

“Fluid Inclusions in the Outokumpu deep drill core: Implications for palaeofluid evolution and the composition of modern deep saline fluids”

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*Für Elisabeth, meine Familie und meine Freunde
die nie aufgehört haben an mich zu glauben.*

Ich erkläre an Eides statt, dass ich die vorliegende Arbeit selbstständig und ohne fremde Hilfe verfasst, andere als die angegebenen Quellen nicht benützt und die den benutzten Quellen wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe.

Leoben, 2014

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Abstract

This study results from a DFG funded project, which was part of the Outokumpu Deep Drilling Project. The sampling occurred in 2006 and was performed by Jochen Kolb and Leila Sharif (former member of the Institute for Mineralogy and Economic Geology, RWTH Aachen University).

This study is based on detailed petrographical, mineralogical, and geochemical investigations of the different rock types, minerals, and fluid inclusions occurring in the Outokumpu drill hole.

Detailed fluid inclusion data (homogenisation temperature, composition) of quartz veins within the Outokumpu deep drill hole, and a discussion of the potential role of palaeofluids preserved in fluid inclusions, which may affect groundwater salinities are presented in this study. Additionally the fluid inclusion data has been used to calculate palaeo p-T conditions of the rock. The analyses of the mineral chemistry (feldspars, biotite, garnet) together with isotopic data of biotite, quartz and fluids and fluid inclusion data, are used to estimate the metamorphic conditions.

Fluid inclusions in quartz veins in the Outokumpu Deep Drill core are characterized by high salinities and high homogenisation temperatures in excess of 330°C. In addition to an aqueous phase, fluid inclusions also contain gaseous phases such as CO₂ und CH₄. Cation ratios of the dissolved salts are higher than seawater with Li/Na ratios indicating the influence of magmatic water in deeper parts of the drill hole. Stable isotope (δD , $\delta^{18}O$) signatures point to a metamorphic origin of the palaeofluids. Deep groundwater in the Outokumpu crystalline basement deviate significantly from fluid inclusions in their stable isotope ratios, which plot to the right of the global meteoric water line in a δD - $\delta^{18}O$ diagram. This suggests that they may have formed as a mixture of meteoric and saline waters. In addition, Cl/Br and Na/Br ratios point to chemical exchange with the host rocks. Many models have been proposed to account for the enhanced salinity of deep groundwater and the shift in the stable isotopes, but the data of this study indicates, that the saline fluids are derived primarily through water–rock interaction. The role of fluid inclusions as important contributors to the saline fluids is not supported.

Zusammenfassung

Diese Arbeit war Teil des “Outokumpu deep drilling projects” und wurde von der DFG finanziert. Die Probenahme erfolgte im Jahr 2006 und wurde von Hr. Dr. Jochen Kolb und Fr. Leila Sharif den Erstbearbeitern dieses Projekts durchgeführt.

Diese Studie basiert auf detaillierten petrographischen, mineralogischen und geochemischen Untersuchungen der verschiedenen dort vorkommenden Gesteinstypen, Mineralien und Flüssigkeitseinschlüsse.

Detaillierte Untersuchungen von Flüssigkeitseinschlüssen (Homogenisierungstemperatur, Zusammensetzung) der im Bohrkern vorhandenen Quarzgänge wurden durchgeführt. Weiters wurde der Zusammenhang zwischen den Flüssigkeitseinschlussdaten und der Beeinflussung der Salinität des Grundwassers dargestellt und diskutiert. Die so erhaltenen Daten wurden zur Bestimmung der Bildungsbedingungen der Gesteine verwendet. Die chemische Analyse von Mineralen (Feldspäte, Granat, Biotit) wurde gemeinsam mit Isotopenanalysen (Sauerstoff und Wasserstoff) und Flüssigkeitseinschlussdaten zur Abschätzung der metamorphen Bedingungen verwendet.

Flüssigkeitseinschlüsse in Quarzgängen, welche im Bohrkern vorhanden sind, sind durch hohe Salinitäten und hohe Homogenisierungstemperaturen (bis zu 300 °C) charakterisiert. Neben diesen wässrigen Phasen beinhalten manche Flüssigkeitseinschlüsse Gase wie CO₂ und CH₄. Die Kationenverhältnisse der gelösten Salze sind höher als die von Meerwasser, wobei die Li/Na Verhältnisse in den tieferen Teilen des Bohrkerns auf den Einfluss von magmatischen Fluiden hinweisen. Messungen stabiler Isotope (δD , $\delta^{18}O$) implizieren einen metamorphen Ursprung der Paläofluide. Die Isotopensignatur der tiefen Grundwässer im Outokumpu Distrikt unterscheiden sich grundsätzlich von den in den Flüssigkeitseinschlüssen gemessenen, welche in dem δD - $\delta^{18}O$ Diagramm rechts der “meteoric water line” plotten. Das lässt darauf schließen, dass sie sich durch eine Mischung von meteorischen und saline Wässern gebildet haben. Außerdem deuten die Cl/Br und Na/Br Verhältnisse auf einen chemischen Austausch zwischen den tiefen Grundwässern und den Nebengesteinen hin. Diese Studie weist darauf hin, dass die Salinität der tiefen Grundwässer hauptsächlich durch Wasser Nebengesteins Wechselwirkung beeinflusst wird. Der Einfluss von Flüssigkeitseinschlüssen auf die Salinität von tiefen Grundwässern konnte in dieser Arbeit nicht nachgewiesen werden.

1) Introduction

The Outokumpu mining district, one of the classical ore provinces of Finland, is best known for its unconventional Cu-Zn-Co-Ni-Ag-Au sulphide deposit, hosted by a 1.96 Ga old ophiolitic sequence (Huhma & Huhma, 1970; Sántti et al., 2006; Peltonen et al., 2008).

The Outokumpu research borehole was drilled in 2004 – 2005 in eastern Finland, approximately 2 km SE from the town of Outokumpu, by the Outokumpu Deep Drilling Project of the Geological Survey of Finland (GTK). The 2,516 m deep hole was drilled into a palaeoproterozoic metasedimentary and ophiolite-related sequence of rocks in the classical Outokumpu Cu-Co-Zn sulphide ore belt (Vähätalo, 1953; Gaál et al., 1975; Koistinen, 1981; Park, 1988; Sorjonen-Ward, 2005; Kukkonen, 2009). In advance to the Outokumpu Deep Drilling Project a crustal-scale seismic reflection survey, the FIRE project, was carried out in Finland in 2001–2005 (Kukkonen et al., 2006) with the FIRE 3 profiles crossing the Outokumpu ore belt (Figure 1.1, Kukkonen et al., 2006; Sorjonen-Ward, 2006; Kukkonen, 2011). High-resolution seismic data, which was obtained during these surveys, show various strong reflectors at depth, which were interpreted to be related to the main ore belt which continues at depth with a gentle dip to the SE (Kukkonen et al., 2006; Heinonen et al., 2009). The main target for the Outokumpu deep drilling project was to reveal the nature of these strong reflectors within the Outokumpu ore belt. The drilling, which started in April 2004, was aimed to reach 2.5 km depth with a borehole diameter of 22 cm and continuous coring. In addition extensive geophysical logging programs, hydrogeological tests and fluid sampling during drilling breaks were carried out (Kukkonen, 2011).

