotten. Where cross-cutting of faults is observed, it is not possible to determine a preferential fault system, indicating that the faults formed contemporaneously. The regional study by Bergman et al. (2001) revealed that the majority of the NW–SE striking brittle faults have a dextral sense of slip, whereas the slip on the SW–NE oriented faults is consistently sinistral. If these two fault groups formed a conjugate system, their senses of slip would indicate N–S compression. Conjugation is assumed, however, not proven (Bergman et al. 2001). Frietsch (1983) reports that the apatite iron ores of the Svappavaara region are found at the intersection of the NW and NE striking faults.

As indicated in the stratigraphic column in Fig. 23, the Kilavaara quartzite usually underlies the volcanic and sedimentary rocks of the Porphyry group. In some places, however, the Kilavaara group seems to be missing and rocks of the Vittangi greenstone group and of the Porphyry group are brought in direct contact along the NW–SE and SW–NE striking faults, e.g. close to lake Särkijärvi.

In the SVKA, faults are locally lined with albitite, indicating that they acted as fluid conduits during faulting.

No detailed metamorphic investigations have been performed in the SVKA. However, the metamorphic grade in the eastern parts of Norrbotten varies between upper greenschist and upper amphibolite facies and is generally higher than to the east of the KADZ. Although timing of metamorphism is not very well constrained, Bergman et al. (2001) interpret a strong correlation between higher-grade metamorphic rocks and the spatial distribution of the Lina type granites (LS) as a result of either deeper crustal erosion in these areas or as an effect of increased heat flow during the 1.8 Ga event.

Mineralisations and alterations

Host rock alterations and mineralisations are common in the Svappavaara region (cf. Fig. 8). The most common types and occurrences of alterations and mineralisations are listed below.

Scapolitisation

In the Svappavaara region, Scapolitisation is wide-spread and particularly affects both volcanic and magmatic mafic rocks in particular. Felsic rocks are less affected (Ödman 1957, Geijer, 1931). Scapolitisation leads to a replacement of first plagioclase and then hornblende by introducing large amounts of chlorine and smaller amounts of carbon dioxide and SO₃ to the host rock. Geijer (1931) describes a close relationship between scapolitisation and Cu-mineralisations in the Svappavaara district. Scapolitisation is generally associated with the intrusion of the Lina suite granites (e.g. Frietsch, 1966).

Albitisation

Frietsch (1966) describes the metasomatic albitisation of the basic volcanic rocks of both, the uVGG and the PG. Usually, the albitites form close to faults. During albitisation, Na and CO₂ are introduced into the volcanic rocks and the metamorphosed host rock parts show characteristic bleaching (Frietsch 1966).

Sulphide mineralisation

Frietsch (1966) distinguishes two types of sulphide mineralisations: (1) the ones related to scapolitisation of the host rock, occurring at Gruvberget and Särkivaara, and (2) syngenetic sulphides in the rocks of the uVGG such as Isovainio, Kiilavaara, and Puttjala.

Iron ores

Apatite iron ores of the Kiruna type are found in the Porphyry group such as in the important deposits at Leveäniemi, Gruvberget and Tansari.

Skarn iron ores are found in association with the limestones of the uVGG (Frietsch 1966). The most important deposits are Alpha, Kiilavaara, Kulleri, and Koivujärvi.

DISCUSSION

A general lack of reliable age data for all rocks in the SVKA, as well as insufficient understanding of the sequence of deformational events make it necessary to undertake more targeted field studies and sampling of the SVKA. 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.

Questions and issues arising from the presented summary of data and subsequent discussions:

- Discrepancy between regional and local databases
- Some faults on the regional databases do not make sense when compared to the magnetic data; there seem to be some faults missing
- What is the meaning of the high magnetic anomaly south of Bergmannivaara?
- How many deformation and folding phases are there? Have the VGG, KQ, and PG undergone the same amount and style of deformation? (e.g., is the Leviäniemi syncline really only one syncline or has it been refolded?)
- Which stratigraphic position does the “andesine porphyrite” hold? And has it seen the same sequence of deformation events as the uVGG rocks in the Svappavaara area? Understanding this may help constraining relative timing of deformational events.
- 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? Could the faults potentially follow ancient reactivated deformation zones?
- What are the ages of the faults/deformation zones and how are they related to the plutons in the area (age wise and kinematic wise)?
- How are the mineralisations and alterations related to deformational events (folding or faulting)?
- Is the Kilavaara quartzite group really equivalent to the Kurravaara conglomerate? Is the contact to the uVGG conformable, an angular unconformity, or a tectonically controlled?
- What is the age of the volcanic rocks and carbonate rocks of the Vittangi greenstone group?
- How did the KADZ affect the rocks in the SVKA?

- Can the carbonate and graphite layers of the uVGG be used to perform indirect dating (with respect to the Lomagundi–Jatuli event)?

