Working Report 2007-48

Petrology, Petrophysics and Fracture Mineralogy of the Drill Core Sample OL-KR23 and OL-KR23B

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June 2007

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ABSTRACT

This report represents the results of the studies dealing with the drill core samples OL-KR23 and OL-KR23B, drilled in the southern part of the Olkiluoto study site. Lithological properties, whole rock chemical compositions, mineral compositions, textures, petrophysical properties and low temperature fracture infill minerals are described.

The drill holes intersect a diatexitic gneiss unit in which the migmatites are rather coarse-grained and rich in granitoid materials, leucosomes and intruding pegmatitic dykes. Several homogeneous, weakly migmatized gneiss intersections and one intersection of various granitoid rocks have been met in the drill core. Detailed petrological properties have been analysed from six samples. The T series is represented by four diatexitic gneiss samples of which one is strongly brecciated. The samples represent moderate types in the sequence of the T-type diatexites by having 60 – 70% SiO_2. The other major element concentrations are directly controlled by the silicity and the numbers will settle just at the anticipated values. One sample is granitic in mineral composition and contains roundish feldspars and also other mineral grains. Chemically this porphyry-like rock is close to identical with the T-type gneisses with 65 – 67% SiO_2. The P series is represented by one single migmatite sample which is classified as diatexitic gneiss on the basis of migmatite structure. The chemical composition of this sample is not the most typical for the P series.

Petrophysical properties were studied from 6 samples. The parameters measured were density, magnetic susceptibility, natural remanet magnetization, electrical resistivity, P-wave velocity and porosity.

Borehole OL-KR23 represents a moderately fractured rock having 2.5 fractures/metre. The chief fracture minerals include illite, kaolinite, unspecified mixed clay phases (mainly illite, chlorite, and smectite-group), iron sulphides and calcite. A number of fracture plains are covered by cohesive chlorite. Iron oxides and oxy-hydroxides are present in fractures at surficial zone, in core length 6.3 – 47 m, while major of graphite occurrences concentrate within few fractures at core length 41-53 m. Pervasive illitization concerns 9.8 % of the total core length and in addition to that the fracture related illite and kaolinite constitute sequences, 8 m core length in average. Calcite occurs as major constituent in fracture fillings and stockwork in 32 % of the drill core length.

Kairanäytteen OL-KR23 ja OL-KR23B petrologia, petrofysiikka ja rakomineralogia

TIIVISTELMÄ

Tässä raportissa esitetään kairausnäytteitä OL-KR23 ja OL-KR23B koskevien tutkimusten tulokset. Kyseiset kairanreiät on tehty Olkiluodon tutkimusalueen eteläosaan. Raportissa esitetään kairausnäytteen litologiaa sekä valittujen näytteiden kokokiven kemiallista koostumusta, mineraalikoostumusta, tekstuuria ja petrofysikaalisia ominaisuuksia käsittelevien tutkimusten tulokset. Samoin kuvataan matalan lämpötilan raontäytemineraalit

Kairanreiät lävistävät diateksiittista gneissiyksikköä, jonka migmatiitit ovat varsin karkearakeisia ja sisältävät runsaasti granitoidimateriaalia, leukosomia ja pegmatiittisia juonia. Useita homogeenisia ja heikosti migmatiitiutuneita gneissijaksoja sekä yksi erilaisista granitoideista koostuva jakso on tavattu kairausnäytteessä.

Petrologiset ominaisuudet on analysoitu yksityiskohtaisesti kuudesta näytteestä. Neljä diateksiittista gneissinäytettä, joista yksi on voimakkaasti breksioiutunut, edustaa T-sarjaa. Kemiallisesti näytteet edustavat keskinkertaisia muunnoksia T-tyypin migmatiittien joukossa, sillä niihin sisältyy 60 – 70 % SiO_2:ta. Pii-pitoisuus kontrolloi muiden alkuaineiden määriä suoraan ja pitoisuudet asettuvat juuri odotettuihin arvoihin. Yksi näyte on mineraalikoostumukseltaan graniittinen, ja se sisältää pyöreitä, maasälvistä ja muistakin mineraaleista koostuvia aggregaatteja. Kemiallisesti tämä porfyyriittimäinen kivi on identtinen 65 – 67 % SiO_2:ta sisältävien T-tyypin kivien kanssa. P-sarjaa edustaa yksi ainut migmatiittinäyte, joka luokittuu migmatiittirakenteensa perusteella diateksiittiseksi gneissiksi. Tämän näytteen kemiallinen koostumus ei ole P-sarjan kiville tyypillisin.

Petrofysikaaliset ominaisuudet on määritetty kuudesta näytteestä. Mitatut parametrit ovat tiheys, magneettinen suskebtibiliteetti, luonnollinen remanentti magnetoituma, sähkövastus, P-aallon nopeus ja huokoisuus.

Kairausnäytteen OLKR23 rakotiheys on kohtalainen, keskimäärin 2,5 rakoa/metri. Rakotäytteitä esiintyy illiittiä, kaoliniittia, erikseen määrittelemättömiä useamman savispesieksen muodostamia savisseostäytteitä (pääasiassa illiitti, kloriitti ja smektiittiryhmä), rautasulfideja ja kalsiittia. Kloriitti muodostaa tyypillisesti rakojen pinnoille kiinteän katteen, joka on usein alustana muille rakotäytteille. Rautaoksideja ja –oksihydroksideja esiintyy useissa raoissa kairauspituusvälillä 6.3 - 47 m ja grafiittia välillä 41-53 m. Kairauslävistyksestä on 9.8 % läpikotaisesti illiittiytynyttä ja rakotäytteisiin liittyvän iliitti-kaoliniittimuuttumisen keskimääräinen kairausleikkauspituus on kahdeksan metriä. Kalsiittivaltaisia täyteseurantoja esiintyy 32 %:ssa kairausnäytteen koko pituudesta.

TABLE OF CONTENTS

1 INTRODUCTION

According to the Nuclear Energy Act, all nuclear waste generated in Finland must be handled, stored and permanently disposed of in Finland. The two nuclear power companies, Teollisuuden Voima Oy and Fortum Power and Heat Oy, are responsible for the safe management of the waste. The power companies have established a joint company, Posiva Oy, to implement the disposal programme for spent fuel, whilst other nuclear wastes are handled and disposed of by the power companies themselves.

The plans for the disposal of spent fuel are based on the KBS-3 concept, which was originally developed by the Swedish SKB. The spent fuel elements will be encapsulated in metal canisters and emplaced at a depth of several hundreds of meters.

At present Posiva has started the construction of an underground rock characterisation facility at Olkiluoto. The plan is that, on the basis of underground investigations and other work, Posiva will submit an application for a construction licence for the disposal facility in the early 2010s, with the aim of starting disposal operations in 2020.

As a part of these investigations, Posiva Oy continues detailed bedrock studies to get a more comprehensive conception of lithology and bedrock structure of the study site. As a part of that work, this report summarises the results obtained from petrological and petrophysical studies and fracture mineral loggings of drill cores OL-KR23 and OL-KR23B.

1.1 Location and General Geology of Olkiluoto

The Olkiluoto site is located in the SW Finland, western part of the Eurajoki municipal and belongs to the Paleoproterozoic Svecofennian domain ca. 1900 - 1800 million years in age (Korsman et al. 1997, Suominen et al. 1997, Veräjämäki 1998,). The bedrock is composed for the most part of various, high grade metamorphic supracrustal rocks (Fig. 1-1), the source materials of which are various epi- and pyroclastic sediments. In addition, leucocratic pegmatites have been met frequently and also some narrow mafic dykes cut the bedrock of Olkiluoto. The practice of naming the rock types follows the orders of Posiva Oy (Mattila 2006).

On the basis of the texture, migmatite structure and major mineral composition, the rocks of Olkiluoto fall into four main classes: 1) gneisses, 2) migmatitic gneisses, 3) TGG gneisses, and 4) pegmatitic granites (Kärki & Paulamäki 2006). In addition, narrow diabase dykes have been met sporadically.

Subdivision of the gneissic rocks has to be based on modal mineral composition. *Mica gneisses*, mica bearing *quartz gneisses* and hornblende or pyroxene bearing *mafic gneisses* are often banded but rather homogeneous types have also been met. Quartz gneisses are fine-grained, often homogeneous and typically poorly foliated rocks that contain more than 60% quartz and feldspars but 20% micas at most. They may contain some amphibole or pyroxene and garnet porphyroblasts are also typical for one subgroup. Mica rich metapelites are in most cases intensively migmatitized but sporadically also fine- and medium-grained, weakly migmatized gneisses with less than 10 % leucosome material occur. The content of micas or their retrograde derivatives

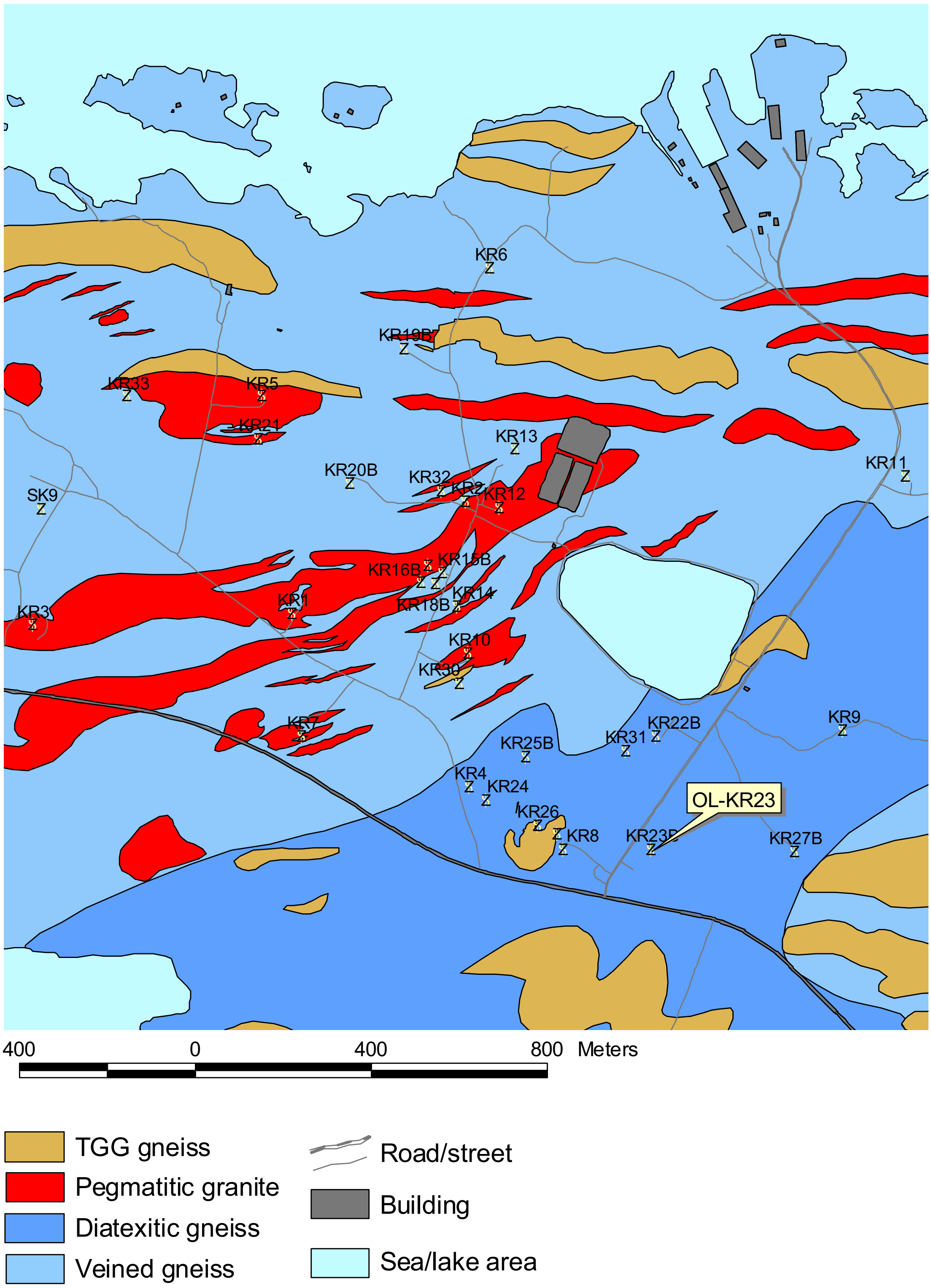


Figure 1-1. *General geology and location of bore hole starting points at Olkiluoto.*