Different geophysical studies have been performed before and after the drilling. Several other strong ‘laminated’ reflectors of unknown geological character in the upper crust of the Outokumpu area were found. The uppermost of these reflectors is located at about 1.5 km depth. One goal of this research borehole was to intersect this strong seismic reflector (Kukkonen et al., 2009), which was interpreted as rocks of the Outokumpu or, alternatively, mafic rocks of an undefined type embedded in Proterozoic mica schist with black schist interlayer. Below this layer of meta-ultramafic rocks it was planned to encounter Proterozoic mica gneisses or Archaean granite gneisses. It was not possible to differentiate between these two formations in advance, due to not significant enough differences between the reflection coefficients of typical Archaean gneisses and Proterozoic metasediments (Kukkonen, 2011).

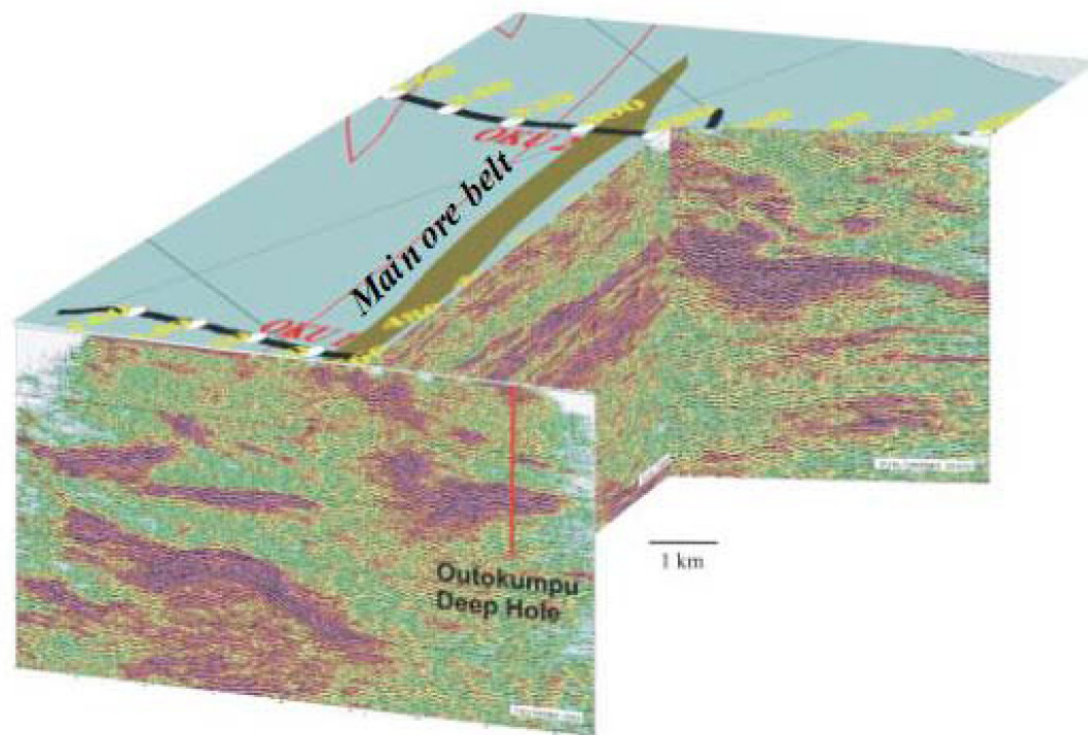


Figure 1.1, The Outokumpu Deep Drill Hole and a 3D visualization of FIRE high-resolution seismic reflection sections with a geological map of the surface. The reflectors show a strong lineation and continuity along the strike of the main ore belt (Kukkonen, 2009)

Kukkonen (2009) defined the main criteria that motivated the Outokumpu Deep Drilling Project as followed:

- 1) Understanding the deep structure of a classical ore province in Precambrian terrain. The Cu-Co-Zn deposit of the Outokumpu district, hosted by a distinct 1.96 Ga old ophiolitic rock type assemblage, was an important mining area for about 80 years. The deep structure of the ore belt is still a matter of discussion. The existing ore potential is still considered high.
- 2) Understanding the composition and origin of the saline fluids and gases identified earlier in drill holes of the Outokumpu region, and studying the deep biosphere.
- 3) Investigating the vertical variation of different geological and geophysical parameters and correlating geological, geophysical and petrophysical data sets.
- 4) Using the Outokumpu research borehole as a deep geolaboratory for various in-situ experiments, fluid sampling, and monitoring.

Drilling started on April 6th 2004 and was completed on January 31st 2005, with a final depth of 2,516 m. The hole is sub-vertical, deviating at maximum only 9° from a vertical direction. The final core recovery was 79%.

The most important findings after the drilling were summarized by Kukkonen (2011):

- 1) The drilled section is dominated by metasedimentary rocks (i.e. mica schists, 72%), ophiolite-derived rock types of the Outokumpu assemblage (8%) and pegmatitic granite (20%). In advance to the drilling the abundance of pegmatitic granite was not predicted. The Archaean basement was not encountered.
- 2) The strong seismic reflector, which was penetrated by the borehole, represent meta-ultramafic rocks (mainly serpentinite, skarn rock, quartz rock) from the Outokumpu rock assemblage, and black schist, which typically host the Outokumpu type sulphide ores. The interpretation of similar reflectors in the upper crust of the Outokumpu area implies that the ore potential of the Outokumpu area is probably much higher than earlier anticipated.
- 3) Saline gas-bearing fluids are present in the fracture zones of the bedrock. The fluids are isolated from the modern meteoric circulation and they are probably a result of long-term water-rock interaction.
- 4) Microorganisms were detected in the sampled fluids at all depth levels in the hole. The microorganisms represent sulphate-reducing bacteria and methanogenic archaea, but in addition there are numerous previously unknown species.
- 5) Geothermal studies have revealed a low conductive temperature gradient and a significant increase in heat flow with depth. This can be attributed to the subsurface thermal regime still being affected by the glaciations during the last 100,000 years.

