Working Report 2007-42

Petrology, Petrophysics and Fracture Mineralogy of the Drill Core Sample OL-KR8

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ABSTRACT

This report represents the results of studies dealing with the drill core sample OL-KR8, 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 borehole intersects down to the drilling length of 120 m diatexitic gneisses and narrow sections of veined gneisses and more homogeneous mica gneisses. Pegmatitic granitoids with narrow diatexitic gneiss and veined gneiss subsections dominate the bedrock below diatexitic unit. In the section from drilling length of 210 m to 265 m TGG gneisses compose the dominating component and, beneath to that, a diatexitic gneiss unit, which contains a lot of leucosome but no broad pegmatites, extends to the drilling length of ca. 520 m. A fluctuating section of migmatites, homogeneous gneisses and narrow pegmatite dykes continues to the drilling length of 565 m and the lowermost part of the core is composed of rather pure pegmatites.

Detailed Petrological properties have been analysed from ten samples. Apatite rich rocks of the P series are represented by two TGG gneiss samples which are chemically typical, phosphorus rich members of their assemblage. The S series is represented by one quartz gneiss sample, which differs chemically from the other gneiss variants due to high, 8% concentration of CaO. Samples from four diatexitic gneiss, one TGG gneiss and one quartz gneiss variant were chosen to represent the T series.

Petrophysical properties were studied from four samples. The parameters measured were density, magnetic susceptibility, natural remanet magnetization, electrical resistivity, P-wave velocity and porosity. The samples consist of two diatexitic gneisses, one T-series TGG gneiss and one S- series quartz gneiss.

The drill hole OL-KR8 has moderate density of fracturing; 2.1 fractures/metre. The clayey infilling sequences are typically less than 10 metres in core length.
The chief fracture minerals include illite, kaolinite, unspecified mixed clay phases, iron sulphides and calcite. The fracture plains are occasionally covered by cohesive chlorite, which typically forms the underside for the other filling phases. Pervasive illitization concerns 19.5 % of the total OLKR 8 core length and even 38.5 % of the bore hole length has calcite as major constituent in fracture fillings. The degree of fracture related sulphidization follows the strength of illitization and kaolinisation at the alteration zones.

The frequency of fracturing shows a relationship with the weight of hydrothermal activity. A number of fractures at core length intervals 332 – 338 m, 549 – 550 m and 552 – 553 m have incohesive clay material that hold textures, which could refer to water flow.

Kairanäytteen OL-KR8 petrologia, petrofysiikka ja rakomineralogia

TIIVISTELMÄ

Tässä raportissa esitetään kairausnäytettä OL-KR8 koskevien tutkimusten tulokset. Kyseinen kairanreikä on tehty Olkiluodon tutkimusalueen eteläiseen osaan. Raportissa kuvataan kairausnäytteen litologiset ominaisuudet sekä valittujen näytteiden kokokiven kemialliset koostumukset, mineraalikoostumukset, tekstuurit ja petrofysikaaliset ominaisuudet. Samoin kuvataan matalan lämpötilan raontäytemineraalit.

Kairanreikä leikkaa 120 m:n kairauspituudelle saakka diateksiittista gneissiä, jossa on kapeita suonigneissi- ja kiillegneissivälikerroksia. Pegmatiittiset granitoidit ja niissä sulkeumina esiintyvät migmatiittikappaleet hallitsevat diateksiittisen yksikön alapuolelle sijoittuvaa kallioperää. TGG gneissit muodostavat valtaosan pituusvälin 210 – 265 m kairausnäytteestä ja sen alapuolella on jälleen hallitsevana diateksiittinen gneissiyksikkö, joka sisältää runsaasti leukosomia mutta ei juurikaan laajoja pegmatiittisia juonia ja joka jatkuu aina 520 m:n kairauspituudelle saakka. Näiden alapuolella, migmatiiteista, homogeenisista gneisseistä ja pegmatiitijuonista koostuva vaihteleva seuranto ulottuu 565 m:n kairauspituudelle ja verrattain puhtaat pegmatiitit ovat hallitsevia näytteen loppuosassa.

Yksityiskohtaiset petrologiset ominaisuudet on analysoitu 10 näytteestä. Kaksi TGG-gneissinäytettä edustaa P-sarjan apatiittirikkaita kivilajeja. Nämä sisältävät ryhmälleen tunnusomaiseen tapaan varsin runsaasti fosforia. Yksi kvartsigneissinäyte edustaa S-sarjaa ja se poikkeaa muista gneissityypeistä korkean, 8 %:n CaO-pitoisuutensa ansiosta. T-sarjaa edustamaan on valittu neljä diateksiittista gneissimuunnosta sekä yksi TGG-gneissi- ja yksi kvartsigneissinäyte.

Petrofysikaaliset ominaisuudet on määritetty neljästä näytteestä. Mitatut parametrit ovat tiheys, magneettinen suskebtibiliteetti, luonnollinen remanentti magnetoituma, sähkö-vastus, P-aallon nopeus ja huokoisuus. Ominaisuudet on määritetty kahdesta diateksiittisesta gneissi- ja yhdestä TGG-gneissinäytteestä, jotka edustavat T-sarjaa sekä yhdestä S-tyypin kvartsigneissinäytteestä

Kairausnäytteen OLKR 8 rakotiheys on keskimäärin 2,1 rakoa/metri. Rakojen täytteinä esiintyy illiittiä, kaoliniittia, erikseen määrittelemättömiä useamman savispesieksen muodostamia savisseostäytteitä (pääasiassa illiitti, kloriitti ja smektiitti-ryhmä), rautasulfideja ja kalsiittia. Kloriitti muodostaa tyypillisesti rakojen pinnoille kiinteän katteen, joka on usein alustana muille rakotäytteille. Kairauslävistyksestä on 19,5 % läpikotaisesti illiittiytynyttä. Kalsiittivaltaisia täyteseurantoja esiintyy 38,5 %:ssa kairausnäytteen koko pituudesta. Useat kairauspituusvälien 332 – 338 m, 549 – 550 m and 552 – 553 m raoista sisältävät irtonaista saviainesta, jossa on piirteitä mahdollisesta veden virtauksesta.

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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 core OL-KR8.

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 (Figure 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