Some potential methods to address these questions are:

- Detailed mapping along profiles, by using GPS, DEM, geophysical measurements and interpretations, and aerial photographs.
- 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.
- Putting relative timing constraints on mineralisations and alteration events by using cross-cutting relationships of fractures showing skapolitisation and/or other hydrothermal alterations, and unaffected fractures.
- Since graphite should have a higher electrical conductivity than its surrounding rocks, ground geoelectric and/or electromagnetic measurements could potentially help to understand the folding patterns around Svappavaara.
- Use of drill cores to create 3D models of the area around Svappavaara to better understand folding patterns.
- Structural modelling (numerical and analogue) to understand the mechanisms behind the observed deformation pattern. C–O isotope geology of carbonate and graphite layers could be tested as an indirect dating method.

PLANNED WORK

The field work that is planned for summer 2013 is divided into 4 sectors presented in table 11 and Fig. 26. In all areas, sampling will be performed with the goal to characterise the geochemistry, metamorphism, and alteration of the rocks. Another goal is to determine locations that may be suitable for later sedimentological or volcanological logging. Geochronological sampling will ideally be done in areas where the field relations are clear.

Table 11: Description of planned field work in sectors indicated in Fig. 26.

Sector	Planned work / sampling / aim	Time estimate
Red	Detailed structural investigation in the uVGG and contacts to younger rock units along profiles if possible; sampling of graphite and carbonate layers for C-O isotopy; potentially ground geophysics (EM); try to identify the source of the magnetic anomaly south of Bergmannivaara; make use of drill cores in the northern red area in order to develop a 3D model?	5 days; plus some days at the Malå archive
Orange	Sampling mainly for geochronology of PG rocks and of so-called “andesine-porphyrite”; if possible, detailed structural geological measurements	2 days
Purple	Detailed structural mapping around Leveäniemi and Gruvberget in order to constrain number and type of folding phases. Potentially ground geophysics (EM).	3 days
Blue	Sampling of Paleoproterozoic intrusives for later U–Pb dating of protolith and potentially metamorphic ages	1 day

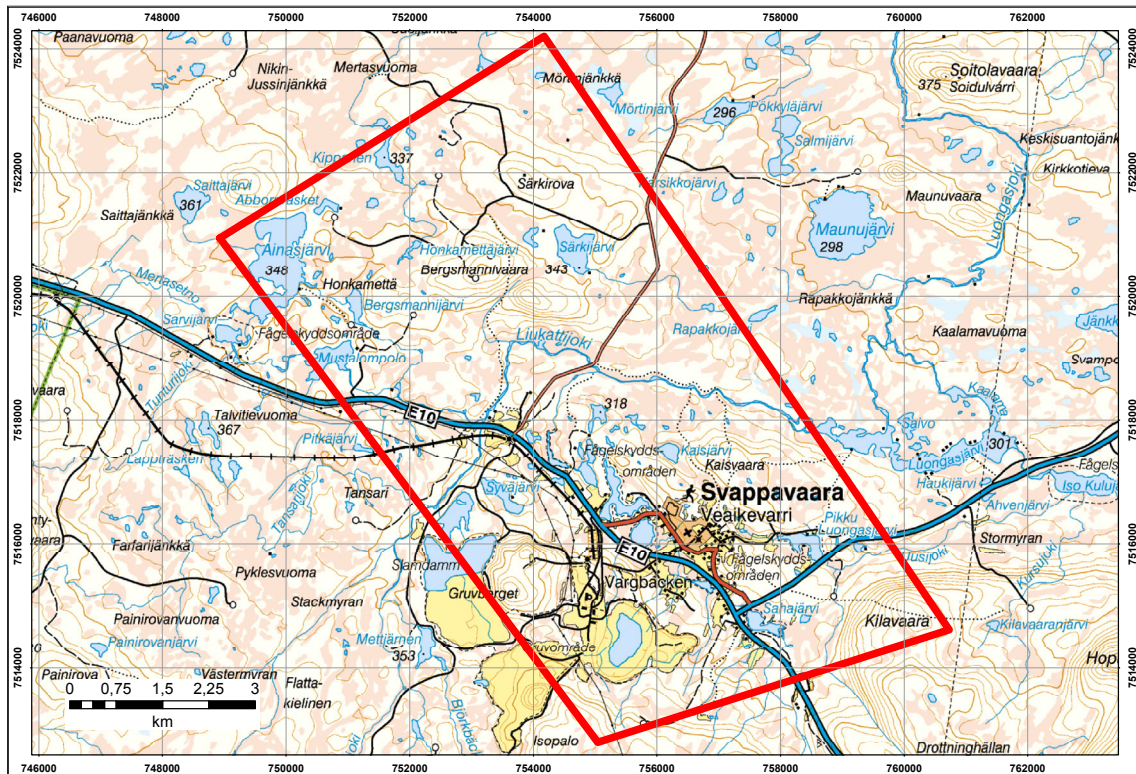


Fig. 26 Proposed areas for structural mapping and sampling within the SVKA. Coloured polygons refer to table 11.

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