A detailed summary of the results from the Outokumpu research group can be found within the extended abstracts of the third international workshop of the Outokumpu Deep Drilling Project and within the Special Publication 51 of the Geological Survey of Finland (Kukkonen, 2011).

The presence of saline brines in crystalline basement rocks is a well-documented phenomenon from many stable cratons (Casanova et al., 2001; Frape et al., 1984; Fritz & Frape, 1982; Herut et al., 1990; Kloppmann et al., 2002; Négrel & Casanova, 2005). The processes of the formation and origin of the high salinity of deep groundwater, however, remain controversial. Nordstrom et al. (1989a, 1989b, 1989c) suggested two

sources for chlorine in crystalline basement rocks: (i) an allochthonous source external to the host rock, such as intrusion of marine waters (e.g. Fritz & Frape, 1982) or brines of sedimentary origin (e.g. Couture & Seitz, 1986; Munz et al., 1995), (ii) an autochthonous source such as release of chlorine through water–rock interaction and hydrolysis of silicate minerals (e. g. Möller et al., 2005), or leakage of secondary fluid inclusions trapped in primary minerals (Nordstrom et al., 1989c). Leakage of fluid inclusions as a possible source for groundwater salinity has been a matter of debate (Smalley et al., 1988; Nordstrom et al., 1989c). Bakker (2009) showed that fluid inclusions can change their composition in a relatively short time, due to bulk diffusion of fluid components along microcracks in quartz. Microcracking can occur as a consequence of i) recent tectonic activity, ii) ancient tectonic activity or iii) anthropogenic activity (Nordstrom et al., 1989c).

During the drilling of the Outokumpu well, saline Na-Ca-Cl fluids were encountered (Ahonen et al., 2009). Nurmi et al. (1988) described saline waters within the area, attributed to long-term water-rock interactions.

Nurmi et al. (1988) already published results from chemical and isotopic analyses of water from drill holes and mines throughout the Fennoscandian shield. They could distinguish an upper layer of fresh groundwater, which is underlain by several saline layers, which differ in salinity, relative abundance of solutes and O, H, Sr and S isotopic signatures. Four major groups of saline groundwater can be differentiated: (1) saline waters in a depth of around 50 – 200 m in coastal areas which represents relict Holocene seawater, modified by reactions with the host rock, (2) brakish and saline water between 300 – 900 m, (3) saline water and brines from 1,000 – 2,000 m and (4) superdeep brines which go down to at least 11 km. The last three occurrences of saline water and brines were encountered inland. The major ions, which were measured within all saline groundwater samples, are Cl, Ca, Na and Mg. They differ with the host rock lithology. Also different gases were encountered like N₂, CH₄ (the main component) and sometimes H₂. The isotopic characteristics of the CH₄ suggest a hydrothermal or metamorphic origin. The oxygen isotopes show meteoric origin for the upper layers and indicate longer mean residence time and low temperature equilibration for deeper waters. The source of the water has not been verified but it is suggested to have a Precambrian hydrothermal or metamorphic origin (Nurmi et al., 1988).

Nordstrom et al. (1989a, b, c) published three papers about the hydrogeochemical characteristics within the international Stripa Project. They investigated the influence

of water-rock interaction (Nordstrom et al., 1989b) and the influence of fluid inclusions from the Stripa granite changing the groundwater chemistry (Nordstrom et al., 1989c). The hypothesis of leaching of fluid inclusions as a major source of solutes in the groundwater is based on (1) mass balance, where only a small amount of fluid inclusions need to leak to account for the salt concentrations in the groundwater, (2) chemical signatures (comparison of the Br/Cl ratios), (3) leakage mechanisms and (4) experimental studies. It was concluded that fluid inclusions can have an influence on the groundwater salinity in low permeable rocks (Nordstrom et al. 1989a, b, c).

Négre and Casanova (2005) compared the Sr isotopic signatures from brines of the Canadian and Fennoscandian shields. These measurements should lead to further knowledge of the origin of the salinity and to evaluate the degree of water-rock interaction. Their measurements indicate a well-mixed system, which corresponds to a large and relatively homogeneous water reservoir, which results from water-rock interaction that does not occur in closed pockets and is associated with fracture and shear zones (Négre & Casanova, 2005).

A detailed summary of the hydrogeological characteristics of the Outokumpu deep drill hole is published in Ahonen et al. (2011). During the drilling, the main hydrogeological parameters have been monitored under a daily basis including electrical conductivity, pH, composition and consumption (loss) of drilling fluid, as well as targeted fluid sampling and hydraulic testing during drilling breaks with the drill stem method. Sampling of the deep groundwater has been carried out three times, after the drilling was finished, with a tube method. The fluids contain Ca, Na, and Cl as major cations and anions with an increase of the Mg content close to the rocks of the Outokumpu rock assemblage. Methane and nitrogen were encountered as the major gas components within the fluid with a concentration of about 900 mL/L. The concentration of the total dissolved solids (TDS) increase from about 12 g/L in the uppermost 1,000 m to about 50 g/L at the bottom of the borehole (Ahonen et al., 2011).

This study results from a DFG funded project, which was part of the Outokumpu Deep Drilling Project. The sampling occurred in 2006 and was performed by Jochen Kolb and Leila Sharif (former member of the Institute for Mineralogy and Economic Geology, RWTH Aachen University).

This study is based on detailed petrographic, mineralogical, and geochemical investigations of the different rock types, minerals, and fluid inclusions occurring in the Outokumpu drill hole.

Detailed fluid inclusion data (homogenisation temperature, composition) of quartz veins within the Outokumpu deep drill hole, and a discussion of the potential role of palaeofluids preserved in fluid inclusions, which may affect groundwater salinities, are presented in this study. Additionally, the fluid inclusion data has been used to calculate palaeo p-T conditions of the rock. The analyses of the mineral chemistry (feldspars, biotite, garnet) together with isotopic data of biotite, quartz and fluids and fluid inclusion data are used to estimate the metamorphic conditions.

2) Geological Overview

The geology of Finland is closely linked to the geological evolution of the Baltic shield, which is comprised of three different major domains: the Archean Domain in the northeast, the Svecofennian Domain in the central part, and the Southwest Scandinavian Domain in the southwest. Different orogenic events, like the Saamian orogeny ($> 3.1 - 2.9$ Ga), the Lopian (or Rebolian) orogeny ($2.9 - 2.6$ Ga), the Svecofennian and Gothian orogeny ($1.75 - 1.5$ Ga), and the Sveconorwegian – Grenvillian orogeny ($1.25 - 0.9$ Ga) formed the continental crust (Gaál & Gorbatshev, 1987).