exceeds 20% in these rocks. Cordierite or pinite porphyroblasts, typically 5 – 10 mm in diameter, are common constituents for one subgroup of mica rich rocks. Mafic gneisses and schists have been seen as different variants that have been called amphibolites, hornblende gneisses and chlorite schists. Certain, exceptional gneiss variants may contain in addition to dark mica and hornblende also some pyroxene or olivine.

Migmatitic gneisses have been defined as migmatites including more than 10% neosome. Ideal *veined gneisses* contain elongated leucosome veins the thicknesses of which vary typically from several millimetres to five – ten centimetres. The leucosome veins show a distinct lineation and appear as swellings of dykes or roundish quartz-feldspar aggregates that may compose augen-like structures the diameters of which vary between 1 and 5 cm. *Stromatic gneisses* represent a rather rare migmatite variety in Olkiluoto and the most characteristic feature of these migmatites is the existence of plane-like, linear leucosome dykes or "layers". Widths of these leucosome layers vary from several millimetres up to 10 – 20 cm. The paleosome is often well foliated and shows a distinct metamorphic banding or schistosity. The name *diatexitic gneiss* is used for other migmatite rocks that are more strongly migmatitized and show more wide variation in the properties of migmatite structures, which are generally asymmetric and disorganized. The borders of paleosome fragments or relicts of them are often ambiguous and they may be almost indistinguishable. This group includes migmatites that may contain more than 70% neosome and the paleosome particles of which are coincidental in shape and variable in size.

TGG gneisses are medium-grained, relatively homogeneous rocks which can show a weak metamorphic banding or blastomylonitic foliation but they can also resemble plutonic, not foliated rocks. One type of these gneisses resembles moderately foliated, red granites and one other grey, weakly foliated tonalites. In places, these rocks are well foliated, banded gneisses that show features typical for high grade fault rocks.

Pegmatitic granites are often leucocratic and very coarse-grained rocks. Sometimes large garnet and also tourmaline and cordierite grains of variable size occur in the pegmatitic granites. Mica gneiss inclusions and xenoliths are also typical constituents for wider pegmatite dykes.

On the basis of whole rock chemical composition these gneisses and migmatites can be divided into four distinct series or groups: T-series, S-series, P-series and mafic gneisses (Kärki & Paulamäki 2006). In addition to those, pegmatitic granites and diabases form their own groups which can be identified both macroscopically and chemically.

The members the T-series build up a transition series the end members of which are relatively dark and often cordierite bearing mica gneisses and migmatites which may have less than 60% SiO_2. Another end in this series is represented by quartz gneisses in which the content of SiO_2 exceeds 75%. These high grade metamorphic rocks have been assumed to originate from turbidite-type sedimentary materials and the end members of that series have been assumed to be developed from greywacke type, impure sandstones in other end and from clay mineral rich pelitic materials in other end of the series.

The members of the S-series have been assumed to originate from calcareous sedimentary materials or affected by some other processes that produced the final, skarn-type formations. The most essential difference between the members of the S-series and other groups is in the high calcium (>2% CaO) concentration of the S-type rocks. Relatively low contents of alkalis and high contents of manganese are also typical for this series. Various quartz gneisses, mica gneisses and mafic gneisses constitute the most typical members of the S series while migmatitic rocks are infrequent.

The P-series deviates from the others due to high contents of phosphorus. P_2O_5 content that exceeds 0.3% is characteristic for the members of the P-series whereas the other common supracrustal rock types in Olkiluoto contain typically less than 0.2% P_2O_5. Another characteristic feature for the members of the P-series is the comparatively high concentration of calcium which falls between the concentration levels of the T- and S-series. Mafic gneisses, mica gneisses, various migmatites and TGG gneisses are the most characteristic rock types of the P series. SiO_2 content of the mafic P-type gneisses varies between 42 and 52%, in the mica gneisses and migmatites it is limited between 55 and 65% and in the P-type TGG gneisses the variation is more wide the concentrations falling between 52 and 71%.

1.2 Borehole and Drill Core Sample OL-KR23 and OL-KR23B

The starting points of the boreholes OL-KR23 and OL-KR23B are situated in the SE part of the Olkiluoto study site (Figure 1-1). The coordinates of the starting point of the borehole OL-KR23 are: X = 6791898.74, Y = 1526251.35 and Z = 7.85. Starting direction (azimuth angle) of the borehole is 289.5^{o} and its dip (inclination angle) is 59.5^{o}. The same values for the borehole OL-KR23B are: X = 6791894.97, Y = 1526250.02 and Z = 7.88. Starting direction (azimuth angle) of the borehole is 289.5^{o} and its dip (inclination angle) is 59.6^{o}. Technical data dealing with these drillings is represented by Niinimäki 2002.

1.3 The aim of this study and research methods

Hitherto, more than 40 deep bore holes have been drilled at the study site. The aim of this report is to represent the results of studies dealing with petrology, petrophysics and fracture minerals of the drill core samples OL-KR23 and OL-KR23B. A description of lithological units and their properties is presented in this report. Petrological properties such as whole rock chemical composition, mineral composition and microscopic texture of selected samples are described as well as the results of petrophysical measurements of the samples. Another aim was to map the locations and types of low temperature fracture infill minerals and, when necessary, to analyse and identify those.

Lithological mapping has been done by naked ayes utilizing the results of geophysical borehole measurements. Whole rock chemical analyses have been carried out in the SGS Minerals Services laboratory, Canada by X-ray fluorescence analyser (XRF), neutron activation analyser (NAA), inductively coupled plasma atomic emission analyser (ICP), inductively coupled plasma mass spectrometer (ICPMS), sulphur and carbon analyser (LECO) and by using ion specific electrodes (ISE). The elements, methods of analysis and detection limits for individual elements have been represented in the Table 1-1.

Mineral compositions and textures of the selected samples have been determined by using Olympus BX60 polarization microscope equipped with reflecting and transmitting light accessories and a point counter.

Petrophysical measurements were carried out in the Laboratory of Petrophysics at the Geological Survey of Finland (GSF). Prior to the measurements, the samples were kept in a bath for 2.5 days using ordinary tap water (resistivity 50 – 60 ohmm). The parameters measured were density, magnetic susceptibility, natural remanet magnetization, electrical resistivity with three frequencies (0.1, 10 and 500 Hz), P-wave velocity and porosity.

Mapping of fracture infill minerals has been done by naked ayes utilizing stereo-microscopy when necessary. More detailed identification of mineral species of selected samples has been done by Siemens X-ray diffractometer at the department of electron optics, University of Oulu under control of O. Taikina-aho, FM.

1.4 Research Activities

Lithological logging and mapping of fracture infill minerals has been done by S. Gehör, PhD and A. Kärki, PhD during a mapping campaign on 28.7. – 1.8.2003 at the drill core archive of Posiva in Olkiluoto. During these studies Henri Kaikkonen and Pekka Kärki acted as research assistants and they also transcribed the data collected during the studies. Engineer Tapio Lahdenperä is responsible for the checking and correcting the data files.

Drill core was sampled for studies of modal mineral composition, texture and whole rock chemical composition and in the latest stage also for measurements of petrophysical properties. The samples were selected by A. Kärki. Materials for detailed further studies have been selected on the basis of their frequency of appearance. Thus, the most common and typical rock types are represented roughly in the same proportion that they build up in the core sample. Polished thin sections have been prepared from these samples at the thin section laboratory of Department of Geosciences, University of Oulu for polarization microscope examinations.

The total number of whole rock chemical analyses and prepared thin sections is 5 from the drill core OL-KR23 and 1from the core OL-KR23B. Modal mineral compositions were determined by using a point counter and calculating 500 points per one sample. Aulis Kärki is responsible for microscope studies and also for description of petrography and handling of the results of the whole rock chemical analyses.

Petrophysical properties have been measured at the Geological Survey of Finland from the same samples that have been selected for petrological studies. Markku Paananen, Lic. Tech. from the GSF is responsible for handling and description of petrophysical data.

S. Gehör carried out the handling of fracture mineral data and he is also responsible for the selection of fracture mineral materials for further studies. S. Gehör also composed the section dealing with the fracture minerals.

