BARENTS PROJECT

Summary report on the geological and geophysical characteristics of the Liviöjärvi key area

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September 2014

SGU-rapport 2014:29

SGU
Sveriges geologiska undersökning
Geological Survey of Sweden

Cover: Young forest located to the south of Liviöjärvi village. Photo: Stefan Luth.

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SAMMANFATTNING

Europas största tillgångar av mineralresurser förekommer i den norra delen av den fennoskandiska skölden. Av särskild betydelse är de stora förekomsterna av apatitjärnmalmer samt koppar- och guldfyndigheter inom Norrbottens län i nordligaste Sverige. Den geologiska utvecklingen av den fennoskandiska skölden är, trots sin ekonomiska betydelse, fortfarande dåligt känd. Data som samlats in från tidigare undersökningar är ofta begränsade och alltför spridda för att erhålla en heltäckande bild. Därför finns det diskrepanser mellan intilliggande kartbladsområden i skala 1:50 000 och en korrelation av geologiska enheter mellan olika kartblad saknas i många fall. Den målinriktade insamling av ny information som tillsammans med integrering av befintliga data nu sker inom Barentsprojektet, syftar till att öka förståelsen av den stratigrafiska och tektoniska utvecklingen i Norrbotten. Detta kan i sin tur bli betydelsefullt för framtida prospektering i regionen.

Barentsprojektet inkluderar undersökningar inom 15, så kallade, nyckelområden i Norrbottens län. Lokalisering och begränsning av nyckelområden utgår från att lösa områdesspecifika frågeställningar på en regional skala. Barentsprojektet fokuserar huvudsakligen på de Paleoproterozoiska ytbergarterna i regionen och syftar till att inom varje nyckelområde förstå och karaktärisera bergarterna enligt följande:

- Stratigrafi och avsättningsmiljö
  - vulkanologi
  - sedimentologi
  - kemisk karaktär
  - geokronologi av metamorft omvandlade vulkaniska bergarter
  - geokronologi av detritiska zirkoner i sediment.
- Regional strukturgeologi och tektonik
  - geometri och kinematik av veckstrukturer och deformationszoner
  - metamorf paragenes
  - åldersbestämning av metamorfos och deformation.
- Hydrotermiska omvandlingar
  - kemisk och mineralogisk karaktärisering
  - koppling till stratigrafi och strukturer.
- Mineraliseringar
  - typ av mineralisering
  - typ av malmbildande process.

SUMMARY

The rocks of the northern Fennoscandian shield contain Europe's largest mineral resources. The region Norrbotten in northern Sweden is particularly important since it hosts large deposits of apatite iron, copper and gold. Despite its economical importance, the development of the Fennoscandian crust and subsequent geological history is still poorly understood. Existing data from earlier field studies are often few and scattered. Hence, good correlations between geological features present on adjacent 1:50 000 map sheets commonly do not exist. Integration between available datasets with new more targeted surveys aims to increase the understanding of the stratigraphic and tectonic development of the Norrbotten area. This may be valuable for future prospecting work.

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

- Stratigraphy and depositional environment
  - volcanology
  - sedimentology
  - chemical characterisation
  - geochronology of metavolcanic rocks
  - geochronology of detrital zircons in sedimentary rocks
- Regional structural geology and tectonics.
  - geometry and kinematics of folding patterns and deformation zones
  - metamorphic paragenesis
  - age determination of metamorphism and deformation.
- Hydrothermal alterations
  - chemical and mineralogical characterisation of alterations
  - linkage to stratigraphy and structures.
- Mineralisation
  - type of mineralization
  - underlying ore-forming processes.

GEOLOGICAL SETTING OF THE PAJALA AREA

The Pajala region is dominated by Early Paleoproterozoic supracrustal rocks (2.4–1.86 Ga) as well as by intrusive rocks related to several magmatic suites (1.96–1.75 Ga, Fig. 1). In similarity with most other parts of northern Sweden, the oldest (Karelian) metasedimentary and metavolcanic rocks in the Pajala region were deposited during rifting along the margins of the Archean crust, whereas most of the overlying sequence as well as the intrusions formed during the Svecokarelian orogen (e.g. Bergman et al. 2001). Widespread magmatism and crustal growth affected the entire northern Fennoscandian shield and was coeval with the main phases of ductile deformation and metamorphism as identified in large parts of Finland and northern Sweden. The Pajala region in particular is characterised by an exceptionally strong north–south trending deformation zone affecting medium- to high-grade, low-pressure metamorphic rocks. Deformation in the area was polyphase and gave rise to superimposed and interfering folding patterns as well as the development of multiple branches of major north–south striking faults. Some of the larger fault zones (e.g. Pajala Shear Zone, PSZ) coincide with major east–west jumps in the metamorphic grade. In addition, most faults underwent several episodes of reactivation and overprinting promoting local hydrothermal alteration and ore formation. Today, many of these structural features can be accurately mapped with the help of existing geophysical data, such as airborne magnetic and electromagnetic measurements combined with gravity measurements. The timing of deformation, however, is more difficult to constrain and more effort is needed during upcoming studies. Contrasting deformation histories on either side of the PSZ were revealed by age determinations on metamorphic monazite and titanite as well as zircon overgrowth (Bergman et al. 2006). The western domain underwent metamorphism around 1.85 Ga whereas the eastern domain was reworked by deformation and high-grade metamorphism in the time interval 1.82–1.78 Ga. A relatively young titanite age of c. 1.74 Ga was interpreted by Bergman et al. (2006) as evidence for localised shearing, retrogression and hydrothermal activity. However, more age determinations on samples taken from major fault zones and their surroundings are needed to better constrain such post-tectonic events.

Short summary of published maps and descriptions

Early geological descriptions of the area date back to the work of Fredholm (1886) who already made a distinction between "the western and eastern schists areas of Pajala", which consisted of rocks different from the surrounding granites. The discoveries of iron ores at Kaunisvaara and Käymäjärvi to the north of Pajala caused new interest in the area immediately after the First World War. The supracrustal rocks were described as different from their western counterparts in the work of Geijer (1931), but the first maps of the area were not produced until 1954 at a scale of 1:200 000 (Eriksson 1954) with larger-scale maps (1:60 000) of the ore districts north of Pajala. In addition to his detailed rock descriptions, he recognised several folding phases, but with a very strong overprint related to the youngest phase that blurred the older fabrics.

A map sheet covering the Pajala area (28M) at a scale of 1:50 000 was published by the Geological Survey of Sweden (SGU) in 1977. During the compilation of this map, focus was on the stratigraphic succession of the supracrustal rocks. Way-up indicators such as graded- and cross-bedding were found in abundant sand-rich and tuffitic horizons and were the basis for the establishment of a stratigraphic column comprising several groups and formations. Subsequently, this

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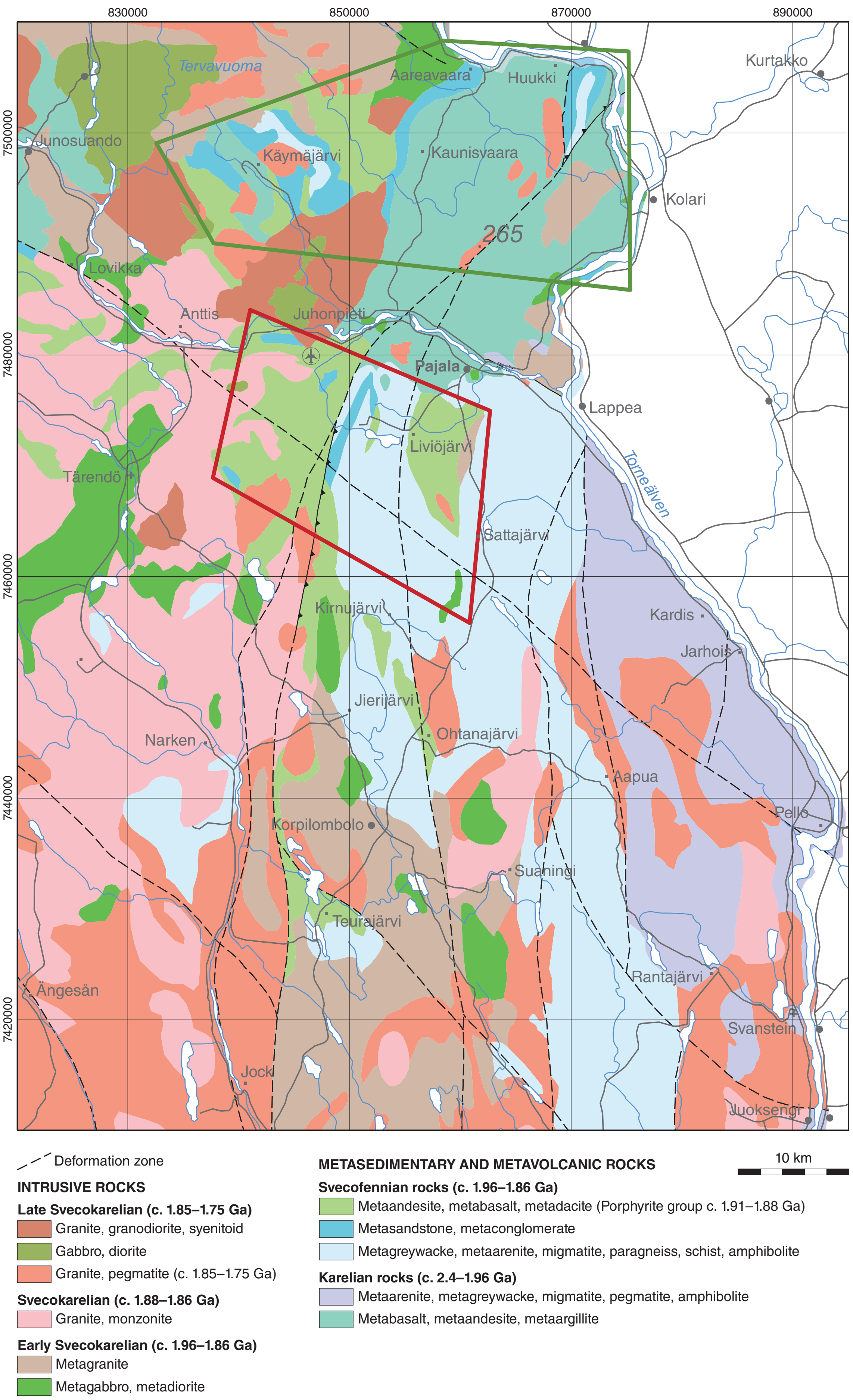
Figure 1. Geological map from the Pajala region extracted from the SGU bedrock database. A red polygon marks the Liviöjärvi key area, green polygon the Käymäjärvi-Ristimella key area.


830000
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Käymäjärvi
Kaunisvaara
Kolari
265
Lovikka
Anttis
Juhonpieti
Pajala
Lappea
Liviöjärvi
Tärendö
Torneälven
Sattajärvi
Kirnujärvi
Kardis
Jarhois
Jierijärvi
Narken
Ohtanajärvi
Aapua
Pello
Korpilombolo
Suaningi
Teurajärvi
Rantajärvi
Ängesån
Svanstein
Jock
Juoksengi
Deformation zone
10 km
INTRUSIVE ROCKS
Late Svecokarelian (c. 1.85–1.75 Ga)
Granite, granodiorite, syenitoid
Gabbro, diorite
Granite, pegmatite (c. 1.85–1.75 Ga)
Svecokarelian (c. 1.88–1.86 Ga)
Granite, monzonite
Early Svecokarelian (c. 1.96–1.86 Ga)
Metagranite
Metagabbro, metadiorite
METASEDIMENTARY AND METAVOLCANIC ROCKS
Svecofennian rocks (c. 1.96–1.86 Ga)
Metaandesite, metabasalt, metadacite (Porphyrite group c. 1.91–1.88 Ga)
Metasandstone, metaconglomerate
Metagreywacke, metaarenite, migmatite, paragneiss, schist, amphibolite
Karelian rocks (c. 2.4–1.96 Ga)
Metaarenite, metagreywacke, migmatite, pegmatite, amphibolite
Metabasalt, metaandesite, metaargillite

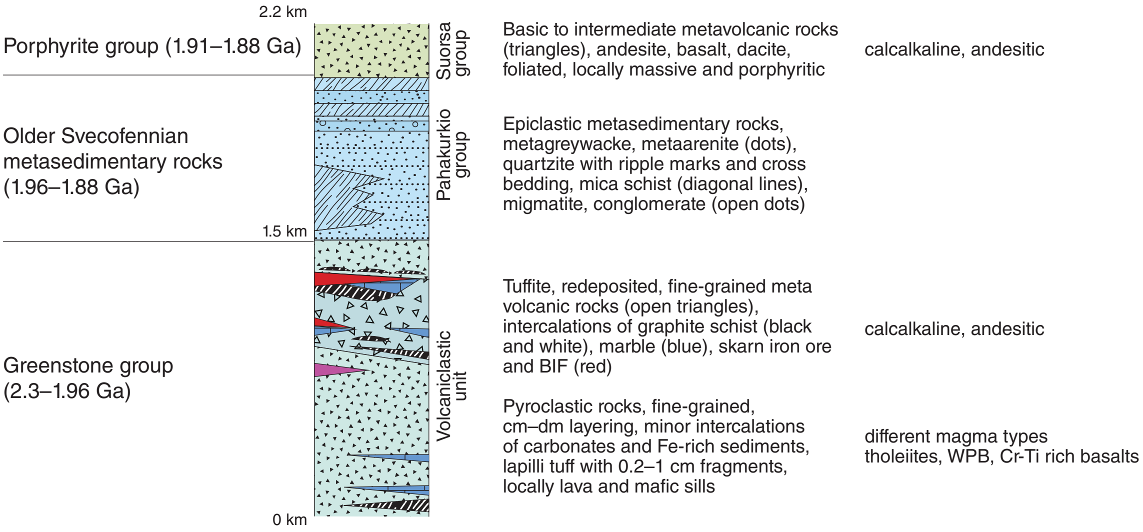


Figure 2. Stratigraphic column of the Pajala area modified after Martinsson (1993). Group names to the left of the column are from Bergman et al. (2001). Colours correspond to the lithological units as displayed in Figure 7.

stratigraphic sequence, together with data from early magnetic surveys, was used to map several large-scale structures, such as the Jupukka-Suorsa anticline and the Mupotkavaara-Liviöjärvi syncline. Major north-west to south-east trending folds (e.g. Kärmäjärvi) were termed F1 while north-east to south-west trending folds (e.g. the Kalix syncline and Saalovuoma trough) were treated as F2 structures. A more regional interpretation of these structures was presented by Lindroos & Henkel (1978), who elaborated on gravity and granitic diapirism as a possible mechanism for folding (see also Ramberg 1967, 1972).

