UNIVERSITY OF TARTU

FACULTY OF SCIENCE AND TECHNOLOGY

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DEPARTMENT OF GEOLOGY

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SKARNOID ROCKS IN THE WESTERN PART OF PITKÄRANTA AREA, ON THE COAST OF SUMERIANLAHTI GULF, AND THEIR METALLOGENIC POTENTIAL

Master's Thesis

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Content

1. Introduction

The Pitkäranta region is located in the northeast of Lake Ladoga, forming part of the Svecofennian and Archean Domens in the southeastern part of the Fennoscandian shield. The area has been well-known for it's ore potential and had been an important mining district from 1810 to 1904. The ores in the Pitkäranta region are of a classical skarn type, formed when granite-related hydrothermal fluids reacted with marble (Valkama et al. 2013).

Several studies have been conducted in this area. The first study was conducted by Alfred Elis Törnebohm using his skarn concept, his work was published in 1891. This was succeeded by several others, e.g Trüstedt (1904; 1907; 1908), Vernadsky (1910), Erämetsä (1938). Other important studies have been conducted by Palmunen (1939), Eskola (1949; 1951) and Khazov (1973). In more recent times, lesser studies have been made, e.g lead isotopic research carried out by Larin et al. (1990) and Sundblad (1991).

This thesis studies metallogenesis and ore deposit formation in the area northwest of Pitkäranta, on the northern shore of lake Ladoga, eastern shore of gulf Sumerianlahti. This specific area and its surroundings has been a study area for St. Petersburg State University and has shown some ore potential before. However, it has not been covered by previous researches nor big scale studies have been conducted in the area before either.

This thesis serves two main purposes. First, to give an accurate geological description of the studied area. This study focuses in identification of the rock bodies opened to surface, to provide the mineralogical-petrological overview of the rocks and describe the relations between the bodies.

Th second purpose is to study and evaluate the ore mineralisation potential in this area. To do so,the assumption was made that some kind of metasomatism had taken place in the area and some ore minerals connected the process are searched.

The central hypothesis of this thesis is that in this area the skarn forming process had taken place, and in connection with this, ore mineralisation occured. This master's thesis follows this hypothesis and tries to either prove or disprove it.

This master's thesis is a done under collaboration between the University of Tartu and Saint Petersburg State University.

2. Geological Background

The studied area is located on the southern part of the Baltic shield, on the north-east shore of Ladoga lake (Republic of Karelia, Russian Federation). This region is situated in the shear zone between Archean Karelian craton (massif) and early Proterozoic Svecofennian belt (Fig. 1). This shear zone is called Raahe-Ladoga zone (Korsman et al. 1988).

The Raahe-Ladoga zone has been known as a main tectonic and ore bearing structure (Kahma 1973, 1978). The transition from predominantly Archean rocks in the northeast to a Proterozoic domain in the southwest occurs over a zone a few tens of kilometres wide is the main geological feature (Simonen et al. 1978). The zone is over 1000 km in length and 80 to 100 km in width (Glebovitskii 2005). A number of economically sound metal occurrences are found in this zone (e.g Kahma 1973), that are mainly hosted by Paleoproterozoic Svecokarelian metasedimentary rocks and metavolcanics (Vaasjoki & Sakko 1988).

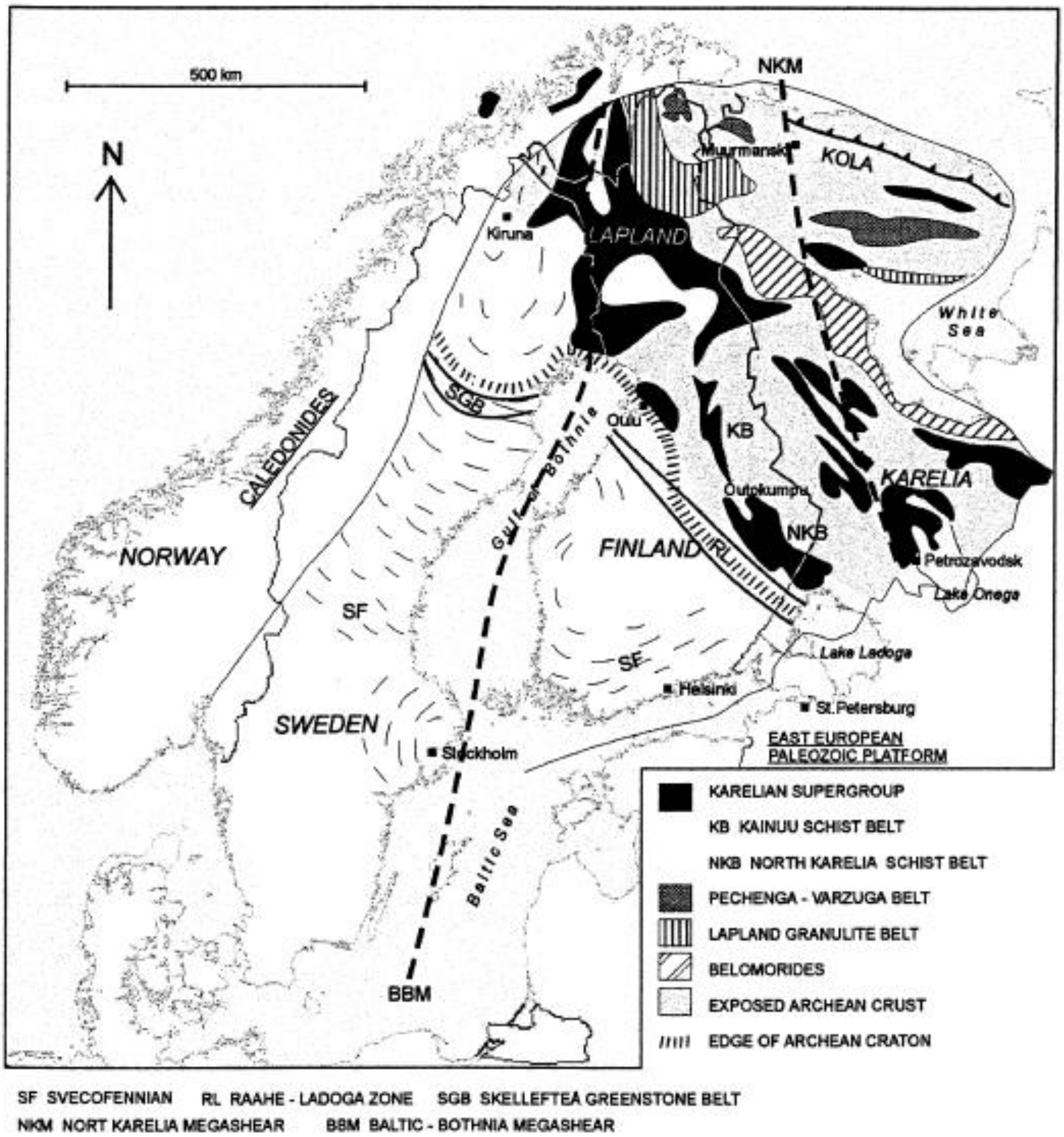
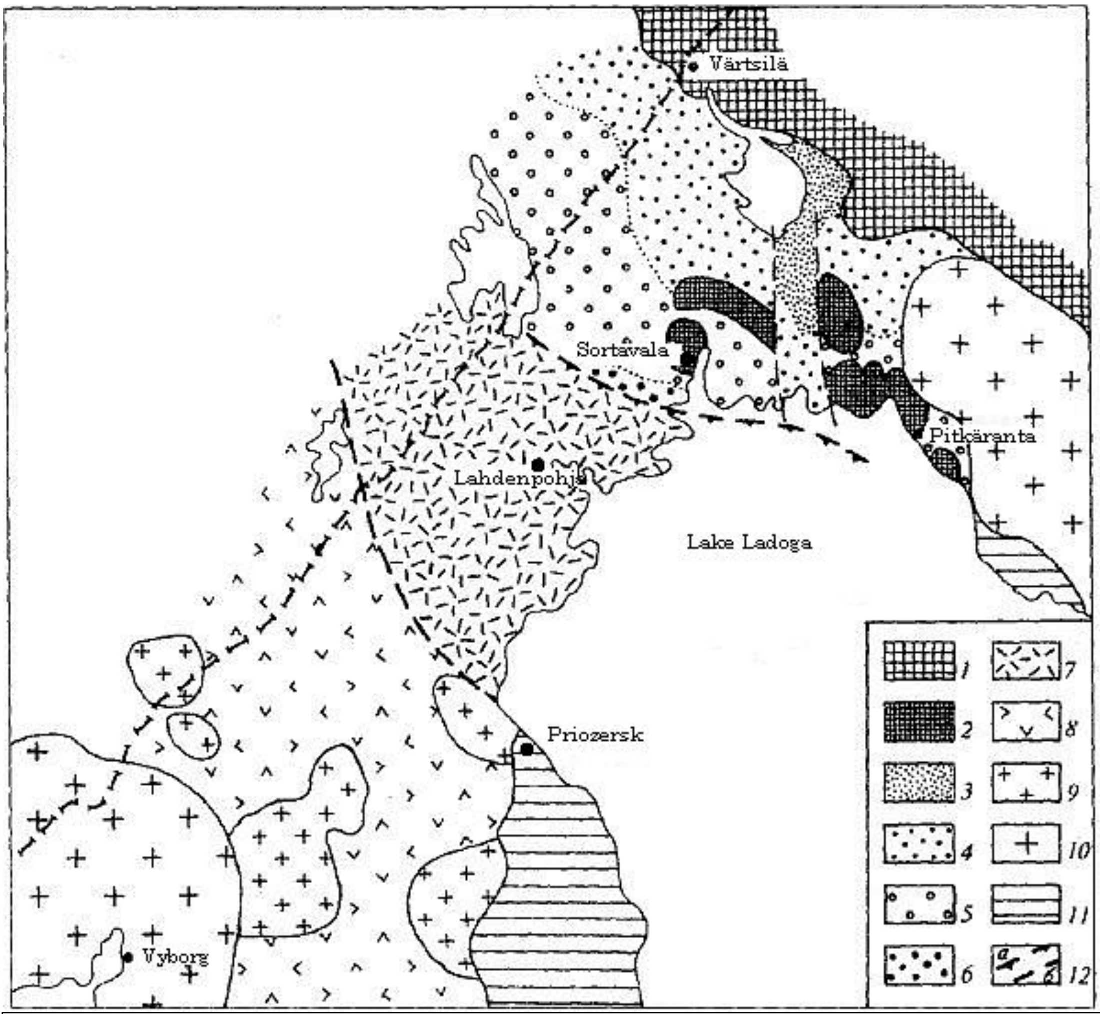


Fig. 1. Simplified geologic map of the Fennoscandian Shield showing distribution of Archean crust, the Karelian Supergroup and related belts of similar age, and various structural features. After Ojakangas et al. (2001).

The northwestern North Ladoga region can be geologically divided into two main blocks (domains) (Fig. 2): Northern and Southern (Baltybaev et al. 2000). The area studied in detail is located in the northern domain.



1-6 Northern Domain: (1) Vyartsilyan zone, protrusion of Archean crystalline basement; 2-6 – Sortavalan zone: , (2) Archean basement in the cores of mantled gneiss domes, (3) Lower Proterozoic volcanic-sedimentary cover metamorphosed into biotite-chlorite schists, (4) staurolite-andalusite schists, (5) sillimanite-muscovite and sillimanite-ortoclase gneisses, (6) garnet-cordierite gneisses; 7-8 - Southern Domain: (7) Lahdenpohjan zone, Early Proterozoic calciferous-sodiferous greywacks, (8) Priozersk zone, potassic metapelites and metaaleurolites; (9) large massif of K-feldspar granitoids, (10) rapakivi massif, (11) Riphean cover, (12) main faults: Meyer zone (a), Hiitolan fault (b).

Fig 2. Tectonic-metamorfic zoning of Northern Ladoga area. Modified after Shuldiner et al. (1997).

The Northern domain is located in the part of Karelian craton composed of Archean crystalline basement, covered by volcanic and sedimentary formations of Paleoproterozoic age. The northern domain is divided into two smaller units: Vyartsilyan zone and Sortavalan zone. The Vyartsilyan zone represents an Archean crystalline basement with the remnants of eroded sedimentary formations. The Sortavalan zone shows an intensive remobilization of the margins of the Karelian craton, where the basement in this area is exposed only in the cores of mantled gneiss domes and most of the area is dislocated and zonally metamorphosed (from greenschist to amphibolite facies) formations of a Proterozoic cover (Baltybaev et al. 2000).

The mantled gneiss domes were first described by P. E. Eskola (1949), who explained them as remnants of older granitoid basement, that has been eroded, then covered with sediments and later deformed into domes when at a sufficient depth which reoriented the layering and foliation (Fig. 3).

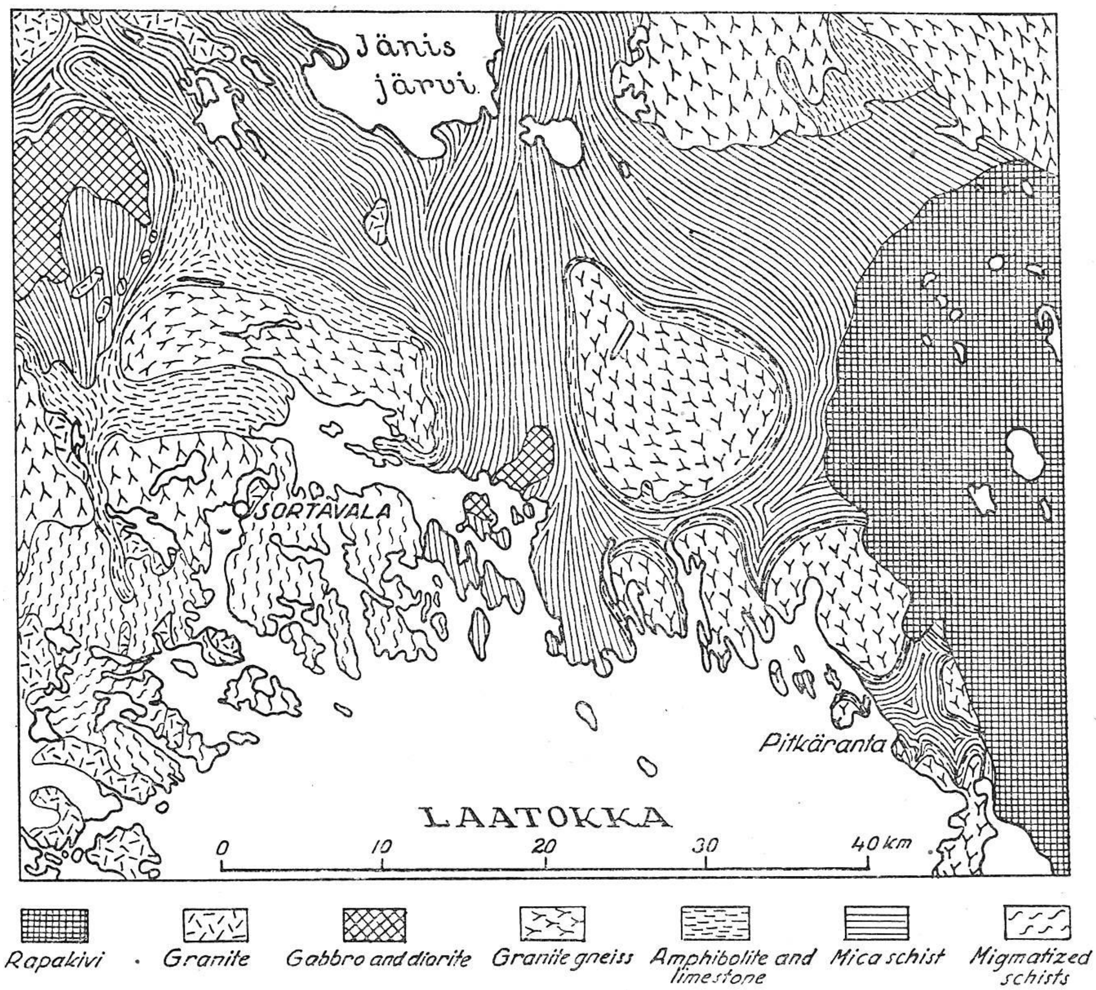


Fig 3. Granite-gneiss domes in the North Ladoga area. Eskola (1949).

The Southern dome consists of rocks from Svecofennian belt, that have undergone a deep metamorphosis, which makes the subdivison of formations into a stratigraphical units difficult (Baltybaev et al. 2000). However, it is recognized, that there are no Archean aged formations present in this part, in fact, they are not present in anywhere in Svecofennian belt (Huhma 1986). The Southern domain is also divided into two zones: Lahdenpohjan and Priozersk zones. Regardless of the deep metamorphism, the subdivision is based on the original composition of metasediments. The Lahdenpohjan zone consist of predominatly Ca-Na greywacke, ubiquitous mergel formations and rarely occurring calciferous-alkaline volcanic formations. The Priozersk zone is characterised by the rythmic and gradual alteration of Ca-metavolcanics, and K-metapelites and metaaleurolites (Baltybaev et al. 2000).

In the Regional Stratigraphic Scheme for Karelia-Kola region (Fig. 4), of Interdepartmental Stratigraphic Committee, Archean is divided into Saamian and Lopian eras and Proterozoic into Karelian and Riphean eras, together with Vendian system (Fig 4) (Kotova & Voinov 2012).

On the international stratigraphic scheme Saamian era corresponds to Paleoarchean (ages lower 3.2 Ga) and Lopian interval to the Meso- and Neoarchean eras (ages between 3.2 and 2.5 Ga). The Lopian era is also divided into 3 lower sections: Lower, Middle and Upper with the defined ages of 3.0 Ga and 2.8 Ga between them.