Table 1-1. *Elements, methods and detection limits for whole rock chemical analysis.*

Element	Method	Detection limit	Element	Method	Detection limit
SiO_2	XRF	0.01 %	Lu	ICPMS	0.05 ppm
Al_2O_3	XRF	0.01 %	Nb	ICPMS	1 ppm
CaO	XRF	0.01 %	Nd	ICPMS	0.1 ppm
MgO	XRF	0.01 %	Ni	ICPMS	5 ppm
Na_2O	XRF	0.01 %	Pr	ICPMS	0.05 ppm
K_2O	XRF	0.01 %	Rb	ICPMS	0.2 ppm
Fe_2O_3	XRF	0.01 %	Sm	ICPMS	0.1 ppm
MnO	XRF	0.01 %	Sn	ICPMS	1 ppm
TiO_2	XRF	0.01 %	Sr	ICPMS	0.1 ppm
P_2O_5	XRF	0.01 %	Ta	ICPMS	0.5 ppm
Cr_2O_3	XRF	0.01 %	Tb	ICPMS	0.05 ppm
LOI	XRF	0.01 %	Tm	ICPMS	0.05 ppm
Mn	ICP	2 ppm	U	ICPMS	0.05 ppm
Ba	ICPMS	0.5 ppm	W	ICPMS	1 ppm
Ce	ICPMS	0.1 ppm	Y	ICPMS	0.5 ppm
Co	ICPMS	10 ppm	Yb	ICPMS	0.1 ppm
Cu	ICPMS	10 ppm	Zn	ICPMS	5 ppm
Cr	ICPMS	10 ppm	Zr	ICPMS	0.5 ppm
Cs	ICPMS	0.1 ppm	Cl	ISE	50 ppm
Dy	ICPMS	0.05 ppm	F	ISE	20 ppm
Er	ICPMS	0.05 ppm	C	LECO	0.01 %
Eu	ICPMS	0.05 ppm	S	LECO	0.01 %
Gd	ICPMS	0.05 ppm	Br	NAA	0.5 ppm
Hf	ICPMS	1 ppm	Cs	NAA	0.5 ppm
Ho	ICPMS	0.05 ppm	Th	NAA	0.2 ppm
La	ICPMS	0.1 ppm	U	NAA	0.2 ppm

2 PETROLOGY

The practice for naming (Mattila 2006) and lithological classification proposed by Kärki and Paulamäki (2006) has been utilized in the description and grouping of lithological units. More detailed classification has to be based on the evaluation of whole rock chemical composition or modal mineral composition and that is not possible without information based on the accurate results of instrumental analysis.

2.1 Lithology

The drill holes intersect a diatexitic gneiss unit in which the migmatites are rather coarse-grained and rich in granitoid materials, leucosomes and intruding pegmatitic dykes. Several homogeneous, weakly migmatized gneiss intersections and narrow intersections of various granitoid rocks have been met in the drill core (Figure 2-1). A more detailed description of lithological units is presented in the Tables 2-1 and 2-2.

Table 2-1. *Lithology of the drill core OL-KR23.*

Drilling length (m)	Lithology
40.40 - 56.00	DIATEXITIC GNEISS which has ca 80% leucosome. The migmatite is often strongly brecciated and the breccia has a dark, chlorite bearing matrix. In addition, the zone includes a number of crushed subzones with brittle deformation structures.
56.00 – 56.50	MAFIC GNEISS which is fine-grained and intruded by reddish, pegmatite-like dykes counting ca. 10% of the rock volume.
56.50 – 120.00	DIATEXITIC GNEISS the migmatite structure, for the most part, is veined structure but in which 1 – 3 m wide subzones of another kind occur. Fine-grained, 10 – 50 cm long mica gneiss subsections have been met sporadically. Fine-grained, less than 0.5 m wide mafic gneiss subsections are common between drilling lengths from 85.90 m to 90.70 m and they count ca. a half of the paleosome volume. A banded TGG gneiss or foliated, medium-grained granite is located in the section between drilling lengths of 70.40 – 72.05. In the section from drilling length of 104.80 m to 107.00 m is located a granitoid with roundish, 1 – 3 cm wide feldspar grains in a dark, biotite rich groundmass. As a whole, the paleosome materials of the migmatites are coarse-grained and the borders between paleosome and neosome are weakly distinguishable.
120.00 – 122.00	PEGMATITIC GRANITE which contains cordierite grains (5 – 10 mm in diameter) in coarse-grained, leucocratic material.

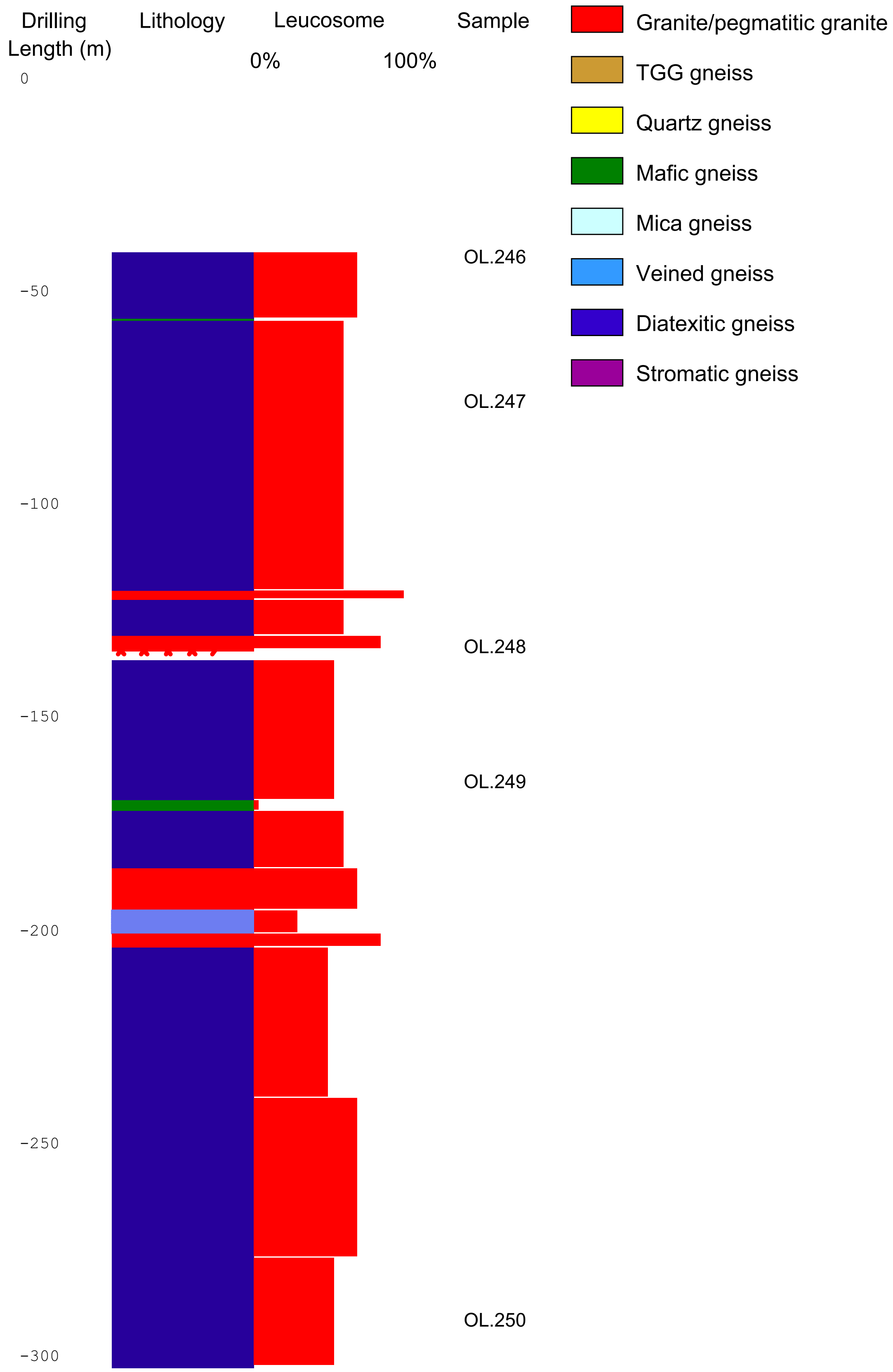


Figure 2-1. *Lithology, leucosome + pegmatite material percentage (= leucosome) and sample locations, drill core OL-KR23.*

122.00 - 130.35	DIATEXITIC GNEISS in which the borders between paleosome and leucosome are irregular, inadequately distinguishable. The paleosome is coarse-grained and includes feldspar grains 5 – 10 mm in diameter. Mafic gneiss subsections, which are 10 – 30 cm wide, have been met at irregular intervals.
130.30 – 133.90	PEGMATITIC GRANITE which is coarse grained and includes plenty of granite-like inclusions.
133.90 – 136.27	PORPHYRY-like dyke rock in which roundish feldspar grains, typically 5 – 20 mm in diameter occur.
136.27 – 169.30	DIATEXITIC GNEISS in which the leucosome for the most part forms 1 – 3 cm wide veins and the migmatite structure is mainly veined structure. The paleosome is relatively coarse-grained and, for a part, assimilated into the leucosome material. The migmatite is also intruded by 10 – 80 cm wide pegmatite dykes.
169.30 – 171.60	MAFIC GNEISS or foliated amphibolite which is intruded by narrow (< 1 cm wide) pegmatite-like dykes.
171.60 – 185.10	DIATEXITIC GNEISS the paleosome of which is rather coarse-grained and, for a part, resembles augen gneisses or porphyroblastic rocks with large K-feldspar grains. The migmatite is intruded sporadically by 10 – 40 cm wide pegmatite dykes.
185.10 – 195.05	Granitoid mixture in which subsections of medium-grained, non foliated granitoids, coarse-grained pegmatites and typical pegmatites fluctuate randomly. At the end of the section, TGG gneiss-like, narrow subsections come along with the mixture.
195.05 -200.65	VEINED GNEISS in which the leucosome occur in form of 1 – 3 cm wide veins.
200.65 – 203.75	PEGMATITIC GRANITE coarse- to medium-grained, leucocratic and rich in gneiss inclusions.
203.75 – 239.10	DIATEXITIC GNEISS in which the paleosome is rather coarse grained and which includes down to the drilling length of 209.00 m a lot of homogeneous gneiss inclusions. The proportion of leucosome is rather low, ca. 50%.
239.10 – 276.90	DIATEXITIC GNEISS, the paleosome of which is rather coarse-grained and the migmatite structure varies from irregular to veined structure. The section includes sporadically narrow, homogeneous and fine-grained mica gneiss subsections.

276.90 – 302.10	DIATEXITIC GNEISS in which the paleosome is rather coarse-grained and barely distinguishable from leucosome. Several subsections of fine-grained gneisses and pegmatitic granites are integrated in this section.

Table 2-2. *Lithology of the drill core OL-KR23B.*

Drilling length (m)	Lithology
3.75 – 14.30	DIATEXITIC GNEISS in which the migmatite structure is irregular or resembles veined structure. The rock is weathered for a part and pervasively altered.
14.30 – 17-10	DIATEXITIC GNEISS in which the proportion of leucosome is great, ca. 80%.
17.10 – 17.35	MAFIC GNEISS, medium-grained, homogeneous.
17.35 – 22.40	DIATEXITIC GNEISS in which the leucosome forms 1 – 3 cm wide augen structures, veins or totally irregular bodies. The subsection from 19.25 m to 19.85 m is composed of mafic gneiss.
22.40 – 23.80	TGG gneiss; a pervasively granitic rock which, for a part, resembles plutonic rocks but has also banded, gneissose volumes.
23.80 – 25.80	Crushed migmatite.
25.80 – 32.80	DIATEXITIC GNEISS – PEGMATITIC GRANITE mixture in which pegmatitic material surrounds mica seams and gneiss bodies of variable size and shape.
32.80 – 45.12	DIATEXITIC GNEISS in which 10 – 30 cm wide mafic gneiss and wider veined gneiss subsections occur. Fine-grained mafic gneisses are intersected in the drilling length intervals: 33.60 – 34.20 m, 34.60 – 35.00 m, 36.85 – 37.05 m, 40.60 – 40.95 m and 42.30 – 42.60 m.