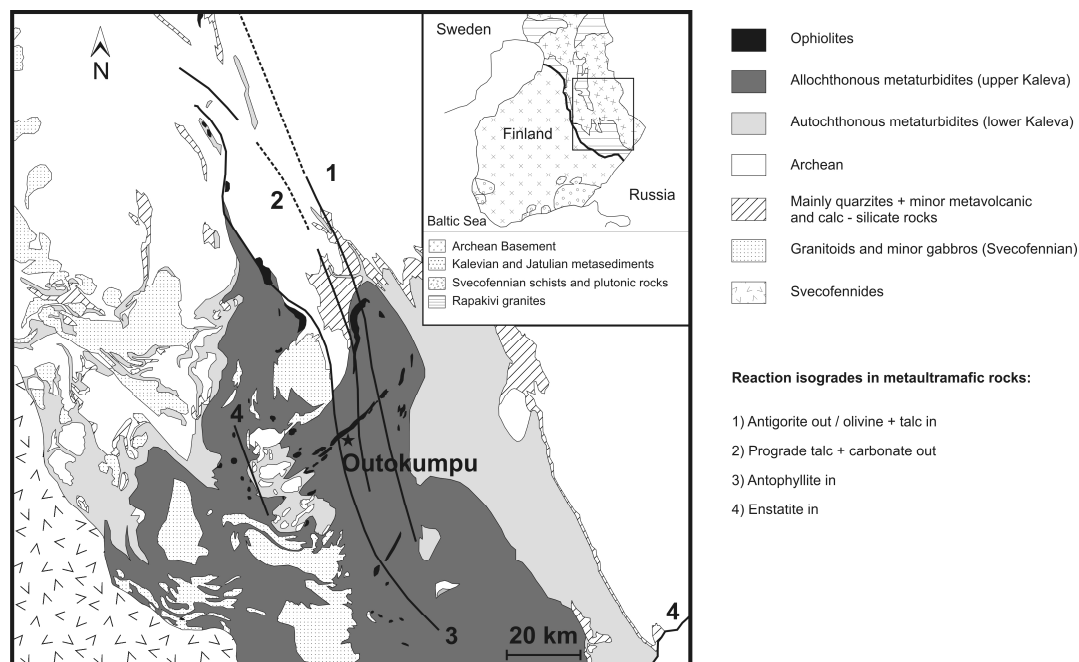


Figure 2.1, Geological map of the Outokumpu area. Modified after Peltonen et al. (2008)

The drill site is located within the Outokumpu allochthon in eastern Finland (Figure 2.1), which represents a 1 - 5 km thick remnant of folded and imbricated overthrust terrane, dominated by 1.92 - 1.90 Ga old metaturbidites (Claesson et al., 1993). It was emplaced over a basement complex, consisting of late Archean gneisses and a thin Palaeoproterozoic cover, during the Svecofennian Orogeny (Gaál & Gorbatshev, 1987; Korsman et al., 1999; Peltonen et al., 2008). The lithologies comprise (1) metasediments, metamorphosed to amphibolite facies mica schists and black schists, and (2) serpentinites, skarns, and sulphide-rich black schists, commonly referred to as the Outokumpu assemblage (Gaál et al., 1975; Koistinen, 1981; Park, 1988; Sântti et al., 2006; Peltonen et al., 2008).

The retrograde to amphibolite facies, high-grade Archean basement was formed between 2.85 and 2.70 Ga, with a minor, older, component at 3.5 to 3.1 Ga (Sorjonen-Ward and Luukonen, 2005; Bogdanova et al., 2008; Peltonen et al., 2008). Between 2.5 to 2.0 Ga, the Archean basement was rifted, which resulted in a breaking of the Archean craton and the opening of an oceanic basin. The closure of this basin resulted in the Svecofennian orogeny at about 1.9 Ga (Bogdanova et al., 2008). The orogeny is represented in a suture between the Archaean Karelian Craton and the 1.93 to 1.80 Ga Palaeoproterozoic Svecofennian island arc complex (Gaál and Gorbatshev, 1987; Korsman et al., 1999; Peltonen et al., 2008), which lies west of the Outokumpu area.

The Outokumpu allochthon is part of the metasediments of the Karelian supergroup (or north Karelian schist belt; Table 2.1), which was deposited on the Archean craton between 2.45 and 1.9 Ga. This supergroup is divided into different groups, which are separated by major unconformities. Lithologically, it can be divided into an arenite – dominated lower sequence, and a turbidite – dominated upper sequence (Ojakangas et al., 2001).

Different authors in Sweden, Finland, and Russia use different names for the geological units. In this thesis the terminology of Ojakangas et al. (2001) will be used. The drillhole itself lies in the amphibolites – facies metamorphosed Kalevian group, which some authors place in the Svecofennian supergroup (Ojakangas et al., 2001). Laajoki (1988, 1990) divided the Kalevian tectofacies into three different subfacies: the Lower Kaleva (rift), the Middle Kaleva (narrow sea), and the upper Kaleva (open sea).

Peltonen et al. (2008) only distinguishes between the Lower Kaleva, which is probably a parautochthonous unit comprising mainly metaturbiditic greywackes with thin intercalations of low-Ti tholeiitic metabasalts and black schists in the upper part, and the Upper Kaleva, which is mainly composed of deep marine metaturbiditic greywackes with thick intercalations of black schists. U – Pb age data of the youngest single detrital zircons in rocks of the upper Kaleva assemblage indicate a depositional age of around 1.92 Ga (Claesson et al., 1993).

Table 2.1, Summary of the Paleoproterozoic stratigraphy of the Karelian Supergroup of the Baltic Shield. Ages are highly generalized, for details see Heiskanen (1991; 1992), Melezhik et al. (1997), Karhu (1993), and Ojakangas et al. (2001). The description of the lithology is from the Russian Karelian part of the Baltic shield, Finland. The Ludicovian, along with parts of the upper Jatulian, is considered marine. For details see Ojakangas et al. (2001).