Saamian and Lower Lopian are represented in the Karelia-Kola region only by plutonic rocks and their metamorphosed analogues. Both Middle and Upper Lopian are represented by metamorphosed sedimentary and volcanic rocks. There are no Lopian age rocks in the studied area of the Northern Ladoga (Kotova & Voinov 2012).

In the regional stratigraphic scheme, Paleoproterozoic named as Karelian eonothem (with ages from 2.5 to 1.65 Ga), is divided into Lower Karealian and Upper Karelian erathems. Both they are in turn divided into three superstages – Lower Karelian corresponding to Sumian, Sariolian and Jatulian superstages and Upper Karelian corresponding to Ludicovian, Kalevian and Vepsian superstages. Karelian rocks are represented mostly by synclinal formations, for which the Archean rocks form basement. Mainly Ludicovian and Kalevian superstages are present in the studied area.

Meso- and Neoproterozoic rocks are defined on the regional stratigraphic scheme as a Riphean eonothem and Vendian (Ediacaran) system. Their age interval is ranging from 1.65 to 0.57 Ga. The Riphean rock complex is divided into Lower, Middle and Upper Riphean erathems. Meso- and Neoproterozoan rocks are not present in the studied area.

EON	AGE, Ma	EONOTHEM	ERATHEM / SYSTEM	SUPERSTAGE
Proterozoic	570			
			Vendian	
	650	Riphean	Upper	
			Middle	
			Lower	Hoglandian
	1650	Karelian	Upper	Vepsan
				Kalevian
				Ludicovian
	2100		Lower	Jatulian
				Sariolian
				Sumian
Archean	2500	Lopian	Upper	Gimolan
			Middle	
			Lower	
	3200	Saamian		

Fig. 4. Russian regional stratigraphic scheme. Modified after Kotova & Voinov (2012).

3. Material and Methods

The studied material was sampled in the area situated on the northern shore of lake Ladoga and is south-east of Impilahti village. The area under research is placed along the coastline of a peninsula, on the eastern shore of Sumerianlahti gulf (Figure 5).

Fig. 5. Location of the study area (marked with a red box).

In summer 2014 as a part of Saint Petersburg State University field course, field work was conducted in the studied area. Part of the area was investigated in great detail, being the main target of authors master’s thesis.

The detailed area reaches in length 67 meters and is about 40 meters wide. It is an uncovered cliff area (Figure 6), representing the main part of geological cross-section. It is located on a peninsula, along the coastline from south-east to north-west direction and between two island in the gulf (Fig. 5). The area mapped in detail is called ’’International’’ (*Международный*).

Fig. 6. A view to the studied area.

The mapping work was done in three groups, from which the author was a member in the first one. The area was divided into three parts, each group was originally responsible for mapping in one part. The middle part, however, was mapped and described by two groups. The groups consisted of students of Saint Petersburg State University, University of Turku, Åbo Akademi and University of Tartu. Each group had 3 members, so all together 9 people were involved in the mapping process.

Three base lines were created in the area, going from south-east to north-west during the mapping process. Base lines were precisely measured by measuring tape and marked down. Cross lines were created along the base lines, starting from 0 and crossing the main base line orthogonally. Along the cross lines rocks were described in great detail. Contacts between the rocks were recognized, described and drawn, later the rock samples were also taken.

All three base lines were aligned by the azimuth of 330 degrees. Base lines were connected to each other by measuring tape and azimuth from ending and beginning points of each base line. Cross line were created on the base lines after every 4 meters, with the exception of the first ten meters on the second base line, where cross lines were created after every 2 meters.

In addition to mapping, 67 rock samples were collected during the field work. The samples represent all the different rock types that were observed in the mapped area. Most of the samples were collected from the middle part of the area. Those samples were described based on the visual characteristics, when possible, the mineral composition was given and the rock types named.

During the mapping process a sketch from each part of the mapped area was drawn on the site. Those sketches contained information about the different rock types, contacts between them, structure elements etc. Afterwards three different maps were drawn based on the sketches. Each map represents a different part of the area and gives the preliminary geological description.

From the collected rock samples, 35 were chosen and made into thin sections at the University of Tartu, in summer 2014. These thin sections were studied under polarising microscope and the structure-texture as well as the mineral composition was described. Preliminary petrological information was revisited and rock types were renamed according to the mineral composition.

Selected polished sections were inspected using analytical sacanning electron microscope Zeiss EVO MA15 in variable pressure mode. Element maps and mineral identification was performed using Oxford Aztec energy-dispersive detector system.

After collecting all this information, the final map was constructed in the scale 1:200, giving the geological overview of the area (Appendix 1). This map was at first drawn by hand in the autumn of 2014 in Saint Petersburg University, and afterwards digitalised in the University of Tartu.

4. Results

4.1 Geological Mapping

The mapped area can be roughly divided in three different parts. The first (south-eastern or lower) part hosts intrusive amphibolitic bodies within the Archean dome granite gneisses. The first intrusion is narrow (maximum visible width 200 cm) and approximately 17.5 m long. The body is split in half by a fault (direction south-west to north-east). It is noticeable that the colour of the granite gneisses in the area of the fault and in contact with the amphibolite body is darkened.

Second body is wider, with maximum visible width approximately 500 cm. The intrusion is truncated by a fault in south-east to north-west direction. The area is cut by another south-east to north-west directed fault, that separates granite gneiss rock on one side (eastern side of the fault) and quartz-amphibole schists on the other (western side of the fault).

The second part (middle) of the mapped area itself could be also roughly divided in three smaller units. Firstly, in the southwestern part of the area, there are quartz-biotite schists, that host several lenses of different rock types, such as skarnoids, biotite schists and marble. These schists are separated from the next smaller unit, quartz-amphibole schists by two faults. First of them is on the eastern side of the quarz-biotite schist body and directs from south-east to north-west. The other one is in the northern side, directs from south-west to north-east and cuts through the whole area. The quartz-biotite schists reach 10 meters in lenght and 3.6-5 meters in width.

The quartz-amphibole schists are the dominant rock type of the middle part of the studied area. Similar Proterozoic rocks belonging to the Pitkäranta suite are typical in this area. From the eastern side, these schists are bordered with another fault that separates them from the Archean granite gneisses. One more intrusive amphibolitic body associated with the granite gneisses is divided in two with the same fault directing from south-west to north-east that cuts through the whole area. The amphibolite body is approximately 14 meters long and about 1 meter wide, and could be a continuation of the larger amphibolitic body that is described in the lower part of the area. One more skarnoid lens is visible north from the fault, inside the quartz-amphibole schists. The middle part is separated from the northernmost part with another fault that is directed from south-west to north-east.

The third, northwesternmost part (upper) of the study area consists of three main rock types. First, the amphibolithic rocks of the Pitkäranta suite. The amphibolites are in contact with amphibole-bearing quartzite rocks (belonging to the upper substage of the Pitkäranta suite). Lens of granitoid rock occurs in this part, approximately 6 meters long and 0,8 meters in maximum width.

The area is cut by a fault in south-east to north-west direction that separates the amphibole-bearing quartzites from the quartz-amphibole schists, but also from another intrusive amphibolitic body and associating granite gneisses. The amfibolitic body is bordered from the western and souhtern side with faults and it is somewhat narrow, maximum two meters in the widest part.

4.2 Petrography of the Rock Types

Granite-gneisses

By the mineral composition, the granite gneises mostly consist of quartz, which is represented by elongated, directional grains (Figs. 7, 8). K-feldspar is also present in big amounts in well-developed crystals, and also hornblende. Gneiss structure is well observable in thin section, the alignment of dark and light minerals is clear.

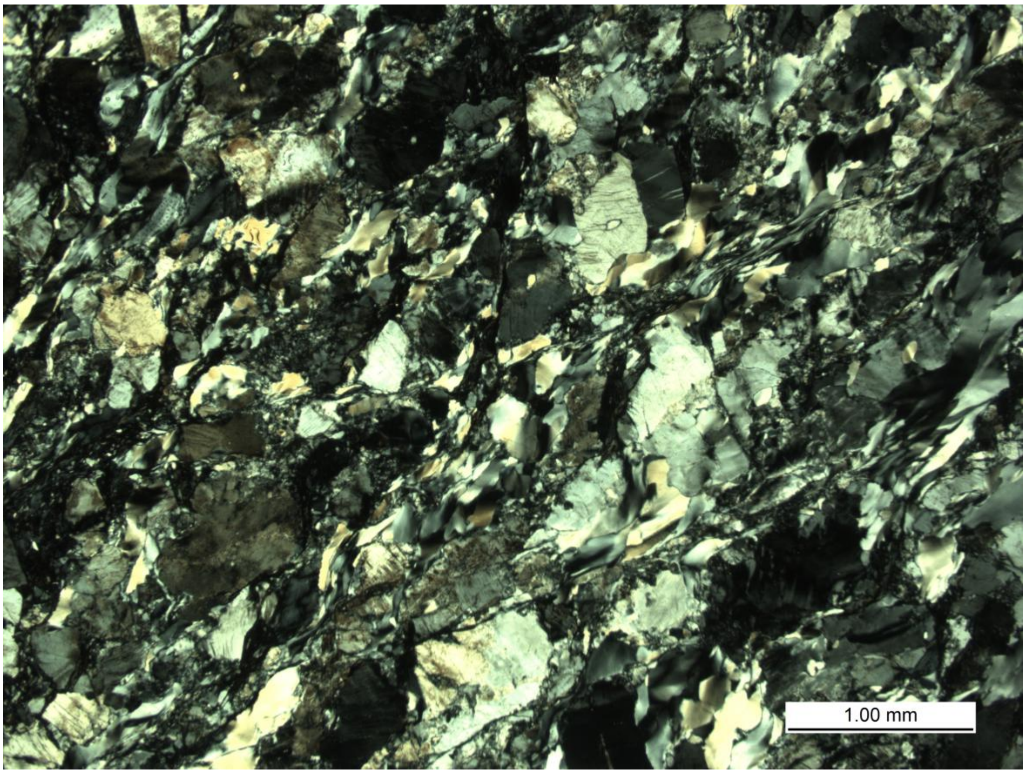


Fig. 7. Granite-gneiss with crossed polars. Sample 46032/2.

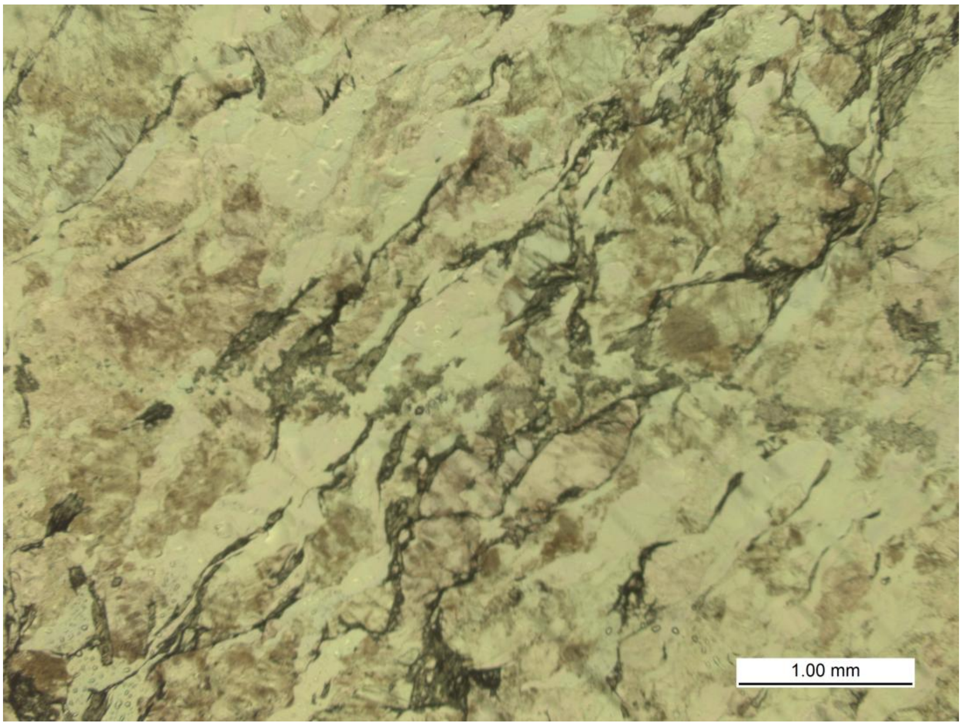


Fig. 8. Granite-gneiss in plain-polarised light. Sample 46032/2.

Intrusive amphibolites

Intrusive amphibolites consist of mostly hornblende and plagioclase (Figs 9, 10, 11). In addition, quartz and mica (mostly biotite) were also present in lesser amounts. Some accessory minerals were also observed, such as zircone. Ore mineralisation also occurred, but in moderate amounts.

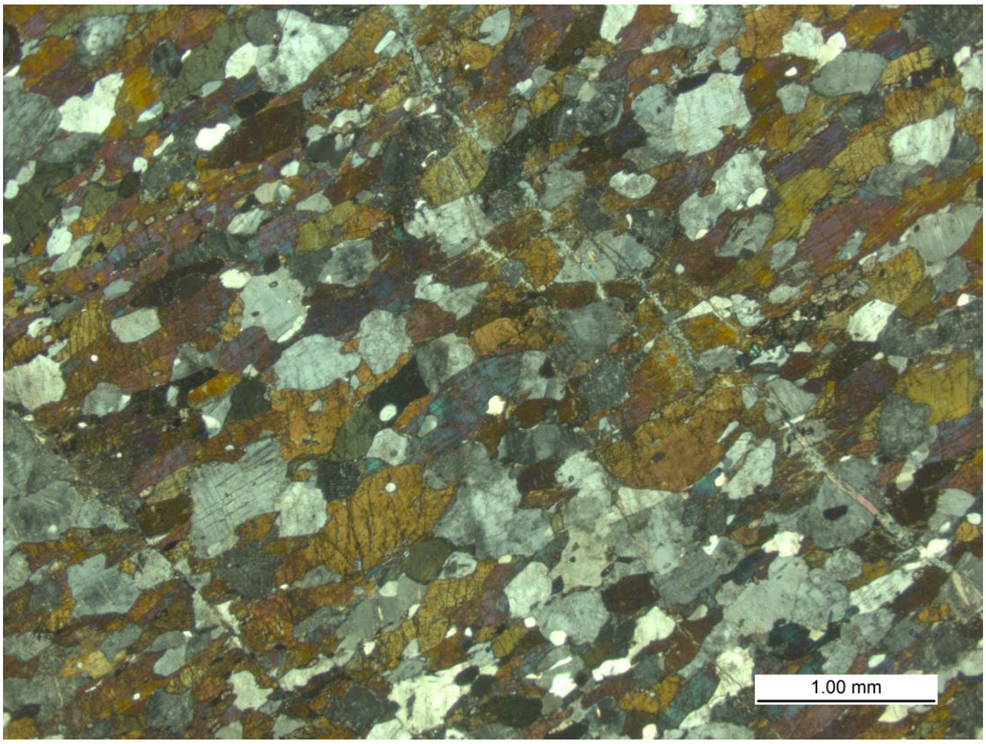


Fig. 9. Intrusive amphibolite with crossed polars. Sample 46053.

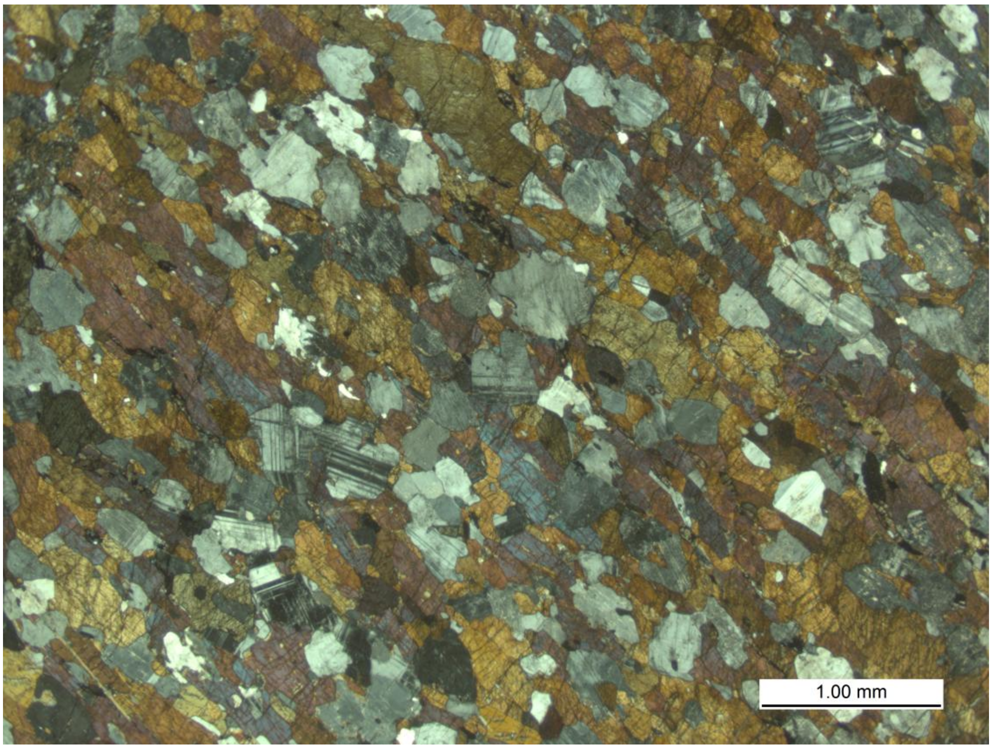


Fig. 10. Intrusive amphibolite with crossed polars. Sample 46032/1.