2.2 Whole Rock Chemistry

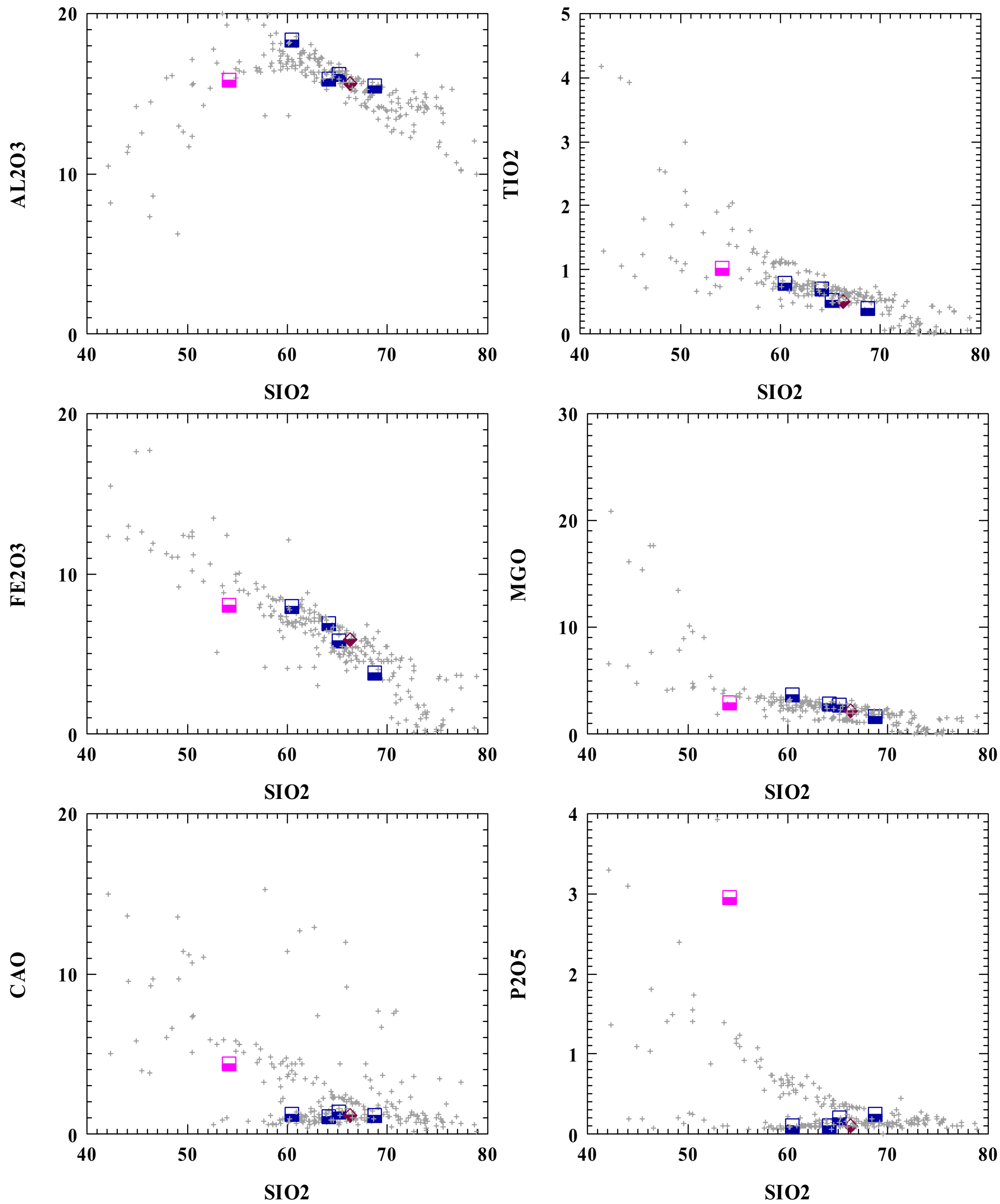
Whole rock chemical composition has been analysed from six samples of which four belong to the T series, one to the P series and one is a granitic rock with roundish feldspar grains and is called K-feldspar porphyry. The numerical results of the whole rock analyses are represented in the Appendix 1.

The T series is represented by four diatexitic gneiss samples of which one (246) is strongly brecciated. The samples represent moderate types in the sequence of the T-type diatexites by having 60 – 70% SiO_2 while typical range in silicity for the whole series is 55 – 75%. The other major element concentrations are directly controlled by the silicity and the numbers will settle just at the anticipated values (Fig. 2-2). Consequently, the REE contents and element ratios are exactly typical for the T-type diatexites of moderate chemical composition (Fig. 2-3). The same similarity can be seen also in other trace element concentrations (Fig. 2-3).

The sample 246 is taken from a brecciated and pervasively altered diatexitic gneiss section but still the major element composition of it resembles that of the sample OL.251 which is taken from fresh looking section. Both of these samples have approximately 65% SiO_2 and the other major element concentrations are also close to identical (Fig. 2-2). The REE patterns (Fig. 2-3) demonstrate exactly the same contents and elements ratios as well as the spider diagrams for the HFS-elements. The only difference can be seen in the contents of alkalis and barium since the brecciated sample is slightly depleted in K_2O and Ba and enriched in Na_2O (Fig. 2-3, Appendix 1).

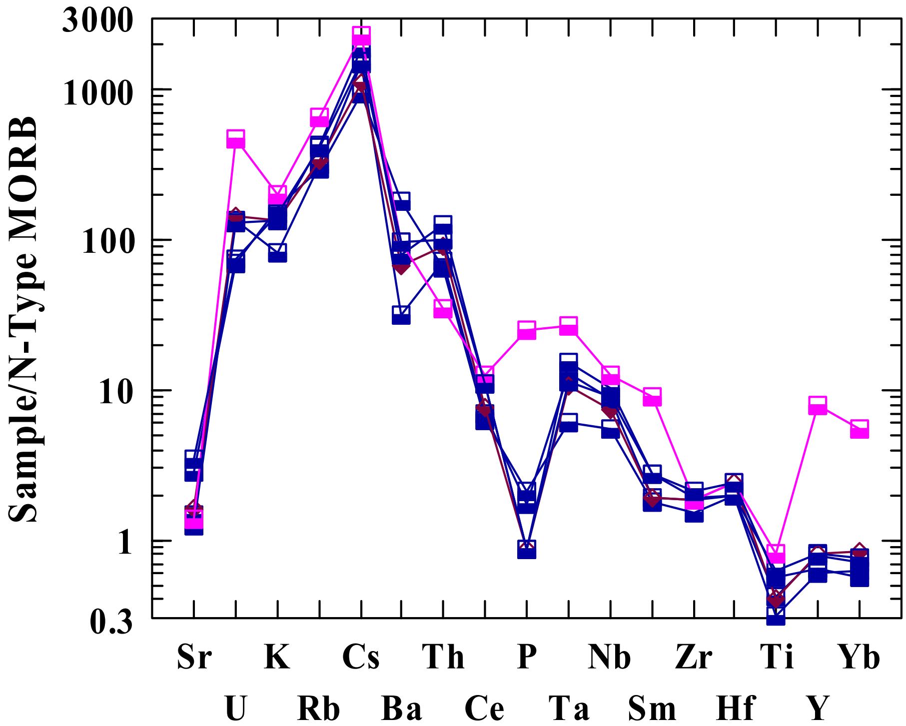
The K-feldspar porphyry sample (248) is granitic in mineral composition and contains roundish feldspars aggregates. Chemically it is similar to the T-type gneisses with 65 – 67% SiO_2. In the assemblage of the T-type gneisses and migmatites this porphyry-like rock is close to identical with the brecciated rock (sample 246). Differences in the major element concentrations are minor and the REE patterns demonstrate the same similarity except to the anomalous, high concentration of Lu which is the only remarkable difference (Fig. 2-3). The other trace element concentrations are close to identical with the T-type gneisses and thus the sample can be classified to the T series despite the fact that the texture is different.

The P series is represented by one single migmatite sample which is classified as diatexitic gneiss on the basis of migmatite structure. The chemical composition of the sample is not the most typical for the P series although there is not visible any drastic divergence. The contents of aluminium, titanium, iron, magnesium and calcium (Fig. 2-2) are a little lower than the lowest values measured from the other, associated samples. On the contrary, the content of potassium (Appendix 1) is higher and the content of phosphorus is evidently higher (Fig. 2-2) than in the most typical gneisses of the P series. The REE pattern of this sample is totally different to all typical patterns. The REE diagram (Fig. 2-3) for the light REE´s is totally flat, Eu-anomaly is exceptional deep and the concentrations of heavy REE´s are 10 – 20 times higher than in typical gneisses of the P series. The same abnormality is also visible in the other trace element concentrations and the sample is apparently enriched in U, Ta, Sm, Y and Yb.

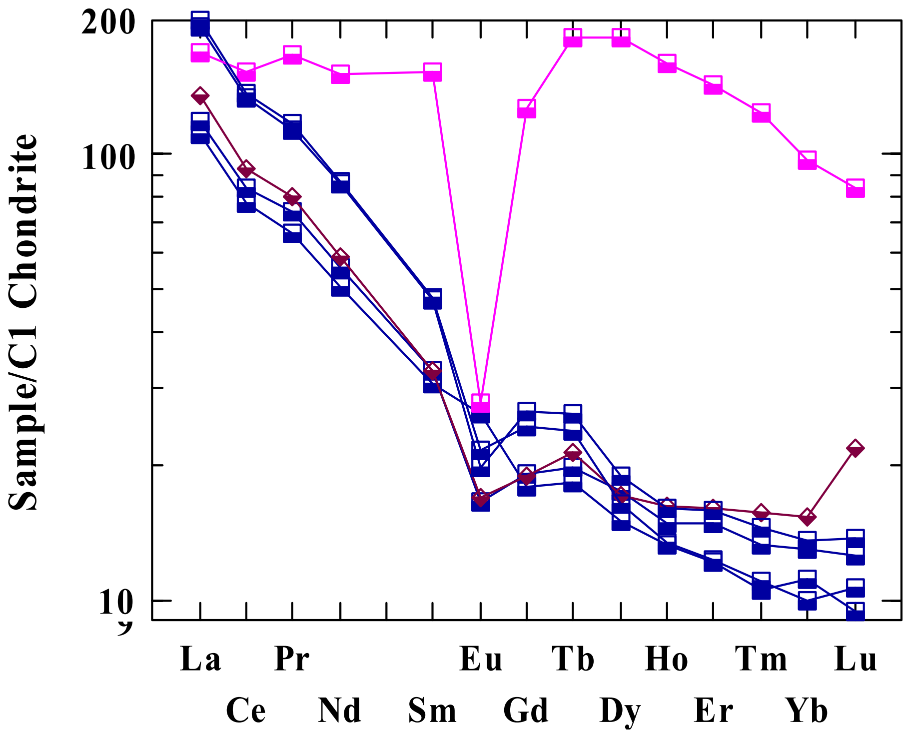


Symbols: ▼ = mafic gneiss (S- or P-series), ⊖ = veined gneiss, ⬓ = diatexitic gneiss, ■ = mica gneiss, ◆ = quartz gneiss, □ = TGG gneiss, ▲ diabase, ▲ = mafic metavolcanic rock, ⬙ = feldspar porphyry, and ● = pegmatitic granite from the drill core OL-KR23. + = sample from some other drill core.
Explanation for the colours: blue = T-series, orange = S-series, violet = P-series, red = granite, green = mafic metavolcanic rock and black = diabase.