In the period 1983–1986, prospecting by LKAB in the Pajala region contributed significantly to the improvement of the geological knowledge. The initiation of various drilling projects as well as geophysical surveys led to better and more detailed stratigraphic and structural constraints (e.g. Hansson et al. 1984). With increasing knowledge, correlations between the stratigraphy of the the Kiruna region and the stratigraphy of eastern Norrbotten were attempt for (e.g. Martinsson 1993 (Fig. 2), Kumpulainen 2000).

Shortly after this, SGU published a synthesis on the geology of Norrbotten (Bergman et al. 2001) containing new results from geochronological and geochemical analysis. For the Pajala region, these new results caused a reinterpretation of supracrustal units from being interpreted as the oldest (e.g. Karelia or Lapponia supergroups in Eriksson 1953 and Padget 1977) to a Svecofennian age. As a consequence, many of the earlier maps and stratigraphic columns covering the Pajala region became outdated and can only partly be used.

For the future field study in the Liviöjärvi area, however, we consider the recently published map and descriptions of the Korpilombolo area (27M) by Jonsson & Kero (2013) as the most relevant background information (Fig. 3). This map sheet is located directly south of the Pajala map sheet (28M) and presumably covers all units exposed in the Liviöjärvi key area.

Karelian rocks (2.4–1.96 Ga) and Svecofennian metasedimentary and metavolcanic rocks (1.96–1.86 Ga)

Within the central and eastern parts of the Liviöjärvi area, the rocks consist mainly of strongly metamorphosed and recrystallised metasedimentary rocks. These gneissic rocks are often strongly brecciated and veined by granitic and pegmatitic rocks. The oldest rocks in the region

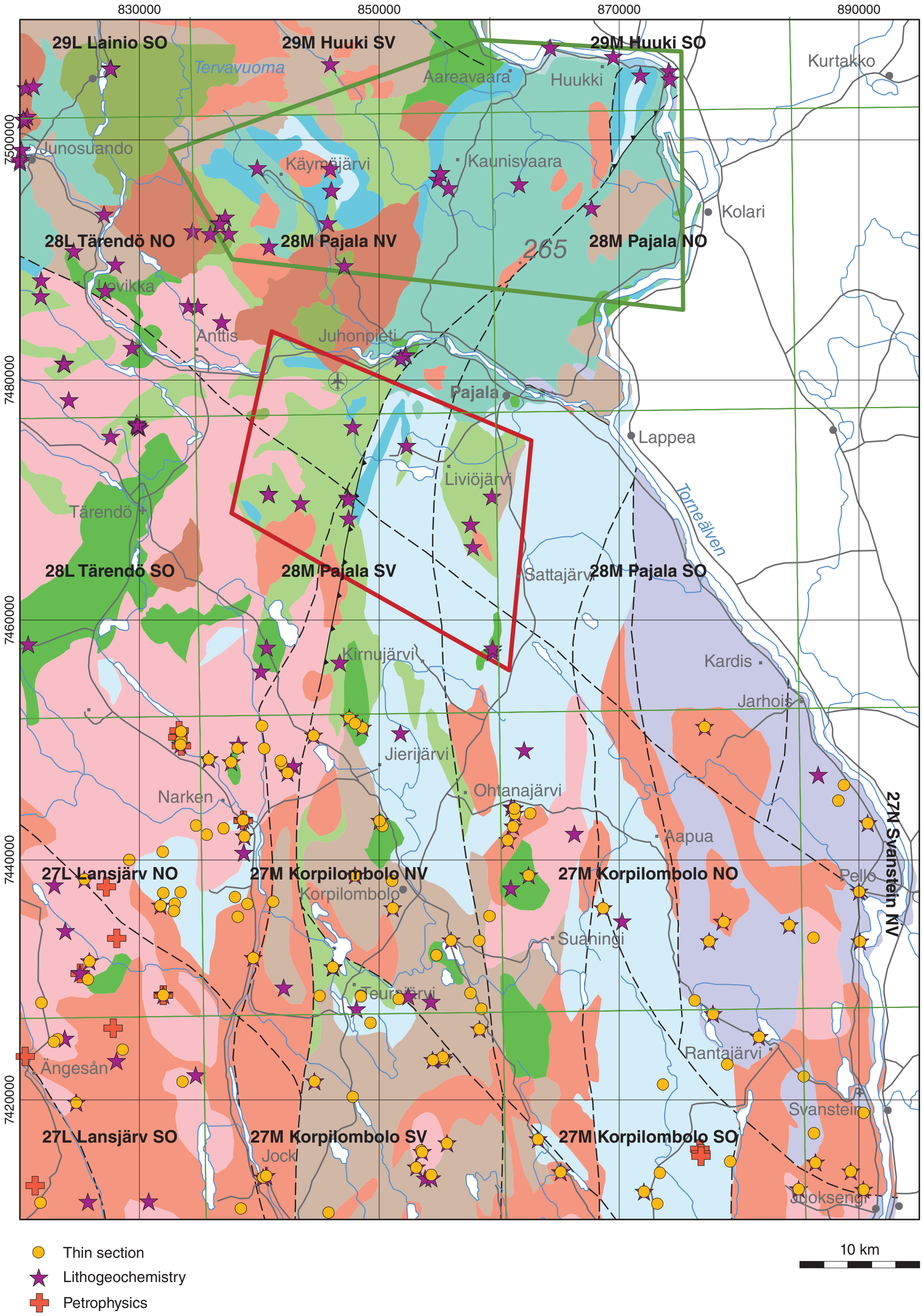


Figure 3. Localities of samples taken for thin section, lithogeochemical analysis and petrophysics in the Pajala region. Names and grid refer to the published SGU 1:50 000 map sheets (thin green squares), which are available in digital format and are compiled from the bedrock database. See figure 1 for complete legend of the background colors.

are located to the south-east of Pajala, just outside the key area towards the border with Finland (see also 27N Svanstein). These rocks have been classified as Karelian (2.4–1.96 Ga), whereas the supracrustal rocks to west are Svecofennian (1.96–1.86 Ga, e.g. Bergman et al. 2001, Jonsson & Kero 2013). A distinction between these units based on lithology is difficult to make since metaarenites and metagreywacke are the dominant rock types in both units. However, the metaarenites are more abundant in the eastern unit, and include banded gneisses which are often quartz-rich (70%) with feldspar (20%) and mica (10%), but also contain zircon, chlorite and opaque minerals. A strong recrystallization, a high mica content and intense veining also make these rocks difficult to distinguish from younger granitic intrusions, which are often weakly foliated. Basic dykes or sills of partly altered amphibolite cut through the Karelian units, but appear mostly discontinuous.

Towards the west, the Svecofennian unit is characterised by voluminous metagreywackes, which are rich in mica and mostly migmatitic. Migmatitisation resulted in an enrichment of granitic and pegmatitic material derived from local as well as more distal melts. Some common minerals are sillimanite, cordierite and garnet.

It is worth noting that in the area of map sheet 27M Korpilombolo NV, the degree of migmatitisation affecting the metasedimentary rocks drops abruptly westward leaving some well preserved metagreywacke and layered quartzite west of the Kalix river. This east–west metamorphic contrast probably results from major vertical displacements along a north–south striking branch of the Pajala shear zone. In general, the metagreywackes have a significantly higher magnetic susceptibility than the metaarenites, which commonly results in a banded pattern of magnetic anomalies in the central part of the 27M Korpilombolo SO map area.

The eastern and western regions within the Liviöjärvi area are dominated by basic to intermediate rocks (Suorsa group, Figs. 1–2). These grey to dark green rocks are mostly fine-grained and rich in amphibole, biotite, chlorite, epidote and pyroxene. Some structures and textures indicate a volcanic origin, but this is based on observations from only a few localities. The rocks are in general foliated, but locally appear massive or even porphyritic. They occur intimately together with the Svecofennian gneissic sedimentary rocks. A geochemical analysis classified the rocks as andesites and basalts. More acidic compositions also occur, including dacites. Most of the rocks in this unit have a very high magnetic susceptibility.

Early Svecokarelian intrusive rocks (1.96–1.87 Ga)

The early Svecokarelian intrusive rocks belong to the Haparanda suite (e.g. Ödman 1957, Bergman et al. 2001), and are exposed to the west and south-west of Liviöjärvi. These rocks are, when compared to the somewhat younger suites, mostly foliated, rich in dark minerals and poor in K-feldspar. Geochemical analyses on samples from the Korpilombolo area showed a dominant granodioritic to dioritic composition, and locally to gabbroic (Jonsson & Kero 2013). High magnetic and gravity anomalies associated with these rocks reveal that they occur as tectonic lenses and isolated bodies surrounded by metasedimentary gneisses, or as fragments within younger granite-pegmatite rocks. In some areas (e.g. the central part of the Korpilombolo map area), the rock is brecciated and contains fragments of sedimentary rocks as well as basic enclaves surrounded by a vein network of acidic composition. It has been suggested that at least some of the brecciation is syn-magmatic and hence predates ductile and brittle deformation (Jonsson & Kero 2013).

Svecokarelian intrusive rocks (1.88–1.86 Ga)

Svecokarelian intrusive rocks are only exposed in the south-western part of the Liviöjärvi area, but become more abundant in the Korpilombolo area further south and south-east. Most of the Svecokarelian intrusive rocks are classified as quartz monzonites to monzogranites, which are often rich in large K-feldspar porphyroclasts. Several samples have been analysed and dated by Jonsson & Kero (2013). They observed a variation in the degree of deformation that ranged between strongly foliated rocks (with the foliation mostly defined by biotite and amphibole) and more undeformed, equigranular rocks. Time constraints by U-Pb geochronology using TIMS (Thermal ionization mass spectrometry) on zircons from both rock types (1.87 Ga) reveal a maximum age on the ductile deformation, which was localised along discrete zones (see also Jonsson & Kero 2013). Note that within the Korpilombolo area several lens-shaped as well as rounded domes were defined by high magnetic anomalies. These domes typically consist of quartz monzonite (both foliated and undeformed) surrounded by dioritic rocks, and are often intruded by younger granites and pegmatites. In addition, observations on basic enclaves and on magma mingling textures as well as the presence of dolerites all suggest co-magmatism of acidic and basic melts.

Late- to postsvecokarelian intrusive rocks (1.85–1.75 Ga)

Exposed along the western border of the Liviöjärvi area are heterogeneous, pegmatitic granites that are interpreted as belonging to the Granite-pegmatite suite (GP, Bergman et al. 2001, Jonsson & Kero 2013), also known as “Lina-type” (e.g. Ödman 1957). In general, these rocks occur as pinkish granite, pegmatite or aplitic rocks locally with a graphic texture which is very characteristic for the GP suite. All rock types are poor in dark minerals. Large areas are dominated by massive rocks. However, some units contain a weak foliation associated with a homogeneous, intermediate grain size and a somewhat higher magnetic susceptibility. These foliated units are commonly intruded or brecciated by pegmatite and aplitic rocks indicating multiple injection events along the Pajala shear zone. The pegmatites are described as primitive and contain quartz, feldspar and mica (mainly biotite) with minor magnetite and ilmenite. The entire GP suite is characterised throughout the region by a relatively high radium index (0.8) and activity index (1.6).

Metamorphism

High grade metamorphism affected the region as indicated by thermobarometry as well as from metamorphic mineral assemblages. Pressure and temperature estimates on coexisting garnet and biotite are around 690 °C at 6,2 kbar and 515 °C at 4,1 kbar, respectively (Bergman et al. 2001). The presence of sillimanite, cordierite and garnet in migmatised gneisses from the central and eastern domains indicates metamorphic conditions of upper amphibolite facies. In addition, observations on spinel within cordierite crystals from a migmatite are interpreted as having formed by contact metamorphism (Jonsson & Kero 2013). Some high temperature indicators, such as corundum porphyroblasts in gneisses from the Isovaara area, overgrow the foliation, which suggests that a thermal event postdated deformation. Furthermore, the degree of metamorphism drops abruptly west of the Kalix river in the Korpilombolo area. Here, regional metamorphism resulted in the growth of andulasite within metasedimentary rocks. Thermobarometric studies of the Narken area by Carlsson (1993) indicated temperatures between 300 and 500 °C at pressures of 0,5 and 4,7 kbar.

Deformation

The Pajala shear zone is characterised by a broad north–south striking high strain belt and includes several parallel shear zones (e.g. Berthelsen & Marker 1986, Kärki et al. 1993, Bergman et al. 2006). In the early studies, the shear zone has also been named the Baltic-Bothnian shear zone. In the Kalix and Korpilombolo areas, the belt is at least 10 km wide but narrows to the north and swings to a north-east orientation were it crosses the border to Finland near Huuki (Fig. 1). Estimates on the subsurface geometry of these zones were derived from local minima in the Bouguer anomaly constraining fault displacements to at least 2.5 to 5 km in depth. Limited field data also indicate sinistral strike-slip movement combined with eastern-side-up movement, which is consistent with observations of a lower metamorphic grade to the west. In general, foliation, banding or schistosity within most rocks are parallel to the major shear zones and are probably formed near the metamorphic peak (Bergman et al. 2001, 2006).