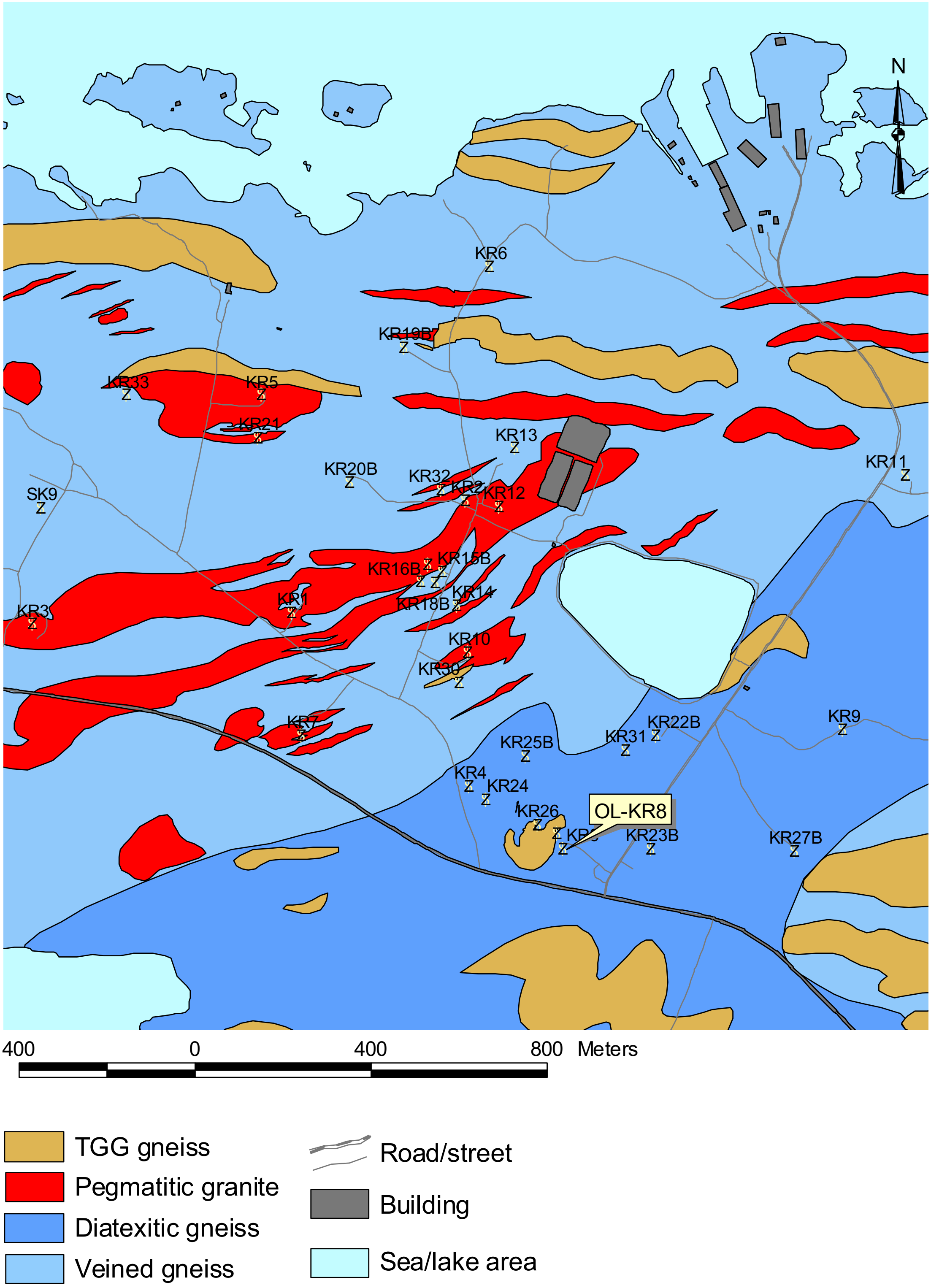


Figure 1-1. *General geology and location of bore hole starting points at Olkiluoto.*

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 linear 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-KR8

The starting point of the borehole OL-KR8 is situated in the central part of the Olkiluoto study site (Figure 1-1). The coordinates of the starting point are: X = 6791894.71, Y = 1526075.19 and Z = 12.24. Starting direction (azimuth angle) of the borehole is 154,6^o and its dip (inclination angle) is 64,4^o.

The borehole OL-KR8 drilled in 1996 is 315.85 m in length and the core sample received extends from drilling length of 2.05 m to 315.85 m thus being 313.80 m in length. Extension drilling has been carried out in 2002 and it yields core sample from drilling lengths between 315.94 m and 600.59 m thus being 284.65 m in total length.

Technical data dealing with these drillings is represented by Rautio (1995) and Niinimäki (2002).

1.3 The goal of this study and research methods

Hitherto, more than 40 deep boreholes have been drilled at the study site. The aim of this report is to represent the results of the latest studies and summarize the results of these and previous works (Gehör et al. 1996) dealing with the drill core sample OL-KR8. An updated description of lithological units and their properties is presented in this report. Petrological properties, 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. The chemical compositions of plagioclase, biotite and amphibole existing as major components in selected samples were determined by JEOL-733 superprobe at the Institute of Electron Optics, University of Oulu (Gehör et al. 1996).

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 stereomicroscopy 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 the first stage mapping of fracture infill minerals has been done by S. Gehör, PhD, A. Kärki, PhD and O. Taikina-aho, FM during a mapping campaign on 11. - 15. 3.1996 at the drill core archive of GSF (Gehör et al. 1996). At this stage, the drill core sample has been studied from the drilling length of 2.07 m to the length of 315.85 m. The logging of fracture infill minerals has been completed to cover description of all fractures during a mapping campaign on 10. – 14.11.2003 by K. Front, Phill. Lic., S. Gehör, K. Kemppainen, MSc and A. Kärki. The sample obtained by OL-KR8 extension drilling was studied by S. Gehör and A. Kärki during a mapping campaign on 28.7. – 1.8.2003. Merja Autiola, Hanna Gehör, Henri Kaikkonen, Sauli Kallio, Antti Kärki, Pekka Kärki, Heikki Pirinen, Sanna Riikonen, Hanna-Kaisa Saari and Antero Taikina-aho assist these works. Antti Kärki transcribed the collected data of the latest stages of studies and 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.

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

Materials for detailed further studies have been selected on the basis of their frequency in appearance. Thus, the most common and typical rock types are represented roughly in the same proportion which they build up in the core sample. Polished thin sections have been prepared from these samples at the thin section lab of the Department of Geosciences, University of Oulu for polarization microscope examinations and micro probe analyses. The total number of thin sections is 10. Six samples of these were studies during the first stage of study (Gehör et al. 1996). In the present stage, four additional samples were analysed and their textures were studied by polarization microscopy. 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 the petrography and handling the results of 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.

2 PETROLOGY

On the basis of the present practice for naming (Mattila 2006) and lithological classification (Kärki and Paulamäki 2006), the most part of the drill core sample is composed of diatexitic gneisses which are strongly migmatitized and contain typically more than a half of leucosome material with pegmatitic granite dykes. Often they are cordierite and sillimanite bearing rocks and, in the most cases, they will classify as T type supracrustal formations of Olkiluoto.

2.1 Lithology

Borehole OL-KR8 intersects to the drilling length of 120 m diatexitic gneisses which contain typically at least 50% leucosome and narrow sections of veined gneisses and more homogeneous mica gneisses. Below that section, down to the drilling length of 210 m, is located a unit in which pegmatitic material is dominating. Narrow diatexitic gneiss and veined gneiss subsections occur along with that. In the section between 210 m and 265 m TGG gneisses are the dominating component but also there narrow pegmatite dykes and homogeneous mica gneiss units have been met. The bedrock beneath to those is composed of diatexitic gneisses which contain typically close to. 50 % leucosome but wide, homogeneous pegmatite dykes are missing down to the drilling length of ca. 520 m. A fluctuating section of migmatites, homogeneous gneisses and narrow pegmatite dykes continues close to the drilling length of 565 m and the lowermost part of the core is composed of rather pure pegmatites continuing down to the end of the hole at the length of 600.59 m.

More detailed description of lithology is represented in the Table 2-1 and a simplified graphical presentation in the Figure 2-1.

Table 2-1. *Lithology of the drill core sample OL-KR8.*

Length (m)	Lithology
2.07 – 14.85	DIATEXITIC GNEISS – TGG GNEISS mixture in which the rocks are relatively coarse-grained and, for a part, banded but for a part rather isotropic, not strongly oriented granitoid rocks. Proportion of leucosome is ca. 50%.
14.85 – 15.45	MICA GNEISS which is fine-grained, homogeneous and contains less than 5% leucosome.
15.45 – 30.80	DIATEXITIC GNEISS – TGG GNEISS mixture in which the paleosome is not strongly oriented and leucosome may contain feldspar porphyroblasts with diameters up to 1 cm. For a part, the rocks show features typical for veined gneisses of porphyritic appearance. Proportion of leucosome is ca. 50%.
30.80 – 55.55	DIATEXITIC GNEISS the paleosome of which is rather coarse-grained and, for a part, resembles granitic TGG gneisses. In places it