Group		Lithology	Thickness	Age
Kalevian and Svecofennian		Mica schist, phyllite, metagreywacke, rocks of the Outokumpu rock assemblage	3,000 – 5,000 m	~1.950 Ma
Ludicovian		Limestone, phyllite, black schist, dolomite, quartzite, iron – fm, metachert, greenstones	1,300 – 2,800 m	~2.080 Ma
Jatulian	Upper	Dolomite, phyllite, black schist, greenstone, quartzite	200 – 2,200 m	~2.150 Ma
	Lower	Arkosite, metaconglomerate, orthoquartzite, sericite, quartzite		
Sariolian		Paleosol: quartz-sericite schist, saprolite, aluminum silicates Arkosite, phyllite, metaconglomerate, metagreywacke, greenstones	300 – 1,200 m	~2.400 Ma
Sumian		Metavolcanics and sediments, greenstones, quartz porphyry	400 – 600 m	~2.500 Ma
Archean Basement				2.700 – 2.850 Ma 3.100 – 3.500 Ma

The Outokumpu assemblage or the Outokumpu “ophiolite complex” (Vuollo & Piirainen, 1989), as described in Peltonen et al. (2008), is incomplete and consists of hundreds of individual massifs and fragments of mainly ultramafic rocks distributed over an area of more than 5,000 km² (Peltonen et al., 2008). Kontinen (1987), and Peltonen and Kontinen (2004), place the Outokumpu assemblage in the upper Kalevian subfacies, whereas Park (1998) places it at the stratigraphic and structural base of the allochthonous Kalevian succession. A detailed stratigraphic description is available

from Park (1988). In this study only the main lithological and stratigraphic features are described. Park (1988) divides the Outokumpu assemblage into three main components:

1. Metasediments, including black schists, listwaenite – birbrite type rocks, calc – silicate skarns rich in Cr, and a suite of talc and fuchsite schist.
2. Metavolcanic rocks
3. Mafic – ultramafic plutonic rocks

The tectonic and metamorphic evolution of the area is dominated by the activation of a passive continental margin along from fault zones at the beginning of the Svecofennian orogeny and the formation of the Svecofennian island arc complex (Gaál and Gorbatshev, 1987; Korsman et al., 1999; Peltonen et al., 2008; Figure 2.2). The docking of the Svecofennian island arc complex to the margin of the Karelian Craton was followed by the obduction of the Outokumpu allochthon. The timing of the obduction is constrained between 1.92 Ga and 1.87 Ga. The thermal peak was recorded at a relatively late stage of the orogeny, in low amphibolite (in the east) to upper amphibolite facies (in the west), with temperatures between 500 and 775 °C and pressures between 3 and 5 kbar (Koistinen, 1981; Korsman et al., 1999; Peltonen et al., 2008; Sääntti et al., 2006).

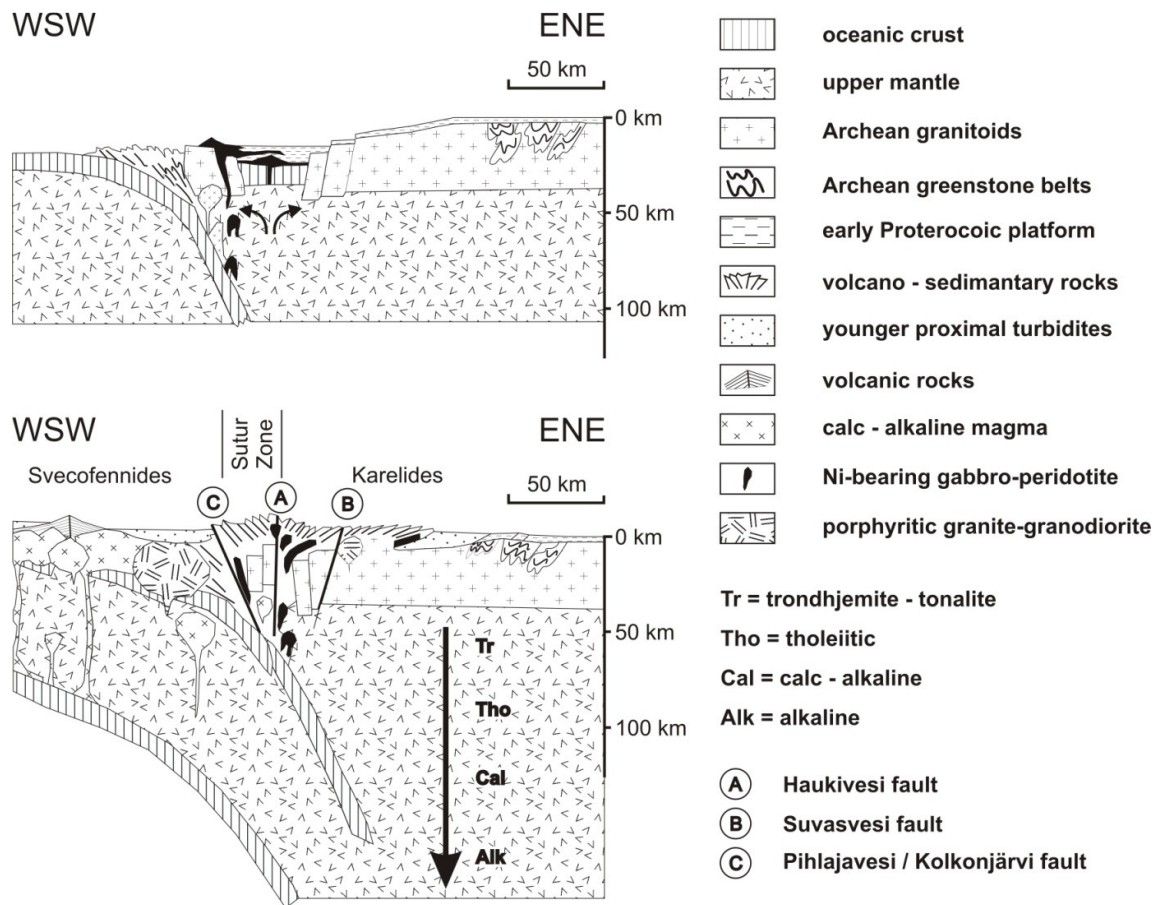


Figure 2.2, Simplified plate tectonic model for the Svecofennian orogeny in central Finland about 1.920 Ma ago (above) and 1.880 Ma ago (below), after Gaál and Gorbatshev (1987).

3) Analytical methods

Petrography/Mineral Chemistry: The petrographic investigation of the mineral assemblages includes 93 thin and polished sections. In order to gain information about the mineralogical, mineral-chemical, and chemical differences between the different rock types, the petrographic investigations were aided by electron microprobe analyses. Additionally the qualitative and quantitative mineralogical composition was determined on 40 samples with XRD analyses.

Whole rock geochemistry: The major and trace element analyses of whole rock were carried out on 40 samples by standard XRF analysis. The samples included all rock types from different depth of the Outokumpu drill hole. To get representative samples, the quartz and carbonate veins were separated from the rocks.