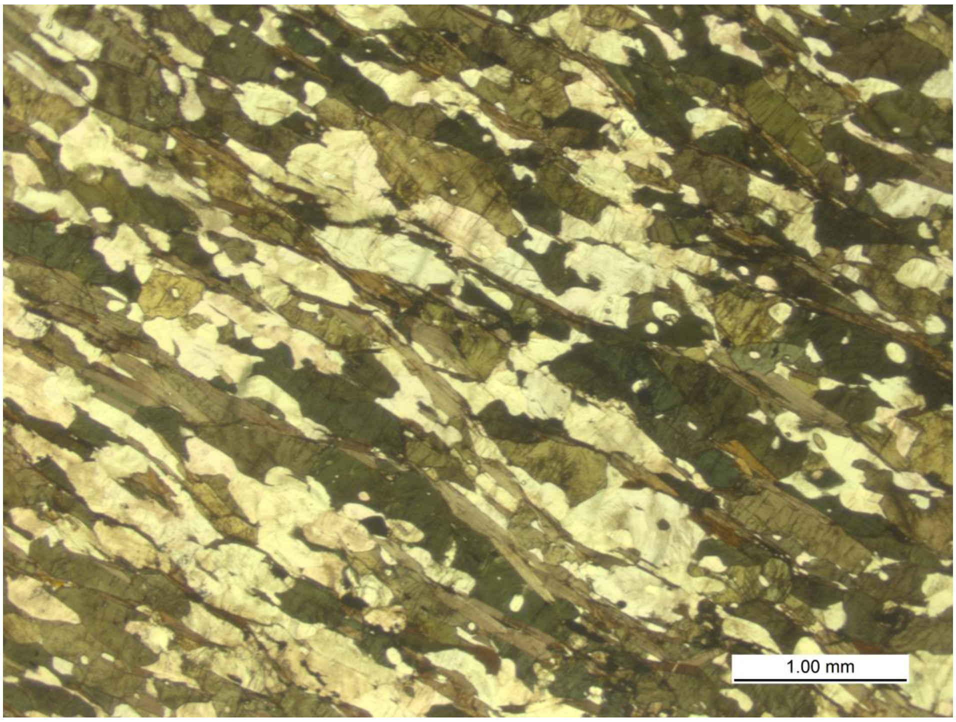


Fig.11. Intrusive amphibolite in plane-polarised light. Sample 45033/8.

Quartz-amphibole schists

These schists are layered, schist-like structure is also well visible in the thin sections. They consist of mostly of amphibolite, with a lesser amount of quartz (Figs. 12, 13, 14). Additional minerals in those schists are plagioclase, garnets, micas (mostly biotite), opaque minerals. The layers in schists tend to differ by the mineral composition a little bit.

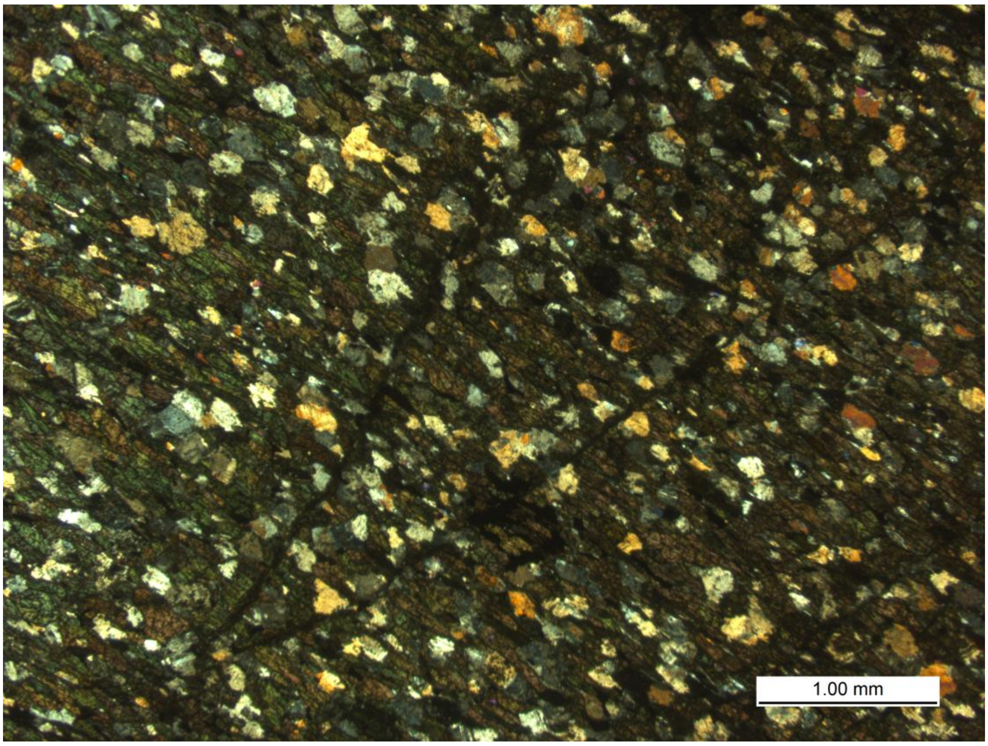


Fig. 12. Quartz-amphibole schist with crossed polars. Sample 46048.

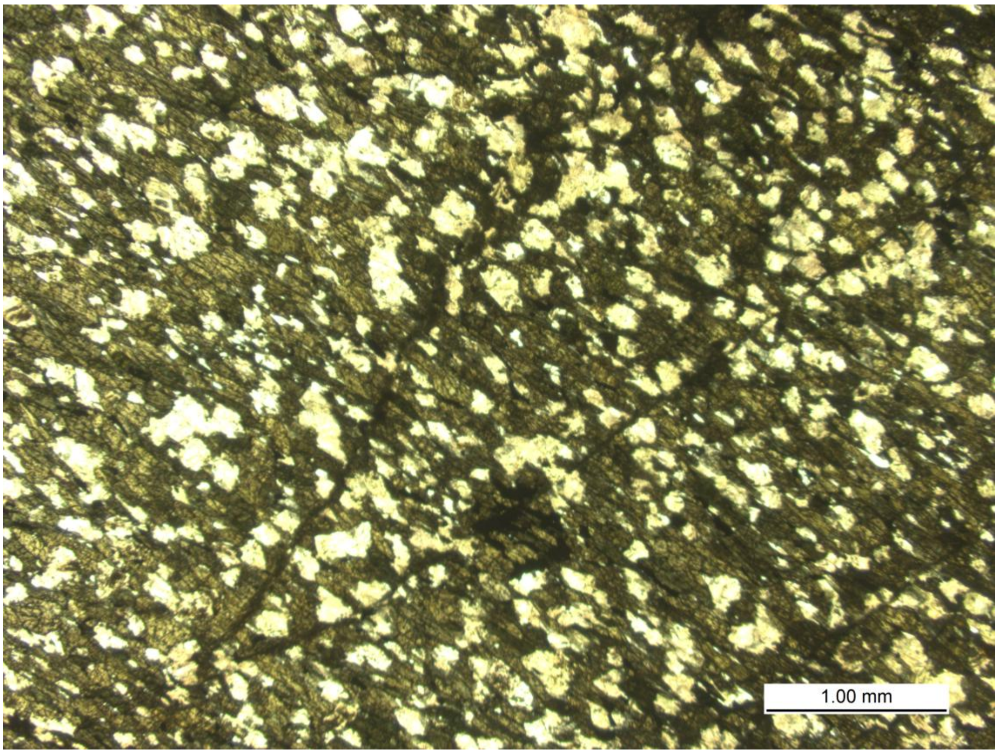


Fig. 13. Quartz-amphibole schist in plane-polarised light. Sample 46048.

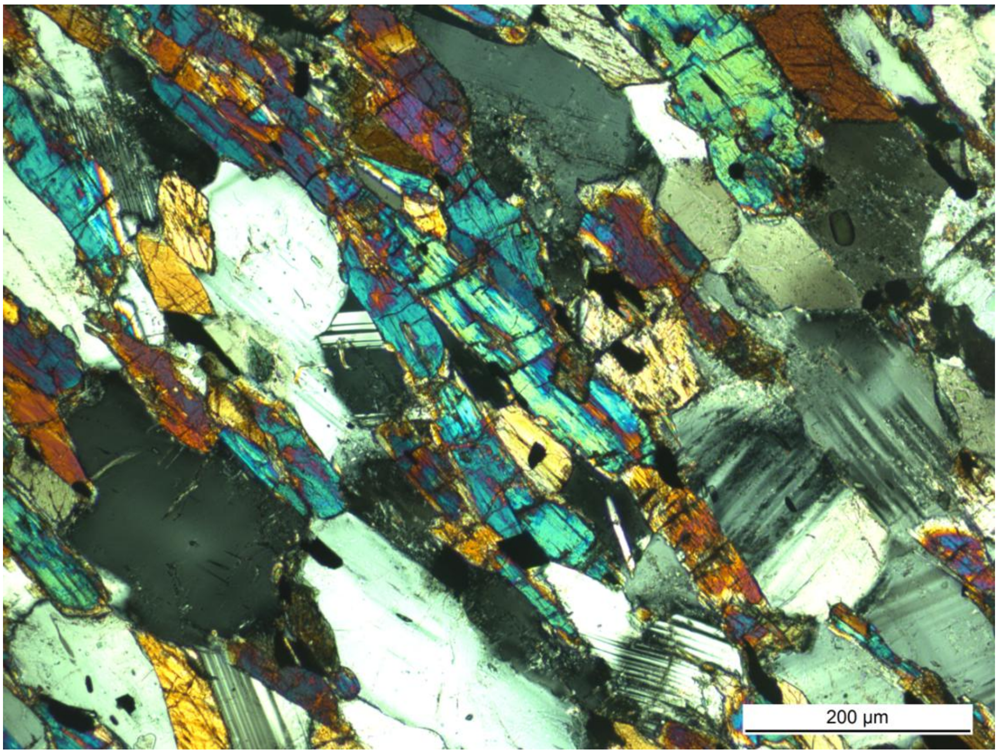


Fig 14. Quartz-amphibole schist with crossed polars. Sample 42023/6.

Quartz-biotite schists

These schist consist of mostly of quartz and biotite. There is also hornblende in lesser amounts, also plagioclase and sometimes opaque minerals. Comparing to the quartz-amphibole schists, they consist of lesser amount of hornblende, and significantly more biotite (Figs. 15, 16, 17).

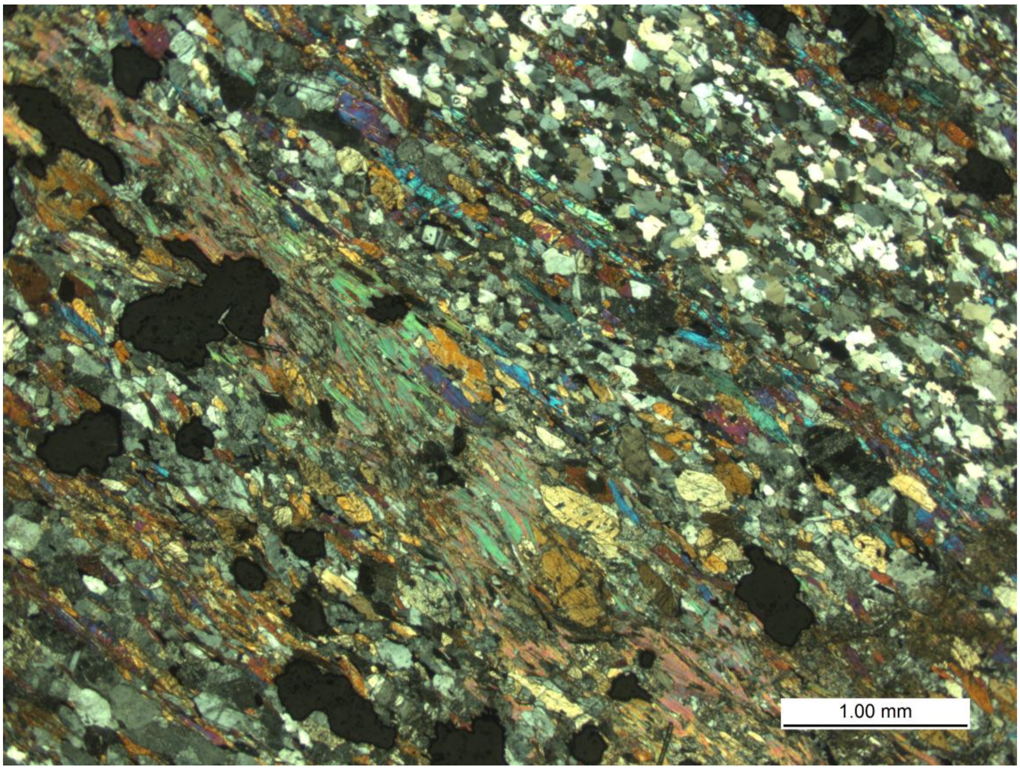


Fig. 15. Quartz-biotite schist with crossed polars. Sample 42023/16.

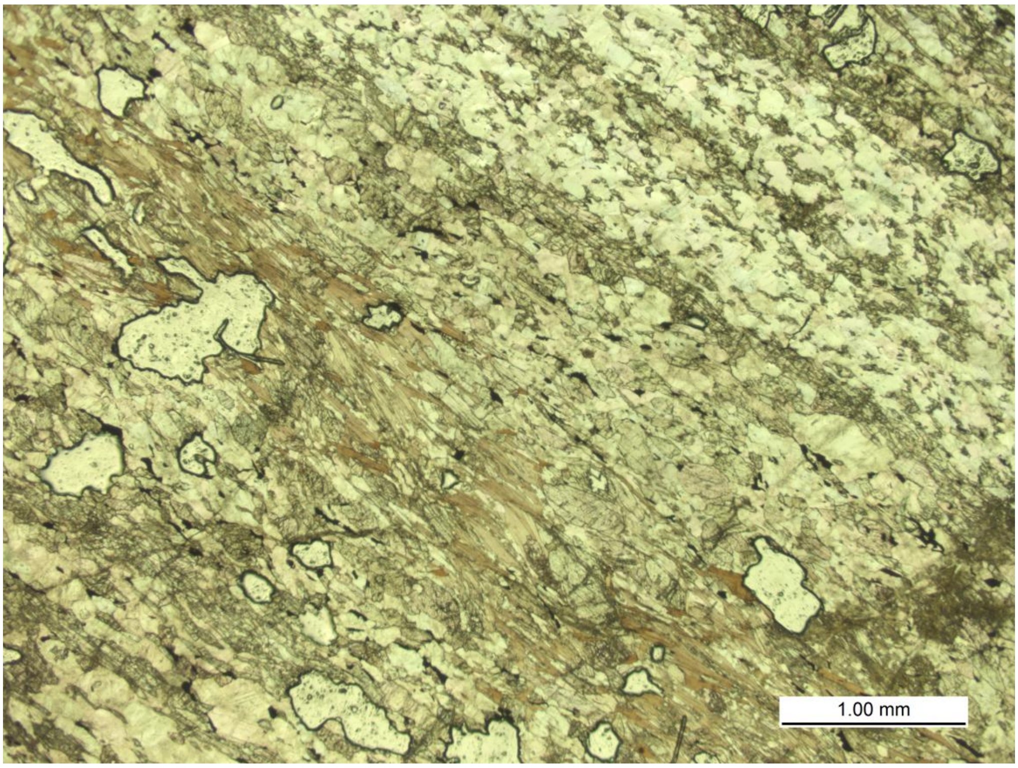


Fig. 16. Quartz-biotite schist in plain-polarised light. Sample 42023/16.

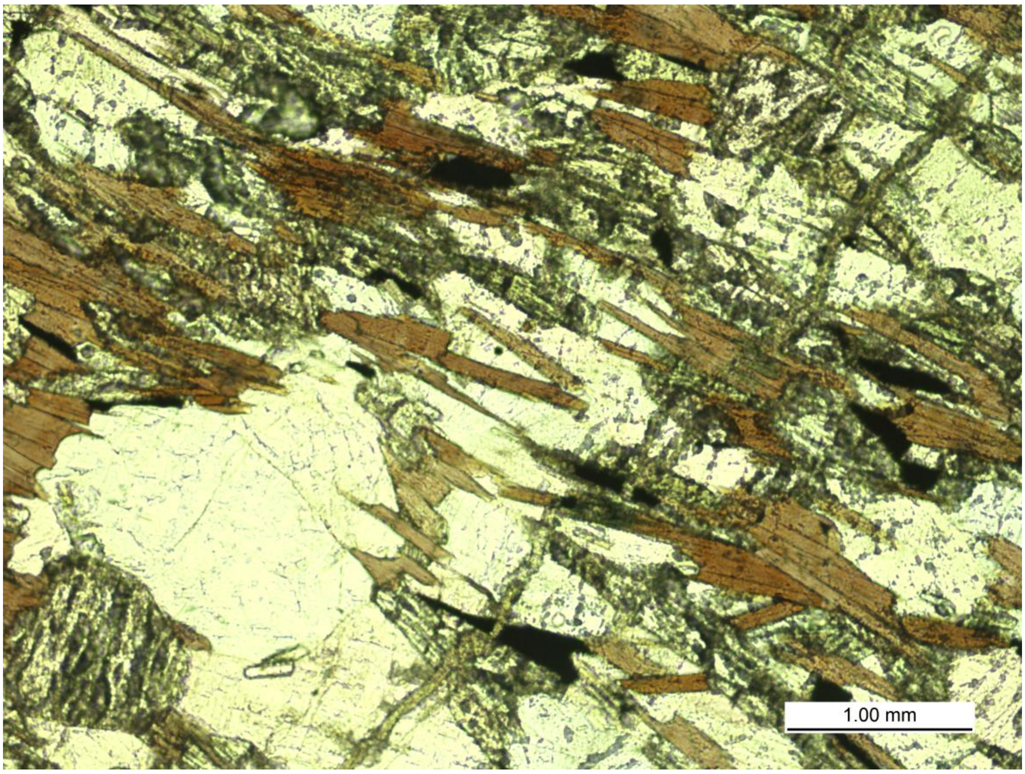


Fig. 17. Quartz-biotite schist in plain-polarised light. Sample 42023/6.