***Figure 2-2**. Chemical variation diagrams, Harker diagrams (weight percentage values) for the rocks of the drill core sample OL-KR23.*



A.



B.

Figure 2-3 A. *Multielement diagram and* ***B.*** *REE-diagram showing the enrichment factors for the samples from the drill core OL-KR23. Symbols as in the Fig. 2-2.*

2.3 Petrography

The drill hole OL-KR23 intersects diatexitic gneisses and four T-type gneiss samples and one P-type gneiss sample were selected for detailed analysis. In addition to those, one sample which is porphyritic in appearance is selected to detailed study. The mineral compositions are given in a numerical form in the Appendix 2.

T-series

The three **diatexitic gneiss samples** (247, 249 and 251) and one strongly brecciated and altered sample (246) of diatexitic origin have chemical characteristics typical for the T-type migmatites. Their mineral compositions are directly controlled by the chemical compositions. The quartz content increases from 26% to 37% following the increase in silicity. Similarly increase the content of plagioclase from 16% to 24% and K-feldspar from 2% to 20%. Biotite is the most important mafic mineral and primary concentration of it decreases from 36% to 7% while SiO_2 concentration increases from 60% close to 70%. The proportion of cordierite is highest in the less silicic sample and primary cordierite content has been ranged from 16% to 6%. Sillimanite is a typical accessory phase counting less than 2% in every of these samples. Opaque minerals are similar in every of these samples. Hematite with minor amount of pyrrhotite, pyrite and sometimes chalcopyrite are the most typical species.

Paleosome materials of the diatexitic gneisses show distinct metamorphic banding but the intensity of foliation is roughly controlled by the mineral composition and amount of mafic minerals. The darkest sample (249) contains 1 – 3 mm wide and almost pure biotite bands sandwiched between slightly wider quartz-feldspar bands. Felsic bands in the sample 251 are up to 5 mm wide while widths of dark bands are less than 1 mm. The lightest sample (247) includes only a few dark bands in the area of one thin section. Lengths of biotite scales vary between 1 and 2 mm and diameters of felsic grains are about the same size in the granoblastic mass of the felsic bands. Cordierite grains are roundish and concentrated with the fibrolithic sillimanite grains into the dark bands.

The **K-feldspar porphyry sample** (248) has close to identical mineral composition with the most silicic diatexite samples. It includes close to 20% K-feldspar and 32% plagioclase which are typical numbers for silicic and fresh diatexitic gneiss samples. The sample contains ca 10% mafic minerals, biotite and chlorite and some pinite thus resembling usual T-type gneisses. The K-feldspar porphyry is coarser-grained than the previous migmatites. Feldspars and quartz compose patches or more or less circular aggregates which have diameters ranging between 0.5 – 1 cm and are mantled by small, often 0.5 – 1 mm long biotite scales and felsic mineral grains. The texture might resemble porphyritic texture of certain plutonic rocks but the present mineral assemblage is evidently metamorphic.

The degree of secondary alteration varies markedly. The sample 249 is almost fresh and only cordierite grains are for a part pinitized. The degree of alteration of the samples 247 and 251 is moderate since cordierite is totally pinitized, a part of biotite is altered to chlorite and plagioclase is for a part pigmented by fine-grained saussurite. Similar alteration can be detected in the porphyry-like sample 248. The brecciated sample (246) is strongly altered as cordierite is totally pinitized, biotite is chloritized for two thirds and the same proportion of plagioclase is saussuritized.

P-series

The P series is represented by one **diatexitic gneiss** sample (250) which belongs to the moderate types on the basis of chemical composition. The sample contains 40% quartz, 35% plagioclase, 15% biotite and close to 1% apatite, which are very typical numbers in this sequence. Similarly, a small amount of sphene and total lack of K-feldspar are typical in this assemblage. Cordierite and pinite are not typical species for the P-type gneisses but in the migmatites those have been detected. Typical opaques are hematite, pyrrhotite and chalcopyrite.

Paleosome material of this migmatite shows a weak metamorphic banding due to small amount of biotite. Felsic bands are 1 - 5 mm wide while the widths of dark bands are 1 - 2 mm at most. Biotite does not compose totally continuous bands but individual scales may compose disjointed chains. Lengths of biotite scales vary between 1 and 2 mm and diameters of felsic grains are about the same size in the granoblastic, leucocratic “ground mass”. The sample is rather fresh and only cordierite is intensively altered to pinite while plagioclase is saussuritized for a small part.

3 PETROPHYSICS

For the petrophysical measurements, the samples were sawn flat, the length of the samples being typically 5 – 6 cm. The measurements were carried out in the Laboratory of Petrophysics at the Geological Survey of Finland. Prior to the measurements, the samples were kept in a bath for 2.5 days using ordinary tap water (resistivity 50 – 60 ohmm). The parameters measured were density, magnetic susceptibility, natural remanet magnetization and its orientation, electrical resistivity with three frequencies (0.1, 10 and 500 Hz), P-wave velocity and porosity.

Densities were determined by weighing the samples in air and water and by calculating the dry bulk density. The reading accuracy of the balance used is 0.01 g and the repeatability for average-size (200 cm^3) hand specimens is 2 kg/m^3.

Porosities were determined by the water saturation method: the water-saturated samples were weighed before and after drying in an oven (three days in 105 °C). The reading accuracy of the balance used for porosity measurements is 0.01 g. The effective porosity is calculated as follows:

$$P=100 \cdot (Mwa - Mda)/ (Mwa - Mww) \quad (1)$$

where Mda = weight of dry sample, weighing in air
Mwa = weight of water-saturated sample, weighing in air
Mww = weight of water-saturated sample, weighing in water
P = porosity.

The magnetic susceptibility was measured with low-frequency (1025 Hz) AC-bridges, which are composed of two coils and two resistors. Standard error of the mean for repeated measurements is c. $10 \cdot 10^{-6}$ SI.

The remanent magnetization was measured with fluxgate magnetometers inside magnetic shielding. For repeated measurements, the standard error of the mean is c. $10 \cdot 10^{-3}$ A/m.

The specific resistivity was determined by a galvanic method using the MAFRIP equipment, constructed at the Geological Survey of Finland. Used frequencies were 0.1, 10 and 500 Hz, allowing also the determination of induced polarization (IP). The measuring error is less than 2 % within the resistivity range of 0.1 – 100000 ohmm.

To determine the P-wave velocity, the length of the sample and the propagation time through the sample must be known. An electronic pulse was produced by a pulse-generator, and the propagation time was measured using echo-sounding elements and an oscilloscope.

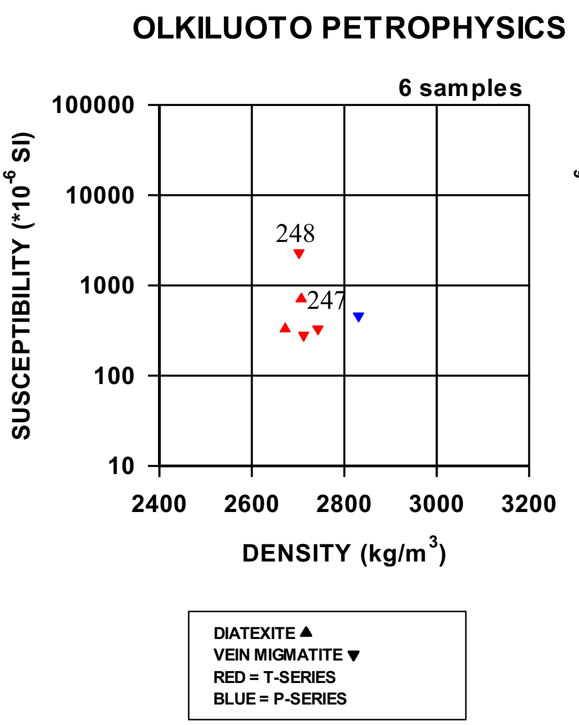
The petrophysical parameters measured are presented in a table in the Appendix 3.

3.1 Density and magnetic properties

Variation in density and magnetic properties in crystalline rocks are dominated mainly by their mineralogical composition, however porosity may have a slight effect in density. The measured density values for these 6 samples range between 2672 and 2831 kg/m^3. The highest value is measured from sample 250, which is a P series veined gneiss.

Most of the samples are paramagnetic or weakly ferrimagnetic with susceptibility values ranging from $330 \cdot 10^{-6}$ SI to $2290 \cdot 10^{-6}$ SI. In Fig. 3-1a, susceptibility vs. density of the measured samples is shown. For comparison, the data previously measured from deep boreholes OL-KR1 – OL-KR6, minidrill holes and shallow boreholes are shown in Fig. 3-1b. Most of the samples measured correspond rather well with the paramagnetic mica gneiss population of the older data. There is one slightly ferrimagnetic sample, number 248 (T type veined gneiss), indicating small amounts of ferrimagnetic minerals. Furthermore, susceptibility-density ratio of sample 247 (T type diatexitic gneiss) shows that it is slightly ferrimagnetic.

a)
Data: Boreholes KR23, KR23B



b)
Data: Boreholes KR1 - KR6
Minidrill samples from outcrops and investigation trenches
Shallow boreholes (POKA)