Fluid inclusion analysis: In order to obtain p-T-x information about the occurring fluids, 32 thick sections of fluid inclusions bearing quartz and carbonate veins, were prepared. The geological history of the area suggests no further metamorphic event other than the Svecofennian orogeny (Gaál et al., 1975), which cannot be confirmed by the petrographic investigations. Most of the fluid inclusions can be considered primary and so the microthermometrical measurements were used to make statements about the p-T-x conditions of vein formation, which occurred at different times and p-T-x conditions.

Additionally, crush-leach analyses of 22 samples have been performed to define the composition of the anions and cations. These analyses were carried out in cooperation with Walter Prochaska (University of Leoben). This analytical method is a bulk method, therefore no statement about single fluid inclusions can be made.

Raman Spectroscopy: In order to gain information about the chemical composition of the entrapped gases in the fluid inclusions, Raman analyses of single fluid inclusions have been carried out at the University of Leoben.

Stable isotope analysis: The O and H isotope analyses were carried out on 7 samples of handpicked biotite separates. Fluid inclusions of 18 handpicked quartz separates were released by thermal decrepitation and analysed for H isotope composition. The quartz residue was used for O isotope determination. The analyses were carried out in

collaboration with Torsten Vennemann (University of Lausanne). This analytical method is a bulk method, therefore no statement about single fluid inclusions can be made.

LA-ICP-MS analysis: In-situ element composition of single fluid inclusions was investigated using LA-ICP-MS equipment of the Institute of Mineralogy and Economic Geology. Small inclusion sizes and relatively low salinity precluded the production of an extensive dataset. Ti in quartz was measured in selected samples to calculate isopleths for the determination of the P-T conditions of the vein formation.

A complete summary of the samples and the analytical data can be found in the appendix.

3.1) Major element and trace element analyses

Major and trace element composition was determined by ED-XRF (Spectro XLab2000, Institute of Mineralogy and Economic Geology, RWTH Aachen University) equipped with a Pd-tube operated at acceleration voltages between 15 and 53 kV and currents between 1.5 and 12.0 mA (Sindern et al., 2008).

Major elements were analysed on fused discs (diluted 1:10 with a Li-tetraborate/Li-metaborate mixture, FXX65, Fluxana, Kleve, Germany). Co, Ti and Al were used as secondary targets. Data computation was performed using a fundamental parameter procedure (Sindern et al., 2008).

Pressed powder pellets were used for trace element determination. For these elements best excitation was achieved by Mo, Al_2O_3 , Pd and Co targets. Chlorine was excited using Pd L of the tube reflected on the sample by a graphite target. For matrix correction the Mo-Compton peak was taken. Precisions are < 0.5 % for the major and < 5 % for the trace elements, except for Ba (precision < 10 %). Loss on ignition was determined by heating the powdered sample for 120 min at 1000 °C. Lower limits of determination are 10 ppm for Cu, Zn, Sr; 20 ppm for V, Cr, Ni, As, Rb, Zr, Pb, and 50 ppm for Ba and Cl (Sindern et al., 2008).

3.2) Fluid inclusion analyses

3.2.1) Microthermometry

Microthermometric measurements are based on the observation of phase changes within fluid inclusions during heating and cooling. By accurate measurements of the temperature, when these changes take place, it is possible with the use of experimental datasets, to estimate conclusions about PVTX conditions of the fluid during its entrapment (Shepherd et al., 1985).

The homogenisation temperature (T_h) of a fluid inclusion can be measured by slowly heating (heating rates between 5 and 30 °C/min). Different modes of homogenisation can be observed:

- a. homogenisation into a liquid phase ($L + V \rightarrow L$),
- b. homogenisation into a vapour phase ($L + V \rightarrow V$) and
- c. critical homogenisation ($L + V \rightarrow \text{supercritical fluid}$)

The homogenisation temperature can be used to calculate the bulk density of the fluids entrapped. The actual trapping temperature of the fluid can only be determined if the formation pressure is known from other analytical methods (Shepherd et al., 1985).

The data obtained during the freezing of a fluid inclusion and the observation of the melting temperature (T_m) refer primary to the composition. Single component fluids show a melting at a well-defined temperature (e.g. H₂O at 0.015 °C, CO₂ at -56.6 °C). Other added components like salt can lower the observed melting temperature, therefore melting is a discrete function of composition and can be used, together with the initial (or eutectic) melting (T_e), to calculate the amount of other phases present. The T_e is in fact very hard to detect. Within H₂O bearing CO₂ - CH₄ rich inclusions the formation of gas hydrates can occur. The melting of these gas-hydrates gives information about the composition (Bakker, 1998; Shepherd et al., 1985).

Microthermometrical measurements were performed with a LINKAM THMS 600 heating cooling stage (Figure 3.1 A+B) attached to a Leitz microscope. The stage has been calibrated using the triple point temperature of CO₂ (-56.6° C), the melting temperature of H₂O (0° C) and the critical homogenisation temperature of H₂O (374.0° C). After the measuring of the homogenisation (T_h) and melting temperatures (T_m), the computer program BULK (Bakker, 2003) was used to calculate the density and salinity.

For microthermometric analyses double polished thick sections were used with a thickness of about 100 to 150 μm .

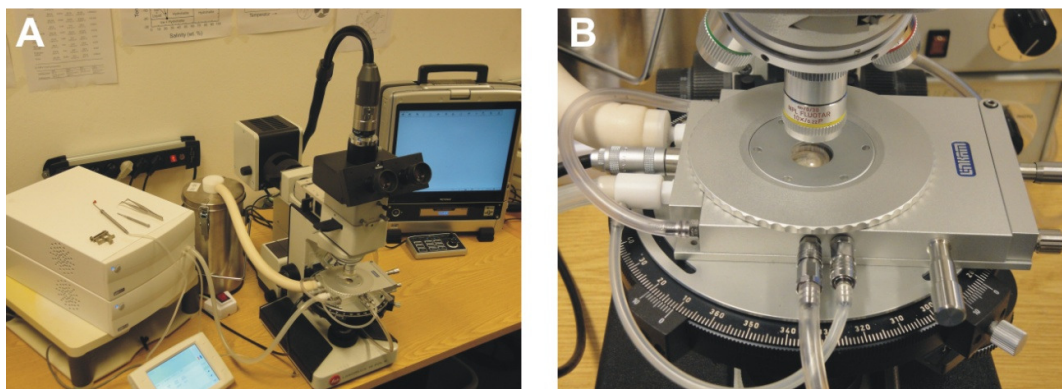


Figure 3.1, Microthermometry; A) general overview; B) detailed image of the heating freezing stage

3.2.2) Ion chromatography (“Crush-Leach method”)

For anion and cation analyses of fluid inclusions, performed at the University of Leoben, handpicked quartz grains with a grain size between 0.5 up to 1 mm were cleaned with diluted nitric acid and washed with double distilled water. After cleaning the samples were dried at 50° C and 1 g cleaned quartz was crushed together with 5 ml double distilled water in an agate mortar. The resulting suspension was filtered through a 0.2 μm nylon filter prior to analysis. The final filtrate was analysed using ion chromatography. Cations and anions were determined on a Dionex system (DX-500) with a micro-membrane suppressor. For standard runs a 25 μl sample loop was used (Kucera et al., 2009).