Skarnoids

Main rock forming minerals in skarnoids are monoclinic pyroxen (diopside) and also carbonate minerals such as calcite and dolomite (Figs. 18, 19). Amphibole group minerals, such as tremolite or actinolite, were also present with the addition of some accesory minerals, such as apatite, epidote or some opaque mineral. The amount of the most common minerals varies from sample to sample, however.

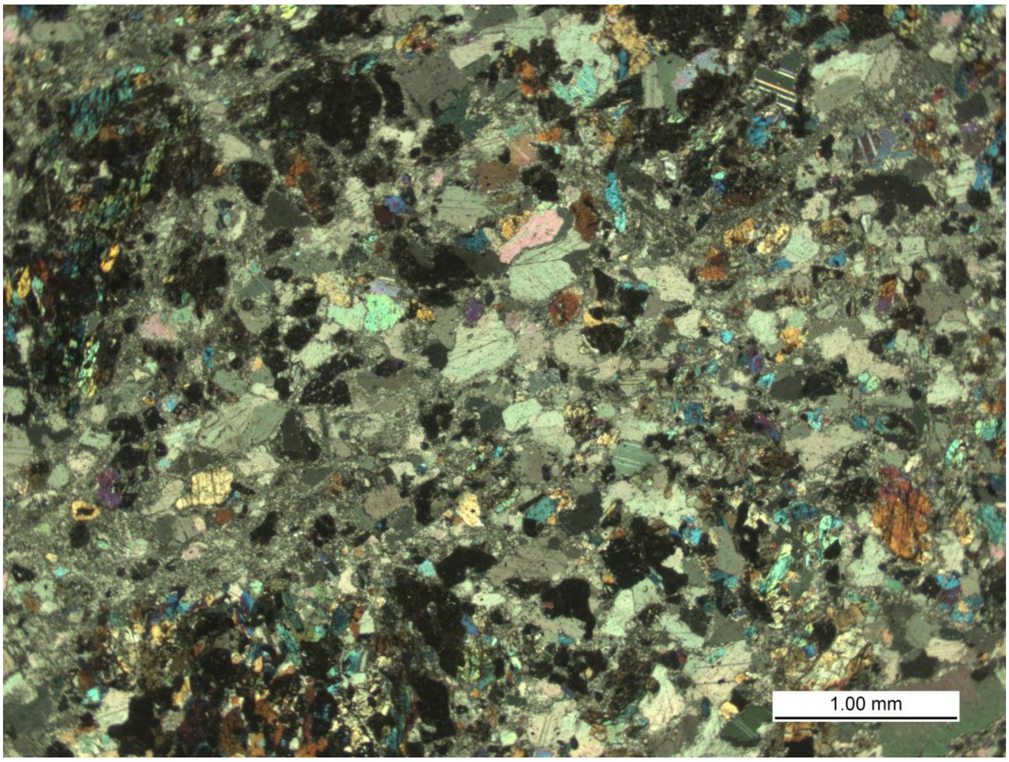


Fig. 18. Skarnoid with crossed polars. Sample 42023/2.

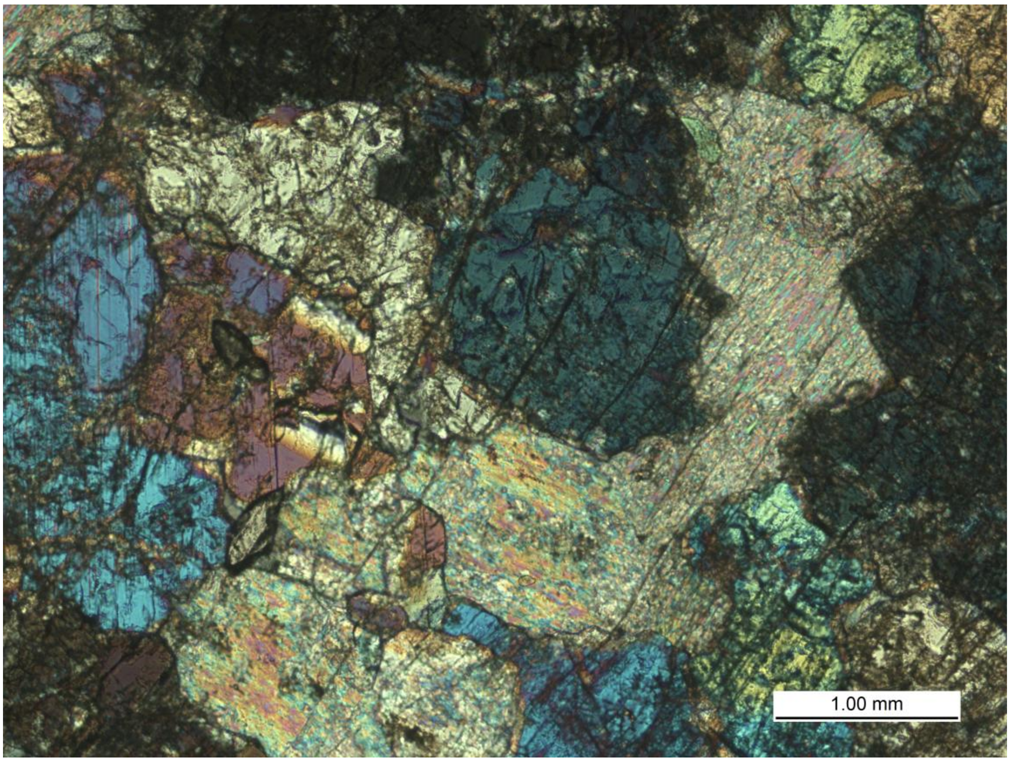


Fig. 19. Skarnoid with crossed polars. Sample 42023/24.

Biotite schists

The biotite schist consist mainly of biotite and quartz (Fig. 20). Graphite was also present in the samples in significant amounts. Comparing to quartz-biotite schists, the amount of biotite is bigger (it is the main mineral in this type of rock) and the amount of quartz is smaller. Also, hornblende is rarely represented. Some ore mineralisation is also noted in the samples.

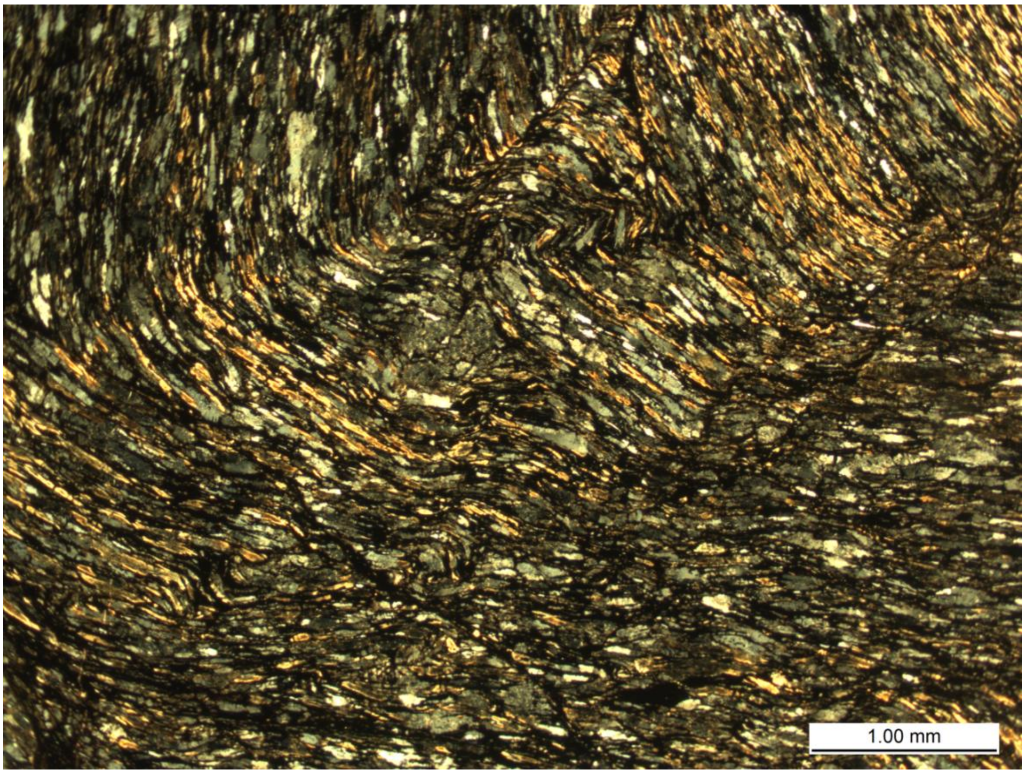


Fig. 20. Biotite schist with crossed polars. Sample 46051.

Marble

The main mineral in the marble is calcite (Fig. 21). In addition, also abundant muscovite and lesser amounts of quartz. From the accessory minerals, some apatite was spotted.

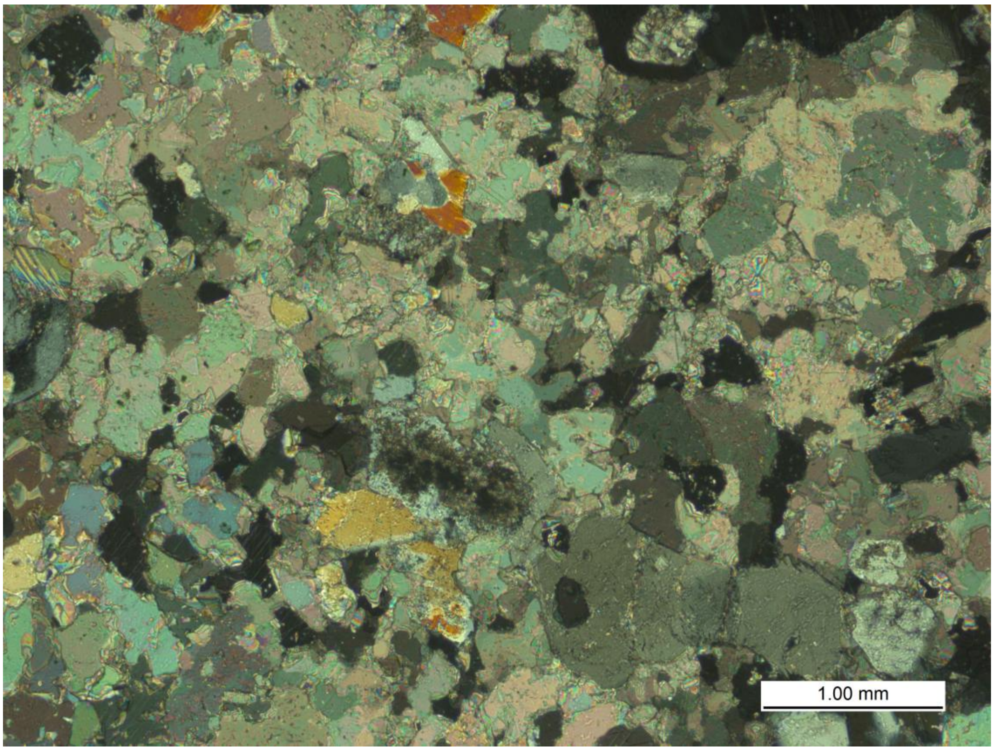


Fig. 21. Marble with crossed polars. Sample 42023/20.

Amphibolites of Pitkärantra suite

The Pitkäranta suite amphibolite, comparing to the intrusive rock, is more fine-grained and the crystals are not so well distinguishable, while in the first one is more coarse-grained and the crystals are well visible.

By the mineral composition, the Pitkäranta suite amphibolite also consist of mostly hornblende, but also quartz, plagioclase, some K-feldspar crystals were also spotted (Figs 22, 23, 24). In some cases, some ore mineralisation (opaque minerals) was noticeable. Sometimes also garnets were found.

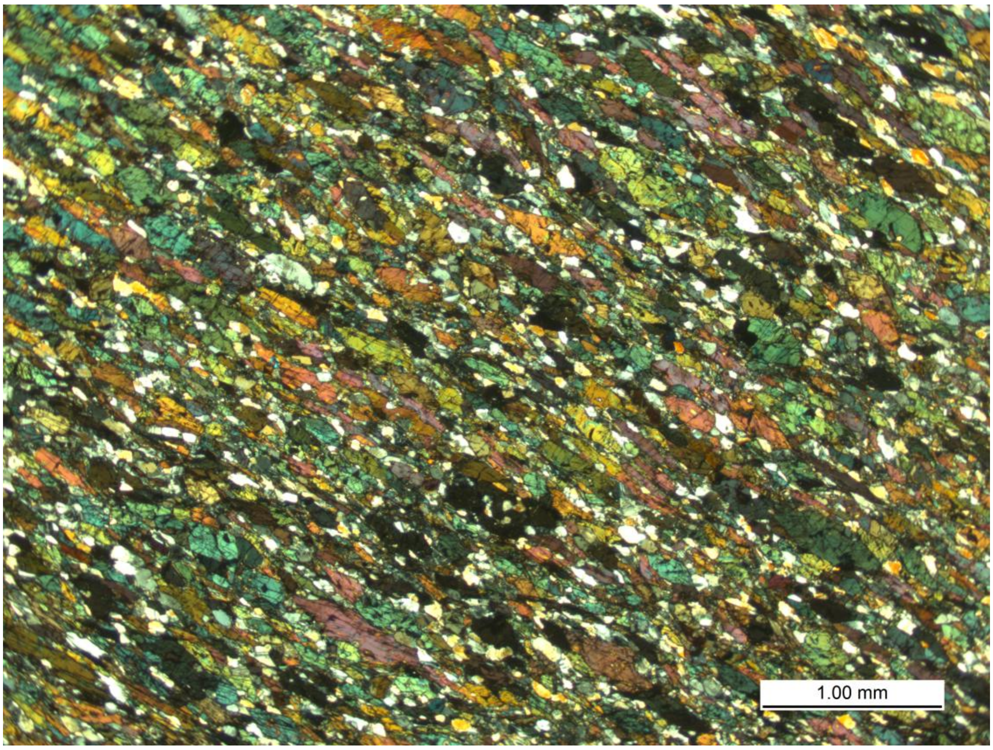


Fig. 22. Amphibolite with crossed polars. Sample 45033/1.

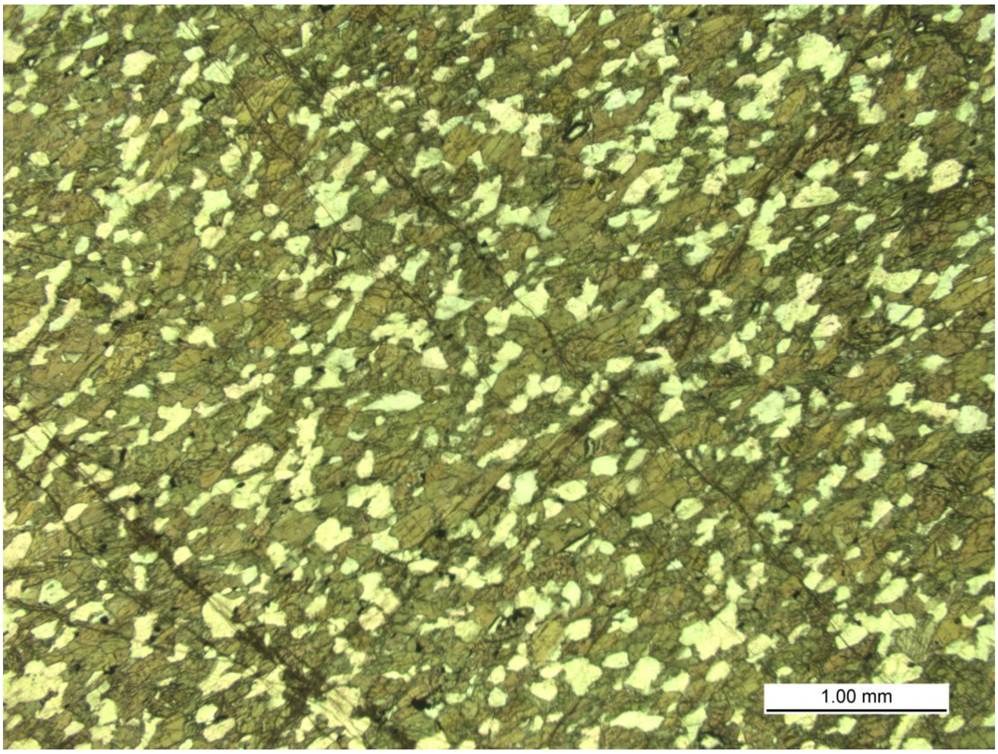


Fig. 23. Amphibolite in plain-polarised light. Sample 46033.

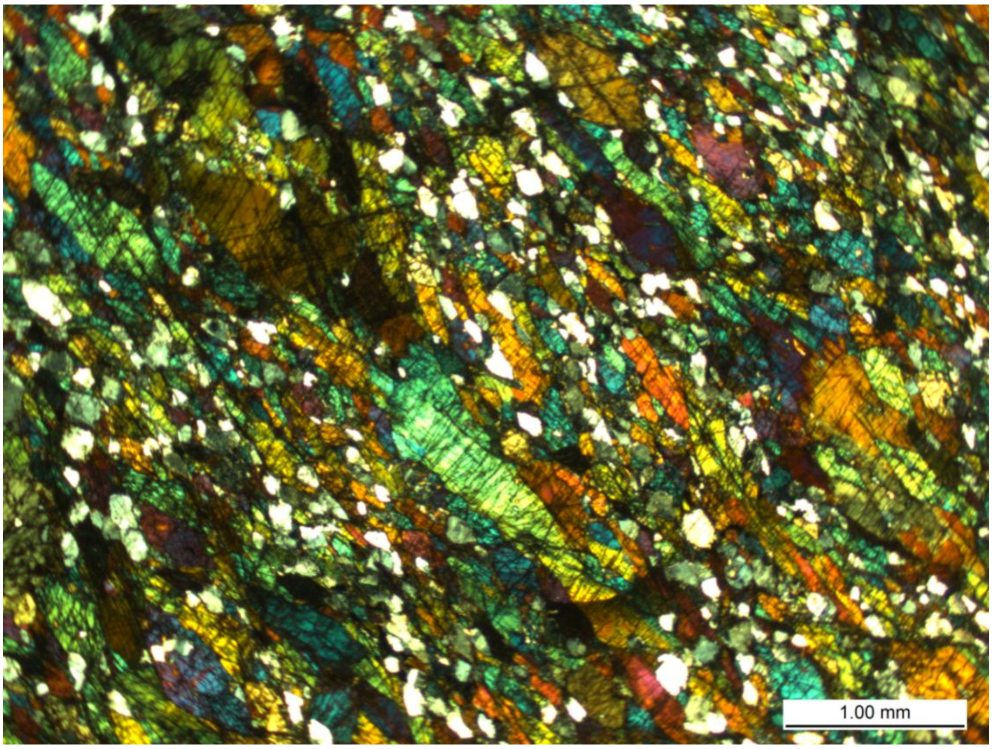


Fig. 24. Amphibolite in crossed polars. Sample 45036/2.