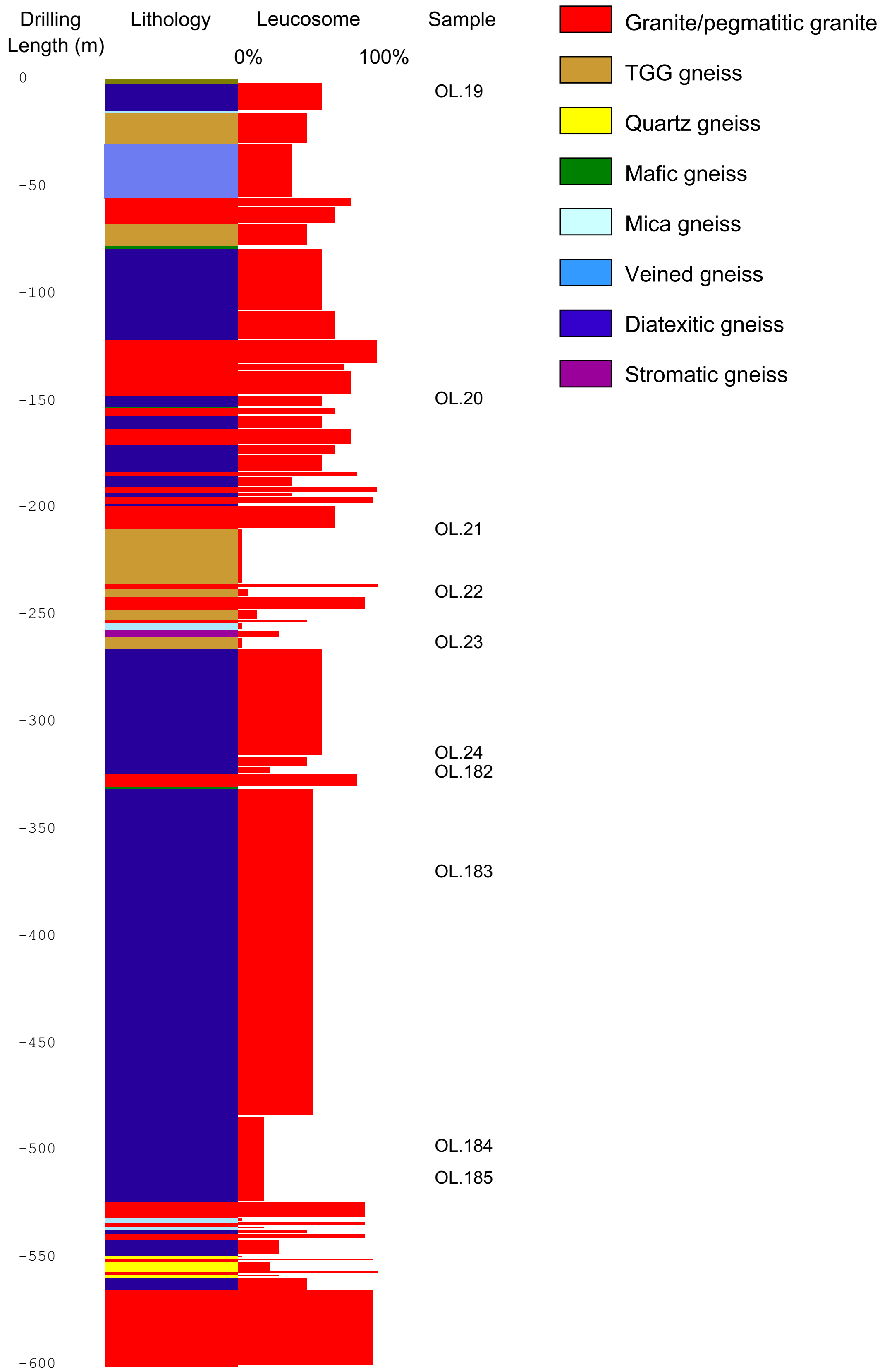


Figure 2-1. *Lithology, leucosome + pegmatite material percentage (= leucosome) and sample locations, drill core OL-KR8.*

	includes 1 - 2 cm wide veins and sometimes also narrow dykes thus resembling veined gneisses. Proportion of leucosome is ca. 40%.
55.55 – 59.60	PEGMATITIC GRANITE, which is leucocratic, medium- to coarse-grained and includes large, dappled feldspar crystals and mica gneiss inclusions ca. 10 – 40 cm in diameter. Proportion of leucosome is ca. 80%.
59.60 – 67.40	PEGMATITIC GRANITE - DIATEXITIC GNEISS mixture in which different components fluctuate randomly as 10 – 50 cm wide subsections. Proportion of leucosome is ca.70%.
67.40 – 77.95	DIATEXITIC GNEISS - VEINED GNEISS mixture, which is strongly sheared and, for a part, the rocks will classify as blastomylonitic TGG gneisses. Leucosome composes ca. 50 % of the rock volume and exists as narrow veins typically less than 1 cm in width.
77.95 - 79.00	MAFIC GNEISS which is fine-grained and homogeneous.
79.00 - 121.60	DIATEXITIC GNEISS which is intruded by 10 - 40 cm wide PEGMATITIC GRANITE dykes. The leucosomes are typically irregular in shapes but in places they form distinct veins, too. The rock contains small skarn-like inclusions or concretions and the proportion of leucosome and pegmatite dykes is ca. 55%. From the drilling length of 108 m onward the proportion of leucosome and pegmatite dykes increases to ca. 70%.
121.60 – 147.75	PEGMATITIC GRANITE - DIATEXITIC GNEISS mixture in which different components exist as sections of variable size and shape. Proportion of granitic component is 80% in average.
147.75 – 152.85	DIATEXITIC GNEISS which contains leucosome ca. 50% and, in places, the migmatite structure of which will classify as veined structure.
152.85 – 153.60	MAFIC GNEISS which is fine or medium-grained, homogeneous and contains no leucosome.
153.60 – 157.40	PEGMATITIC GRANITE which contains 5 – 40 cm wide gneiss and migmatite inclusions ca. 20 – 30 %.
157.40 – 163.00	DIATEXITIC GNEISS in which the proportion of leucosome is ca. 60%.
163.00 – 170.95	PEGMATITIC GRANITE which contains, particularly in the lower part of the section, a lot of gneiss inclusions which build up ca. 20 %

of the total rock volume. Except to dark, roundish crystals, typically 5 – 10 mm in diameter, the pegmatite material is leucocratic.

170.95 – 175.30 DIATEXITIC GNEISS in which the proportion of leucosome is ca. 55%.

175.30 – 183.20 DIATEXITIC GNEISS with narrow VEINED GNEISS subsections. Proportion of leucosome is ca. 60%.

183.20 – 185.60 PEGMATITIC GRANITE which is coarse-grained and leucocratic but includes a great amount of gneiss inclusions which compose more than a quarter of the rock.

185.60 – 190.20 DIATEXITIC GNEISS with roughly 40% leucosome.

190.20 – 193.00 PEGMATITIC GRANITE which is heterogeneous and includes mica rich seams and fragments up to 10 %.

193.00 – 194.85 DIATEXITIC GNEISS in which the proportion of leucosome is ca. 40%.

194.85 – 198.10 PEGMATITIC GRANITE which contains ca. 5 % mica seams and mica gneiss inclusions the diameters of which vary between 1 and 10 cm.

198.10 – 199.40 DIATEXITIC GNEISS in which the proportion of leucosome and pegmatite dykes is ca. 65%.

199.40 – 210.20 PEGMATITIC GRANITE which, at the upper part of the section, is leucocratic and homogeneous but contains from the drilling depth of 204.40 m onward a great amount (up to 30%) of gneiss inclusions.

210.20 – 235.95 TGG GNEISS which is dark, homogeneous and medium-grained. Narrow, 5 – 30 cm wide pegmatites intersect the gneiss sporadically. The proportion of these dykes is ca. 5%.

235.95 – 237.45 PEGMATITIC GRANITE which is coarse-grained and contains biotite and dark crystals ca. 10%.

237.45 – 241.90 TGG GNEISS which is dark, homogeneous and medium-grained. Narrow, 5 – 30 cm wide pegmatites intersect the gneiss sporadically. The proportion of these dykes is ca. 5%.

241.90 – 247.50 PEGMATITIC GRANITE which contains 10 – 30 cm wide gneiss inclusions and a lot of biotite especially in the lower part of the section. The proportion of inclusions and biotite seams is ca 10 %.

247.50 – 252.50 TGG GNEISS - MICA GNEISS – STROMATIC GNEISS mixture in which the components fluctuate randomly. Proportion of leucosome is ca. 25 %.

252.50 – 254.00 PEGMATITIC GRANITE which contains ca. 40% gneiss inclusions almost totally assimilated into the pegmatite material.

254.00 – 257.20 MICA GNEISS which is intersected by narrow, 1 – 2 cm wide granitoid dykes and contains a lot of dark porphyroblasts in the upper part of the section. The content of dark minerals decreases and the gneiss transforms to more homogeneous at the end of the section. The proportion of intersecting dykes is ca. 5%.

257.20 – 260.35 STROMATIC GNEISS in which the proportion of leucosome is ca. 20%.

260.35 – 266.15 TGG GNEISS which is medium-grained and weakly oriented. PEGMATITIC GRANITE dykes are 1 – 5 cm wide or even wider and sporadically intersect the gneiss. They build up ca. 5% of the rock volume.

266.15 – 314.94 DIATEXITIC GNEISS in which the paleosome is mostly medium-grained but the contacts between paleosome and leucosome are irregular, often diffuse. Narrow, homogeneous gneiss and veined gneiss subsections have been met sporadically. The proportion of the leucosome and intersecting granite material is ca. 60%.

314.94 – 320.60 TGG GNEISS – DIATEXITIC GNEISS mixture in which the paleosome is rather coarse-grained and often strongly granitized. At the beginning of the section, the rock is altered and thoroughly greenish. The proportion of leucosome is ca. 50%.

320.60 – 324.40 DIATEXITIC GNEISS - VEINED GNEISS mixture in which the medium-grained paleosome shows a distinct metamorphic banding. The proportion of leucosome is ca. 25%.

324.40 – 330.70 PEGMATITIC GRANITE which is coarse-grained and reddish at the upper part of the section and grey in the lower part. The pegmatite contains ca. 15% gneiss inclusions and mica seams.

330.70 – 331.35 MAFIC GNEISS, fine-grained and homogeneous and intersected by pegmatites building up ca. 25% of the section.