3.2.3) LA-ICP-MS

Laser ablation ICP-MS is a powerful and efficient multi element microanalytical technique for the analysis of major and trace elements within solids and liquids.

The general layout of LA-ICP-MS system is shown in figure 3.2. Heinrich et al. (2003) describe 3 major instrumental components for successful microanalytical work:

- laser beam,
- sample cell and
- detection system.

Laser Optics Viewing Optics & Laser-Imaging Mass Spectrometer

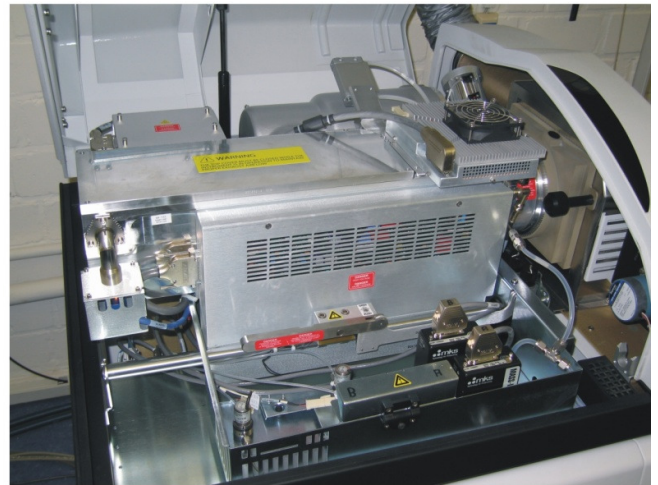
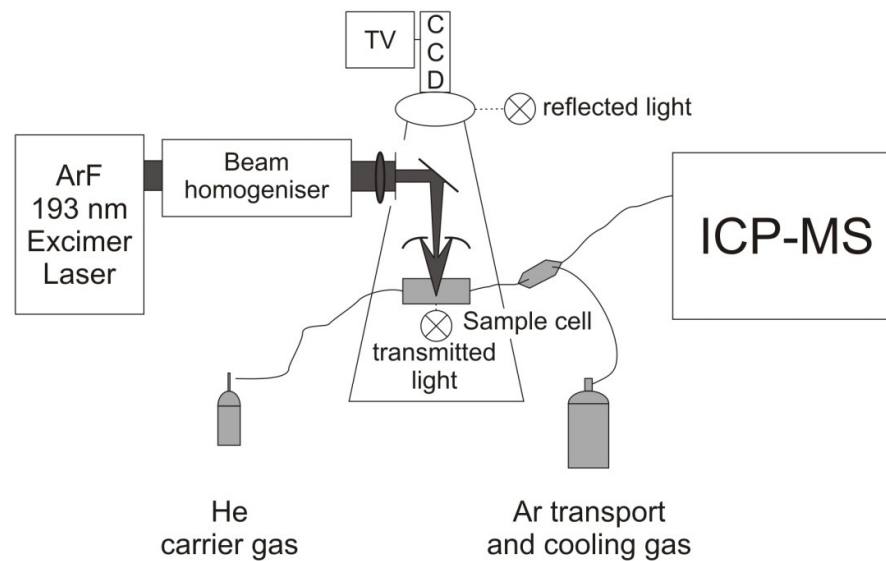


Figure 3.2, Layout of the laser ablation system developed at ETH Zürich and also used by the Institute of Mineralogy and Economic Geology at the RWTH Aachen, modified after Heinrich et al. (2003)

The physical process of “laser ablation” depends on the mechanisms of absorption and dissipation of laser energy in the target material. The key characteristics of a laser are wavelength, pulse width, irradiance and fluency. A 193 nm excimer laser, as used at the Institute of Mineralogy and Economic Geology at the RWTH Aachen, showed the

best results in the efficiency of aerosol uptake and signal smoothness. The advantage of these UV laser systems is the reduction of mechanical spalling or thermal melting and sputtering of melt droplets during the ablation process (Moenke-Blankenburg & Günther, 1992; Darke & Tyson, 1993; Jeffries et al., 1996; Heinrich et al., 2003).

The optical components, which are delivering the laser beam onto the sample surface are considered as important as the wave length of the laser. A beam homogeniser delivers an adjustable and laterally homogeneous energy density (fluency) on the sample surface (Guillong & Günther, 2001; Horn et al., 2001; Guillong et al., 2002; Heinrich et al., 2003).

The volume of the sample cell is the most influential parameter in terms of aerosol dispersion along the transport path from the ablation site to the plasma. The cell volume primarily affects the time attenuation and shape of the ICP-MS signal resulting from a short ablation event (Heinrich et al., 2003). The parameters, which can be influenced with the cell volume, are the signal length and the signal-to-noise ratio. A large volume leads to relatively long signals of low intensity, which lead to a more representative and reproducible analysis. Smaller sample cells show higher signal-to-noise ratios with an improvement of the detection limits with reduced representative sampling and a less reproducible analysis (Bleiner & Günther, 2001; Heinrich et al., 2003). Other parameters, which influence the transport efficiency, are the cell geometry and the used carrier gas. Helium reduces the loss of analyte through condensation back onto the sample and improves the signal intensities because of the improvement in aerosol uptake (Eggins et al., 1998a; Günther & Heinrich, 1999a; Bleiner & Günther, 2001; Horn et al., 2001; Heinrich et al., 2003).

According to different authors (e.g. Heinrich et al., 2003), measurements of fluid inclusions are complicated because of the small amount of analyte and the unknown volume of the inclusion. Therefore, the use of an internal standard next to an external standard is unavoidable. Heinrich et al. (2003) presented a flow diagram for the quantification of element concentrations in natural fluid inclusions (Figure 3.3).