Amphibole-bearing quartzites

Amphibole-bearing quartzites consist of mainly quartz and amphibole, with some plagioclase and K-feldspar also present (Figs. 25, 26, 27). Compared with quartz-amphibole schist in the middle part, this rock is less layered and the amount of quartz is also slightly bigger.

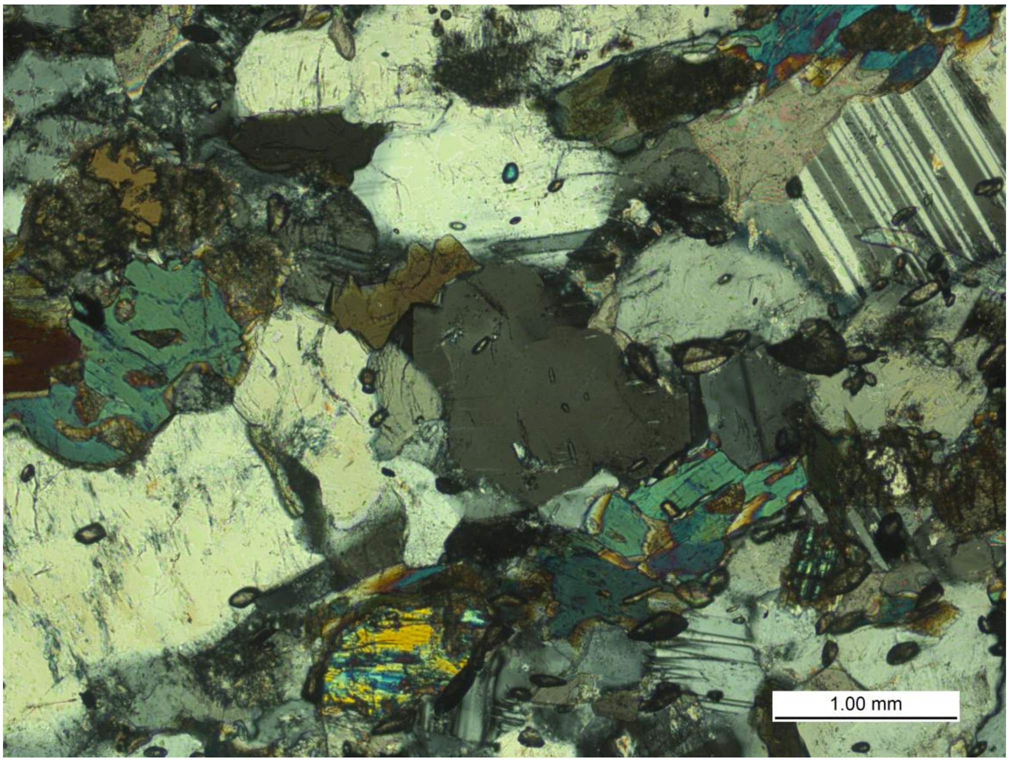


Fig. 25. Amphibole-bearing quartzite with crossed polars. Sample 45033/4.

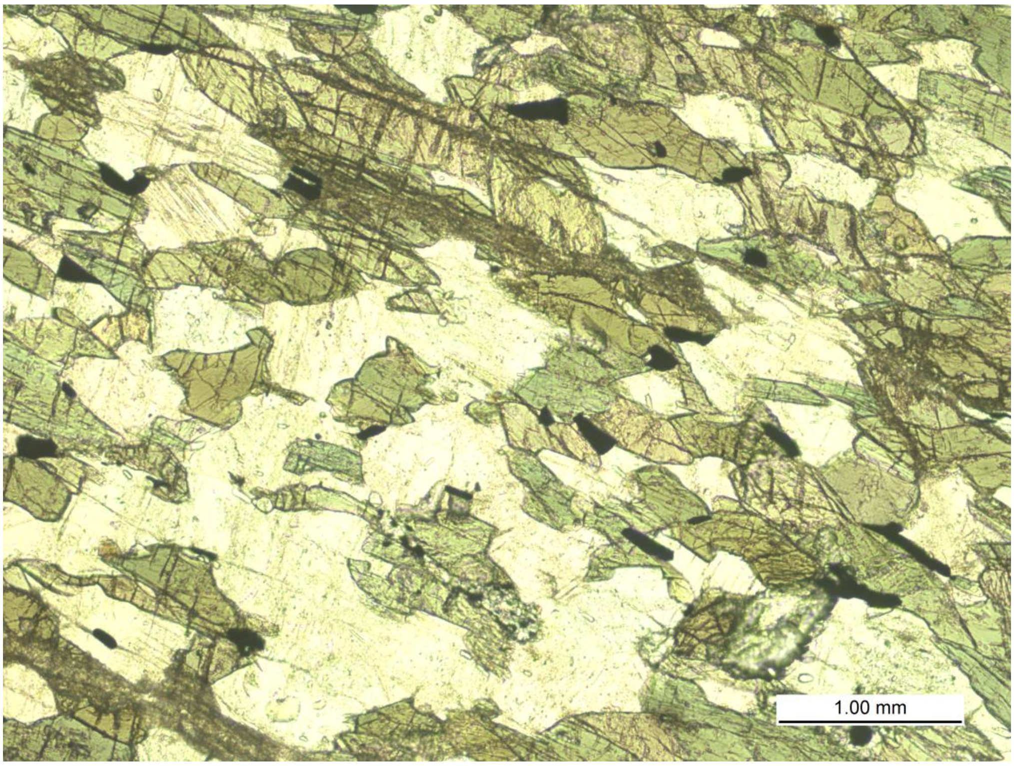


Fig. 26. Amphibole-bearing quartzite in plain-polarised light. Sample 45033/6.

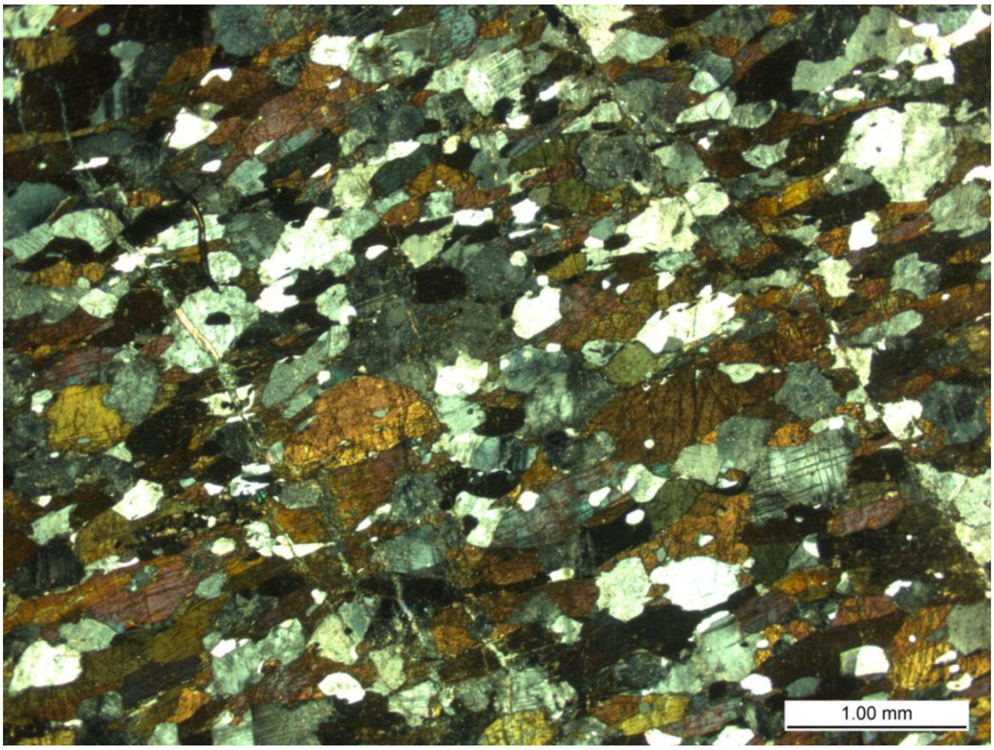


Fig. 27. Amphibole-bearing quartzite with crossed polars. Sample 45032/4.

Granite

Main rock forming minerals are quartz, plagioclase and K-feldspar (Fig. 28). It lacks dark minerals such as hornblende or biotite, differing so by composition from the granite gneisses described in the lower part of the area. The overall impression of the sample is its gneiss-like structure: the minerals are aligned more or less directionally, but not enough for a clear gneiss structure.

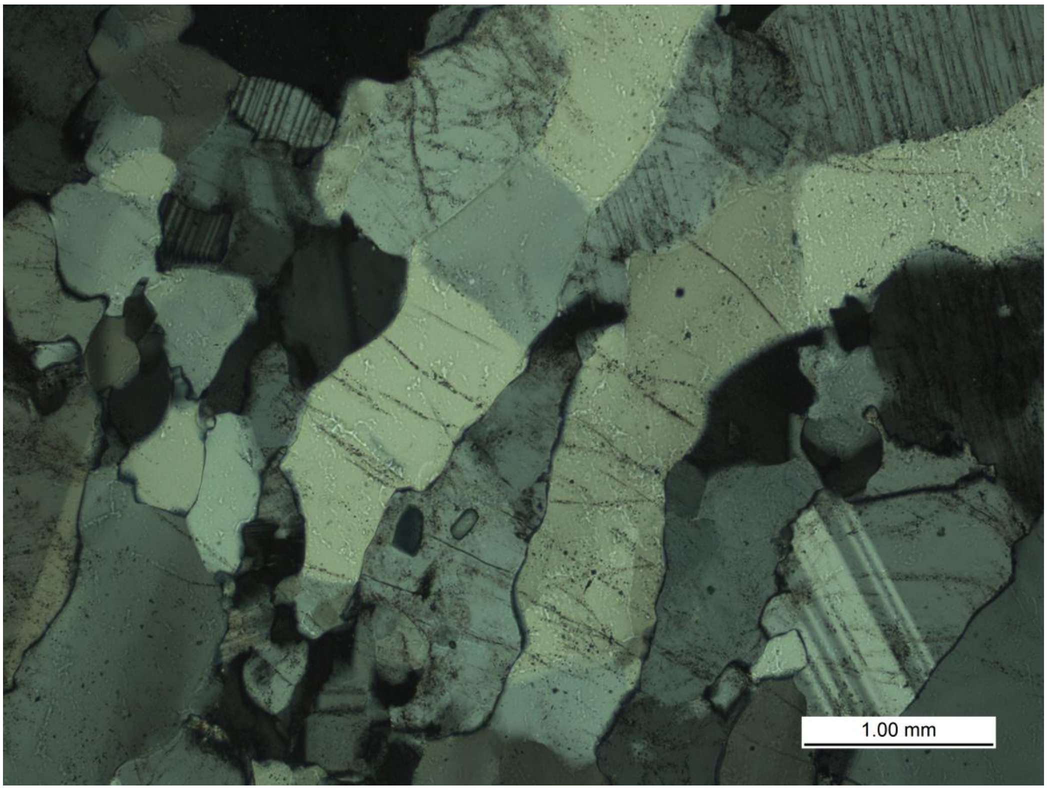


Fig. 28. Granite with crossed polars. Sample 46037.

4.3 Ore Minerals

After carefully analysing the thin sections and giving the petrological description, all together 11 samples were chosen for ore mineralisation analysis. While choosing the samples, it was taken into consideration, that they would represent the full potential of ore mineralisation that is connected to supposed skarn processes taken place in the area.

After the choice was made, pieces of sample rocks were cut and polished into polished sections. The work was done in the rock laboratory of Saint Petersburg University.

4.3.1 Petrographic Studies in Reflected Light

First, the preliminary study was done in Saint Petersburg University, where polished sections were observed under reflected light. Ore minerals occurring in the samples were described and distinguished. In all the samples, pyrite, chalcopyrite, ilmenite and titanite were identified (Figs. 29-35). In addition to ore minerals, graphite was also noted (Fig. 30). All the identifications were made based on a visual observation.

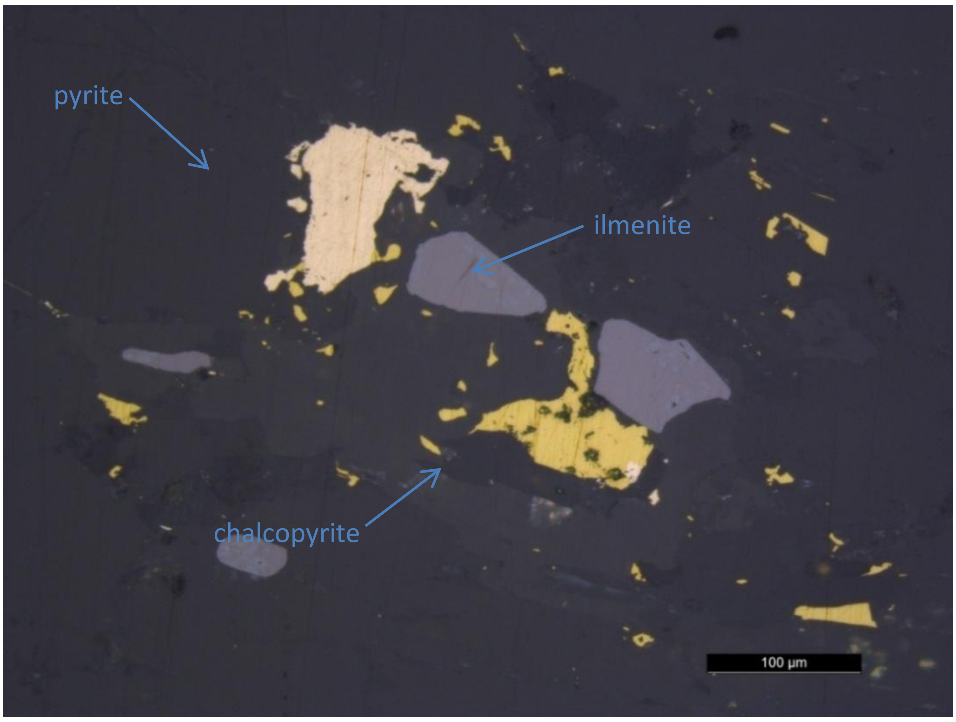


Fig. 29. Pyrite, chalcopyrite and ilmenite in reflected light, sample 42023/9.

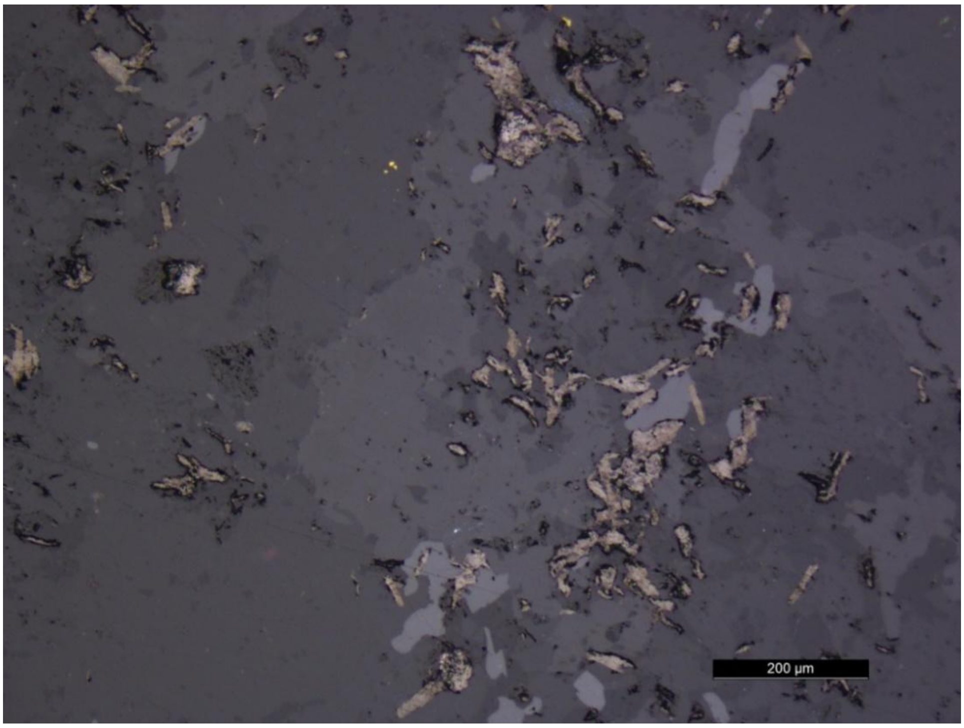


Fig. 30. Graphite in reflected light, sample 42023/9.

Resulting from the preliminary study, pyrite was found to be the most common opaque mineral, appearing in 9 polished section in total. The pyrite was found to appear in two main different forms: firstly, more or less well-developed grains (as shown in figure 3), or xenomorphic forms, filling cracks and veins or cavernous space in sample (figures 4, 5).