331.35 – 484.20 DIATEXITIC GNEISS the paleosome of which is coarse-grained and, for a part, resembles igneous, plutonic rocks. The components are assimilated into each other and the contacts between paleo- and leucosome are unclear. Homogeneous, fine-grained sections are 20 – 50 cm, rarely even 1 m long and randomly located in the section.

Feldspars in the coarse-grained rocks build up phenocrysts or porphyroblasts with diameters varying between 5 and 10 mm. These gneisses look like TGG gneisses and their textures resemble porphyritic igneous rocks. The proportion of leucosome is 50% in average.

484.20 – 524.40 MICA GNEISS - DIATEXITIC GNEISS mixture which contains homogeneous, 1 – 2 m long MICA GNEISS and quartz gneiss subsections in the more migmatitic environment. In addition to the small amount of leucosome (ca. 20%) the migmatite is intersected by 20 – 60 cm wide pegmatitic granite dykes.

524.40 – 531.45 PEGMATITIC GRANITE which is coarse-grained and leucocratic but contains several, 20 – 50 cm wide gneiss inclusions in particular at the beginning of the section. The average amount of inclusions is ca. 10%.

531.45 – 533.50 MICA GNEISS which is rather coarse-grained and contains leucosome dykes less than 5%.

533.50 – 535.45 PEGMATITIC GRANITE which is grey and leucocratic for the most part.

535.45 – 539.25 MICA GNEISS, a medium-grained and banded gneiss which alters to DIATEXITIC GNEISS at the drilling length of 537.00 m. In the latter the proportion of leucosome is ca. 50%.

539.25 – 542.00 PEGMATITIC GRANITE which is grey, biotite bearing and contains ca. 10% gneiss inclusions typically 10 – 20 cm in diameter.

542.00 – 549.10 DIATEXITIC GNEISS which is coarse-grained and the migmatite structure of which is irregular. The paleosome and leucosome are strongly assimilated into each other. The average proportion of leucosome is 30%.

549.10 – 550.70 QUARTZ GNEISS, homogeneous and medium-grained. The rock contains ca. 5% granitic dykes.

550.70 – 551.88 PEGMATITIC GRANITE which contains ca. 5% gneiss inclusions.

551.88 – 556.36 MICA GNEISS and QUARTZ GNEISS which are medium-grained and homogeneous and in which the proportion of intersecting, 20 – 40 cm wide pegmatite dykes is 25% at most.

556.36 – 558.05 PEGMATITIC GRANITE which is grey and contains 1 – 5% small, 10 - 20 mm wide biotite rich seams.

558.05 – 559.30 MICA GNEISS which is medium-grained and, at the end of the section, transforms to a migmatite containing ca. 25 % leucosome.

559.30 – 565.40 DIATEXITIC GNEISS the paleosome of which is coarse-grained. The proportion of leucosome is not very high but pegmatitic granites are common and the total amount of granitoid component increases to 50 - 70%.

565.40 – 600.59 PEGMATITIC GRANITE which is coarse-grained and contains sporadically gneiss inclusions and biotite bearing seams the amount of which is 2 – 3%.

2.2 Whole Rock Chemistry

Whole rock chemical composition has been analysed from ten samples of the drill core. The results of the first six analyses have been published in the report by Gehör et al. (1996) and results of the latest four analyses in this report (Appendix 1). Chemical classification and grouping follows the rules represented by Kärki and Paulamäki (2006).

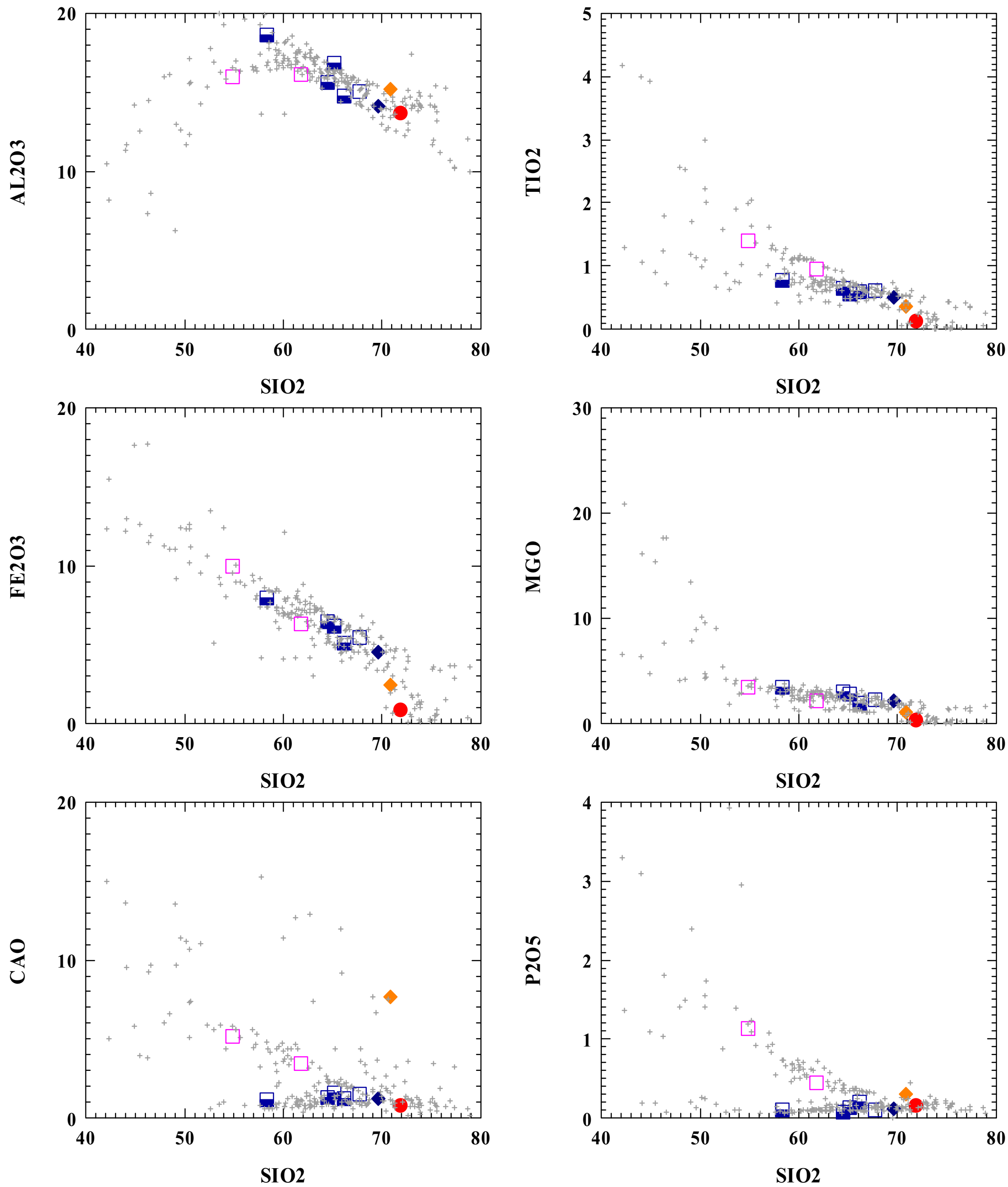
The P series is represented by two TGG gneiss samples (22 and 23), which are chemically typical members of their assemblage (Figure 2-2). The sample 22 is rather dark and rich in biotite. It is one of the most basic TGG gneiss variants found in the P series and contains SiO_2 ca. 55%. Another P-type TGG gneiss sample (23) is more silicic and contains ca. 62% SiO_2 being an intermediate variant among the assemblage of the P-type TGG gneisses. Critical element concentrations, phosphorus and calcium fall into their typical ranges. P_2O_5 content is over 0.4% in the silicic sample and exceeds 1% in the more basic one. CaO content exceeds 3% in the sample 23 and is close to 5% in the more basic one. The content of aluminium is rather low being ca. 16% Al_2O_3 in the both samples. Fe_2O_3 content is ca. 10% in the basic gneiss variant and a little above 6% in the silicic one. Fe_2O_3 concentration follows strictly the trend typical for the TGG gneisses of the P-series. Similarly behaves the content of MgO being ca. 3.5% in the sample 22 and a little above 2% in the other one. Na_2O content is ca. 1.5% in the sample 22 that is typical for most basic, mica rich gneisses of the P-series. Analysed Na_2O content, ca. 3.5% is also typical for more felsic P-type TGG gneisses like the sample 23. Rather low concentrations of potassium are typical for the less migmatitized gneiss variants of the P-series and the K_2O contents between 2.5% and 3.5% analysed from both of these samples just fall into the characteristic range.