Older structures, in particular north-west to south-east trending folds and foliations, are locally refolded and dragged into the north–south striking shear zones. Consequently, most fold axes have a moderate to shallow plunge towards the south-west. This folding pattern correlates well with the form lines derived from aeromagnetic images.

These images are also of great help in the interpretation of smaller shear zones and faults, which are present in large numbers but mostly unexposed. Two fault sets can be distinguished that both correlate with narrow, low magnetic anomalies, one set striking north-west and one set striking north-north-east to north-east. The latter have mainly been observed along river Torneälven. Many of these faults are actually fractures with little or no displacement. Associated fluid flow has led to alteration and the crystallisation of epidote, chlorite and amphibole. Observations from the Korpilombolo NV area on strongly brecciated host rocks containing iron oxide mineralisations stress the interplay between deformation, hydrothermal alteration and ore formation along the Pajala shear zone (Jonsson & Kero 2013).

Mineralisations

The iron deposits are the economically most important deposits in the Pajala area. They occur mainly north-west of Pajala and investigations have demonstrated their stratiform or stratabound character (e.g. Eriksson 1954, Padget 1977, Bergman 2001). The major Sahavaara deposit occurs in the upper part of the Greenstone group, at the contact between volcaniclastic rocks in the footwall and Svecofennian clastic metasedimentary rocks in the hanging-wall. This deposit comprises three lenses of skarn-rich iron ore. For more information about these deposits the reader is referred to the SGU Barents summary report on the Käymäjärvi-Ristimella key area by Grigull et al. (2014).

South of Pajala, prospecting activities has resulted in the availability of detailed local maps, drill cores and geochemical data, and the discovery of some minor copper and iron mineralisations. Extensive till sampling by NSG (Swedish State Mining Property Commission) indicated that most of the high copper concentrations are related to basic and intermediate volcanic rocks, which occur mainly in the western and central parts of the region (Fig. 4). Geochemical analyses on the associated basic rocks, which often contain pyrite and chalcopyrite, reveal high gold concentrations in addition to a high copper content. High copper and gold concentrations have also been found in a quartz dominated sample taken from a road cut north-east of Korpilombolo (Jonsson & Kero 2013).

In the Narken area, sulphide bearing iron oxide occurs within a breccia-type of rock. The matrix consists of iron oxides (mainly hematite), epidote, chlorite, sulphides and apatite surrounding fragments of layered metasedimentary rocks. Good exposures can be found along the road at Vattuvaara (Frietsch 1972). In addition, this rock contains relatively high concentrations of uranium and thorium. Jonsson & Kero (2013) described this type of mineralisation as possibly an IOCG-type deposit (iron-oxide-copper-gold, see also Jonsson & Kero, 2013, and references therein). Most metal deposits throughout northern Norrbotten are hosted by rocks of the Greenstone group, whereas the minor deposits of graphite schist south of Pajala are hosted by the overlying Svecofennian metasedimentary rocks. Several deposits, such as the Liviövaara deposit, were investigated for possible production of graphite (Gerdin et al. 1990). However, the small grain size (<0.1 mm) and a graphite content between 12 and 40% turned out to be uneconomical.

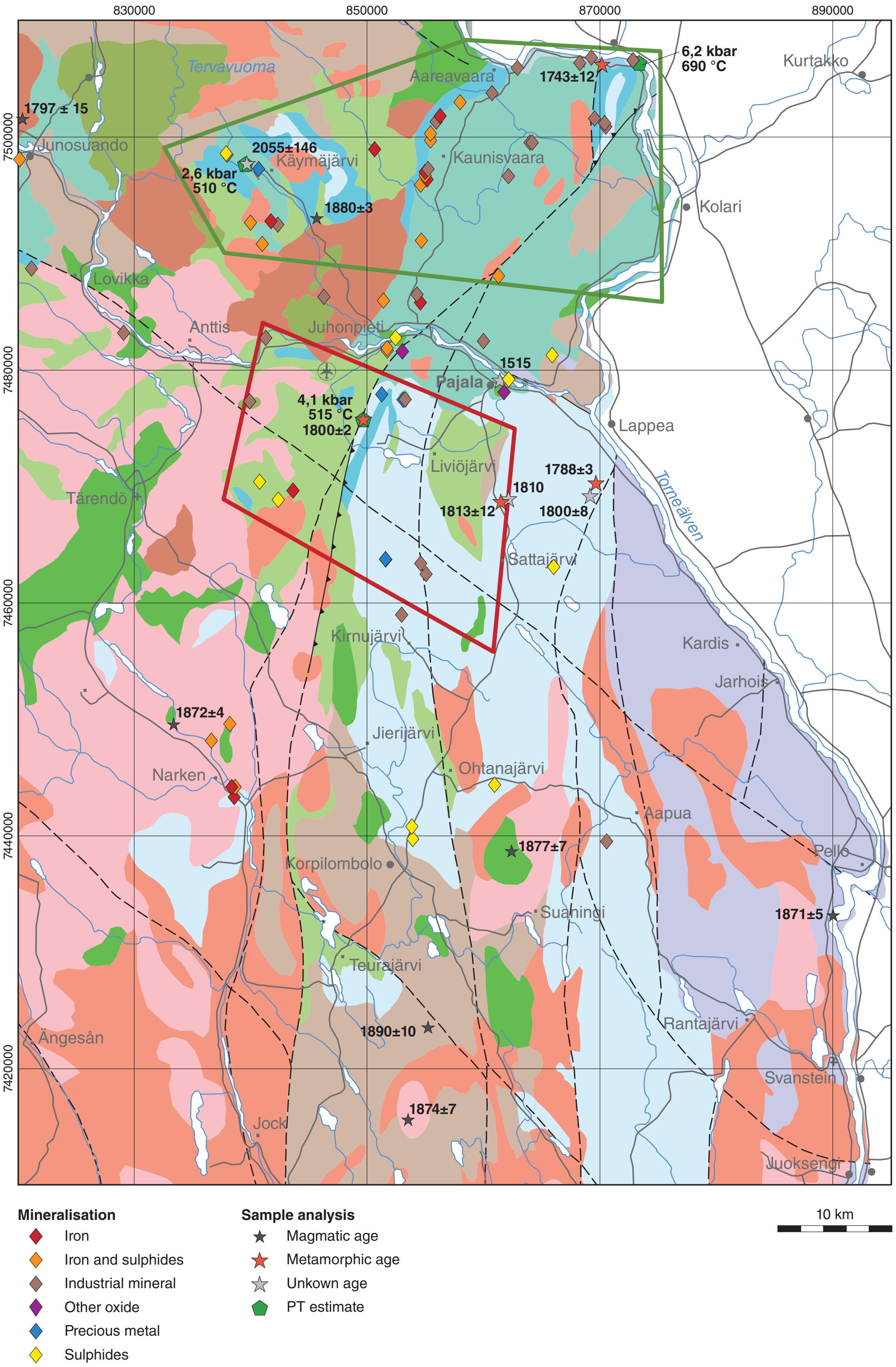


Figure 4. Localities of documented mineralisation and samples taken for geochronology and PT-analysis in the Pajala region. See Figure 1 for complete legend of the background colors.

Some of the folded and banded paragneisses, including quartzites, which are often coloured green by fuchsite, are suited as building or ornament stone and are currently being mined on a small scale.

Geochronology

Most of the geochronological data from the Pajala region has already been summarised and interpreted in Bergman et al. (2006). Their U-Pb ages on zircon, monzanite and titanite range between 1.86 and 1.74 Ga, and were subdivided into age clusters corresponding to different magmatic, metamorphic and hydrothermal events (Fig. 4, Table 1). Note that most ages from the Korpilombolo map area cluster between 1.89 and 1.87 Ga and are considered magmatic ages (Haparanda and Perthite monzonite suites) corresponding to an early orogenic phase (Wikström & Persson 1997, Bergman et al. 2006, Jonsson & Kero 2013).

Bergman et al. (2006) interpreted the ages between 1.86 and 1.85 Ga as reflecting a period of both magmatism and metamorphism, which was most prominent west of the Pajala shear zone (PSZ). Since most of the granites that crystallised during this time period are only weakly deformed, the penetrative deformation must be older than c. 1.85 Ga. Alternatively, the younger deformation was heterogeneous and did not significantly affect the intrusive bodies. The latter interpretation is preferred based on observations on metamorphic mineral assemblages formed during the same time interval within adjacent metasedimentary rocks. PT-estimates of 500 °C at 4 kbars promoted growth of monazite, which is present as inclusions in biotite that forms the main foliation.

Table 1. Details on the geochronological data shown in Figure 4. ID-TIMS: Thermal Ionization Mass Spectrometry Isotopic Dilution, SIMS: Secondary Ion Mass Spectrometry

Age	Error	Interpretation	Northing (Sweref 99)	Easting (Sweref 99)	Lithology	Isotope system	Method	Mineral	Reference
1515	0	not known	7479108	861420	Granite	K-Ar	Not known	Not known	Magnusson 1970
2055	146	not known	7497724	839678	Picrite	U-Pb	Not known	Zircon	Bergman et al. 2001
1880	3	Magmatic age	7493092	845668	Metadacite	U-Pb	Not known	Zircon	Bergman et al. 2001
1797	15	Magmatic age	7501593	820409	Monzonite	U-Pb	ID-TIMS	Zircon	Bergman et al. 2001
1874	7	Magmatic age	7415690	853517	Quartz monzonite	U-Pb	ID-TIMS	Zircon	SGU database*
1877	7	Magmatic age	7438730	862406	Monzodiorite	U-Pb	SIMS	Zircon	SGU database*
1890	0	Magmatic age	7423612	855227	Quartz diorite	U-Pb	ID-TIMS	Zircon	SGU database*
1872	4	Magmatic age	7449626	833368	Granite, red	U-Pb	ID-TIMS	Zircon	SGU database*
1871	5	Magmatic age	7433237	890047	Quartz monzodiorite	U-Pb	ID-TIMS	Zircon	SGU database*
1743	12	Metamorphic age	7506221	870166	Paragneiss	U-Pb	ID-TIMS	Titanite	Bergman et al. 2006
1813	12	Metamorphic age	7468679	861495	Metaarenite	U-Pb	SIMS	Zircon	Bergman et al. 2006
1810	0	Metamorphic age	7468679	861495	Metaarenite	U-Pb	ID-TIMS	Monazite	Bergman et al. 2006
1800	8	Metamorphic age	7470305	869674	Pegmatite	U-Pb	ID-TIMS	Monazite	Bergman et al. 2006
1800	2	Metamorphic age	7475755	849684	Metasedimentary rock	U-Pb	ID-TIMS	Monazite	Bergman et al. 2006

* In SGU's database Radiometric age determinations on rocks.

The age interval with ages between 1.82 and 1.78 Ga dominate east of the PSZ. The rocks in this area were significantly heated resulting in zircon overgrowth in metaarenite (1813±12 Ma), and migmatitisation. In addition, the textural setting of many of the monazite grains together with the presence of variably deformed leucosomes suggest that both the ductile deformation and the peak metamorphism along the PSZ occurred during this period. The monazite may have grown during more than one distinct deformation event. Based on the above, Bergman et al. (2006) stated that the PSZ was active during the time period 1.82–1.78 Ga, and coeval with, or in part earlier, than the post-Svecokarelian intrusions to the west. The 1.80 Ga old intrusive rocks in the Tärendö area were only weakly deformed, whereas deformation was more intense in the PSZ. Moreover, it has been suggested that these granites and the migmatites are the result of the same metamorphic event. The fact that the 1.80 Ga old migmatites commonly are situated adjacent to unaffected 1.88 Ga old granite demonstrates that deformation was localised to specific zones or domains. A rheological contrast between the metaplutonic rocks and the metasedimentary rocks was possibly created by thermal softening of the latter, which in turn may have been the result from the interplay between high-grade metamorphism, magmatism and ductile deformation.

Bergman et al. (2006) interpreted a fourth age cluster at 1.75–1.73 Ga as occurring only locally in the eastern domain. They relate the crystallisation of a 1.74 Ga old titanite obtained from the Huuki paragneiss to retrograde processes. Even though a few similar ages have been derived from elsewhere in the Fennoscandian shield their tectonic significance is still poorly constrained. Most likely they reflect more local, late events of shearing, retrogression, fracturing or hydrothermal activity (see also Witschard 1996). Upcoming field studies will aim to better constrain these relatively late and localised events.

LIVIÖJÄRVI KEY AREA

In this section, topographical, geological and geophysical maps of the Liviöjärvi key area are presented. The data shown on each map was extracted from the SGU bedrock database in the period February to April 2014. The purpose of this compilation of maps is to present an overview of the geological (Figs. 5–9) and geophysical (Figs. 10, 12–17) work carried out earlier in this area, and to use it as a starting point for the future field studies. In the next section we elaborate further on the areas of interest that may rise from this compilation as well as from the descriptions presented in the previous section.

Drilling in the Liviövaara area

Drilling in the Liviövaara area was carried out by Sveriges Geologiska AB under the assignment of NSG (Fig. 9, Table 2, Gerdin et al. 1991). Their goal was prospecting for graphite, which included mapping, sampling and drilling in the Kiruna and Pajala areas. The target for the drilling was a 700 m long, high-electric and high-magnetic conductor found by airborne measurements carried out by LKAB (magnetic and slingram). The result from their analysis on four drillcores was, however, disappointing as it yielded only 0.5 million tonnes of very fine-grained graphite (<0,05 mm), varying in grade between 14% and 30%. The graphite occurs together with significant concentrations of iron oxides hosted in what they described as greenstone formation intruded by monzonites. Based on their map, this unit is tightly folded along north-north-east to south-south-west trending axes and fragmented mainly along north-west striking faults, but also along older north-north-east striking faults.