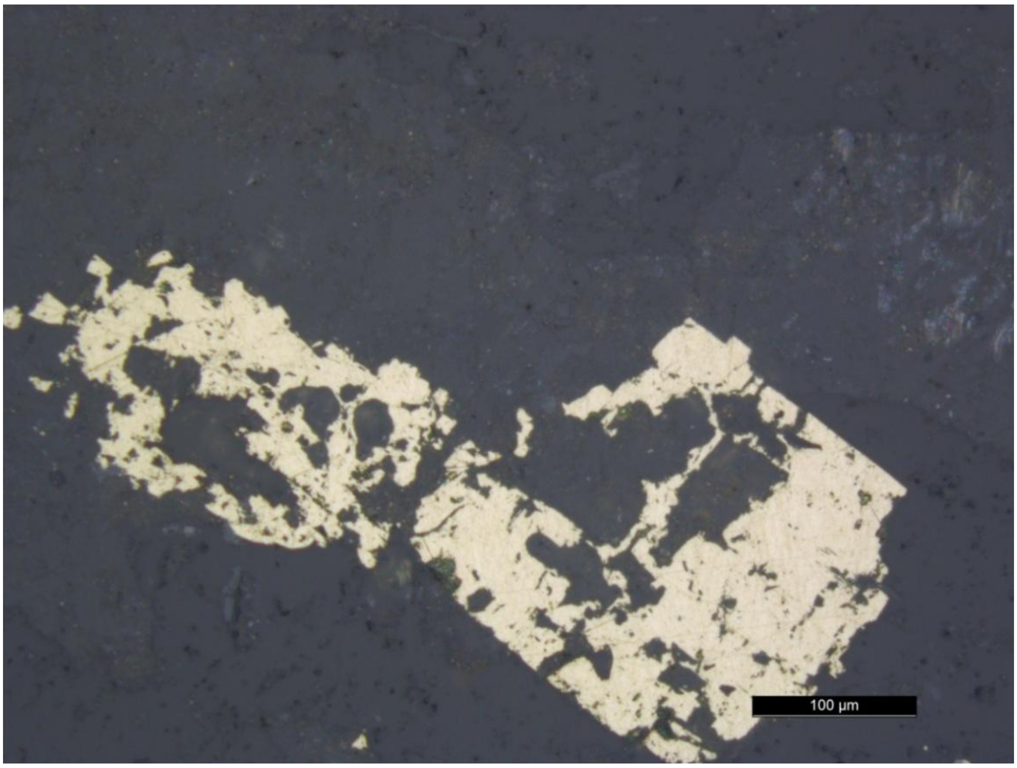


Figure 31. Pyrite in reflected light, sample 46034.

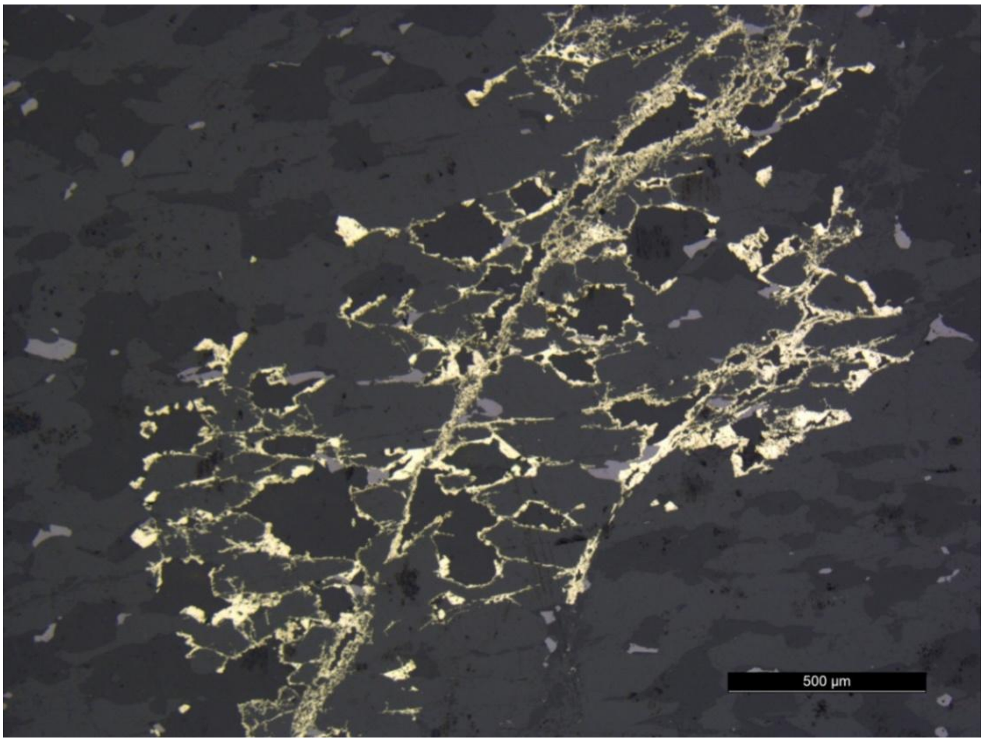


Fig. 32. Pyrite in reflected light, sample 46048.

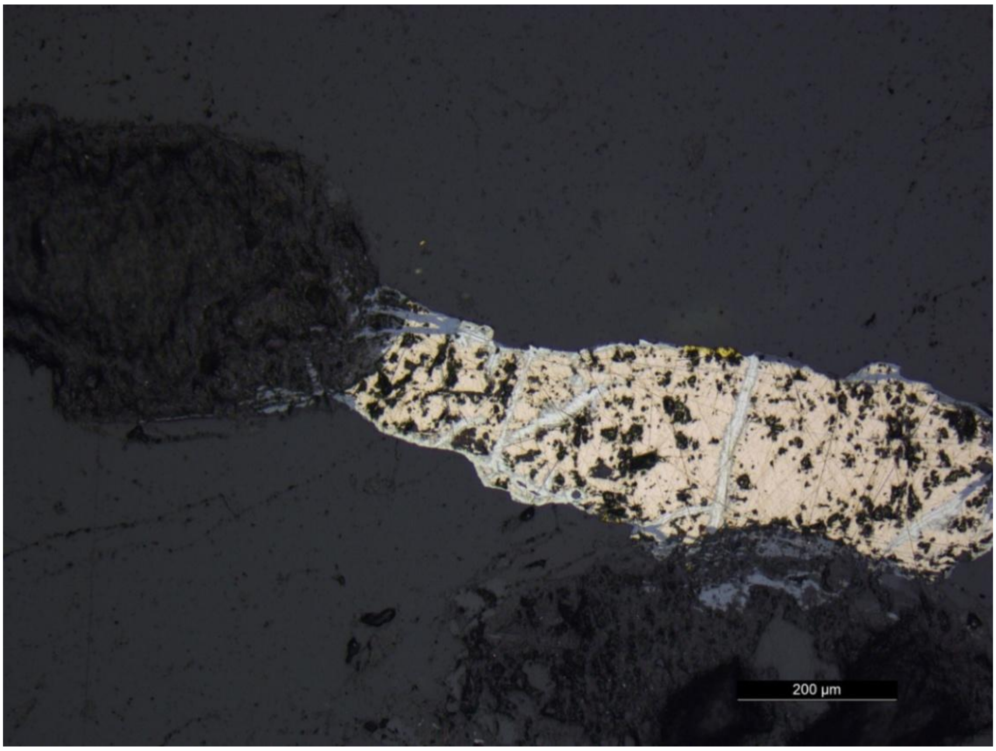


Fig. 33. Pyrite in reflected light, sample 46034.

Chalcopyrite was found to occur in more rare cases, in four polished sections and possibly in one more. Chalcopyrite also appears as xenomorphic grains, small clusters, and not in fully-developed grains (seen only in few cases), in some cases developing inside or on the edges of pyrite clusters.

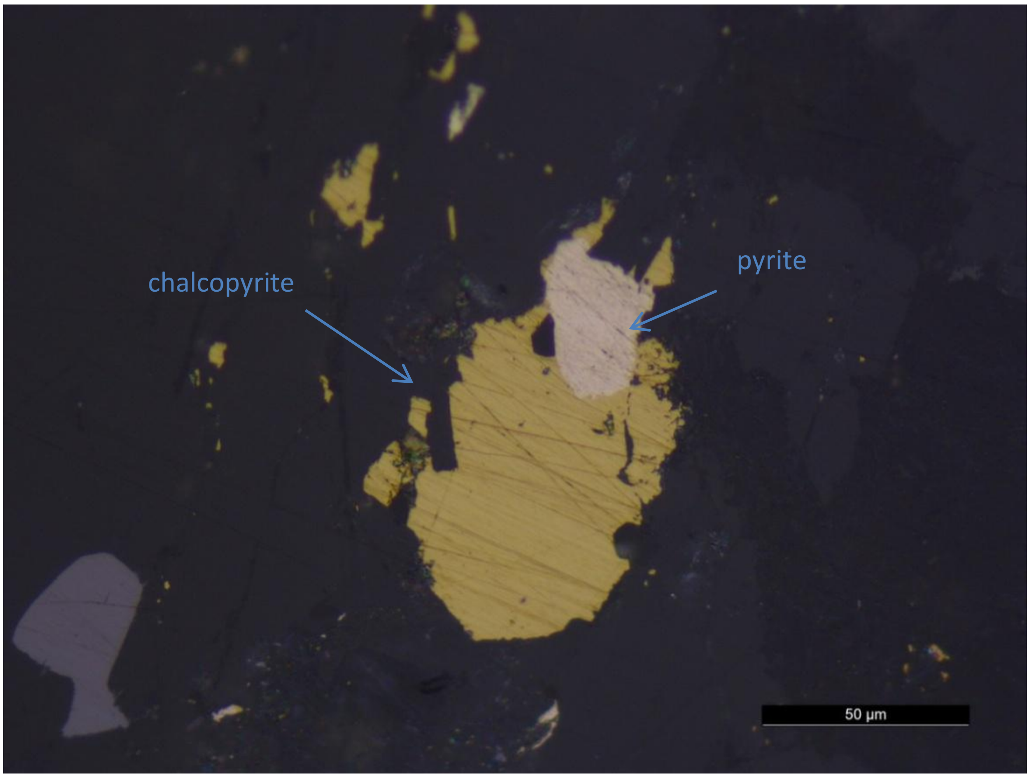


Fig. 34. Chalcopyrite with pyrite in reflected light, sample 42023/9.

Ilmenite and titanite were also described as common opaque minerals, from which first one was found to apper in most of the analysed polished sections and the latter in more rare cases. Ilmenite appeared both in xenomorfic form and also in oval-shaped grains. Titanite was observed to develop with and/or inside of ilmenite masses, giving rather xenomorfic shapes (Fig. 35). Graphite was described in two polished sections.

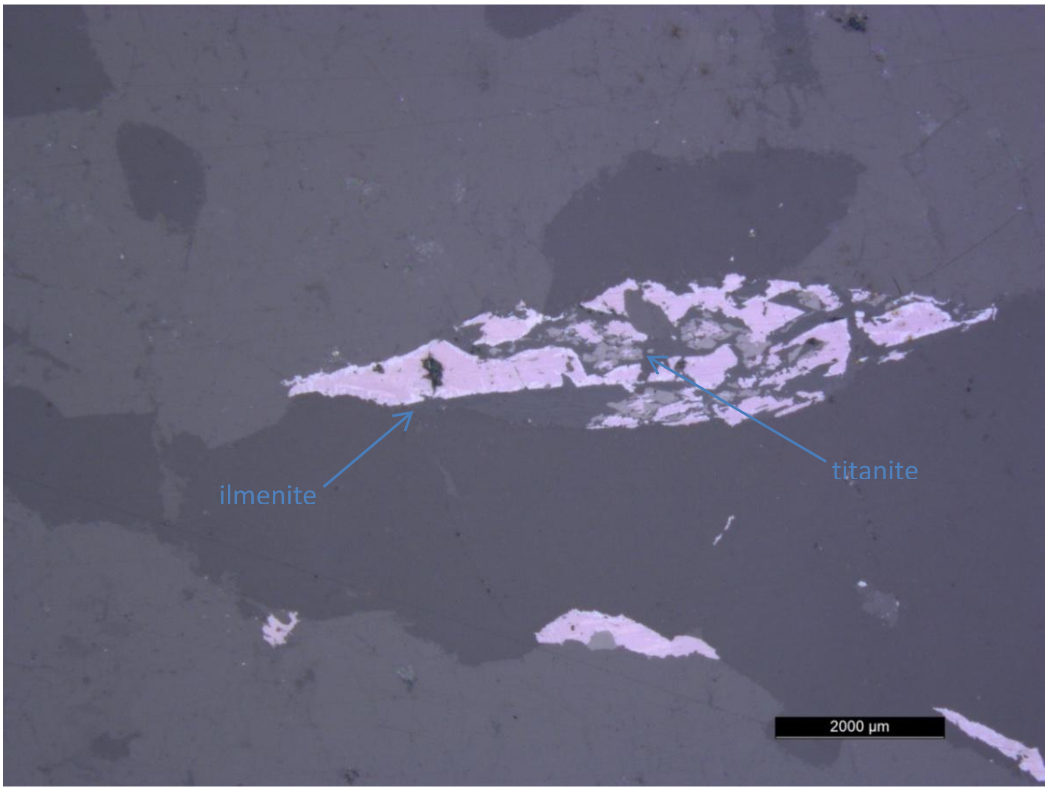


Fig. 35. Ilmenite and titanite in reflected light, sample 45033/8.

4.3.2 Scanning Electron Microscopy

After getting the preliminary results in ore mineral composition, a more detail study was conducted in the University of Tartu, using scanning electron microscope (SEM) with acquiring chemical data, using EDS dectector.

Each polished section was carefully and wholly observed, opaque minerals were spotted and identified by measuring the composition of chemical elements in them. Both point-id analyse and element mapping methods were used. As a result of SEM work, more accurate description of ore mineralisation was gained in the investigated samples.

Pyrite was found to appear in all samples investigated (Fig. 36, 37). The amount and distribution pattern, however, varied from sample to sample.

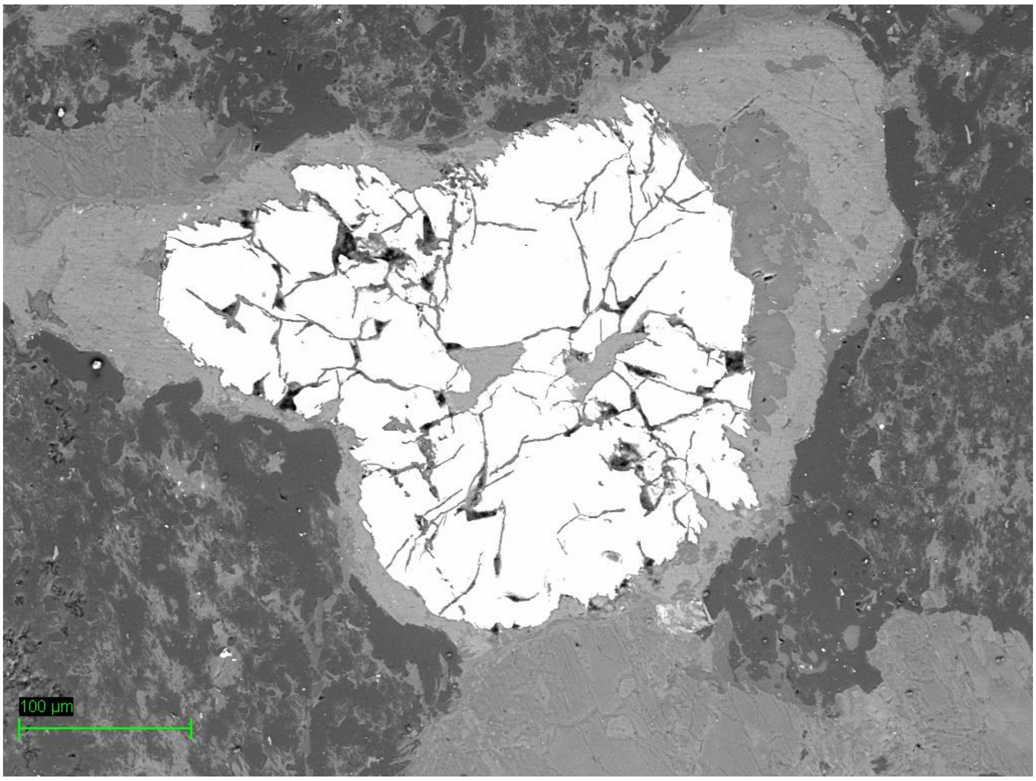


Fig. 36. Pyrite in sample 42023/21. Backscattered electron image.