REE concentrations are not analysed from these samples but other trace element contents (Figure 2-3) show a distinct similarity with the typical P-type TGG gneisses (Kärki and Paulamäki 2006).

The S series is represented only by one quartz gneiss sample (184) which differs chemically from other mica poor gneiss variants due to its high CaO concentration which is close to 8%. Other major element contents are typical for this kind of silicic and felsic gneiss variant (Figure 2-2). SiO_2 concentration is ca. 71%, Al_2O_3 15%, Fe_2O_3 2.5%, MgO 1.1%, Na_2O and K_2O both 0.6%. P_2O_5 content is relatively high, 0.3% that might be an indication of some relation to the P series rocks. Except to this and rather low iron concentration, the sample represents typical skarn-like gneisses of the S-series.

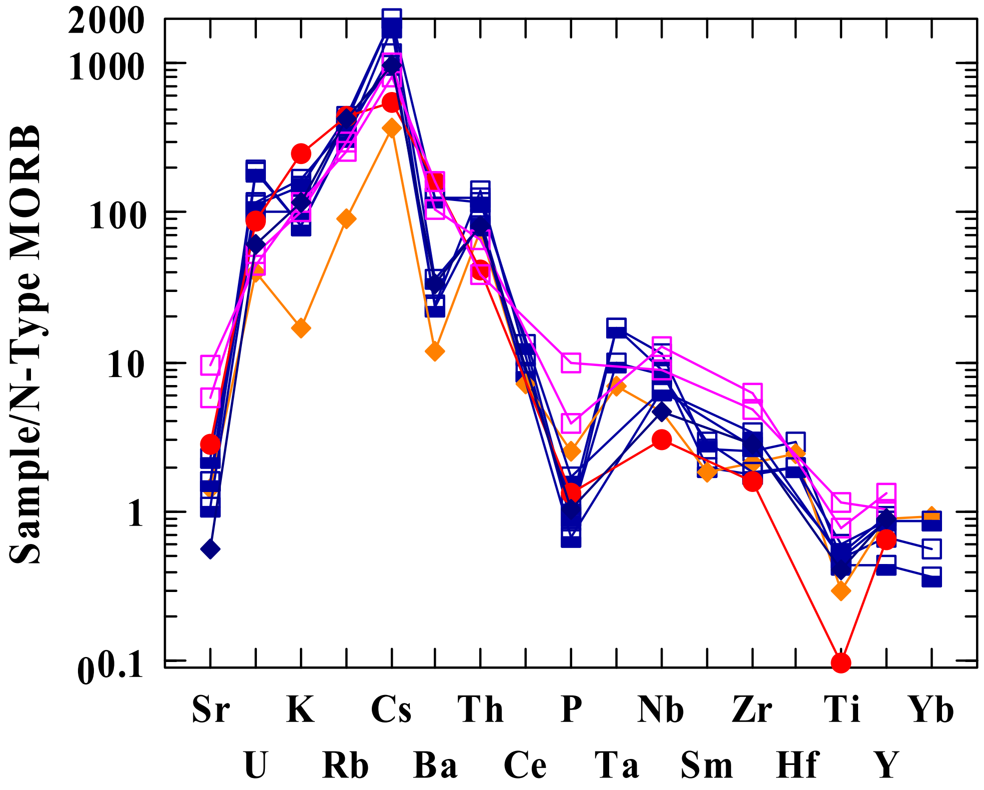
REE distribution shows an exactly similar trend as other S-type quartz gneisses (Kärki & Paulamäki 2006) and the other trace elements show the same similarity as well.

The T series is represented by six samples of which 19. 20, 183 and 185 are diatexitic gneisses, the sample 182 is TGG gneiss and the sample 24 a biotite bearing quartz gneiss. The diatexitic gneisses at the upper part of the drill hole are coarse-grained and often resemble certain porphyritic granitoids. However, the gneisses are clearly banded and also the sample 182 (drilling depth 317.95) classified as a TGG gneiss shows a distinct metamorphic banding. Mica poor quartz gneiss sample, 24 is more homogeneous and fine-grained.

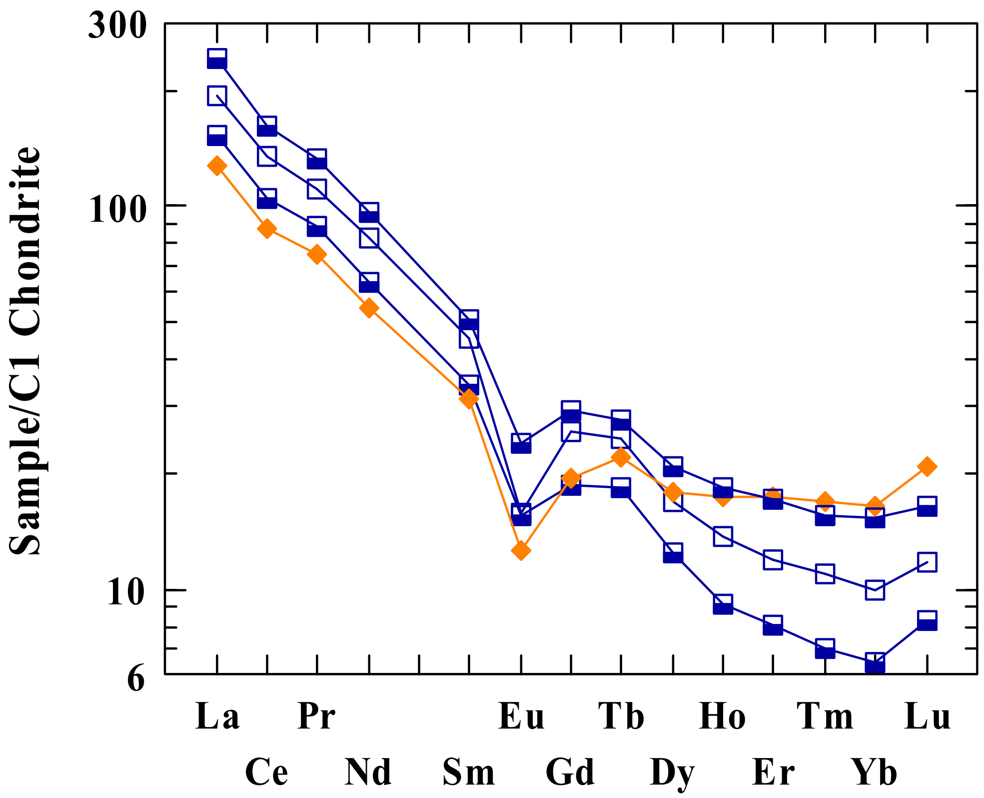


Symbols: ▼ = mafic gneiss (S- or P-series), ◒ = veined gneiss, ⬓ = diatexitic gneiss, ■ = mica gneiss, ◆ = quartz gneiss, □ = TGG gneiss, ▲ diabase, ▲ = mafic metavolcanic rock, and ● = pegmatitic granite from the drill core OL-KR8. + = sample from some other drill core.
Explanation for the colours: 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-KR8.*



A.



B.

Figure 2-3. A. *Multielement diagram and* ***B.*** *REE-diagram showing the enrichment factors for the samples from the drill core OL-KR8. Symbols as in the Figure 2-2.*

Chemically the members of the T-series build up a series in which the sample 185 represents the most basic and contains ca. 58% SiO_2 (Figure 2-2). Quartz gneiss (24) represents the most silicic end and contains close to 70% SiO_2. Other element concentrations are directly controlled by the silicity and all analysed concentrations are typical for the T series (Kärki & Paulamäki 2006). Following the increase in silicity, the content of Al_2O_3 decreases from 19% to 14%, Fe_2O_3 from 8% to 4%, MgO from 3.5% to 2% and TiO_2 from 0.8% to 0.5% (Figure 2-2). Na_2O concentrations are below 3.5%, K_2O below 5% and CaO below 1.5% but they vary more randomly. Total alkali concentrations of the most typical T-type TGG gneisses are close to 8% while that in the TGG gneiss sample 182 falls below 6%.

REE distributions are evidently similar to those of typical members of the T-series and the same similarity is visible in the other trace element concentrations, too (Figure 2-3).

2.3 Petrography

Modal mineral composition and texture has been determined from the same ten samples that have been selected for chemical analysis. TGG gneisses of the P-series are represented by two samples (22 and 23); S-type quartz gneisses by one sample (184) and leucocratic pegmatitic granites one sample (21). The samples 19, 20, 183 and 185 are diatexitic gneisses of the T-series; the sample 182 is a rather coarse-grained TGG gneiss and 24 quartz gneiss of the same series. Modal mineral compositions of the samples 19 – 24 have been represented by Gehör et al. 1986 and compositions of the samples 182 – 185 in the Appendix 2.