The same area was drilled in 1986 by LKAB in their search for copper and gold (Hansson 1986). Three types of mineralisation were distinguished: 1) Cu (0.31%) and Au (0.025 ppm) hosted in silicified rhyolites, 2) Cu (0.30%) and Au (0.2 ppm) hosted in limestones and 3) intrusive rocks containing 1.8% Cu. They documented a stratigraphic transition in the area from mafic

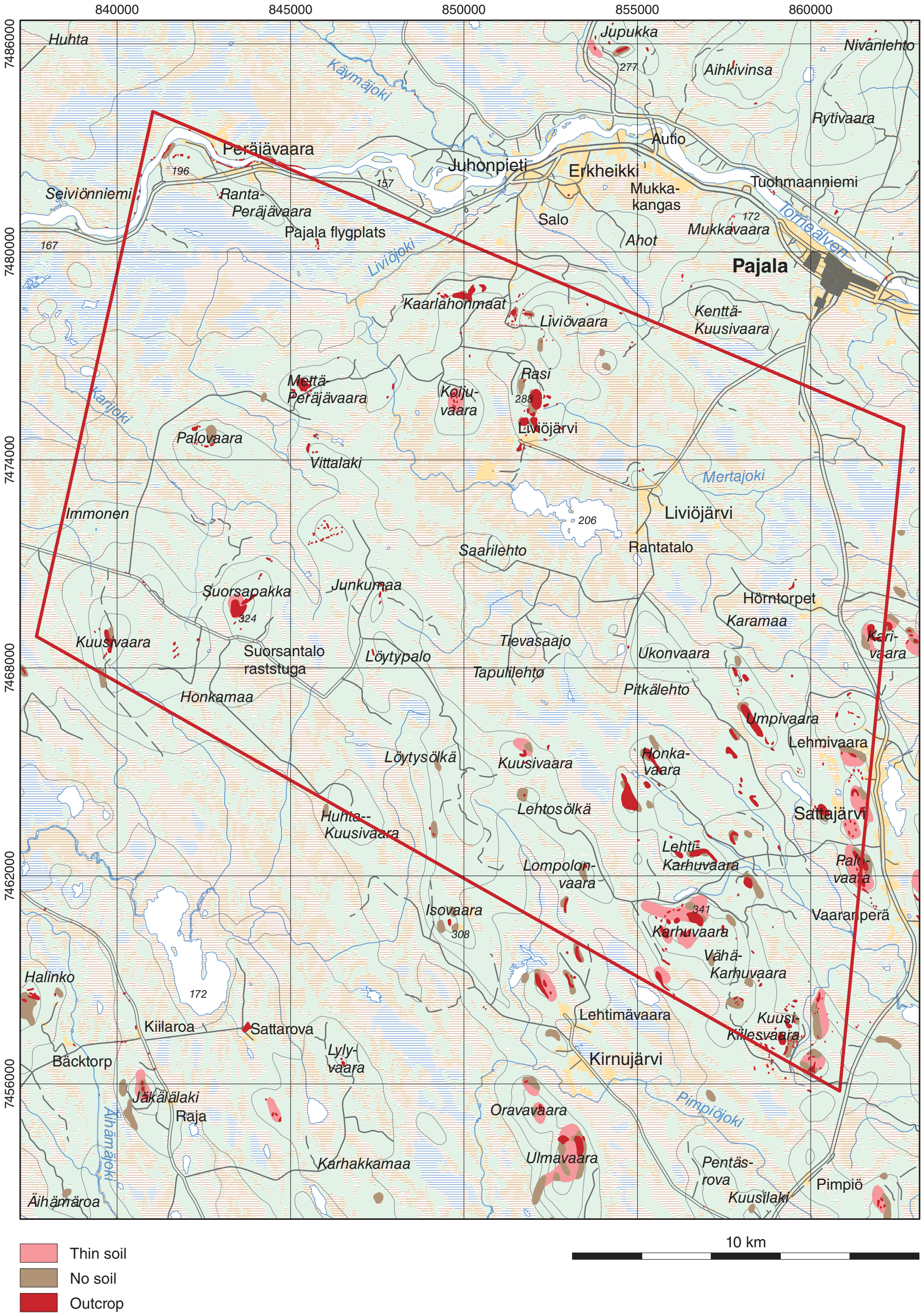


Figure 5. Topographic map (Vägkartan) of the Liviöjärvi key area from Lantmäteriet showing previously investigated outcrops.

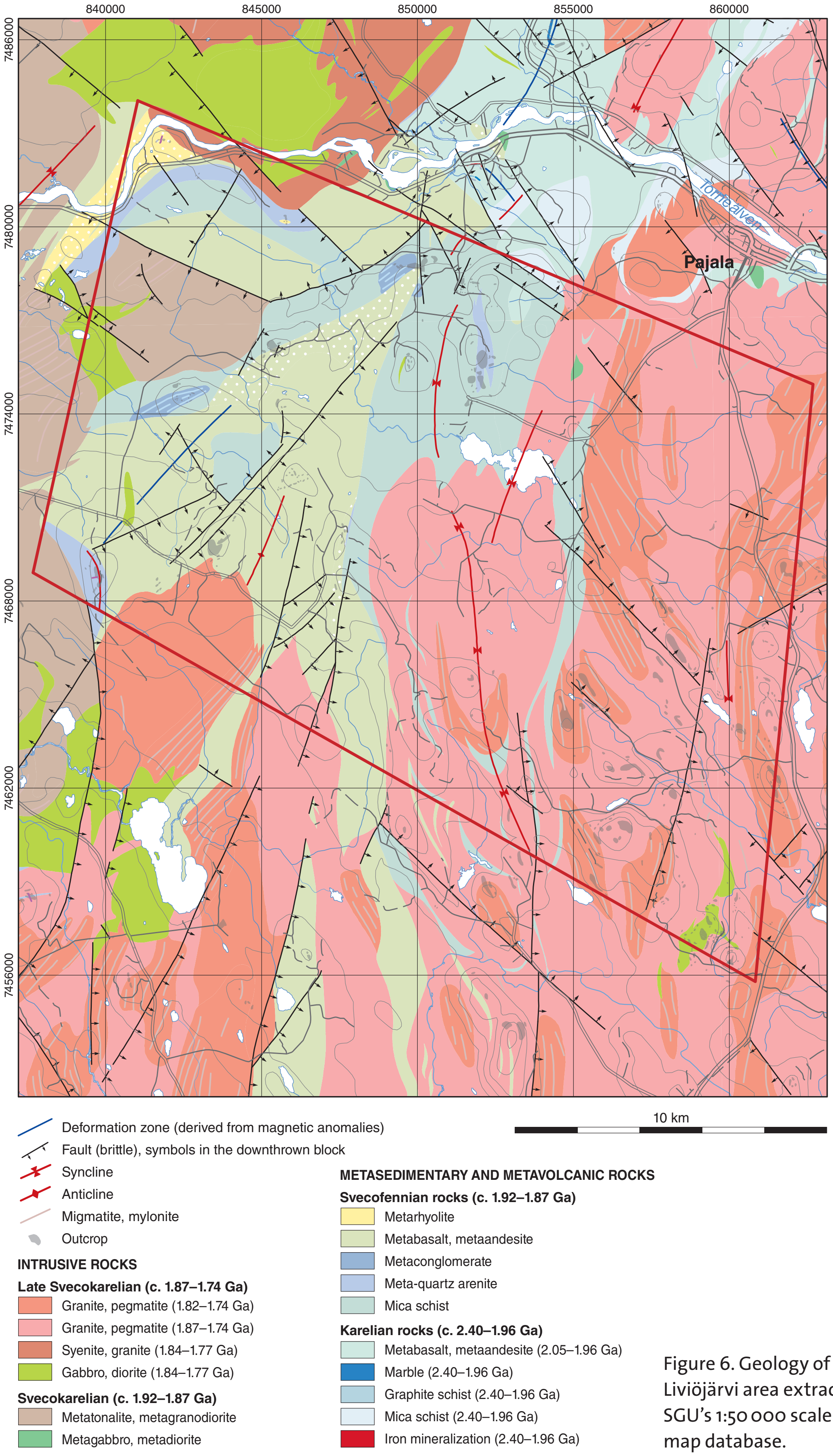


Figure 6. Geology of the Liviöjärvi area extracted from SGU's 1:50 000 scale bedrock map database.

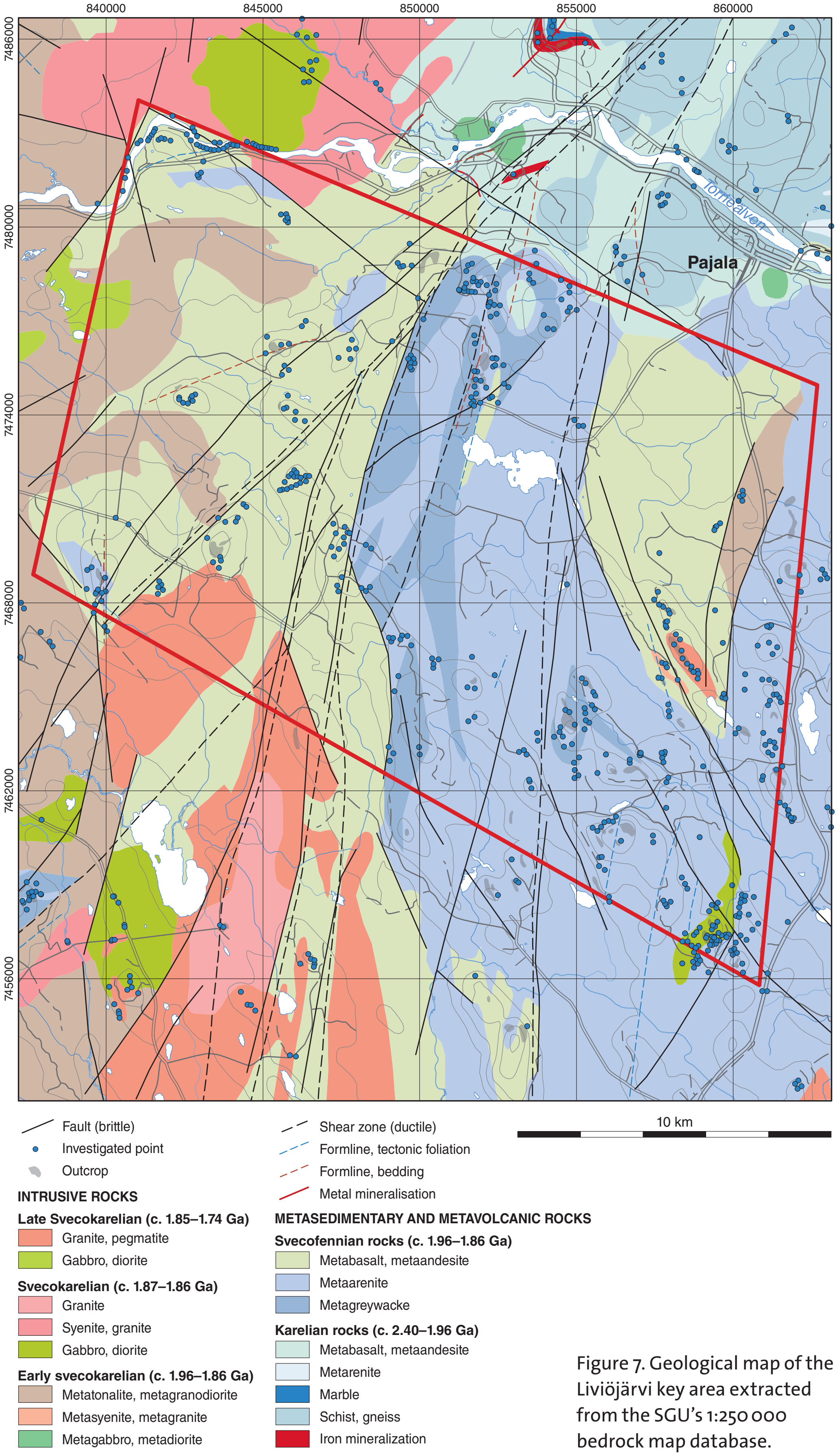


Figure 7. Geological map of the Liviöjärvi key area extracted from the SGU's 1:250 000 bedrock map database.