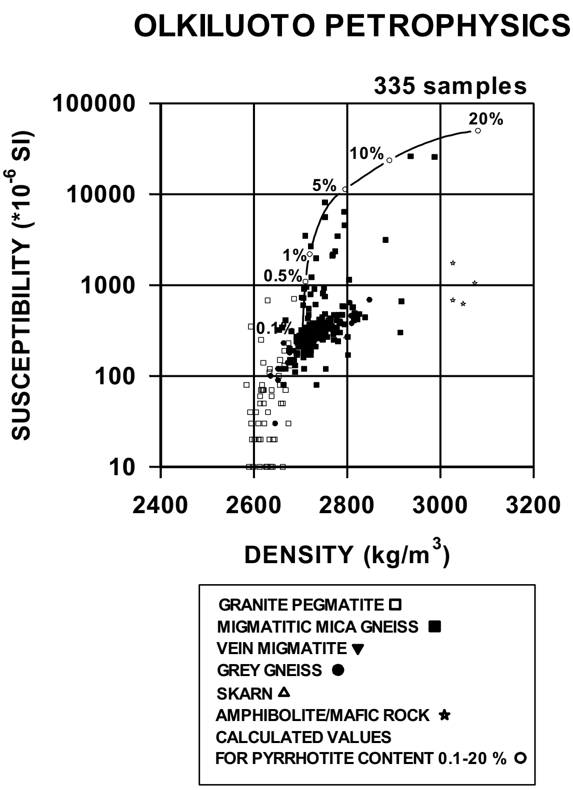


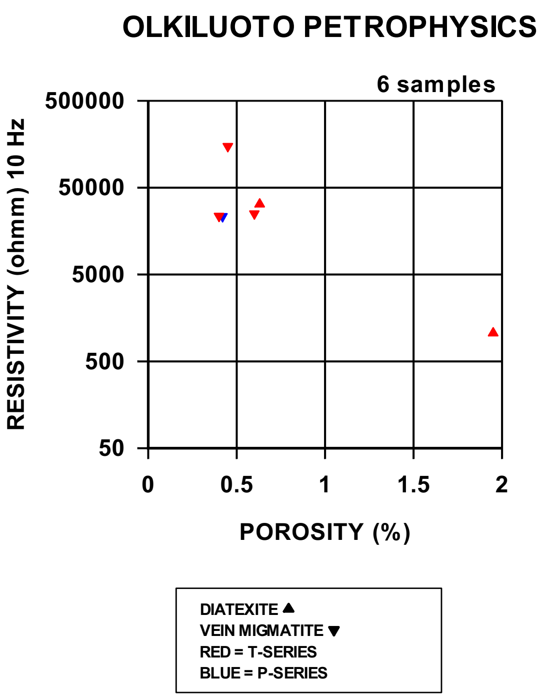
Figure 3-1. *Susceptibility vs. density, a) samples 246 – 251, boreholes OL-KR23 and OL-KR23B, b) data from previously examined deep boreholes OL-KR1 – OL-KR6, minidrill samples and shallow boreholes.*

Most of the samples are mainly paramagnetic (susceptibility < $1000 \cdot 10^{-6}$ SI), and they do not carry significant remanent magnetization. The measured remanence values for four samples are 10 – 30 mA/m, being below the practical detection limit of the measuring device. However, there are two clearly higher remanence values, 280 and 850 mA/m, related to previously described slightly ferrimagnetic samples 247 and 248. The determined orientation of the remanent magnetization for the most strongly magnetized sample 247 is 86.6°/58.2° (declination/inclination).

3.2 Electrical properties and porosity

The samples are poor electric conductors with resistivity values ranging from c. 1000 ohmm to at least 150 000 ohmm, depending on the used frequency. There appears to be a reverse correlation between porosity and resistivity as indicated in Fig. 3-2a. Usually the porosities are 0.4 – 0.6 % with resistivity values of 20 000 – 35 000 ohmm. There is one clearly anomalous sample (number 246, diatexitic gneiss of the T series) with porosity of c. 2 % and resistivity of c. 1000 ohmm. Opaque minerals have only an insignificant effect on resistivity, as indicated in Fig. 3-2b.

a)



b)

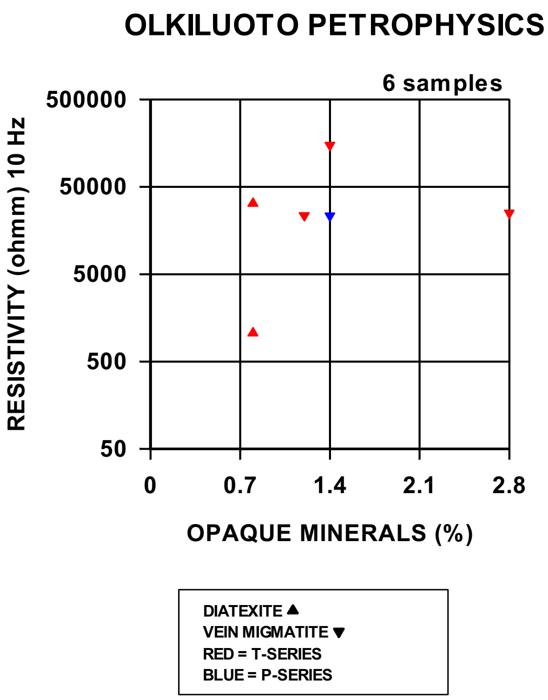


Figure 3-2. *Effect of porosity and content of opaque minerals in electric resistivity, a) porosity vs. resistivity, b) opaque minerals vs. resistivity, OL- KR23 and OL-KR23B.*

3.3 P-wave velocity

P-wave velocity of rocks depends on their porosity and mineral composition. Furthermore, the rocks in Olkiluoto, especially mica gneisses, veined gneisses and diatexitic gneisses are often anisotropic, resulting anisotropy also in P-wave velocity. Typically the highest values are measured along the foliation and the lowest ones perpendicular to it. Measured P-wave velocities are 4950 – 5860 m/s, indicating typically rather unfractured and unaltered crystalline rocks. The porosity vs. P-wave velocity diagram (Fig. 3-3) indicates that velocity is affected by porosity.

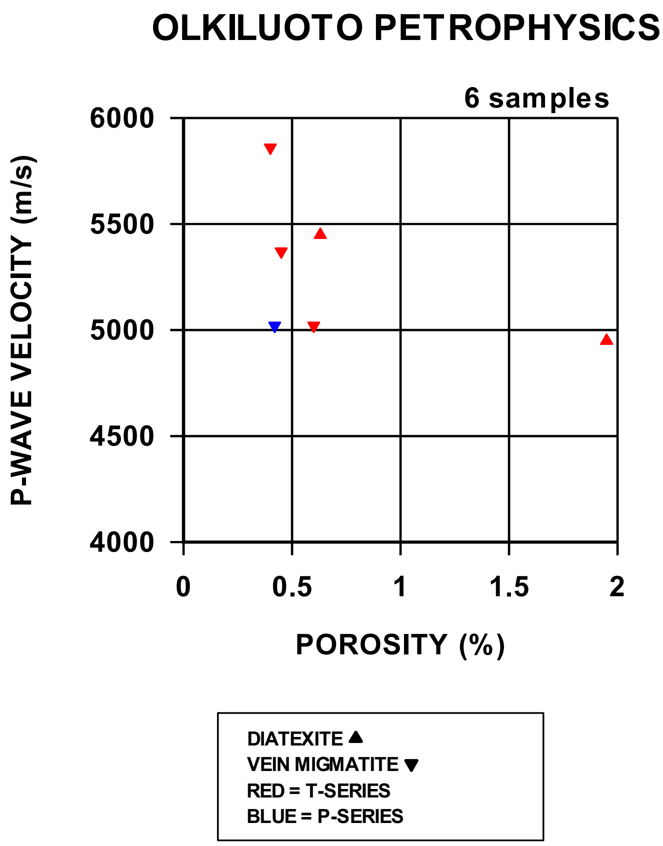


Figure 3-3. *Porosity vs. P-wave velocity, OL-KR23 and OL-KR23B.*

4 FRACTURE MINERALOGY

The account on fracture mineralogy of drill core OL-KR23 aims to following targets:

1. Determinate the position and character of all the open fractures in drill core sample
2. Produce geological classification of the fracture types
3. Make macroscopic identification of fracture filling phases
4. Visually estimate of filling thicknesses of the open fractures
5. Approximation the percentage that the fracture mineral phase coats of the fracture plain area.
6. Characterize the occurrence of cohesive/semi cohesive fracture mineral phases on the fracture plains (cf. chlorite, sericite, graphite, quartz) and the corroded surfaces
7. Make observations of obvious water flow on the fracture plain

Figure 4-1 summarizes the information of the fracture mineralogy, filling characteristics and observations of lithology (logged by A. Kärki), hydrothermal alteration (K. Front and M. Paananen, 2006), zone descriptions (S. Paulamäki et al, 2006) and water conductivity measurements (Pöllänen et al, 2005).

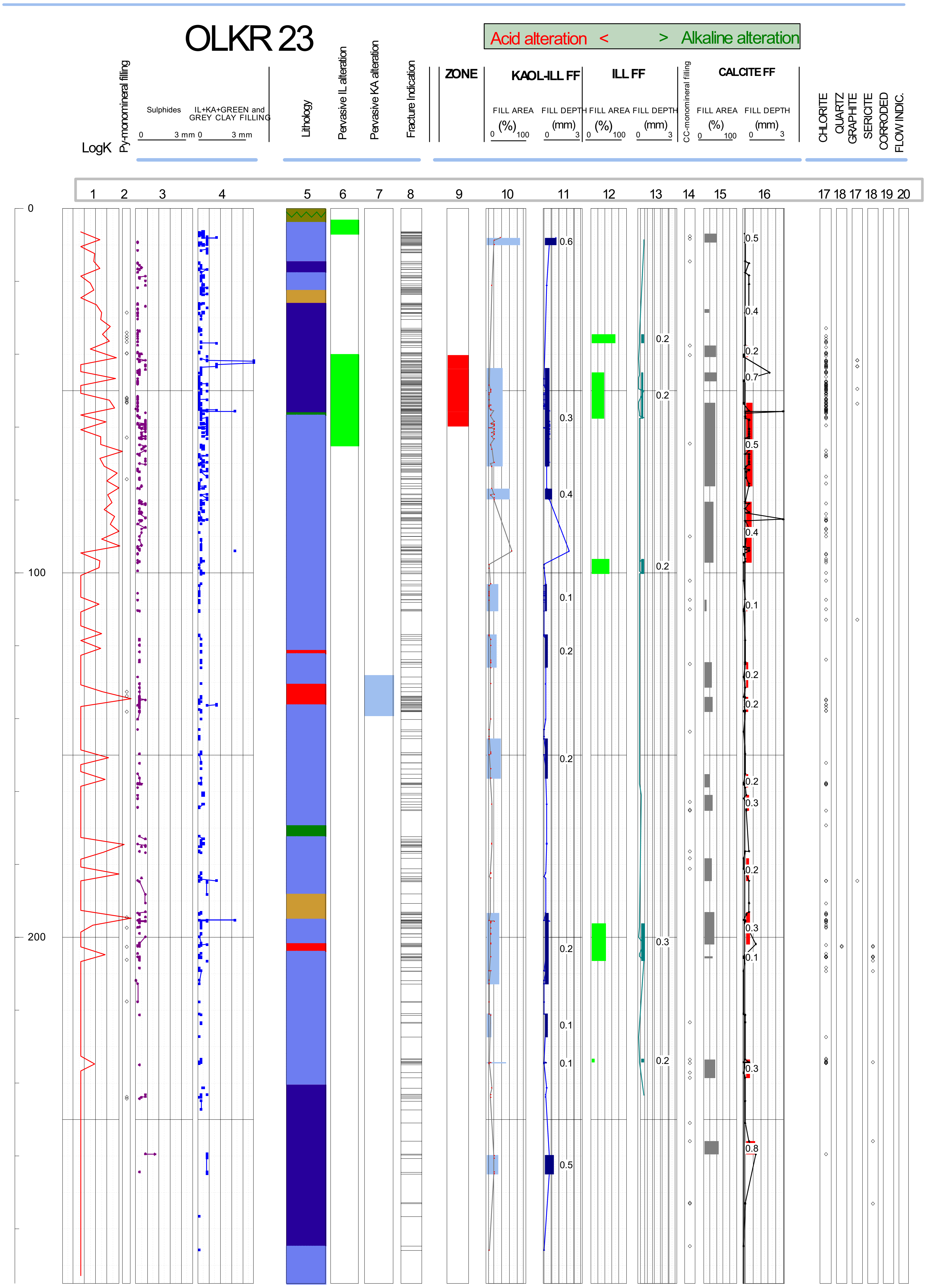
The borehole OL-KR23 contains 740 fractures in total, which indicates a moderate fracture density; 2.5 fractures/metre. The chief fracture minerals include illite, kaolinite, unspecified clay phases (mainly illite, chlorite, and smectite-group), iron sulphides (mainly pyrite, minor pyrrhotite) and calcite. The occurrence of main fracture fillings are given in the Figure 4-1.