T series

T-type diatexitic gneisses 19, 20, 183 and 185 are very typical members in their group according to their modal mineral compositions. They contain ca. one third of quartz and close to the same proportion of biotite and feldspars. The proportion of cordierite and pinite varies between 6 and 12% and in addition to that, the samples 183 and 185 contain some sillimanite. Pyrhotite, pyrite and chalcopyrite are the most typical sulphide minerals except to the sample 185 in which hematite is the only remarkable opaque mineral. The paleosome material is granblastic and shows a more or less distinct metamorphic banding. Biotite and often also cordierite are concentrated into the dark bands that are 1 – 2 mm wide at most and typically contain a half of felsic minerals in addition to mafic phases. Leucocratic bands consist of quartz and feldspars and they are typically wider than the mafic bands, mostly 1 – 5 mm in width. Preferred orientation of micas within the dark bands is not complete and the mica scale directions may deviates several tens of degrees from general direction of the dark bands. The dark bands are not linear but more likely compose anastomosing networks or otherwise twisty structures making rock cleavage not linear. The paleosome material is medium-grained in general and the average diameters of biotite and felsic mineral grains vary between 1 and 2 mm. The samples 182 and 183 are a little more coarse-grained with average grain size ca. 2 – 4 mm.

The degree of alteration of these T-type migmatite samples varies greatly. The samples 183 and 185 are almost fresh and only a small proportion of cordierite is pinitized and plagioclase saussuritized. The ample 20 represents a more altered type in which cordierite is totally pinitized, biotite is for a part, ca 10% from the area chloritized and a distinct part of plagioclase is saussuritized.

The TGG gneiss sample (182) resembles diatexitic gneisses both being somehow banded but the former still being more coarse-grained, 2 – 3 mm in average diameter of felsic minerals. On the basis of quartz-feldspar ratio the sample will classify granitic and the relative amount of K-feldspar is higher than in typical diatexitic gneisses. Plagioclase grains are for a part roundish but for a part hypidiomorphic, longish crystals. They are saussuritized for 2 – 5 % of most grains. K-feldspar grains are also roundish and 2 - 5 mm in diameter. In places, they contain a lot of small, circular quartz and plagioclase inclusions. Independent quartz grains are also roundish but typically no more than 2 mm in diameter. Melanocratic bands are 1 – 5 mm wide and contain most of biotite as well as of circular, 5 - 10 mm wide pinite agglomerates and opaques which are mostly hematite and pyrrhotite.

Quartzitic T type gneiss (24) is granoblastic and medium-grained with average grain size roughly 0.5 mm. Quartz content exceeds 42% and the quartz grains are roundish and clear. Feldspar grains have been originally similar, but now they are almost totally saussuritic. Biotite proportion is roughly 16% and biotite scales are for a third of area chloritized. Saussurite material and biotite scales surround individual quarts grains which are roundish and 0.5 mm in diameter. Secondary hematite is the most important opaque mineral.

P series

P-type TGG gneisses (22 and 23) are tonalitic on the basis of their quartz-feldspar ratios. The sample 23 is even- and medium-grained. Plagioclase grains are 1 – 2 mm in diameter, for a part roundish and, for a part, tabular grains. The mineral contacts against surrounding crystals are undulating and never sharp, linear crystal faces. Quartz crystals are 1 mm in average diameter and also roundish. Biotite scales are typically 1 mm long and interfingered with surrounding minerals. Plagioclase grains in the sample 22 are similarly 1 - 2 mm in diameter but the shapes of those are totally irregular and they contain small, roundish quartz inclusions in abundance. Biotite scales are 1 mm long in average and their contacts against surrounding minerals are irregular, often undulating zones. Diameters of roundish quartz crystals vary from 1 mm to less than 0.1 mm and in apart from independent grains they occur often as inclusions in plagioclase and biotite. Apatite is the most important accessory phase that can be found in the both samples as rather large, often at least 0.5 mm long, idiomorphic crystals. Magnetite and small amounts of pyrite, pyrrhotite and chalcopyrite compose the most part of opaque minerals. Feldspar crystals in the both samples are saussuritized for a part but in the sample 22 alteration is much stronger and in addition to microcrystalline saussurite it contains rather large, independent epidote crystals and carbonate that can be identified also by polarization microscope.

S series

Quartzitic S-type gneiss (184) is homogeneous and rather fine-grained. It is granoblastic consisting of roundish quartz grains typically 0.2 – 0.4 mm in diameter and a little more angular plagioclase grains about the same size. Biotite scales are as small as the felsic minerals and also small amphibole splints have been met sporadically. Similarly small apatite crystals have been detected in the sample although they are not the most typical constituents for the S-type gneisses. Magnetite, hematite, pyrite, chalcopyrite and pyrrhotite represent sulphide and oxide minerals of the rock.

Pegmatitic granite sample, 21 is a typical allotriomorphic granular, coarse-grained pegmatite. Feldspar crystals are rather wide with diameters typically more than 5 mm and also the quartz crystals are often 2 - 5 mm in size. Biotite content is less than 5 % and 1 – 2 mm long biotite scales are randomly situated in the rock. Couple percents of the feldspar crystals have been altered to saussurite or sericite but locally even more than a half of feldspar is pigmented by these microcrystalline minerals. Biotite scales are for a part chloritized, but also totally fresh biotite scales have been met in the rock.

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, electrical resistivity with three frequencies (0.1, 10 and 500 Hz), P-wave velocity and porosity.

The petrophysical parameters measured are presented in a table in 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 four samples range between 2725 and 2740 kg/m3. All the samples are paramagnetic with susceptibility values between 110 - 400·10-6 SI. In Figure 3-1, susceptibility vs. density of the measured samples is shown (red dots), compared to the data previously measured from boreholes OL-KR1 – OL-KR6. Figure 3-2 shows a more detailed susceptibility-density diagram with sample numbers.

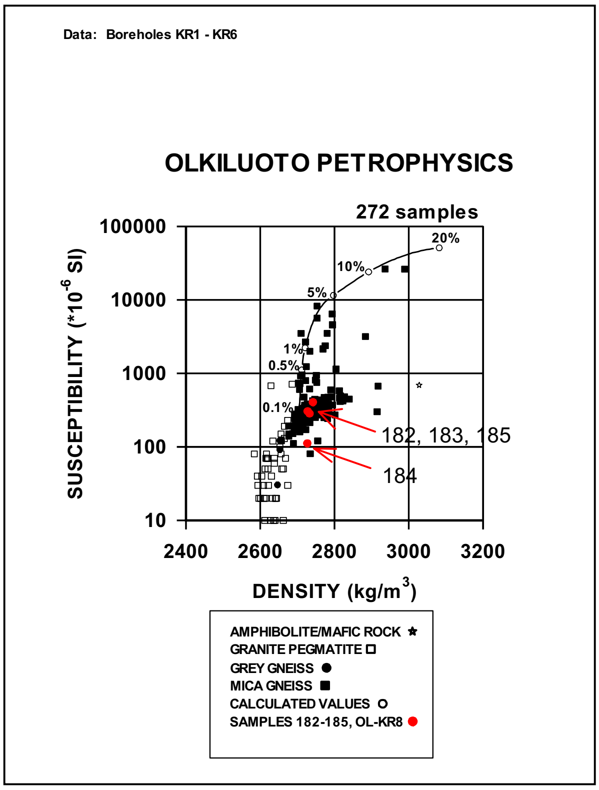


Figure 3-1. *Susceptibility vs. density, samples 182 – 185, borehole OL-KR8 (red dots). Data from previously examined boreholes OL-KR1 – OL-KR6 is also shown for comparison.*

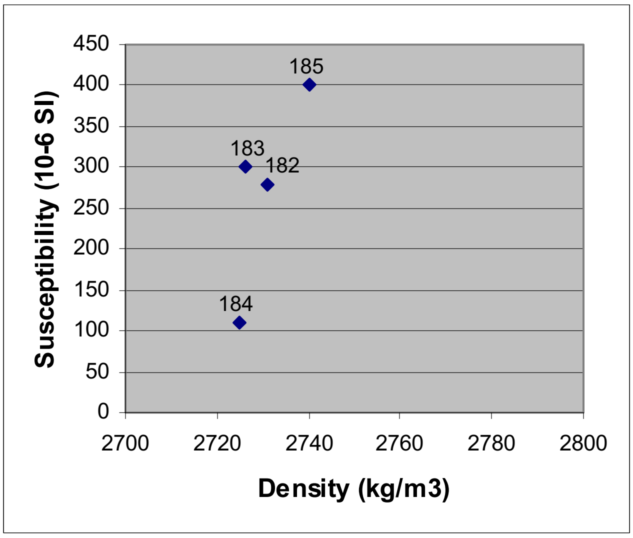


Figure 3-2. *Density vs. magnetic susceptibility and sample numbers, OL-KR8.*

According to the chemical compositions, two the samples (183 and 185) are diatexitic gneisses and one is TGG gneiss (182) of the T series. Their susceptibility and density values are typical for previously examined paramagnetic migmatites from boreholes OL-KR1 – OL-KR6 (Figure 3-1), showing rather small variation in their mineral composition. One of the samples (184) is quartzitic gneiss of the S series. Higher quartz and lower mica content in this sample is reflected by decreased susceptibility (quartz is a diamagnetic mineral with negative susceptibility).