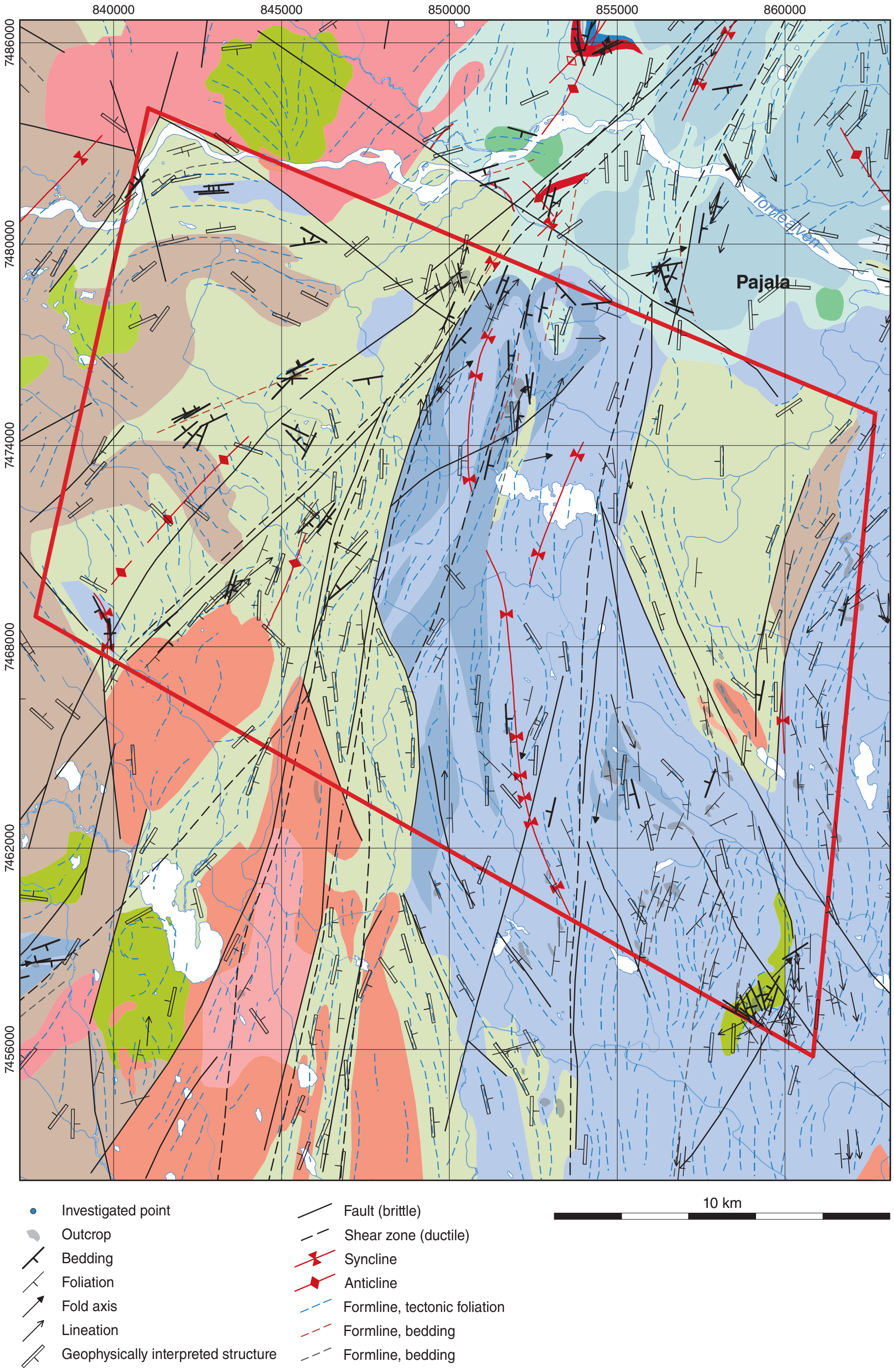


Figure 8. Structural map of the Liviöjärvi key area extracted from the SGU's 1:250 000 bedrock map database. See Figure 7 for complete legend of the background colors.

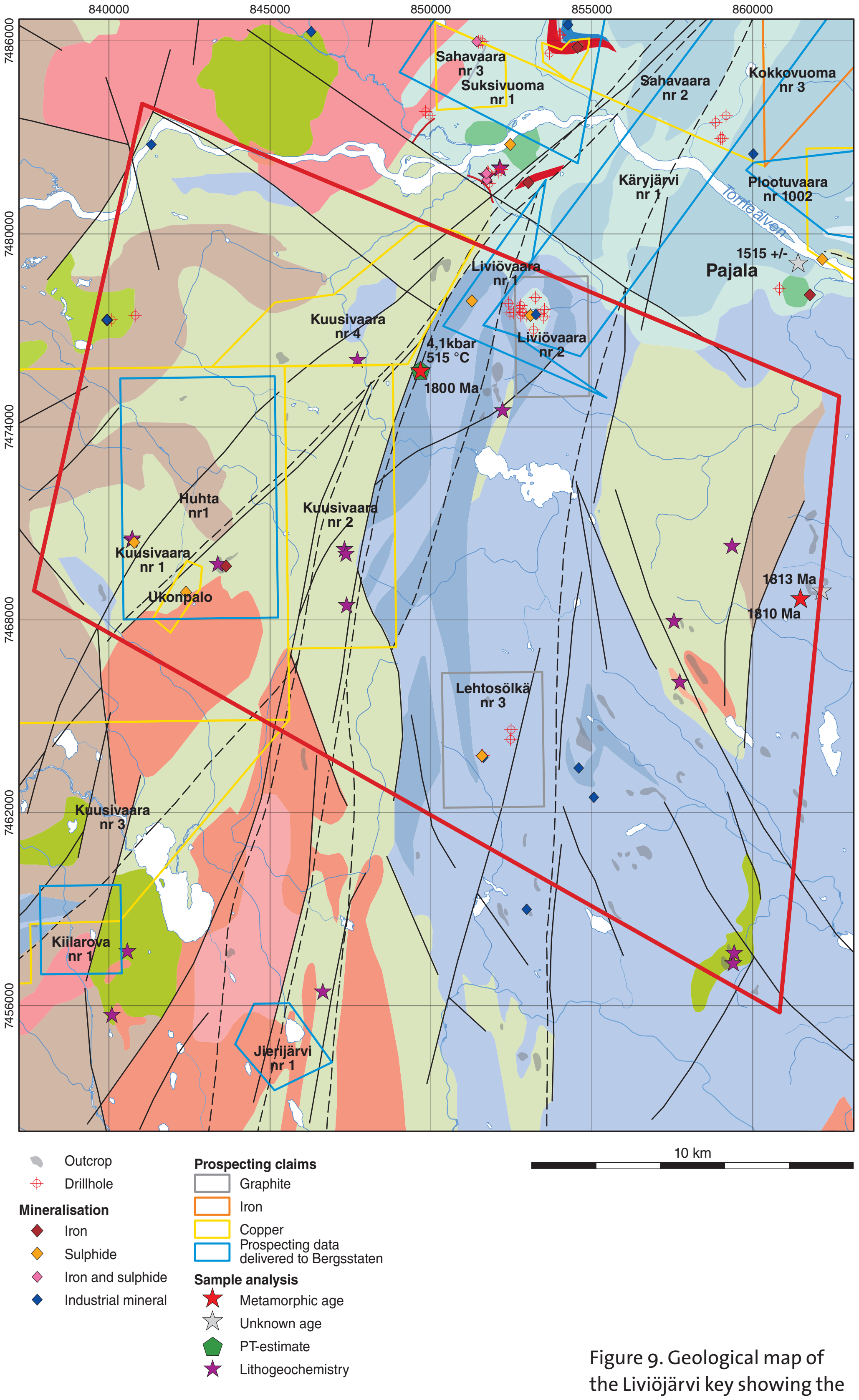


Figure 9. Geological map of the Liviöjärvi key showing the most relevant point data and prospecting claims. See Figure 7 for complete legend of the background colors.

Table 2. Details of all the drill cores from the Liviöjärvi area shown in Figure 9. NÖN: Nordöstra Norrbotten, LKAB: Luossavaara Kirunavaara Aktiebolgag, NSG: Nämden för statens gruvegendomar.

Name	Drillhole	Northing (Sweref)	Easting (Sweref)	Length (m)	Report	Archived in Malå	Previous owner	Drill year
Karhujärvi	003	7486187	854034	132.2		Yes	Kiruna last 1 1992	1960
Karhujärvi	004	7487029	854362	122.0		Yes	Kiruna last 1 1992	1960
Karhujärvi	002	7486200	854007	60.8			Kiruna last 1 1992	1960
Karhujärvi	6101	7485630	853693	100.3		Yes	Kiruna last 1 1992	1961
Pajala Syd	67001	7478306	860845	119.6			SGU	1967
Erkheikki	69001	7483814	849848	290.5		Yes	SGU	1969
Erkheikki	69003	7481906	851803	130.7		Yes	SGU	1969
Erkheikki	69002	7481937	851777	136.0			SGU	1969
Erkheikki	70001	7481937	852118	245.9		Yes	SGU	1970
Erkheikki	70002	7481572	851819	154.2		Yes	SGU	1970
Erkheikki	70003	7482016	852195	165.2		Yes	SGU	1970
Peräjävuoma	70001	7477477	840822	140.2		Yes	SGU	1970
Peräjävuoma	70002	7477342	840079	107.1		Yes	SGU	1970
Erkheikki	71001	7483700	849945	231.5		Yes	SGU	1971
Liviövaara	002	7477477	852993	139.7	K 86-42,Prap 91045	Yes	NÖN/LKAB/NSG/ VOLVO	1986
Liviövaara	003	7477487	853103	134.7	K 86-42,Prap 91045	Yes	NÖN/LKAB/NSG/ VOLVO	1986
Liviövaara	001	7477424	853510	0.0	K 86-42		NÖN/LKAB/NSG/ VOLVO	1986
Liviövaara	004	7477506	853302	0.0	K 86-42		NÖN/LKAB/NSG/ VOLVO	1986
Liviövaara	005	7477564	852845	0.0	K 86-42		NÖN/LKAB/NSG/ VOLVO	1986
Välivaara	05	7487588	852200	0.0		Yes	Viscaria AB Exploration/Outokumpu	1996
Välivaara	06	7485978	851490	0.0		Yes	Viscaria AB Exploration/Outokumpu	1996
Välivaara	07	7485979	851560	0.0		Yes	Viscaria AB Exploration/Outokumpu	1996
Välivaara	15	7485980	851610	0.0		Yes	Viscaria AB Exploration/Outokumpu	1996
Käryjärvi	00002	7482981	859066	125.2		Yes	Anglo American	2000
Käryjärvi	00003	7483478	858860	125.0		Yes	Anglo American	2000
Liviövaara	00LIV001	7477682	852765	196.0		Yes	Anglo American	2000
Liviövaara	00LIV002	7477485	852804	137.6		Yes	Anglo American	2000
Liviövaara	00LIV003	7477019	853193	189.3		Yes	Anglo American	2000
Liviövaara	00LIV004	7478029	853256	192.2		yes	Anglo American	2000
Liviövaara	00LIV005	7477786	852801	201.1		yes	Anglo American	2000
Käryjärvi	01001	7482980	859016	214.6		yes	Anglo American	2001
Käryjärvi	01004	7483683	859182	83.1		yes	Anglo American	2001
Liviövaara	01LIV006	7477564	852571	185.5		yes	Anglo American	2001
Liviövaara	01LIV007	7477554	852461	109.8		yes	Anglo American	2001
Liviövaara	01LIV008	7477852	852424	188.9		yes	Anglo American	2001
Liviövaara	01LIV009	7477652	853529	288.3		yes	Anglo American	2001
Pajala	001	7480499	863974	288.4			Boliden	2003
Pajala	002	7480416	863814	242.3			Boliden	2003
Pajala	003	7480252	863667	283.5			Boliden	2003
Pajala	004	7480126	863577	244.7			Boliden	2003
Lethosölkä	001 B	7463785	851619	13.8	Prap 91045	1	NÖN/LKAB/NSG/ VOLVO	
Lethosölkä	002	7464592	852499	35.0	Prap 91045	1	NÖN/LKAB/NSG/ VOLVO	
Lethosölkä	003	7463780	851579	94.5	Prap 91045	1	NÖN/LKAB/NSG/ VOLVO	
Lethosölkä	004	7464292	852483	81.9	Prap 91045	1	NÖN/LKAB/NSG/ VOLVO	