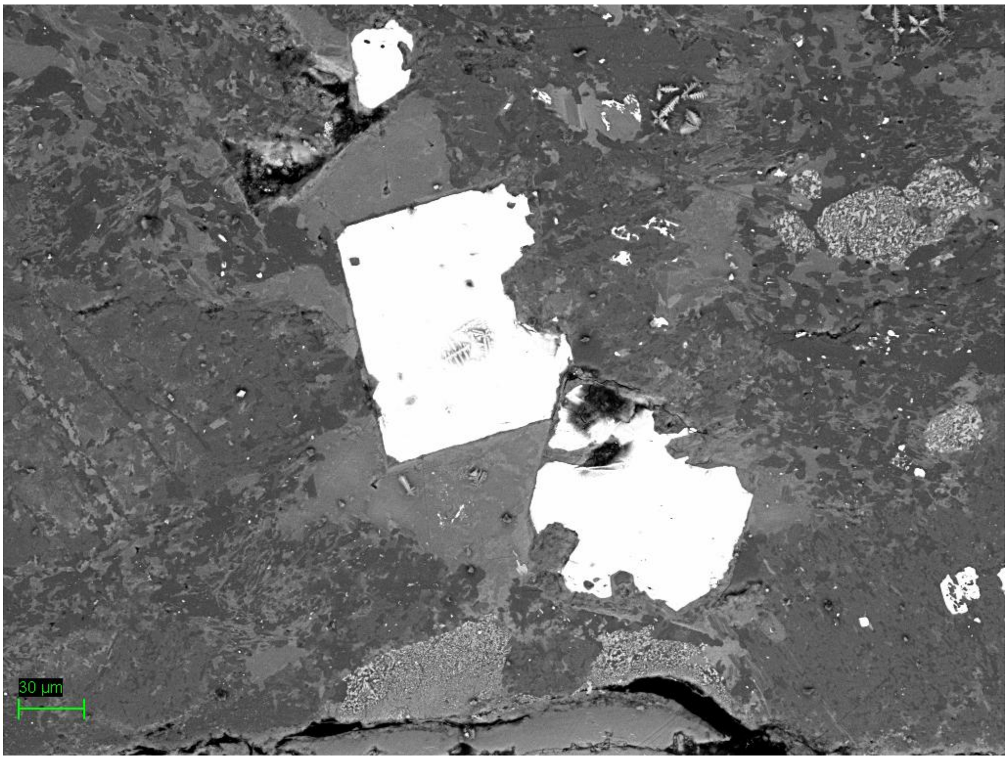


Fig. 37. Pyrite in sample 42023/21. Backscattered electron image.

Distribution of pyrite was mostly found to be undirectional, not following a certain pattern. However, as it was suggested before, pyrite often filled cracks in the rock samples and/or was distributed nearby to them.

Occurrence of chalcopyrite was also indicated in more samples than suggested before (Fig. 38). Chalcopyrite was not present in only one of the samples investigated. The amount and the size of the mineral clusters, however, were smaller, as suggested before using reflected light petrographic analysis, compared to the pyrite distribution. In some cases, there were only a few small grains of chalcopyrite in a sample, or it was very fine-grained. Also, as indicated before, chalcopyrite is often associated with pyrite, growing inside or on the edges of the pyrite clusters (Fig. 38).

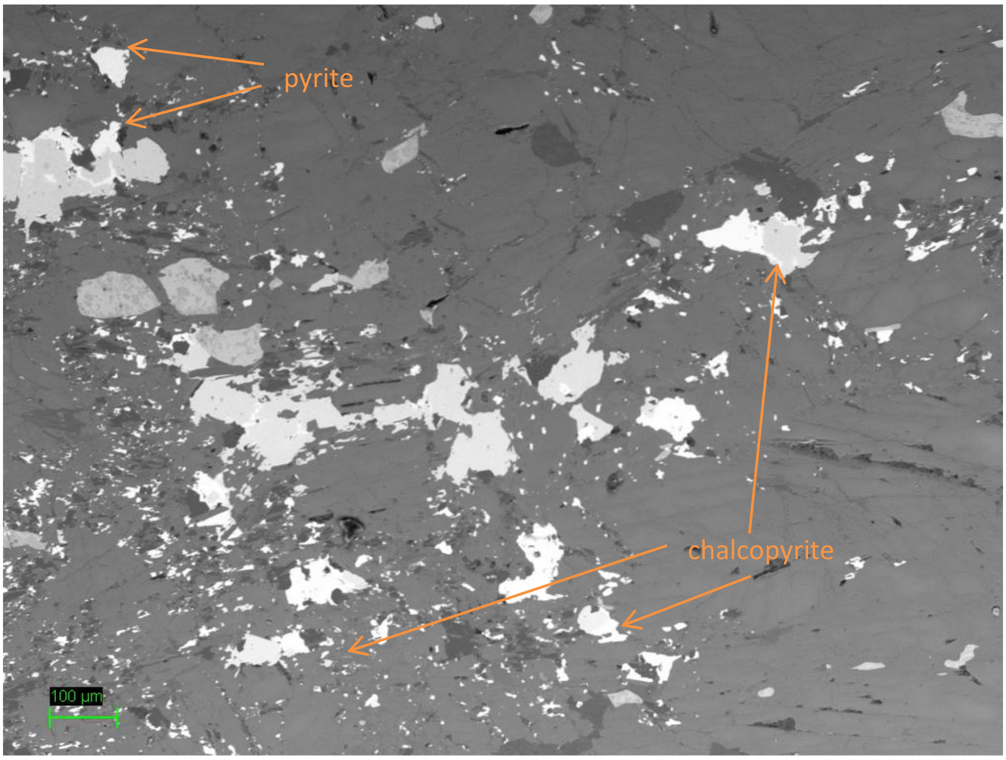


Fig. 38. Pyrite and chalcopyrite in sample 42023/9. Backscattered electron image.

Ilmenite that was identified using reflected light, was found to represent a composition in magnetite – ilmenite solid solution series, which could be either ilmenite or titaniferous magnetite, therefore it will be referred as Fe-Ti oxide thereafter. Fe-Ti oxide was present in 10 samples out of 11 in total. The distribution of Fe-Ti oxide was relatively large in all the samples (Fig. 39). It was usually following the directionality of rock structure, and in some rare cases, also was found filling the cracks in the sample. Supposed titanite was also concurred to be a Ti-oxide mineral and was found occurring together with Fe-Ti oxide.

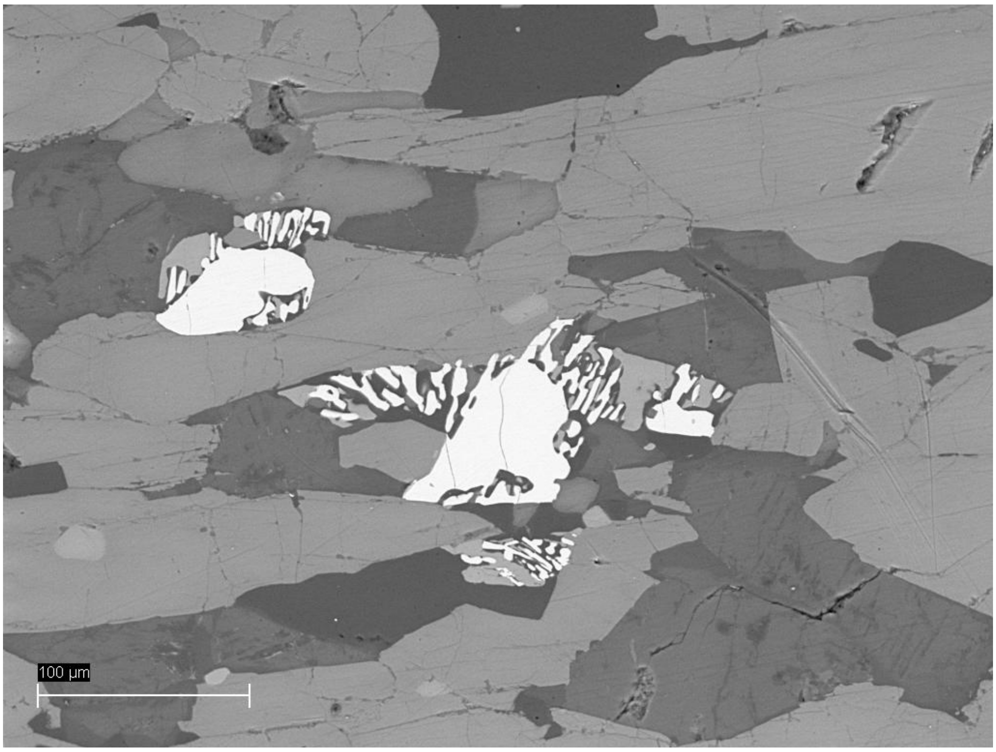


Fig. 39. Fe-Ti oxide mineral in sample 46044. Backscattered electron image.

Graphite was indicated in four samples. It appeared either as big clusters or as single strips (Fig. 40).

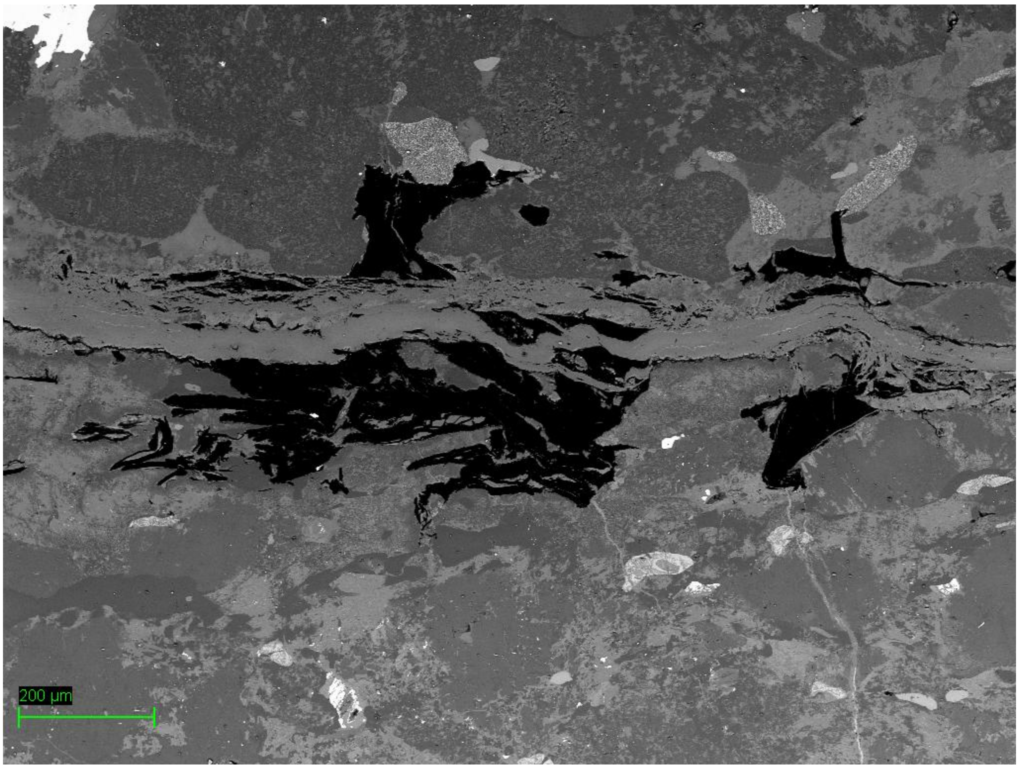


Figure 40.. Graphite in sample 42023/21. Backscattered electron image.

In addition, the SEM analysis showed also galenite in two samples (Fig 41, 42) and sphalerite in one sample (Fig 43). However, in both cases, galenite occurred as an inclusion in pyrite and all the sphalerite that was found was one single grain developing together with pyrite.

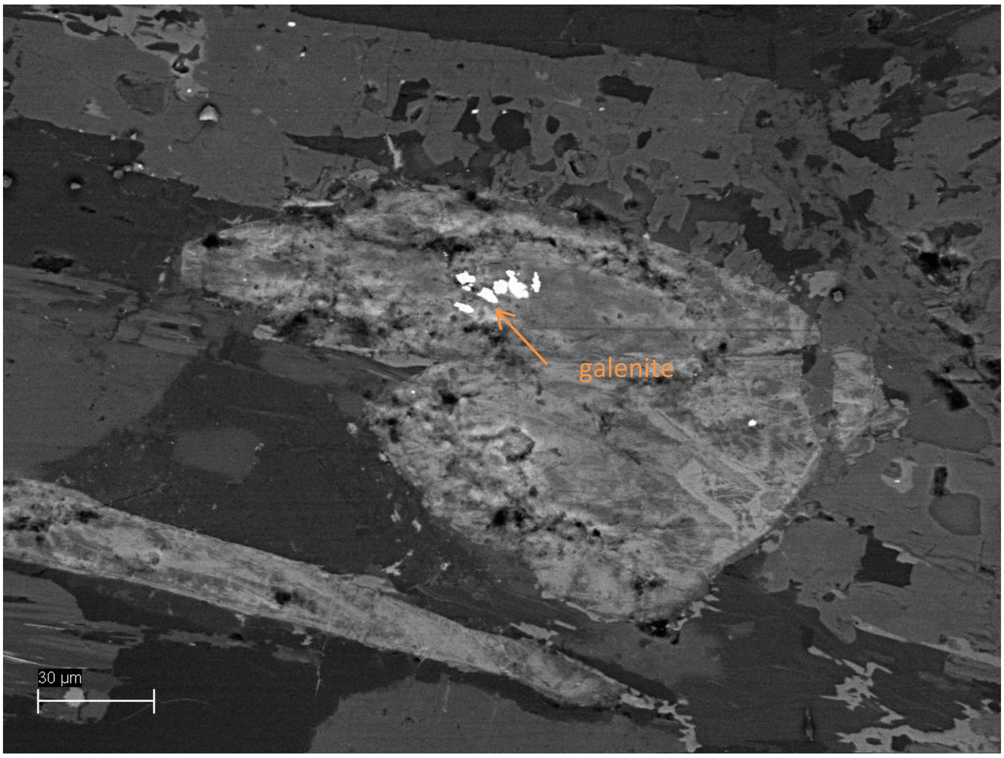


Fig. 41. Galenite in sample 46051. Backscattered electron image.

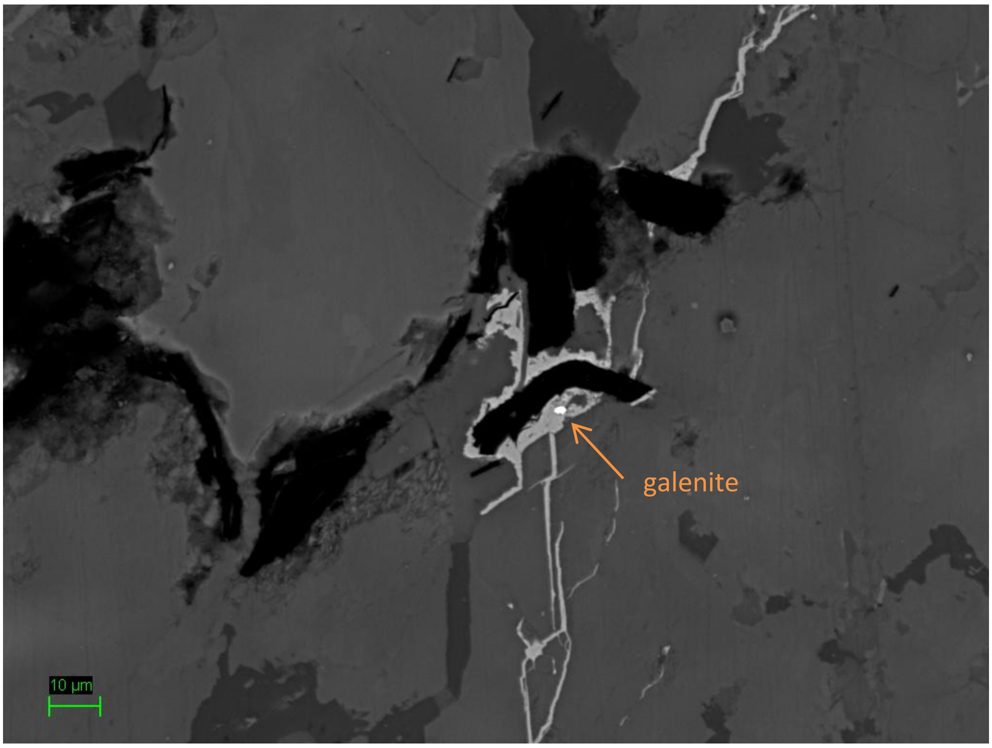


Figure 42. Galenite in sample 42023/9. Backscattered electron image.

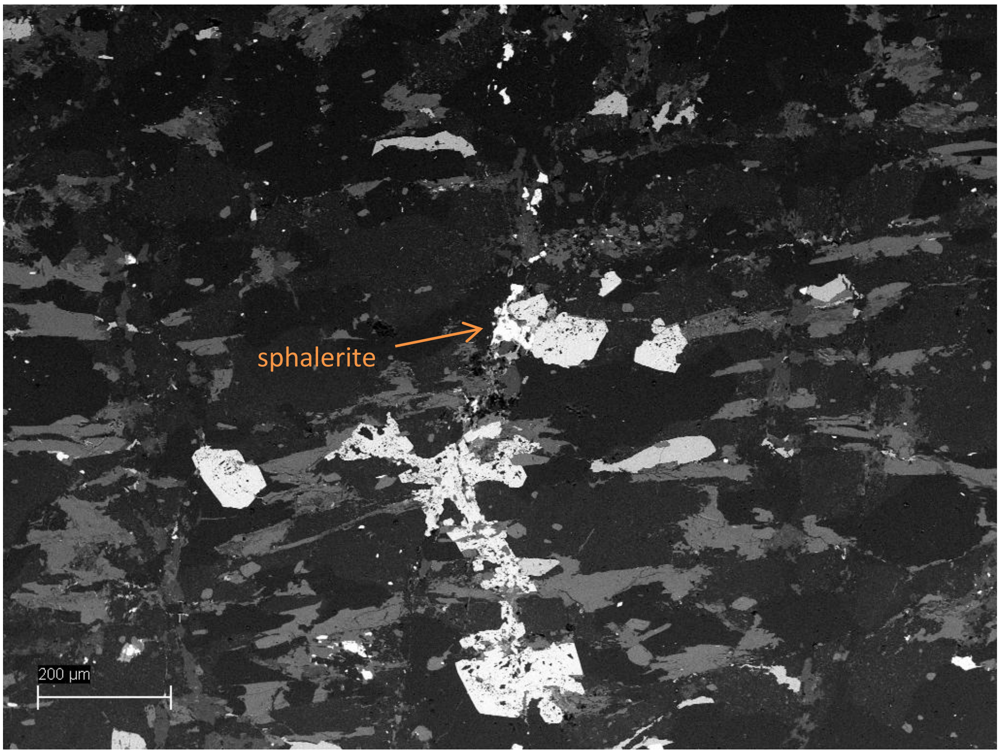


Fig. 43. Sphalerite in sample 46049. Backscattered electron image.