Since the samples are mainly paramagnetic, they do not carry significant remanent magnetization. The measured remanence values, ranging from 0 to 30 mA/m, are below the practical detection limit of the measuring device. Therefore it was not relevant to determine the orientation of the remanent magnetization.

3.2 Electrical properties and porosity

The samples are poor electric conductors with resisitivty values ranging from c. 20 000 to c. 40 000 ohmm depending on used frequency. Their porosities are low (0.16 – 0.4 %), corresponding typical values for intact and unaltered samples of Olkiluoto. However, there is no clear correlation between porosity and resistivity as indicated in Figure 3-3. Relatively low resistivity value of sample 182, compared to other samples, may to some extent be related to higher content of opaque minerals (c. 1 %) and possibly the thorough alteration of cordierite. However, this alteration does not affect the measured porosity, which is less than 0.3 %.

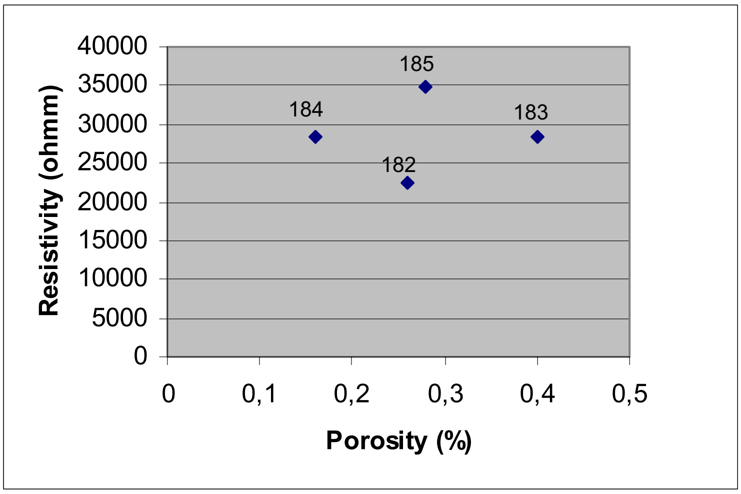


Figure 3-3. *Porosity vs. resistivity, OL- KR8.*

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 and migmatites 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 5770 – 6120 m/s, indicating rather unfractured and unaltered crystalline rocks. From the measured samples, the S series quartz gneiss (number 184) has the lowest porosity and highest P-wave velocity (Appendix 3). Accordingly, this sample is least fractured from the examined population.

4 FRACTURE MINERALOGY

The account on fracture mineralogy of drill core OL-KR8 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 and Rouhiainen, 2005).

The main fracture minerals of Borehole OL-KR8 include illite, kaolinite, unspecified clay phases (mainly illite, chlorite, smectite-group), iron sulphides (mainly pyrite, minor pyrrhotite) calcite. In addition minor Fe-oxides/oxy-hydroxides are present in some fractures at the first 6 metres of the drilling. The occurrence of main fracture fillings are demonstrated in the Figure 4-1.

Numerous fracture plains are covered by cohesive chlorite, which typically forms the underside for the above-mentioned phases (Fig. 4-1). Quartz is present as idiomorphic crystallites. Graphite forms slickensides in few fractures at drill core length 50 - 160 metres.

4.1 Fracture fillings at the major pervasive alteration zones

The Borehole OL-KR8 contains 1271 fractures in total, which makes 2.12 fractures/metre. The chief fracture minerals include illite, kaolinite, unspecified clay phases (green and grey clay-phases), iron sulphides (mainly pyrite, minor pyrrhotite) and calcite. The occurrence of main fracture fillings are given in figure 4-1.

The fracture filling phases have a close relation with the hydrothermal alteration system. Pervasive illitic alteration is found at the drill core transverses having core lengths form 1 to 15 metres (Table 4-1). The core length of the pervasively altered rock in is 41 m, which makes only 6.8 % of its total core length.

Table 4-2. *Pervasive illite alteration zones*

drill core length from (m)	drill core length to (m)
303	314
316	317
350	353
469	470
547	562
587	597

4.2 Fracture fillings outside the major hydrothermal fracture zones

At the zones where bore hole cross cuts fracture zones of second-rate hydrothermal activity, the hydrothermal overprint on lithology is typically meagre; the alteration derivatives are present only in the fractures. 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 sequences

Fracture sets in which kaolinite ± illite is present as major filling phase are typically defined by occurrence of calcite and sulphides in same assemblages. Figure 4-1, column 8 indicates that the drill core lengths 10 - 60 m, 170 – 190 m, 255 – 310 m in which kaolinite and illite form the main filling phases, the fracture frequency is visibly elevated.

2. Illitic fracture filling sequences

Illite is dominating as single phase fillings but more typically the illite-dominating fractures have variable amounts of kaolinite sulphides and/or calcite. These zones are placed at the drill core lengths 80 – 150 m, 300 – 310 m, 450 – 455 m and 550 – 600 m.

3. Calcitic fracture filling sequences

The calcitic fracture filling sets are composed of thin coatings, hair dykes or stock works in which the amount of calcite can reach tens of percents of the rock volume. The total core length of the calcite fracture sequences is 231 metres, thus 38.5 % of the whole core length has calcite as major infilling phase. Likewise the kaolinitic and illitic fracture filling sequences, also calcitic zones are characterized by higher fracture density than in the zones in which the influence of hydrothermal activity is insignificant.

Table 4-3. *Calcite fracture filling sequences.*

Start (m)	End (m)	Average filling thickness (mm)	Core length (m)
2.25	11.41		9.16
32.66	36.9	0.22	4.24
47.66	49.9	0.23	2.24
76.74	78.74	0.2	2
81.56	83.68	0.28	2.12
104.84	149.1	0.59	44.26
155.49	159.83	0.3	4.34
175.11	178.41	0.22	3.3
187.28	196.34	0.3	9.06
204.44	207.66	0.34	3.22
250.64	259.91	0.53	9.27
262.44	265.04	0.26	2.6
268.17	286.71	0.19	18.54
288.2	322.89	0.31	34.69
325.1	328.08	0.29	2.98
332.03	337.64	0.3	5.61
345.21	354.32	0.28	9.11
376.84	382.82	0.26	5.98
394.07	397.54	0.35	3.47
416.51	417.15	0.4	0.64
442.52	444.29	0.35	1.77
453.21	458.11	0.14	4.9
469.68	482.6	0.3	12.92
535.46	561.62	0.13	26.16
581.63	587.61	0.44	5.98
591.55	592.43	0.13	0.88
598.15	600.47	0.26	2.32

A number of the calcite fracture filling sequences are less than couple of metres in core section. More extensive zones situate at core lengths 110 – 150 m, 175 – 210, 250 – 355 m, 376 – 395 m , 440 – 470 m and 535 – 560 m. Last mentioned core section contains a quartz gneiss transverse and has comparatively bulky calcite fracture fillings, 3-5 mm in thickness. That particular zone is defined by illitic and kaolinite alteration and has moderate amount of sulphides. Addition to these in few fractures green and grey clay fillings are exceptionally thick, 30 mm in maximum.

As is demonstrated in Fig. 4-1 the calcitic fracture sequences overlie the hydrothermally featured rock. For this reason the grade of carbonatization appears to have importance when the influence of hydrothermal activity in bedrock is evaluated.

4.3 Water flow indication

In a small number of fractures the secondary (grey – green) clay fillings have textural indication of having been acting as conduits for water flow in the core lengths 331.91 – 338 m, 549.5 – 549.8 m and 552.4 – 553 m. First of all the last mentioned core length which contains both hydrothermal alteration and zone intersection, contains several thick clay fillings and has corrosional features. Thus it has potency of being significant pathway.