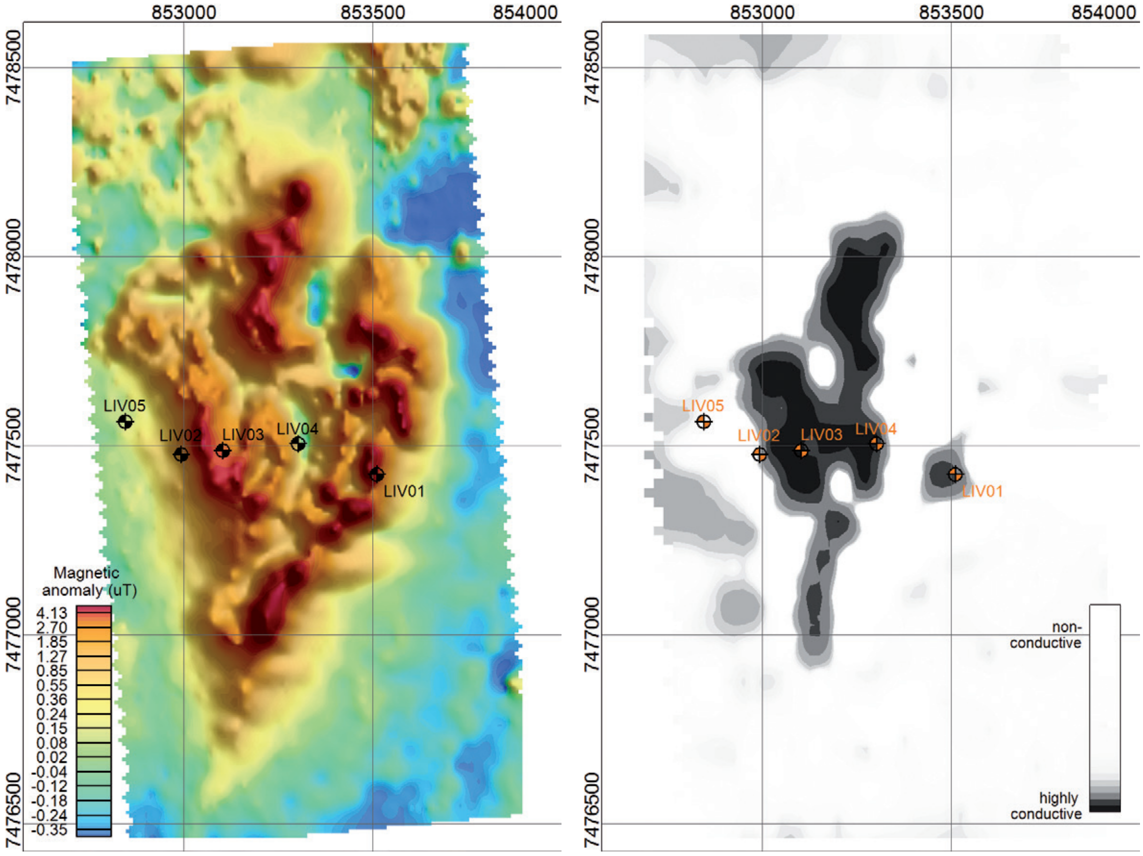


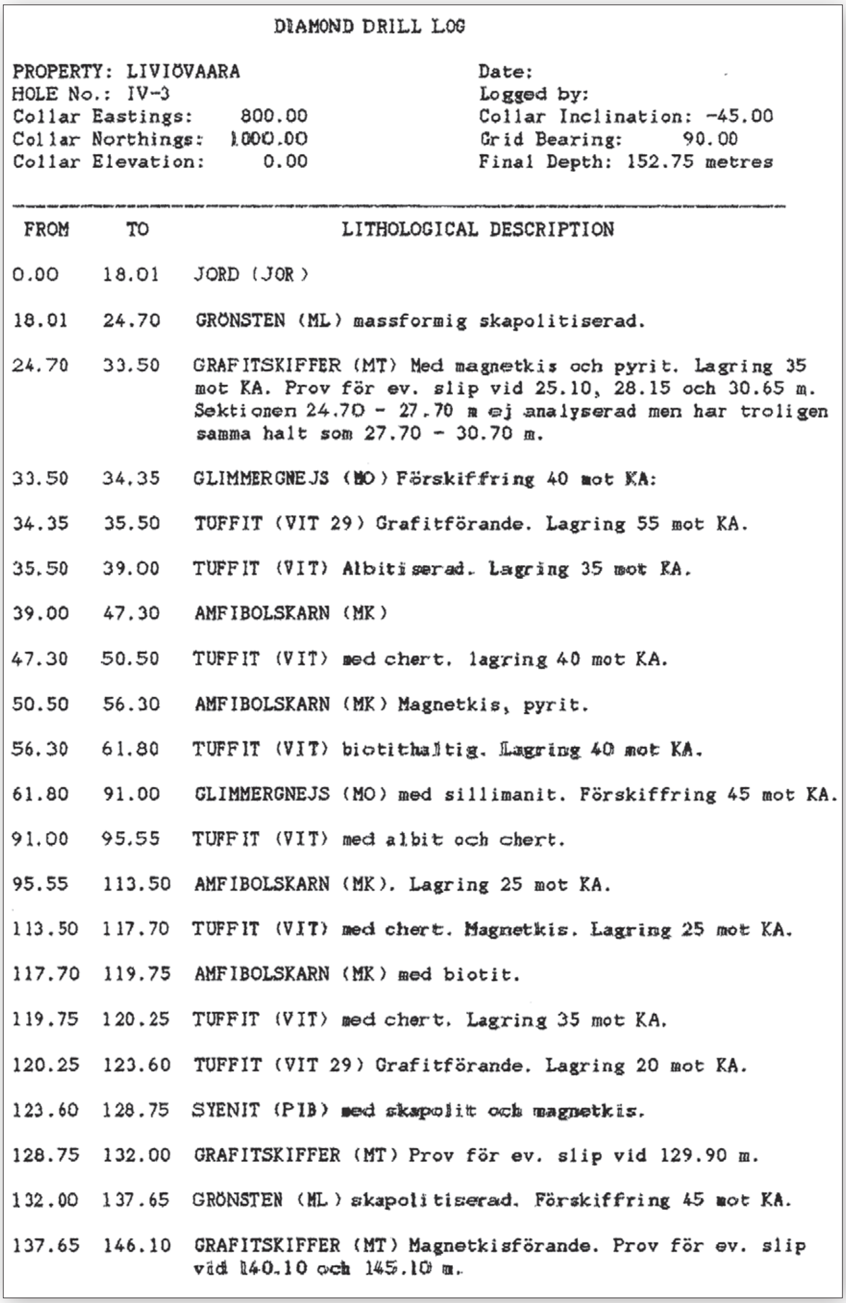
Figure 10. Ground geophysical surveys in the Liviövaara area (upper left and right) in combination with drilling (lower right) revealed an antiform geometry. Notice that the high slingram anomaly (upper right) is monitored between drillholes Liv03 and Liv04, confirming that the high conductivity is caused most likely by high graphite concentrations.

volcanic rocks towards more felsic rocks with rhyolitic composition to finally mica schists. Concerning the larger structure they considered the greenstone formation as an antiform which was cut off towards the north by major faults. This geometry was based on interpretations from slingram and magnetic ground measurements (Johansson 1985, Fig. 10). To the south, the antiform plunges 25° towards the south-south-west whereas its northern part plunges only very gently towards the north and is cut by several E-W striking faults which are down-thrown to the north. The eastern flank of the antiform dips steeply (90–80°) to the east and the western flank moderately (50–85°) towards the west. The antiforms high magnetic properties gave rise to estimates of 10% magnetite embedded in intermediate to mafic volcanic rocks, whereas a high conductivity can be explained by the presence of graphite (Figs. 10–11).

Geophysical measurements

Airborne data

The airborne geophysical data was collected in the Liviöjärvi key area and its surroundings during the 1980s by the Luossavaara Kiirunavara AB (LKAB). During 2008 and 2009, SGU measured a large area south of the key area including the map sheets 27K–N. The older airborne measurements were done with a flight altitude of 30 m above ground while the more recent measurements are done at 60 m above ground. All airborne measurements within this area are flown in an east–west direction. A complete list of airborne measurements in relation to the key



DIAMOND DRILL LOG

PROPERTY: LIVIÖVAARA
HOLE No.: IV-3
Collar Eastings: 800.00
Collar Northings: 1000.00
Collar Elevation: 0.00

Date:
Logged by:
Collar Inclination: -45.00
Grid Bearing: 90.00
Final Depth: 152.75 metres

FROM	TO	LITHOLOGICAL DESCRIPTION
0.00	18.01	JORD (JOR)
18.01	24.70	GRÖNSTEN (ML) massformig skapolitiserad.
24.70	33.50	GRAFITSKIFFER (MT) Med magnetkis och pyrit. Lagring 35 mot KA. Prov för ev. slip vid 25.10, 28.15 och 30.65 m. Sektionen 24.70 - 27.70 m ej analyserad men har troligen samma halt som 27.70 - 30.70 m.
33.50	34.35	GLIMMERGNEJS (MO) Förskiffring 40 mot KA:
34.35	35.50	TUFFIT (VIT 29) Grafitförande. Lagring 55 mot KA.
35.50	39.00	TUFFIT (VIT) Albitiserad. Lagring 35 mot KA.
39.00	47.30	AMFIBOLSKARN (MK)
47.30	50.50	TUFFIT (VIT) med chert. lagring 40 mot KA.
50.50	56.30	AMFIBOLSKARN (MK) Magnetkis, pyrit.
56.30	61.80	TUFFIT (VIT) biotithaltig. Lagring 40 mot KA.
61.80	91.00	GLIMMERGNEJS (MO) med sillimanit. Förskiffring 45 mot KA.
91.00	95.55	TUFFIT (VIT) med albit och chert.
95.55	113.50	AMFIBOLSKARN (MK). Lagring 25 mot KA.
113.50	117.70	TUFFIT (VIT) med chert. Magnetkis. Lagring 25 mot KA.
117.70	119.75	AMFIBOLSKARN (MK) med biotit.
119.75	120.25	TUFFIT (VIT) med chert. Lagring 35 mot KA.
120.25	123.60	TUFFIT (VIT 29) Grafitförande. Lagring 20 mot KA.
123.60	128.75	SYENIT (PIB) med skapolit och magnetkis.
128.75	132.00	GRAFITSKIFFER (MT) Prov för ev. slip vid 129.90 m.
132.00	137.65	GRÖNSTEN (ML) skapolitiserad. Förskiffring 45 mot KA.
137.65	146.10	GRAFITSKIFFER (MT) Magnetkisförande. Prov för ev. slip vid 140.10 och 145.10 m.

Figure 11. Example of a drill log from Liviövaara (drill core Liv04, Gerdin 1991) to highlight the variety in rock types on a metre scale in this region.

area is found in Table 3. A full coverage of the key area is available in the magnetic, radiometric and slingram data. The residual total magnetic field map is shown in Figure 12.

For the electromagnetic VLF data, a large section is missing where only the response from one transmitter was recorded. Processing of directional independent VLF maps (peaker, current density and apparent resistivity) require data from two different transmitters (Pedersen et al. 1994) and hence is not available for the entire area (Fig. 13). A power line transects the area causing a strong response in the data. Such artificial sources are important to identify prior to interpretation. From the VLF data, conductive horizons and possibly also brittle deformation zones can be identified.

The real part of the electromagnetic slingram data is shown in Figure 14. The response reflects the conductivity in the ground where darker areas are more conductive.

Table 3. List of the airborne geophysical surveys covering the Liviöjärvi key area.

Year	Company	Gephysical methods used	Area	Flight direction	Flight line separation (m)	Flight altitude (m)	Project ID
1986	LKAB	Magnetics, gamma spectrometry, VLF (1-transmitters), slingram	27M NV, western half of 27M NO and part of 27L NO	E-W	200	30	R 31
1982	LKAB	Magnetics, gamma spectrometry, VLF (2-transmitters) not complete coverage, slingram	28L NO, 28M NV and parts of 29M SV, 29M SO and 28M NO	E-W	200	30	R 4
1984	LKAB	Magnetics, gamma spectrometry, VLF (2-transmitters) not complete coverage, slingram	28M SV and most of 28M SO	E-W	200	30	R 1
1985	LKAB	Magnetics, gamma spectrometry, VLF (2-transmitters) 50% coverage, slingram	two thirds of 29L SO	E-W	200	30	R 5
1985	LKAB	Magnetics, gamma spectrometry, VLF (2-transmitters), slingram	Large part of 28L SO	E-W	200	30	R 2
2008	SGU	Magnetics, gamma spectrometry, VLF (2-transmitters)	Almost entire 27L and part of 27KMN	E-W	200	60	27KLMN

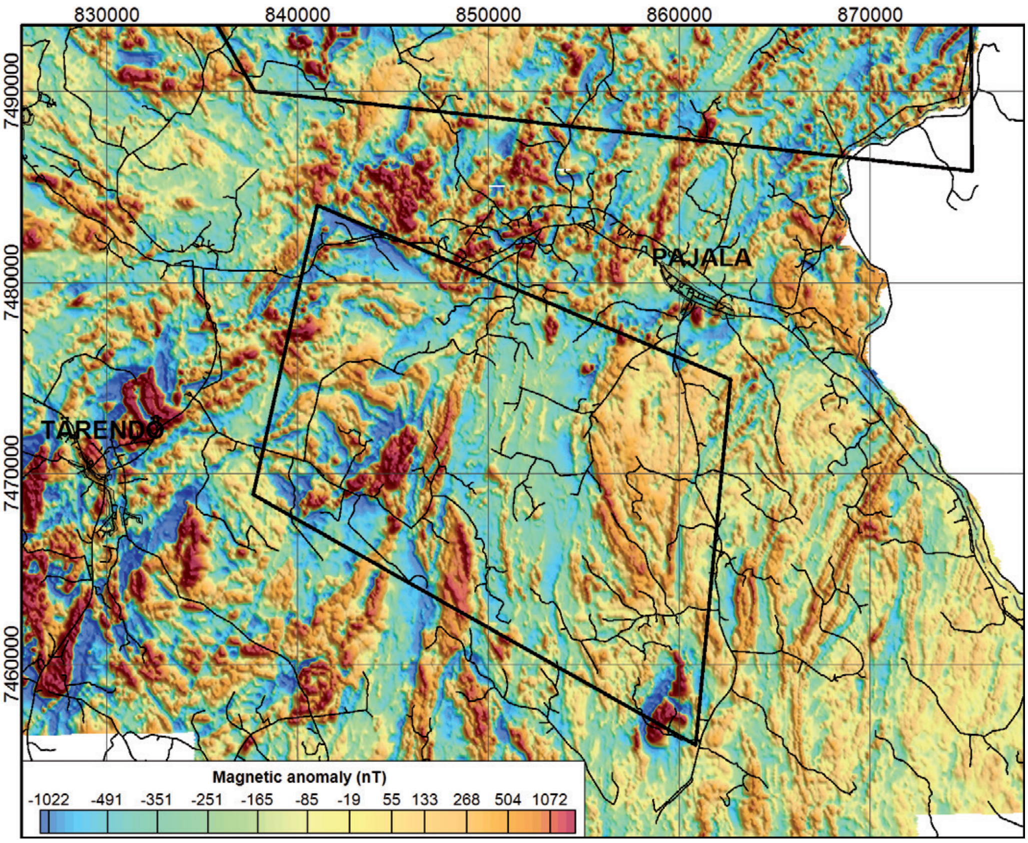


Figure 12. Magnetic anomaly map of the Liviöjärvi key area. The data has been filtered to enhance the response from the shallowest (approximately 500 m) parts of the bedrock. The polygon in the north shows part of the Käymäjärvi key area.

Figure 13. Imaginary part of the peaker anomaly VLF response. Dark blue colour indicates conductive structures. The location of a power line crossing the key area is outlined.