All together, four different rock types were represented with the polished sections. Most of the samples were from amphibole-bearing quartzite rock, that was more or less layered. Those samples contained all Fe-Ti oxide, pyrite, also chalcopyrite. One of the quartzite samples showed sphalerite appearance.

Skarnoid samples contained both – pyrite, chalcopyrite and also galenite inclusions. One of the skarnoid samples did not contain Fe-Ti oxide, while it was present in the other one.

Quartz-amphibole schist that was represented contained pyrite, Fe-Ti oxide, but was the only analysed sample that did not show any chalcopyrite. In this sample, Fe-Ti oxide was developing in cracks.

Intrusive amphibolite sample contained few big clusters of pyrite and a little amount of very fine-grained chalcopyrite. In this sample, too, Fe-Ti oxide was seen to develop inside fine cracks that covered the whole sample.

5. Discussion

In the Pitkäranta-Impilahti area, flattened, upright and dome-shaped gneiss-masses are considered to be linked to Archean basement, underlaying the surrounding Proterozoic strata (Trüstedt 1907, Hackman 1933). It is suggested that the Archean basement at the craton margin was greatly involved in Paleoproterozoic Svecofennian tectonism. The basement has undergone two cycles of tectonism and metamorphism: firstly Archean, then Paleoproterozoic (Koistinen et al. 1996).

The mapping results showed that the studied area has undergone an extensive tectonic activity, resulting in several faults, directing either from south-west to north-east or from south-east to north-west. It is possible to assume that most of the tectonic activity has occurred in the Proterozoic, as the faults cut both Proterozoic and Archean rocks. All the borders between the Proterozoic and Archean rocks have also been defined by faults. Also it is possible to assume that the faults directing from south-east to north-west are probably older, meaning they have occurred before and the faults directing from south-east have occurred later, as most of the faults directing from south-west to north east cut the faults directing from south-east to north-west.

The main ore deposit type in the Pitkäranta area is skarn deposits with different metal mineralisation. These deposits are related to carbonate horizons of the Pitkäranta suite enclosing the granite-gneiss domes (Amelin et al. 1991). Metals, such as Fe, Pb, Zn, Ag, Sn and Cu were exploited in the area over period of almost 90 years (Valkama et al. 2013)

From the study of polished sections all together four ore minerals were found: pyrite, chalcopyrite, Fe-Ti oxide and titanite. In addition to those, also graphite was present. The most common mineral was pyrite, that appeared in every sample. Fe-Ti oxide and chalcopyrite were present in 10 samples out of 11. The amount of Fe-Ti oxide and titanite associating with the latter was rather abundan. However, the array of these minerals follows the rock's own structure, therefore it could be assumed that the occurrence of Fe-Ti oxide and titanite is not a result of skarn forming process, but rather connected to the original composition of metamorphosed sedimentary rock.

The occurrence of chalcopyrite was also very common, but the amount of the mineral was not considerable in any of the cases and was commonly associated with the pyrite distribution. Overall, the existence of chalcopyrite in the samples can be considered if not marginal, then at least not sufficient to signify an ore deposit.

No other indication of some different metal mineralisation was noted, except for the rare and therefore insignificant occasions of galenite and sphalerite. For that reason and according to the samples analysed, it can be concluded that there is not enough evidence to suggest an ore mineralisation connected to the skarn in the area, and by that, it could be said that the central hypothesis of the thesis is disproven at this point.

The mineral composition of skarnoid samples is mostly monoclinic pyroxen (diopside), carbonates (calcite, dolomite) and amphibole (actinolite, tremolite), with the addition of some accessory minerals, such as apatite, epidote or some opaque minerals. According to Meinert (1992), skarn and skarn deposit are used mostly as descriptive terms, based upon their mineral composition, free of any genetic implications, as suggested by Einaudi et. al (1981). Although skarns can be subdivided in many different types, minerals useful both for exploration and classification, such as garnet, pyroxene and amphibole, are present in all skarn types and show marked compositional variability (Meinert 1992).

In the skarnoid samples studied, there were both pyroxene and amphibole present, however, no sample showed any garnet mineralisation. As the mineralogy is the key for recognising and defining skarns, it can be supposed that none of the samples are an actual skarn. However, skarnoid is been used as a descriptive term for relatively fine-grained, iron-poor calc-silicate rock, that shows at least in part, the compositional control of the protolith (Korzkinskii 1948; Zharikov 1970). In general, it could be said that the skarnoid is an intermediate between purely metamorphic and purely metasomatic rock (Meinart 1992). Although skarn-like and containing garnet or pyroxene assemblages, their origin is uncertain (Ray & Webster 1991). Therefore, it cannot be entirely excluded that no skarn forming process have taken place in the area, resulting in skarnoids, but the area lacks of any actual skarn. The central hypothesis can be for that reason disproven, as there is no ore mineralisation connected to the skarn forming process present.

6. Conclusion

The aim of this thesis was to study the small area on the northern shore of the lake Ladoga, in the Pitkäranta district, on the eastern shore of the gulf Sumerianlahti. The study had two main purposes: firstly to get a theral geological and mineralogical overview of the area, and secondly, to investigate the possible metallogenesis there. A central hypothesis was formed that a skarn forming process has occurred in the area and connected to this, ore mineralisation is present.

Field work was conducted in the area, during which the area was mapped and rock samples were collected. The samples were later investigated: both thin sections and polished sections were made and analysed, using the polarized light microscope, reflected light microscope and scanning electronic microscope.

The mapping showed that the area has undergone to serious tectonics comprising both Archean and Proterozoic rocks. The tectonics has resulted in several faults, directed either from south-west to north-east or south-east to north-west.

The mineralogical study showed that the rocks from Archean in the area are granite-gneisses, from the mantle granite-gneiss domes, and intrusive amphibolites inside the domes. The rocks from Proterozoic are mostly mica- and amphibole-schists in the lower substage of Pitkäranta suite, and amphibole-bearing quartzites and amphibolites in the upper substage of Pitkäranta suite.

During the mapping process, several skarn-like lenses were discovered in the area, but the mineralogical composition of those lenses indicated, that they are skarnoids of uncertain origin, rather than actual skarns. They did consist of pyroxen, amphibole and carbonates, but lacked garnets.

The study of polished sections showed all together four ore minerals (pyrite, chalcopyrite, Fe-Ti oxide, titanite) and graphite. Both Fe-Ti oxide and titanite follow the rock’s own texture, and therefore are origining from the preliminary sedimentary rock. The amount of chalcopyrite was moderate and did not indicate an ore deposite either.

From the results it can be concluded that the original hypothesis of skarn forming process and ore mineralisation was disproven by it, as no actual skarn was identified and no evidence of significant ore mineralisation was found.

Acknowledgments

There is a number of people, who have contributed one way or another to the creation process of this thesis, and therefore deserve to be metioned below.

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Kokkuvõte

Lääne-Pitkäranta piirkonna, Sumerianlahti ranniku skarnoidkivimid ja nende metallogeeniline potentsiaal

Karin Kungla

Käesolev magistritöö uuris metallogeneesi Karjalas, Laagoga põhjakaldal, Pitkäranta piirkonna lääneosas, Sumerianlahti lahe idarannikul. Töö aluseks oli suureskaalaline kaardistamine piirkonnas, kus paljandub kristalne aluskord ja võimalik on jälgida kontakti Arhaikumi ja Paleoproterosoikumi kivimite vahel.

Magistritööl oli kaks põhilist eesmärki:

1) Anda antud uuringuala detailne geoloogiline ja mineraloogiline ülevaade, mis hõlmab kivimikehade identifitseerimist, nende omavaheliste suhete kirjeldamist ja mineraalse koostise määramist
2) Uurida antud piirkonna maavaravõimalikkust, teisisõnu selgitada välja, kas ja missugune maakmineraalide teke on uuritaval maa-alal aset leidnud, seoses eeldatava metasomaatilise protsessiga

Magistritöö keskmeks oli hüpotees, mille kohaselt uuritaval maa-alal on toimunud skarnistumise protsess, mis on toonud enesega kaasa ulatusliku maagistumise.

Vajalikud uuringud ja tööd teostati kolmes etapis. Esiteks viidi uuritaval maa-alal läbi välitööd, mille käigus maatükk kaardistati ja koguti vajalikud kivimiproovid. Teiseks valmistati õhikud, mille põhjal selgitati välja kivimid nende mineraloogilise koostise põhjal. Kolmandaks valmistati lihvid, uurimaks maakmineraalide leidumist.

Kaardistamine viidi läbi rannaäärsel maa-alal kogupikkusega 67 ja umbkaudse laiusega 40 meetrit. Kaardistamise käigus kirjeldati uuritav piirkond detailselt, määrati esialgsed kivimitüübid- ja nimetused ning võeti ühtekokku 67 kivimiproovi.

Kogutud kivimiproovidest valiti välja 35, millest valmistati õhikud. Õhikuid uuriti polariseeriva valgusega mikroskoobi all, eesmärgiga selgitada välja proovide mineraalne koostis ning selle põhjal anda kivimitüüpidele nimetus. Kokku eristati uuritaval maa-alal 10 erinevat kivimit. Kaardistamise ja mineraloogilise uurimistöö koondtulemusena loodi uuritava maa-ala geoloogiline kaart.

Lihvide valmistamiseks valiti välja kokku 11 proovi, mis esindasid nelja kivimitüüpi. Valmistatud lihve uuriti kahes etapis. Esiteks vaadeldi lihve peegelduva valgusega mikroskoobi all, mille käigus omandati esialgne ettekujutus võimalike erinevate maakmineraalide arvu ja iseloomu kohta. Teises etapis viidi läbi põhjalikum ja täpsem uuring skaneeriva elektronmikroskoobi (SEM) all koos keemilise analüüsiga.

Lihvide uurimise tulemusena leiti ühetkokku 4 põhilist maakmineraali, milleks olid püriit, kalkopüriit, Fe-Ti oksiid ja titaniit. Fe-Ti oksiidi ja sellega koosesineva titaniidi kristallid proovides järgivad otseselt kivimi enese tekstuuri, mis viitab, et nende mineraalide esinemine tuleneb algse settekivimi koostisest ning ei ole seotud mingi hilisema protsessiga.

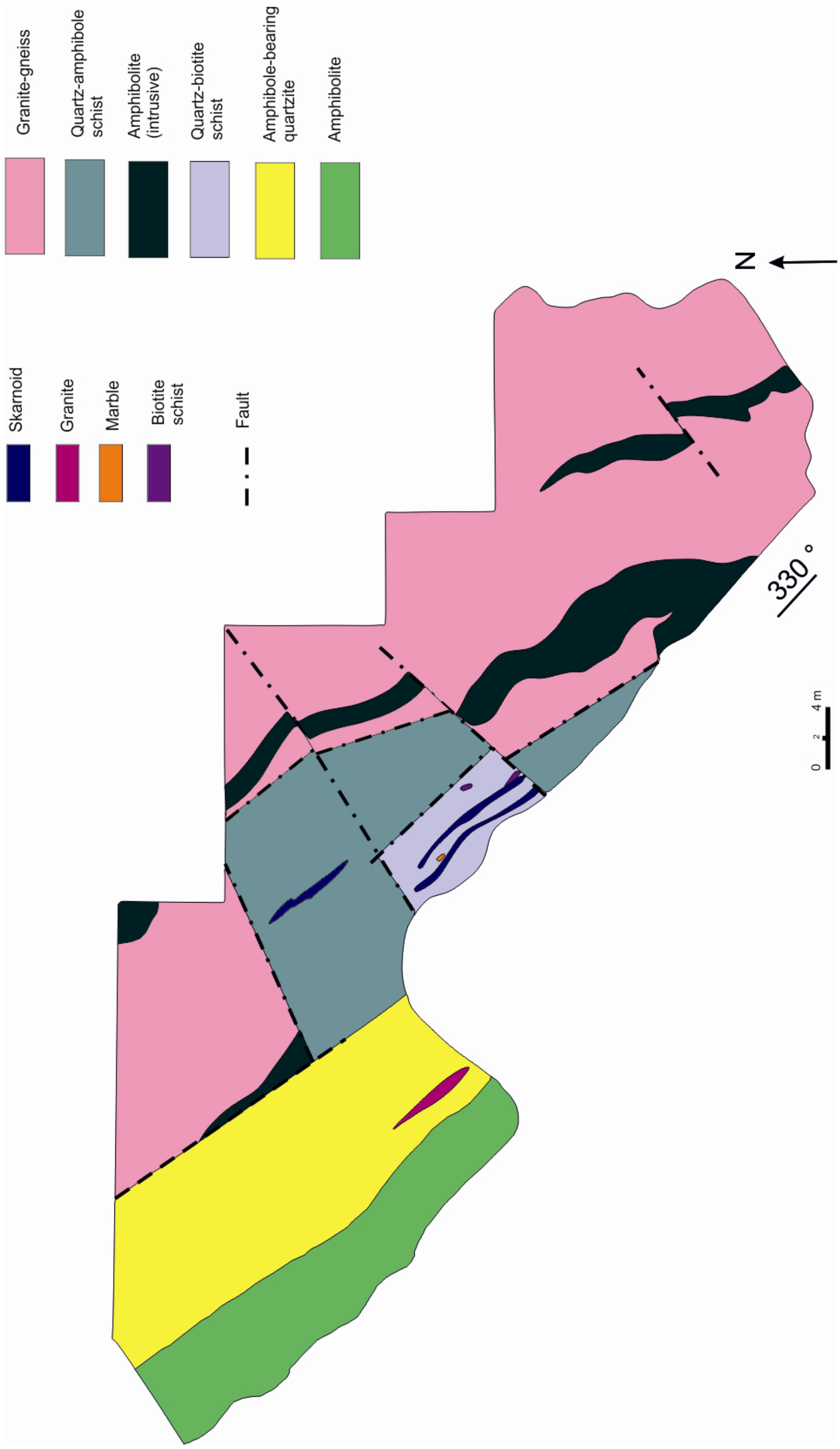
Püriidi ja kalkopüriidi esinemissagedus proovides oli suur, ent viimase hulk polnud üheski proovis küllaldane, et oletada tegelikku maavarade leiukohta. Samuti pole püriidi ja kalkopüriidi esinemine tüüpiline skarnistumisega seotud metallogeneesi nähtus, mistõttu võib väita, et kokkuvõttes ei pea hüpoteesi see pool, mis oletab piirkonnas aset leidnud ulatuslikku maagistumist, paika.

Uuritud skarnilaadsete kivimite mineraloogia on küll skarnile sarnane, kuid ei esinda siiski klassikalist skarnile omast mineraloogilist pilti. Seetõttu võib need liigitada pigem skarnoidideks, mis oma olemuselt on ebaselge tekkelooga. Sellest lähtuvalt ei saa küll metasomatoosiprotsessi toimumist uuritud maa-alal täielikult välistada, ent piisavaid tõendeid tegelikust skarnistumisest ei ilmnenud.

Kokkuvõttes võib öelda, et antud magistritöös püstitatud keskne hüpotees ei ole osutunud paikapidavaks, kuna uuringualal leitud skarnilaadsete kivimite tegelikeks skarnideks pidamine pole piisavalt põhjendatud, samuti puudub maa-alal maakmineraalide levikupildi põhjal tegelik maagistumise potentsiaal.

Appendixes

Appendix 1. Map of the studied area.



Appendix 2. List of the Rock Samples

Granites
46037

Granito-gneisses
46032/2

Intrusive amphibolites
45033/8
46053
46032/1

Amphibolites of Pitkäranta series
45036/1
45036/2
45035/1
45035/2
45034/1
45033/1
45033/2
46033
46041

Skarnoids
42023/24
42023/22
42023/5
42023/2
42023/14
42023/9

Marbles
42023/20

Biotite Schists
46051
42023/3
42023/23
42023/7

Quartz-biotite schists
42023/26
42023/16
42023/6
42023/8
42023/10
42023/17
42023/21
42023/15
42023/12

Quartz-amphibole schists
46034
46035
46036
46038
46039
46040
46042
46043
46044
46045
46046
46047
46049
46050
42023/4
42023/13
42023/1
46052
42023/25
42023/11

Amphibole-bearing quartzites
45036/3
45035/3
45034/2
45033/3
45033/4
45033/6
45032/1
45032/2
45032/3
45032/4
45033/5
45033/7
46048

Lihtlitsents lõputöö reprodutseerimiseks ja lõputöö üldsusele kättesaadavaks tegemiseks

Mina, Karin Kungla,

1. annan Tartu Ülikoolile tasuta loa (lihtlitsentsi) enda loodud teose SKARNOID ROCKS IN THE WESTERN PART OF PITKÄRANTA AREA, ON THE COAST OF SUMERIANLAHTI GULF, AND THEIR METALLOGENIC POTENTIAL,

mille juhendajad on Kalle Kirsimäe ja Ivan Alexeev

1.1. reprodutseerimiseks säilitamise ja üldsusele kättesaadavaks tegemise eesmärgil, sealhulgas digitaalarhiivi DSpace-is lisamise eesmärgil kuni autoriõiguse kehtivuse tähtaja lõppemiseni;
1.2. üldsusele kättesaadavaks tegemiseks Tartu Ülikooli veebikeskkonna kaudu, sealhulgas digitaalarhiivi DSpace´i kaudu kuni autoriõiguse kehtivuse tähtaja lõppemiseni.

2. olen teadlik, et punktis 1 nimetatud õigused jäävad alles ka autorile.

3. kinnitan, et lihtlitsentsi andmisega ei rikuta teiste isikute intellektuaalomandi ega isikuandmete kaitse seadusest tulenevaid õigusi.

Tartus, 20.05.2015