4.4 Relationship between fracture filling data and calvanic connection measurements

Electrical measurement data (Lehtonen 2006) on the galvanic connections concerning the boreholes in the Table 4-2. All the groundings from OL-KR8 represent weak or detectable connections, while the strong connection points have not been detected. The comparison of electric measurements and fracture fillings/alteration reveal that there are at least four core lengths in which the connection point is inside altered rock zone; core lengths 170 – 180 m, 310 m and 315 m are distinguished (310 and 315 m are surrounded by pervasive illite and bulky hydrothermal kaolinite-illite filling. Moreover the “discernable” connection point at the core length 540 m situates at the margin of an advanced alteration zone.

Table 4-2. *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 4-3. *Galvanic connections grounded from OL-KR8 (connecting grounding core lengths in rows) to the drill holes OL-KR4, 25, 28 and 29. The charge potentials from categories "weak" and "obvious" are selected to this table from the original data (Lehtonen 2006).*

OL-KR 8	OL-KR 4	OL-KR 25	OL-KR 28	OL-KR 29	Fracture filling of the connected core length of OL-KR8
160 m				130 m	**Calcite - sulphides**
170-180 m	80 m				**Chlorite-kaolinite-illite**
170 m	116 m				**see above**
180 m		122 m			**see above**
250 m			179 m		Calcite-sulphides-(clay)
310 m			245 m		**Pervasive illite-calcite-sulphides**
310 m			368 m		**see above**
310 m				213 m	**see above**
315-324 m	314 m				**see above**
330 m			442 m		Chlorite-sulphides
330 m		383 m			Chlorite-sulphides
330 m		518 m			Chlorite-sulphides
440 m		383 m			-
440 m			442 m		-
475 m				335 m	Calcite (slight pervasive illite zone in immediate vicinity)
540 m			442 m		**Sulphides-calcite (pervasive illite zone in immediate vicinity)**
540 m		518 m			**see above**
540 m		383 m			**see above**

5 SUMMARY

The borehole OL-KR8 intersects in the southern part of the Olkiluoto study area the diatexitic gneiss domain and the most part of the drill core sample is composed of diatexitic gneisses which are strongly migmatitized and contain typically more than a half of leucosome material with pegmatitic dykes. Often they are cordierite and sillimanite bearing rocks and, in the most cases, they will classify as T type supracrustal formations of Olkiluoto.

The borehole intersects to the drilling length of 120 m diatexitic gneisses which contain narrow sections of veined gneisses and more homogeneous mica gneisses. Below that section, down to the drilling length of 210 m, a pegmatitic unit with narrow diatexitic gneiss and veined gneiss subsections occur. TGG gneisses dominates the section from drilling length of 210 m to 265 m but also narrow pegmatite dykes and homogeneous mica gneiss units have been met. The bedrock below the TGG gneiss unit is composed of diatexitic gneisses which contain typically close to. 50 % leucosome but wide, homogeneous pegmatite dykes are missing down to the drilling length of ca. 520 m. A fluctuating section of migmatites, homogeneous gneisses and narrow pegmatite dykes continues close to the drilling length of 565 m and the lowermost part of the core is composed of rather pure pegmatites continuing down to the end of the hole at the drilling length of 600.59 m.

Whole rock chemical composition has been analysed from ten samples. The P series is represented by two TGG gneiss samples, which are typical members of their assemblage. The other sample is rather dark, rich in biotite and one of the most basic TGG gneiss variants found in the P series. Another sample is more silicic being an intermediate variant among the assemblage of the P-type TGG gneisses. The concentration of P_2O_5 content is over 0.4% in the silicic sample and exceeds 1% in the more basic one. The other major and trace element concentrations are typical for this assemblage as well. The S series is represented only by one quartz gneiss sample which differs chemically from other mica poor gneiss variants due to its high CaO concentration which is close to 8%. Other major element contents are typical for this kind of silicic and felsic gneiss variants and the sample is typical skarn-like gneiss of the S-series. The T series is represented by six samples of which four are diatexitic gneisses, one is TGG gneiss and one is a biotite bearing quartz gneiss. The diatexitic gneisses at the upper part of the drill hole are coarse-grained and resemble porphyritic granitoids. Chemically the members of the T-series build up a series in which the most basic sample contains ca. 58% SiO_2 and most silicic quartz gneiss contains close to 70% SiO_2. Other element concentrations are directly controlled by the silicity and all analysed concentrations are typical for the T series.

The T-type diatexitic gneisses are very typical members in their group according to their modal mineral compositions. They contain ca. one third of quartz and close to the same proportion of biotite and feldspars. The proportion of cordierite and pinite varies between 6 and 12% and in addition to that, the samples contain some sillimanite. The paleosome material shows a more or less distinct metamorphic banding. The TGG gneiss sample resembles diatexitic gneisses both being somehow banded but the former still being more coarse-grained, 2 – 3 mm in average diameter of felsic minerals. On the basis of quartz-feldspar ratio this sample will classify granitic and the relative amount of K-feldspar is higher than in typical diatexitic gneisses. The T type quartz gneiss is granoblastic and medium-grained with average grain size roughly 0.5 mm. Quartz content exceeds 42% and biotite proportion is roughly 16%.

The P-type TGG gneisses are tonalitic on the basis of their quartz-feldspar ratios. One of the samples is even- and medium-grained with tabular plagioclase grains varying from 1 to 2 mm in diameter. Plagioclase grains in the other sample are also 1 - 2 mm in diameter but the shapes of those are totally irregular and they contain small, roundish quartz inclusions in abundance. Diameters of individual quartz grains vary from 1 mm to less than 0.1 mm. Biotite scales are 1 mm long in average and their contacts against surrounding minerals are irregular, often undulating zones. Apatite is the most important accessory phase that can be found in the both samples as rather large, often at least 0.5 mm long, idiomorphic crystals.

The S-type quartz gneiss is homogeneous and rather fine-grained. It is granoblastic consisting of roundish quartz grains typically 0.2 – 0.4 mm in diameter and a little more angular plagioclase grains about the same size. Biotite scales are as small as the felsic minerals and also small amphibole grains have been met sporadically.

According to the petrophysical measurements, the samples are paramagnetic (110 – $400*10^{-6}$ SI) with density values varying between 2725 – 2740 kg/m^3. The lowest susceptibility and density values are related to S type quartz gneiss. The samples are poor electric conductors with resistivity values ranging from c. 20 000 to c. 40 000 ohmm depending on used frequency. Their porosities are low (0.16 – 0.4 %), corresponding typical values for intact and unaltered samples of Olkiluoto. Measured P-wave velocities are 5770 – 6120 m/s, indicating rather unfractured and unaltered crystalline rocks. From the measured samples, the S type quartz gneiss has the lowest porosity and highest P-wave velocity. Accordingly, this sample is least fractured from the examined population.

The drill hole OL-KR8 has moderate density of fracturing; 2.12 fractures/metre. The clayey infilling sequences are typically less than 10 metres in core length. The chief fracture minerals include illite, kaolinite, unspecified clay phases, iron sulphides and calcite. The fracture plains are occasionally covered by cohesive chlorite, which typically forms the underside for the other filling phases. Pervasive illitization concerns 6.8 % of the total and in addition to that the fracture related kaolinite and illite occur as unevenly distributed fracture sequences all along the drill core. The percentage of calcitic fracture fillings is 38.5 % of the core . The degree of fracture related sulphidization follows the strength of illitization and kaolinisation at the alteration zones.

The frequency of fracturing shows a relationship with the weight of hydrothermal activity. At core length intervals 80 – 150 m, 300 – 310 m, 450 – 455 m and 550 – 600 m calcitic illite-kaolinite alteration overlies the zone intersections and these two zones are discernible also in fracture frequency. A number of fractures at core length intervals 332 – 338 m, 549 – 550 m and 552 – 553 m have incohesive clay material that hold textures, which could refer to water flow.

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APPENDICES

Appendix 1.

File KR8_APP1 in the disk enclosed. The Appendix contains the results of whole rock chemical analyses.

Appendix 2.

File KR8_APP2 in the disk enclosed. The Appendix contains the results of modal mineral composition analyses.

Appendix 3. Petrophysical parameters, drill core OL-KR8.

							RESISTIVITY VALUES (Ωm)				IP-ESTIMATES	
SAMPLE	**FROM**	**TO**	**D(kg/m^3)**	**K(μSI)**	**J(mA/m)**	**P-wave (m/s)**	**R0.1[Ωm]**	**R10 [Ωm]**	**R500[Ωm]**	**PL (%)**	**PT (%)**	**Pe(%)**
182	317.95	318.05	2731	280	30	5770	24800	22500	18900	9	24	0.26
183	369.28	369.37	2726	300	30	5860	31900	28500	23200	11	27	0.4
184	497.06		2725	110	30	6120	30700	28500	24700	7	20	0.16
185	512.03		2740	400	0	5680	38500	34800	27000	10	30	0.28

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