In addition to the above mentioned phases, graphite is relatively abundant in few sequences, especially at the core length 20 -50 m. Similarly idiomorphic quartz crystallites, sericite, iron-oxides and oxy/hydro-oxides are present in a number of fractures. The fracture plains are occasionally covered by cohesive chlorite, which typically forms the underside for the above-mentioned phases (Fig. 4-1).

A zone intersection is reported at the core length 40.3 – 55.5 m (Fig. 4-1, column 10). This core length is marked by pervasive illite alteration and by fracture related hydrothermal kaolinite-calcite-fracture sequences.

4.1 Fracture fillings at the major pervasive alteration zones

Pervasive illitic alteration form three two zones (see Table 4-2), which range from 4 to 16 m in core length. The single pervasive kaolinite zone occurs at the core length 128 - 139 m which overlies the water conductivity peak at core length 137 m. It overlies also a pegmatite granite dyke that locates at 130 – 136 m core length. The core length of the pervasively altered rock in bore hole OL-KR 23 is only 29 m in total. That makes just 9.8 % of it’s the total core length.



OLKR 23
Acid alteration < > Alkaline alteration
LogK
Py-monomineral filling
Sulphides
IL+KA+GREEN and GREY CLAY FILLING
Lithology
Pervasive IL alteration
Pervasive KA alteration
Fracture Indication
ZONE
KAOL-ILL FF
ILL FF
CC-monomineral filling
CALCITE FF
FILL AREA (%)
FILL DEPTH (mm)
CHLORITE
QUARTZ
GRAPHITE
SERICITE
CORRODED
FLOW INDIC.

Figure 4-1.

Table 4-1. *Explanations of the columns in Fig. 4-1.*

Column No.	Explanation
1	Water conductivity measurement with 2 m packer interval. data from Pöllänen, Pekkanen, Rouhiainen 2005
2	Sulphide as monomineralic fracture filling
3	Sulphide fracture filling (thickness of filling on scale 0 - 3 mm)
4	All clay phases in fracture including hydrothermal and secondary phases (thickness scale 0 - 3 mm)
5	Lithology of drill core, see legend for the lithology on the right. Data logged by A. Kärki.
6	Pervasive illitic alteration of the rock Data from K. Front & M. Paananen 2006.
7	Pervasive kaolinite alteration of rock . Data from K. Front & M. Paananen 2006.
8	Fracture density
9	Deformation zone intersection. Brittle fault zone intersection, brittle joint cluster intersection, semi-brittle fault intersection Data from Paulamäki et al 2006.
10	Percentage[1] of kaolinite illite of the fracture plain area in drill core section (scale: 0 -100 %)
11	Thickness[2] of kaolinite-illite filling in fracture plain area (scale: 0 -3 mm).
12	Percentage[1] of illite of fracture plain in drill core section area (scale: 0 -100 %).
13	Thickness[2] of illite filling on fracture plain area (scale: 0 -3 mm).
14	Occurrence of calcite as monomineralic fracture filling
15	Percentage[1] of calcite of the fracture plain in drill core section area (scale: 0 -100 %).
16	Thickness[2] of calcite on fracture plain in drill core section (scale: 0 -3 mm)
17	occurrence of chlorite in fracture plain
18	occurrence of quartz in fracture plain
21	occurrence of graphite in fracture plain
22	occurrence of sericite in fracture plain
23	occurrence of corrosion on fracture plain
24	Indication of flow marks on fracture plain

The zones are defined by somewhat denser fracturing than the rock outside the zones and for the most part the fractures are chloritic. All these zones contain other types of filling phases, mainly sulphides, clay minerals, calcite.

4.2 Fracture fillings outside the pervasively altered zones

At the zones where bore hole cross cuts fracture zones of second-rate hydrothermal activity, the hydrothermal overprint on lithology is typically meagre; only the fractures

Table 4-2. *Pervasive illite and kaolinite alteration zones in bore hole OL-KR23.*

Start (m)	End (m)	Core length (m)
Illite alteration		
3.0	7.0	4.0
40.0	56.0	16.0
56.0	65.0	9.0
Kaolinite alteration		
128.0	139.0	11.0

contain the alteration derivatives. These types of fracture zones are described next within three categories 1) kaolinite-illite fractures 2) illite fractures and 3) calcite fractures.

1. Kaolinite-illitic fracture filling sequencess

Fracture sequences in which kaolinite ± illite is present as major filling phase. Typically these fractures contain other clay phases, calcite and sulphides in the same assemblages. The kaolinite-illite fracture fillings at core lengths 8 – 9 m, 44 – 71 m and 77 – 80 m (highlighted in grey in the Table 4-3) situate inside or in immediate surrounding rock volume of pervasive illitization zones. The second one of those core lengths contains thick clay (core lengths 42 and 56 m) and calcite fillings and abundant chlorite on the fracture walls. Likewise the core length 193 – 213 m, which overlays a tiny pegmatite granite, is connected with a water conductivity peak. It is accompanied by thick clay fillings, sulphides, calcite and chlorite.

Table 4-3. *Kaolinite- illite fracture filling zones. Highlighted in grey are the core lengths which have elevated water conductivity.*

Kaolinite- iillite fractures Start (m)	End (m)	Average filling thickness (mm)	Core length (m) of the fracture filling zones
8	9.1	0.6	1.9
43.9	70.8	0.3	26.9
76.9	79.8	0.4	3.0
103.0	110.5	0.1	7.5
117.0	126.1	0.2	9.1
145.5	156.3	0.2	10.8
193.3	212.8	0.2	19.4
221.1	227.3	0.2	6.2
234.4	234.6	0.1	0.3
259.9	264.9	0.5	5.0

2. Illitic fracture filling sets

The zones in which illite is the predominating fracture related filling phase (Table 4-4) are relatively tiny. A special attention is to be focused into the illitic cross sections; 34 – 37 m, 45 -58 m and 196 – 206 m, that partially cover the above described kaolinite-dominating zones.

Table 4-4. *Illite fracture filling zone. Highlighted in grey is the zone in which the water conductivity value is raised.*

Iillite fractures Start (m)	End (m)	Average filling thickness (mm)	Core length (m)
34.6	36.82	0.2	2.2
44.9	57.6	0.2	12.7
96.1	100.2	0.2	4.1
196.1	206.5	0.3	10.4
233.4	234.2	0.2	0.8

2. Calcitic fracture filling sequences

The calcitic fracture filling sequences are composed of hair dykes or stock works in which the amount of calcite can reach tens of percents of the rock volume. Typically those fracture zones, which have calcite as major phase, are characterized by higher fracture density than in the zones in which the influence of hydrothermal activity is insignificant.

Main zones of carbonatization generally overlie the illite and kaolinite alteration zones and only in few cases the calcite zones are outside those zones.

The total core length of the calcite fracture sequences is 94 metres (= 32 % of whole core length). Particular attention is subjected at the zones 37 – 97 m 177 -184 m, 192 - 202 m and 233 – 238 m, that associate with water conductivity peaks. Fractures at 256 – 259 m core length contain few fractures with coarse calcite and euhedral pyrite as filling major filling phases.

Table 4-5. *Calcite fracture filling zones. Highlighted in grey are the zones which represent advanced carbonatization.*

Kaolinite-illite fractures Start (m)	End (m)	Average filling thickness (mm)	Core length (m)
6.9	9.3	0.5	2.5
27.7	28.6	0.4	1.0
37.5	40.7	0.2	3.2
45.1	47.4	0.7	2.3
53.4	76.3	0.5	22.8
80.5	97.2	0.4	16.7
107.3	110.5	0.1	3.2
124.5	131.5	0.2	7.0
134.1	138.0	0.2	3.9
155.2	158.9	0.2	3.8
161.0	165.2	0.3	4.2
178.4	184.5	0.2	6.1
193.1	201.8	0.3	8.8
205.4	205.7	0.2	0.3
233.6	238.5	0.3	4.9
256.1	259.6	0.8	3.5

4.3 Iron-oxides and oxy-hydroxides in fracture assemblages

Iron oxides and oxy-hydroxides occur in 28 fractures as red-brown coloured fillings at surficial zone at core length 6.35 – 47.72 m. (Table 4-6). Texturally iron-oxide/hydroxide phases are identified as Fe-hydroxides (goethite, limonite).

__Table 4-6.__ List of iron oxide and oxy-hydroxide bearing fractures and their hosting lithology in bore hole OLKR23.

VGN	6.35		TGG	22.43
VGN	6.4		TGG	22.81
VGN	6.44		TGG	22.88
VGN	10.03		TGG	22.97
VGN	10.06		TGG	23.15
VGN	10.07		TGG	23.74
VGN	10.09		DGN	46.38
VGN	10.1		DGN	46.69
VGN	10.14		DGN	47.25
VGN	12.17		DGN	47.43
VGN	21.72		DGN	47.58
VGN	22.01		DGN	47.62
VGN	22.23		DGN	47.66
VGN	22.26		DGN	47.72

4.4 Relationship between fracture filling data and calvanic connection measurements

Electrical measurement data (Lehtonen 2006) on the galvanic connections concerns the drill holes mentioned in the Table 4-7. All the groundings from OL-KR23 represent strong (green in the Table 4-8) and weak (yellow) galvanic connections. The relationship of fracture fillings/alteration data and the findings of electric measurements are brought together in the Table 4-8.