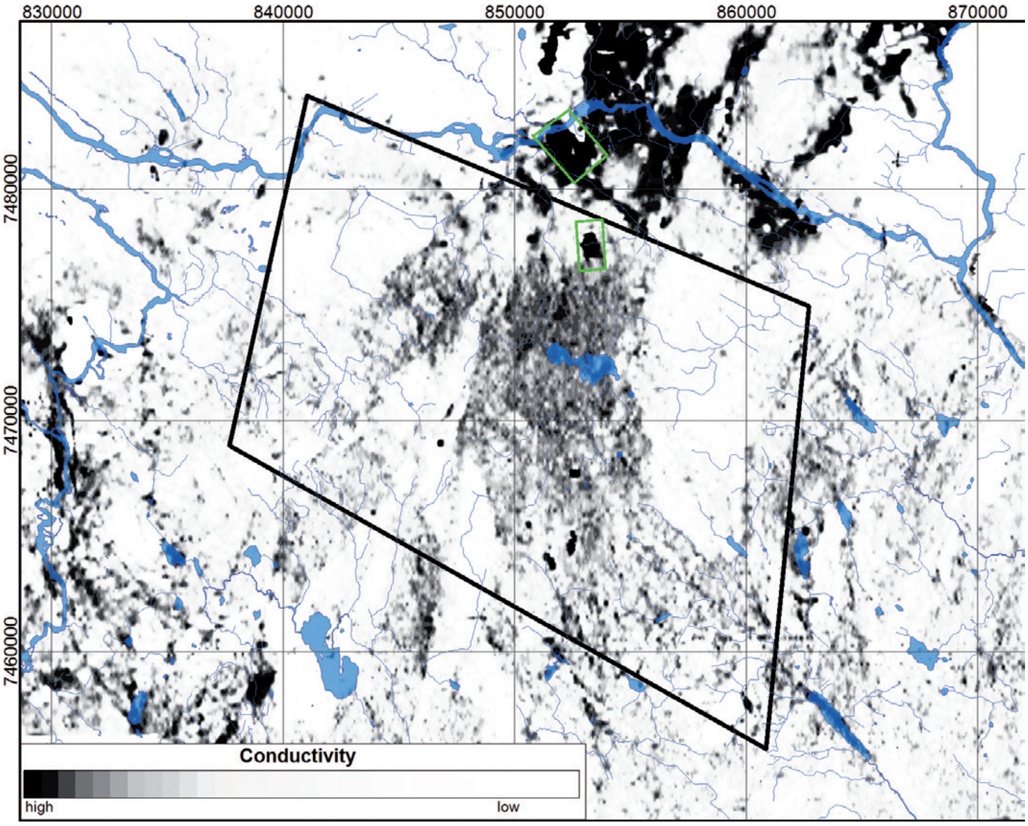


Figure 14. Real part of the electromagnetic slingram data, measured with a frequency of 3720 Hz. Green polygons show the location of ground based slingram measurements.

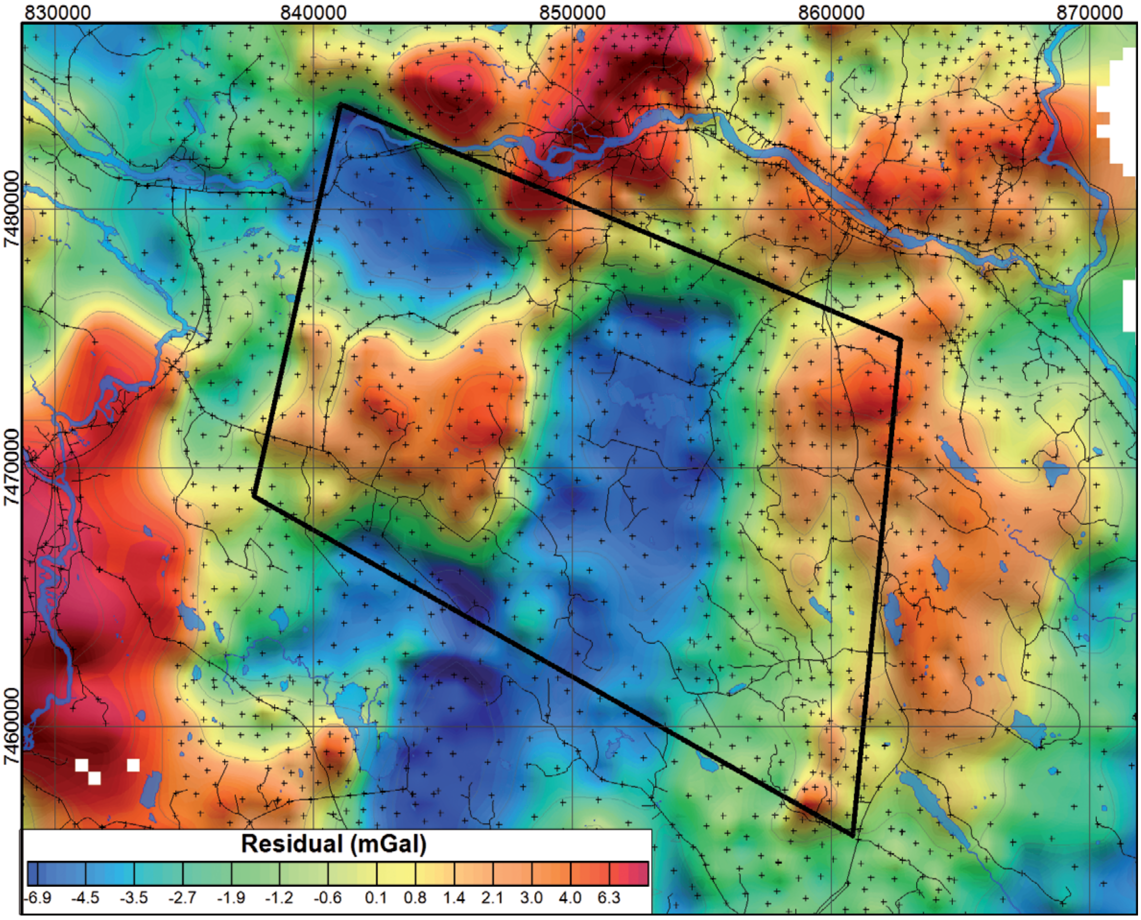


Figure 15. Residual map of terrain corrected Bouguer anomaly data. The data has been filtered to remove the responses from deeper parts of the bedrock. The map approximately corresponds to the responses from the top 3 km. The crosses show the location of the regional gravimetric measurements.

Ground based measurements (gravity, magnetic, electromagnetic)

The regional gravity measurements in the area are well distributed covering the whole key area and have a point distance of approximately 1 km or less (Fig. 15). The vast majority of the gravity data were collected in 1968. Five detailed gravity surveys were carried out in the area (Fig. 16 and Table 5) during 1967 and 1968. The point distances for these measurements range from 10 to 40 m.

All ground surveys are shown in Figure 5 with correlating information in Tables 4 and 5. The magnetic measurements dominate but there are two areas where slingram measurements have been conducted. North of the key area, between the Liviöjärvi and Käymäjärvi key areas, two transient electromagnetic (TEM) surveys have been conducted. The TEM measurements can give information on the resistivity of the ground down to a depth of several hundred meters.

Measurement of single magnetic and electromagnetic profiles has been performed in 1995 as a part of the regional mapping project described in Bergman et al. (2001). The profiles are shown as black lines in Figure 16 and the profile information is presented in Table 5.

Petrophysics

There are 431 petrophysical samples collected from the area and the sample points are shown in Figure 17. For all these samples there is information on rock density, magnetic susceptibil-

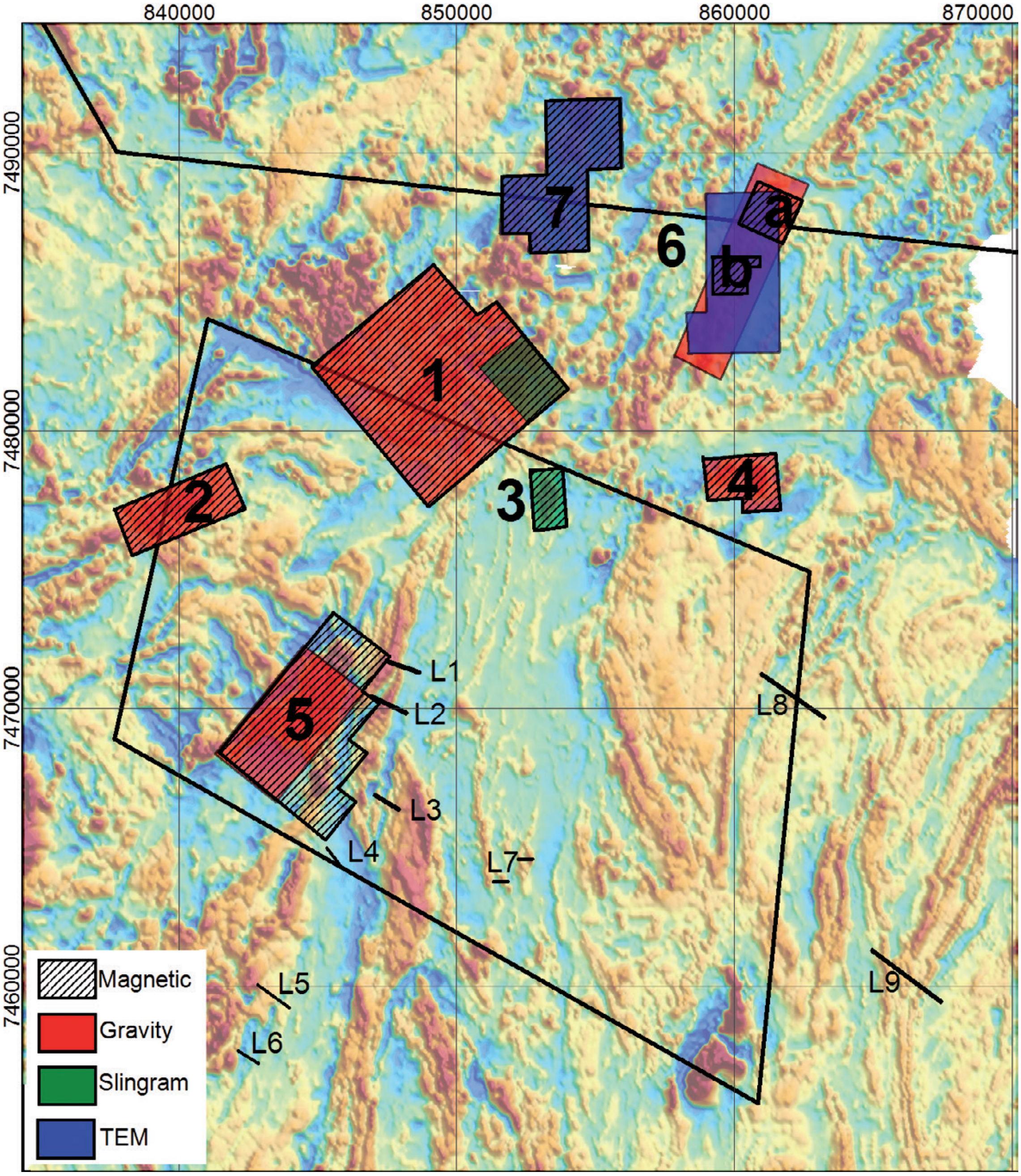


Figure 16. Polygons showing the coverage of ground geophysical measurements in the area refer to Table 4. Black lines show the locations of ground geophysical profile measurements. Information on these measurements is found in Table 5.

ity and size of remanent magnetization. For the majority of the samples the rock type has been determined. The directions of the magnetic remanence has been measured in 49 samples. The are few outcrops within the key area (Fig. 17) and hence the sampling distribution has been controlled by this.

Areas of interest within the Liviöjärvi key area

An important aim for the geological mapping in the Liviöjärvi key area is to better constrain the stratigraphy of the area by regional correlations among supracrustal units observed in other key

Table 4. Ground measurements with polygon numbers correlating to figure 16.

Polygon no	Name	Method	Parameter	Year
1	Erkheikki	Magnetic	z-anomaly	1968
		Gravity	terrain corrected Bouguer anomaly	1968
		Slingram	Im and Re	1971
2	Peräjävuoma	Magnetic	z-anomaly	1968
		Gravity	terrain corrected Bouguer anomaly	1968
3	Liviövaara	Magnetic	z-anomaly	1983
		Slingram	Im and Re	1985
4	Pajala syd	Magnetic	z-anomaly	1967
		Gravity	terrain corrected Bouguer anomaly	1967, 1968
5	Suorsa	Magnetic	z-anomaly	1967
		Gravity	terrain corrected Bouguer anomaly	1968
6a	Käryjärvi	Magnetic	z-anomaly	1969
b		Magnetic	total field	-
		Gravity	terrain corrected Bouguer anomaly	1968
		TEM		-
7	Suksivuoma	Magnetic	total field	-
		TEM		-

Table 5. Ground geophysical profile measurements. Line ID correlates to Figure 16.

Line ID	Method	Profile ID	Measurement date	Point distance (m)	Length of profile (m)
L1	Mag	MP95TIP1016	1995-08-09	10	1130
	VLF	VF95LUK1017	1995-08-09	10	1160
L2	Mag	MP95TIP1020	1995-08-13	10	1530
	VLF	VF95TIP1018	1995-08-13	10	1450
L3	Mag	MP95TIP1021	1995-08-16	10	1000
	VLF	VF95LUK1019	1995-08-16	10	500
L4	VLF	VF95TIP1020	1995-08-16	10	700
L5	VLF	VF95TIP1009	1995-07-15	10	1400
L6	VLF	VF95TIP1008	1995-07-15	10	880
L7	Slingram	SRAlehtosolka (800)	1985-11-XX	20	500
L8	Mag	MP95TIP1015	1995-08-01	10	2790
L9	Mag	MP95TIP1014	1995-08-01	10	3100

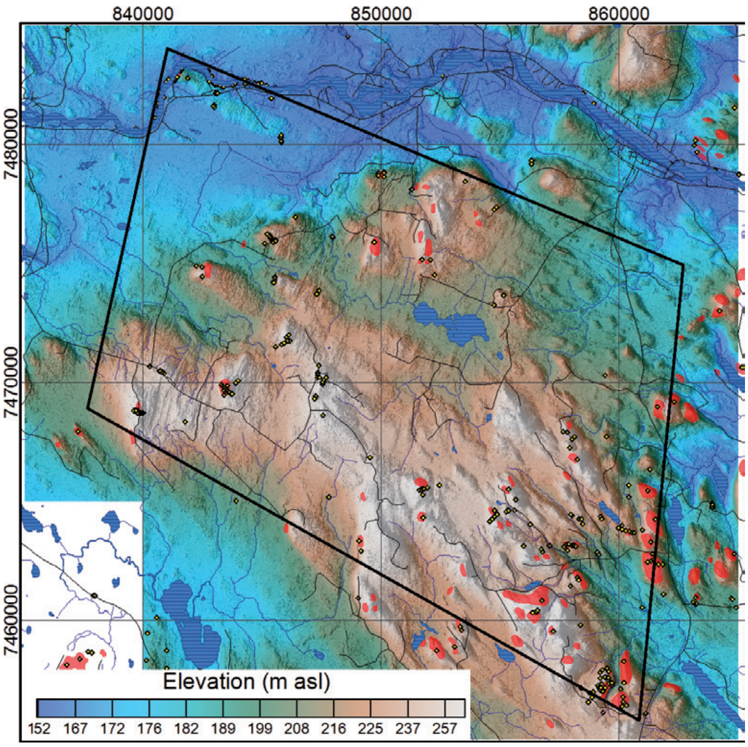


Figure 17. Topography map based on LiDAR data (2x2 m DEM) from Lantmäteriet. Red areas show the distribution of outcrops and yellow dots the location of the 431 petrophysical samples.

areas (See Table 6 for further details). The greenstones (basic and intermediate volcanic rocks) north of Pajala are interpreted as the upper part of the Greenstone group, whereas most of the greenstones in the Liviöjärvi area are considered to belong the Porphyrite group (locally named Suorsa group, Fig. 2).The upcoming field study, in combination with lithogeochemical and geochronological analysis, should aim to confirm or dispute this interpretation. It is also possible that this contrasting stratigraphy may be fault related. We therefore suggest that detailed mapping also should cover the narrow strip located between both key areas. In addition, our aim to characterise the geochemical signature of the Suorsa group may help to understand its regional context with respect to other greenstone units to the west (e.g. Kiruna area) or east (Finland, Central Lapland Greenstone Belt).

Characterisation of the metasedimentary rocks in the Liviöjärvi has two aims: Firstly, the formation age of the "Svecofennian" rocks needs to be better constrained and compared to the "Karelian" counterparts to the south-east of the study area. A comparison with the geochemistry of rocks from the Peräpohja Belt in Finland should also be done (see also Kyläkoski et al. 2012). Secondly, PSZ-related deformation needs to be documented. Despite the overall low-magnetic signature of the metasedimentary rocks, several easily traceable anomalies have been recorded (e.g. Fig. 12).The often elongated and tightly folded geometry of the anomalies suggests that this unit accommodated intense shearing. Whether these dome-like geometries represent sheath folds or are the result of several overprinting folding phases needs to be investigated.

Another observation primarily based on magnetic anomalies are several faulting patterns (Fig. 12). West-north-west striking faults dominate in the eastern part while north-east striking faults dominate in the west. However, most faults seem to curve into the north–south trending central zone, which consists mainly of metasedimentary rocks. From these observations it appears that the metasedimentary rocks represent a zone of localised deformation and are therefore considered an important target to further constrain the kinematics of the PSZ. In addition, observations from the western part on well preserved primary textures (e.g. wave ripples and cross-bedding) indicate little to no overprinting by deformation and metamorphism. This east–west contrast in metamorphic grade makes this stratigraphic unit a good candidate in which to study the processes which caused deformation, metamorphism, migmatitisation and also late alteration and mineralisation.

Furthermore, the deformation pattern observed in Liviöjärvi area is different from the pattern seen in the Käymäjärvi-Ristimella area. In the latter area, deformation associated with the PSZ appears more localised along a major north-east trending fault. More detailed structural mapping in both areas should aim to distinguish between regional and more local features as well as their spatial connections and timing of (re)activation (Fig. 18, Table 6). Integration of local observations into a more regional context is essential to understand the tectonic setting of the Pajala shear zone and its control on the formation of mineral deposits in the area.

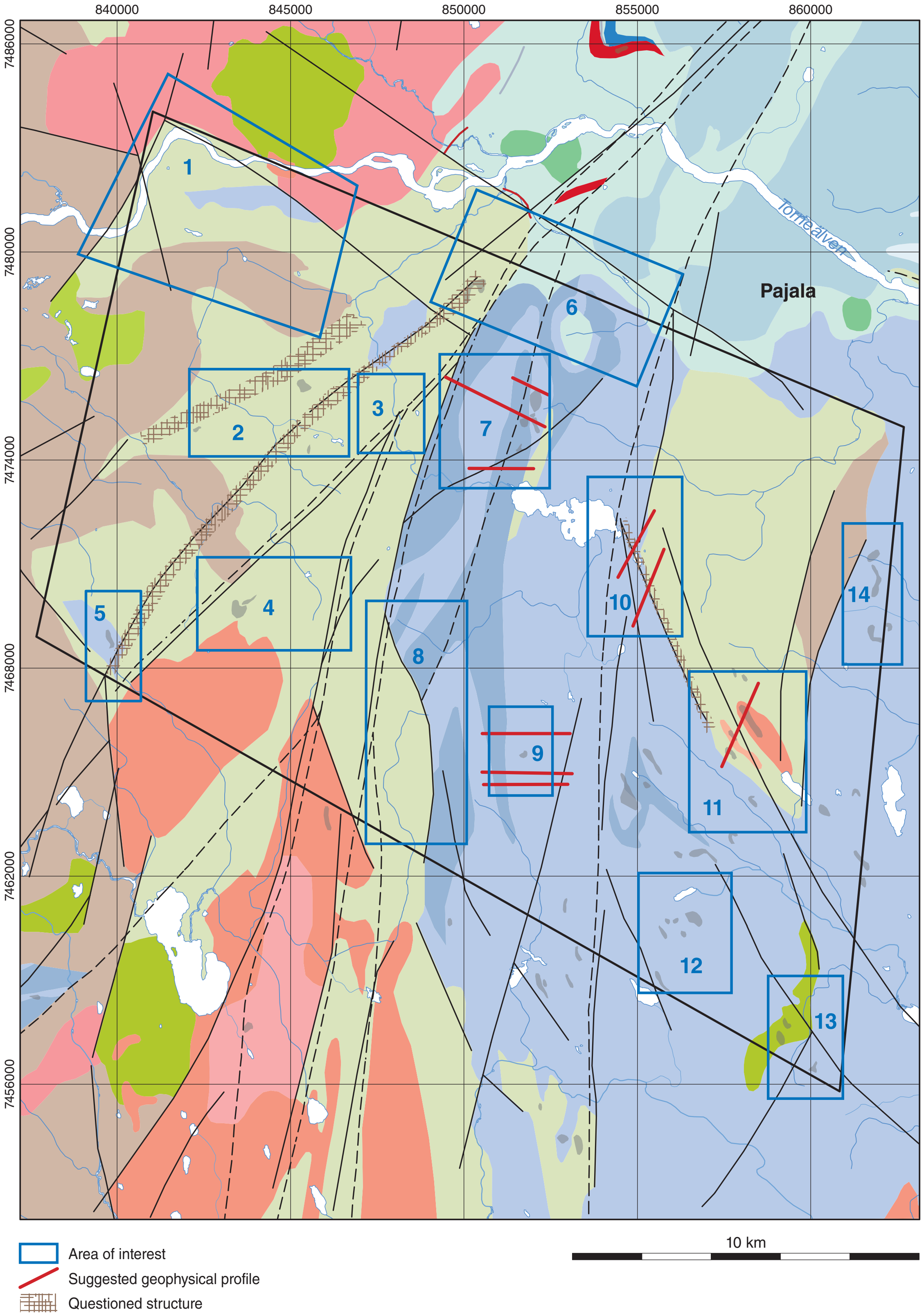


Figure 18. Areas of interest within the Liviöjärvi key area. See Table 6 for descriptions and figure 7 for complete legend of the background colors

Table 6. Descriptions of the areas of interest chosen for field studies in the Liviöjärvi key area.

Area of interest (polygon)	Previous relevant observations	Interesting issues	Method
Western domain			
1	Sandstone layers trending east–west (geol.) West-north-west trending-fault (geol. and mag.) Gently curved (folded?) east–west trending magnetic anomalies in a generally low magnetic region. Also the Bouguer anomaly is exceptionally negative and sharply bounded in all directions. The negative bouguer anomaly is not explained in the mapped geology.	Structural formlines indicate east–west folding. Is there evidence for a north–south overprint? Are the rocks strongly altered due to several nearby intrusion? Is characterisation of the contact zones possible? Is the west-north-west-striking fault exposed? What does the high magnetic anomaly along the road represent? Relation between metasedimentary rocks and greenstones. Chemical signature.	Study of outcrops along roads and river. Compile available petrophysical data of the different bedrock units. Model the current bedrock units and compare the response in the geophysical data.
2	Folded bedding and north-east trending faults. A major fault is not observed in existing geophysical data. However, the deflection of structural formlines suggest some sinistral faulting. In the north-west of the area, electromagnetic data represent a conducting structure.	Relation between folding and north-east trending faults. Is faulting sinistral? Is there an additional fault in the north-west? Many bedding measurements suggest the presence of sedimentary layering. What is the lithology, degree of metamorphism and are there way-up indicators preserved?	Outcrops near the road. VLF profiling over suggested and previously mapped structures.
3	Intersection between a major north-east trending fault and a north trending fault.	What is the overprinting relationship at the intersection point between a major north-east trending fault and north trending fault? What is their kinematics?	Search for outcrops along trail. Magnetic profiling.
4	Region of very high magnetic anomaly and a Bouguer anomaly bounded by faults.	What causes the geophysical anomalies? How are these related to faulting? Did faulting cause alteration and possibly mineralisation? Geochemical signature of the greenstones. What is their magmatic age?	Mapping and sampling within and along the borders of the anomaly area.
5	Metasandstones. North and north-east striking faults seen on magnetic anomaly maps.	Are the sandstones altered by nearby intrusion? Is there a contact with the volcanic rocks exposed. Faulting overprints? Relation between metasedimentary rocks and greenstones.	Detailed mapping around top of hill. Magnetic profiling in the southern part.
Central Domain			
6	Several north–south folds, south-east as well as south striking bedding (hinge zones?), a west-north-west striking fault, high magnetic anomalies around Liviövaara. Drill cores available in Malå.	Detailed mapping of the north–south structural features (folds and faults). How do they continue just north of the key area? What structure causes the northward discontinuation of the metasedimentary rocks? Is it a west-north-west striking fault, fold plunging, or something else? Are there contacts between the basalts and the metasedimentary rocks exposed at Liviövaara? Are these tectonic? What is their age relation and chemical signature? Is there an east–west contrast in metamorphic grade?	Try to find new outcrops at the northern slope of Liviövaara.

Area of interest (polygon)	Previous relevant observations	Interesting issues	Method
7	Almost dome-shaped, north–south elongated feature indicated by a narrow, high magnetic anomaly. A north-east trending fault is mapped in the south.	1) Is the north–south elongated feature closing as a ring? 2) Does it represent a stretched sheath fold indicating vertical shear, or does it relate to later north–south stretching of a more rounded basin and dome structure? 3) What does the positive magnetic anomaly actually relate to? Can it be coupled to a stratigraphic horizon? Can the north-east trending fault be localised and kinematic revealed?	Magnetic profiling and detailed geological mapping.
8	Fault-bounded high magnetic anomaly zone striking north–south marking the boundary between the western and central domains.	What does the high magnetic anomaly represent? Is there a north–south trending ductile fabric overprinted by localised brittle faults?	Poorly to not exposed. Search for outcrops along the road. VLF profiling.
9	Syncline in metasandstones. Drill cores are available in Malå.	Can the syncline be confirmed? What do the anomalies in this unit represent?	Detailed mapping around hill top. VLF profiling.
10	Tectonic contact between metasandstone and basalts. Major north–south faults as well as north-west trending faults.	Do the north-west trending faults continue in the central zone? If not, are these faults overprinted or cut-off by a north–south striking fabric?	Poorly to not exposed. Search for outcrops along the road and trail. VLF or magnetic profiling.
Eastern domain			
11	Stratigraphic contact between metasandstones and basalts. Lens-shaped granite intrusion.	Is the contact between the sandstone and basalts depositional? What is the younging direction? Are there structural overprinting relations visible? Is there a structural grain in the granite. Can it be dated to constrain north-west faulting? Relation between metasedimentary rocks and greenstones. Chemical signature.	Detailed mapping and sampling for thin sections to observe structural overprints in more detail. Age sample from the granite. Magnetic profiling and petrophysical sampling of the different bedrock units.
12	Metasandstones. Dominant north–south structural trend (formlines) overprinted by north-east striking faults.	What is the variety in lithology and metamorphic grade? Is the dominant structural fabric overprinted?	Detailed mapping and sampling for thin sections to observe structural overprints in more detail.
13	Faulted and folded gabbro lens.	What do the structural measurements taken within the gabbro represent? Is the gabbro deformed? Was deformation more intense along the contact?	Study and sample the already mapped outcrops.
14	Metasandstone. Western limb of a dome elongated north–south.	Are there indications for dome-like folding? What are the rock types?	Study and sample the already mapped outcrops.
15	Rounded positive magnetic anomaly within metasedimentary unit.	Mafic intrusion?	Search for outcrops. Magnetic ground measurements.

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