__Table 4-7.__ List of the bore holes in which the data of galvanic connections is available.

OL-KR1
OL-KR2
OL-KR4
OL-KR6 - 8
OL-KR10
OL-KR13 - OL-KR14
OL-KR19
OL-KR22 -25
OL-KR27 – 32

Table 4-8. *Galvanic connections, grounded from OL-K23 (connecting grounding lengths are given in rows) to the bore holes OL-KR25, KR28 and KR29. Detected charge potentials, reported in Lehtonen 2006 fall either in category "strong" (highlighted in green or "weak" (highlighted in yellow).*

KR23	KR25	KR28	KR29	Fracture fillings in KR23
220	122			Scanty fracture kaolinisation
225		179		As above
255-300		245		Bulky calcite, euhedral pyrite
285-350		368		-
260/300			130	Fracture kaolinite, sulphides
300			213	-

5 SUMMARY

The boreholes OL-KR23 and OL-KR23 start in the south eastern part of the Olkiluoto study area and intersect a diatexitic gneiss unit in which the migmatites are rather coarse-grained and rich in granitoid materials, leucosomes and intruding pegmatitic dykes. In addition, several homogeneous, weakly migmatized gneiss intersections and narrow intersection of various granitoid rocks have been met in the drill core

Whole rock chemical composition has been analysed from six samples of which four belong to the T series, one to the P series and one is a granitic rock which contains roundish feldspar grains and is called K-feldspar porphyry. The T series is represented by four diatexitic samples of which one is strongly brecciated. The samples represent moderate types among this assemblage by having 60 – 70% SiO_2. The other major element concentrations are directly controlled by the silicity and the numbers will settle just at the anticipated values. The brecciated and pervasively altered diatexitic gneiss is chemically close to identical with one unaltered diatexitic gneiss. Equally, the porphyry-like rock is identical with the corresponding T-type migmatites. The P series is represented by one single migmatite sample which is classified as diatexitic gneiss. The chemical composition of it is not quite typical as the contents of aluminium, titanium, iron, magnesium and calcium are a little lower, the content of potassium is higher and the content phosphorus evidently higher than in typical gneisses of the P series.

The T-type migmatites and the strongly brecciated and altered rock have similar chemical characteristics which is typical for the T series. Mineral composition is directly controlled by the chemical composition. The quartz content increases from 26% to 37% following the increase in silicity. Similarly increase the content of plagioclase from 16% to 24% and K-feldspar from 2% to 20%. Biotite content decreases from 36% to 7% while SiO_2 concentration increases from 60% close to 70%. The proportion of cordierite is highest in the less silicic sample and primary cordierite concentration has been varied between 16% and 6%. Sillimanite is a typical accessory phase counting less than 2% in every of these samples. The K-feldspar porphyry sample has close to identical mineral composition with the most silicic diatexite samples. It contains close to 20% K-feldspar and 32% plagioclase which are typical numbers for silicic and unaltered diatexitic gneisses. The sample contains ca 10% mafic minerals, biotite and chlorite and some pinite thus resembling usual T-type rocks.

Paleosome materials of the diatexitic gneisses show a distinct metamorphic banding but the intensity of foliation is roughly controlled by the mineral compositions. The darkest sample includes wide and almost pure biotite bands between wider quartz-feldspar bands. Felsic bands in the moderate sample are up to 5 mm wide while the dark bands are less than 1 mm wide, and the lightest sample includes only a few, narrow dark bands. The porphyry-like rock is coarser-grained. Feldspars and quartz compose wide, more or less circular aggregates which are mantled by fine-grained biotite bearing matrix. The texture might resemble porphyritic texture of certain plutonic rocks but the mineral assemblage is evidently metamorphic.

The P-type diatexitic gneiss contains 40% quartz, 35% plagioclase, 15% biotite and close to 1% apatite, which are very typical numbers in this sequence. Similarly, a small amount of sphene and total lack of K-feldspar are typical in this assemblage. Paleosome material of this migmatite shows a weak metamorphic banding and felsic 1 - 5 mm wide bands are interfingered with 1 - 2 mm wide dark bands or biotite chains.

Petrophysical properties were measured from 6 samples. Their measured density values range between 2672 and 2831 kg/m^3. The highest value is measured from P-type veined gneiss. Most of the samples are paramagnetic or weakly ferrimagnetic with susceptibility values ranging from $330 \cdot 10^{-6}$ SI to $2290 \cdot 10^{-6}$ SI. Most of the samples measured correspond rather well with the paramagnetic mica gneiss population of the older data. There is one slightly ferrimagnetic sample (T-type veined gneiss) indicating small amounts of ferrimagnetic minerals. Furthermore, susceptibility-density ratio of one T-type diatexitic gneiss shows that it is slightly ferrimagnetic. The measured remanence values for four samples are 10 – 30 mA/m, being below the practical detection limit of the measuring device. However, there are two clearly higher remanence values, 280 and 850 mA/m, related to previously described slightly ferrimagnetic samples.

The samples are poor electric conductors with resistivity values ranging from c. 1000 ohmm to at least 150 000 ohmm, depending on the used frequency. There appears to be a reverse correlation between porosity and resistivity. Usually the porosities are 0.4 – 0.6 % with resistivity values of 20 000 – 35 000 ohmm. There is one clearly anomalous sample (T-type diatexitic gneiss) with porosity of c. 2 % and resistivity of c. 1000 ohmm. Opaque minerals have only an insignificant effect on resistivity in these samples. Measured P-wave velocities are 4950 – 5860 m/s, indicating typically rather unfractured and unaltered crystalline rocks. The porosity vs. P-wave velocity diagram indicates that velocity is affected by porosity.

Borehole OL-KR23 has 2.5 fractures/metre, which indicates moderate fracture density. Pervasive illitization concerns 9.8 % of the total core length and 32 % of the bore hole length has calcite as major constituent in fracture fillings. The fracture fillings are composed mainly of hydrothermally derived or secondary clay phases; illite, kaolinite, smectite group phases, calcite and iron sulphides. Fracture fillings contain also cohesive chlorite on the fracture walls, quartz and graphite. Graphite, although it is distributed all along the drill core length, forms a distinguished sequence at the core length 41 – 53 m.

The frequency of fracturing is higher at pervasive illite and kaolinite alteration zones at core lengths 3 -7 m, 40 – 56 m and 56 – 65 m as well as pervasive kaolinite alteration zone at the core length 128 – 139 m. Iron oxides and oxy-hydroxides occur in a number of fractures fillings at surficial zone at the core length 6.35 – 47.72 m.

The water conductivity peaks generally combine with the hydrothermal zones and as a rule the occurrence of calcitic fracture filling sequences seems to indicate the increased water conductivity.

REFERENCES

Front, K. & Paananen, M. 2006. Hydrothermal alteration at Olkiluoto: mapping of drill core samples. Working Report 2006-59. Posiva Oy, Olkiluoto.

Gehör, S., Kärki, A., Määttä, T., Suoperä, S. & Taikina-aho, O., 1996. Eurajoen Olkiluodon kairausnäytteiden petrologia ja matalan lämpötilan rakomineraalit. Työraportti PATU-96-42. Posiva Oy, Helsinki.

Korsman, K., Koistinen, T., Kohonen, J., Wennerström, M, Ekdahl, E., Honkamo, M, Idman H. & Pekkala, Y. (editors) 1997. Suomen kallioperäkartta -Berggrundskarta över Finland -Bedrock map of Finland 1: 1 000 000. Geologian tutkimuskeskus, Espoo, Finland.

Kärki, A. & Paulamäki, S. 2006. Petrology of Olkiluoto. Posiva 2006-2. Posiva Oy, Olkiluoto, 77 p.

Mattila, J. 2006. A System of Nomenclature for Rocks in Olkiluoto. Working report 2006-32. Posiva Oy, Olkiluoto. 16 p.

Lehtonen, T. 2006. Visualization and Interpretation of the Year 2004 Mise-a-la-Masse Survey Data at Olkiluoto Site. Working Report 2006-08. Posiva Oy, Olkiluoto.

Niinimäki, R. 2002. Core drilling of deep borehole OL-KR23 at Olkiluoto in Eurajoki 2002. Working Report 2002-60. Posiva Oy, Olkiluoto. 108 p.

Paulamäki, S., Paananen, M., Gehör, S., Kärki, A., Front, K., Aaltonen, I., Ahokas, T., Kemppainen, K., Mattila, J. & Wikström, L. 2006. Geological model of the Olkiluoto site, version 0. Working Report 2006-37. Posiva Oy, Olkiluoto.

Pöllänen, J., Pekkanen, J., Rouhiainen, P. 2005. Difference flow and electric conductivity measurements at the Olkiluoto site in Eurajoki, boreholes KR19 – KR28, KR19B, KR20B, KR22B, KR23B, KR27B and KR28B. Working report 2005-52. Posiva Oy, Olkiluoto.

Suominen, V. 1991. The chronostratigraphy of southwestern Finland with special reference to Postjotnian and Subjotnian diabases. Geological Survey of Finland Bulletin 356, 100 p.

Suominen, V., Fagerström, P. & Torssonen, M. 1997. Pre-Quaternary rocks of the Rauma map-sheet area (in Finnish with an English summary). Geological Survey of Finland, Geological Map of Finland 1:100 000, Explanation to the maps of Pre-Quaternary rocks, Sheet 1132, 54 p.

Veräjämäki, A. 1998. Pre-Quaternary rocks of the Kokemäki map-sheet area (in Finnish with an English summary). Geological Survey of Finland, Geological Map of Finland 1:100 000, Explanation to the maps of Pre-Quaternary rocks, Sheet 1134, 51 p.

APPENDICES

Appendix 1.

File KR23_APP1 in the disk enclosed. The Appendix contains the results of whole rock chemical analyses.

Appendix 2.

File KR23_APP2 in the disk enclosed. The Appendix contains the results of modal mineral composition analyses.

Appendix 3. Petrophysical parameters, drill core OL-KR23.

								RESISTIVITY VALUES (Ωm)			IP-ESTIMATES		
HOLE	**SAMPLE**	**FROM**	**TO**	**D(kg/m³)**	**K(μSI)**	**J(mA/m)**	**P-wave (m/s)**	**R0.1[Ωm]**	**R10 [Ωm]**	**R500[Ωm]**	**PL (%)**	**PT (%)**	**Pe(%)**
KR23	OL.246	43.96	44.10	2672	330	20	4950	1090	1060	973	3	11	1.95
KR23	OL.247	77.82	77.91	2707	710	280	5450	36600	32300	26400	12	28	0.63
KR23	OL.248	135.57	*	2702	2290	850	5860	27700	23600	18400	15	34	0.4
KR23	OL.249	167.14	167.23	2743	330	10	5370	resistivities > 149240					0.45
KR23	OL.250	293.61	293.71	2831	460	30	5020	27900	23400	18500	16	34	0.42
KR23B	OL.251	18.61	18.65	2712	280	30	5020	34000	25200	18200	26	46	0.6

D = density
K = magnetic susceptibility
J = remanent magnetization
P-wave = velocity of seismic P-wave
R0.1 = electric resistivity, 0.1 Hz frequency
R10 = electric resistivity, 10 Hz frequency
R500 = electric resistivity, 500 Hz frequency
PL = IP effect = 100*(R0.1-R10)/R0.1
PT = IP effect = 100*(R0.1-R500)/R0.1
Pe = effective porosity

* The depth value was not readable from the sample