The internal standard needs to be an independently measured element concentration. In the case of fluid inclusions, this can be the salinity measured by microthermometry. After a representative sampling of the inclusion, as described in Heinrich et al. (2003), the intensity contributions of the host mineral must be subtracted from the intensities measured from the fluid inclusion (eqn. 1; *I*...intensity, *INCL*...inclusion, *MIX*...host mineral + inclusion, *HOST*...host mineral; Heinrich et al., 2003).

$$I_i^{INCL} = I_i^{MIX} - I_{Si}^{MIX} \times \frac{I_i^{HOST}}{I_{Si}^{HOST}} \quad (1)$$

Equation 2 shows the basic relationship of LA-ICP-MS quantification, which relates the integrated net signal intensities of the fluid inclusion to those of the external standard (Longerich et al., 1996b; Heinrich et al., 2003).

$$\frac{C_i^{SAMP}}{C_r^{SAMP}} = \frac{C_i^{STD}}{C_r^{STD}} \times \frac{I_i^{SAMP} \times I_r^{STD}}{I_r^{SAMP} \times I_i^{STD}} \times \frac{S_i^{SAMP} \times S_r^{STD}}{S_r^{SAMP} \times S_i^{STD}} \quad (2)$$

$$\frac{C_i^{INCL}}{C_{Na}^{INCL}} = \frac{C_i^{STD}}{C_{Na}^{STD}} \times \frac{I_i^{INCL} \times I_{Na}^{STD}}{I_{Na}^{INCL} \times I_i^{STD}} \quad (3)$$

After the concentration ratio of elements in the inclusion was obtained relative to the internal standard, the absolute element concentrations are calculated by the combination of the element ratios from the LA-ICP-MS with the microthermometric NaCl equivalent mass%, which requires knowledge of the effect of dissolved components other than NaCl upon the melting temperature (eqn. 3 and 4; Heinrich et al., 2003).

$$C_{NaCl} + 0.5 \times (C_{KCl} + C_{CaCl_2} + C_{FeCl_2} + \dots) \quad (4)$$

During the measurements of fluid inclusions with LA-ICP-MS a slightly different method for the element quantification was used as described in Gagnon et al. (2004). Therefore the elements within the fluid inclusions are measured with an external standard. For H₂O – NaCl fluid inclusions the salinity is calculated with the equation of Bodnar (1993), the Na content is used as an internal standard. For quartz-hosted, Ca-bearing L–V inclusions, total salinity can be calculated using equation of Oakes et al. (1990) and the Ca:Na ratio measured from LA–ICP–MS analyses (Gagnon et al. 2004).

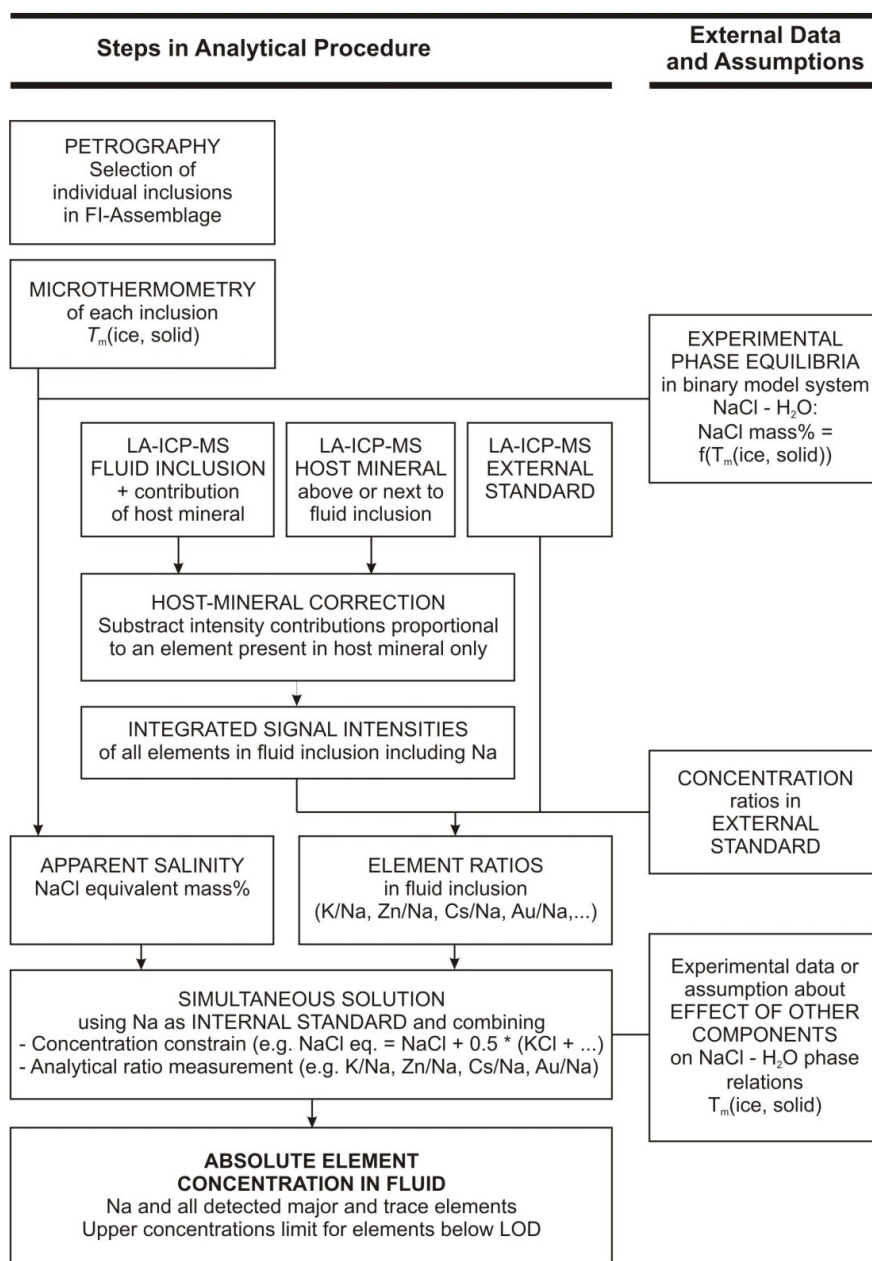


Figure 3.3, Flow diagram for the quantification of element concentrations in natural fluid inclusions after Heinrich et al. (2003)

3.2.4) Isochor calculation

With the results of microthermometrical measurements bulk density, molar volume and composition of the fluid inclusions were calculated with the program BULK (Bakker, 2003). The corresponding isochores were calculated with the program ISOC (Bakker, 2003). An isochor is a line of constant density within p-T space. This isochor represents the range of p-T conditions over which a fluid of this density was trapped (Hollister, 1981).

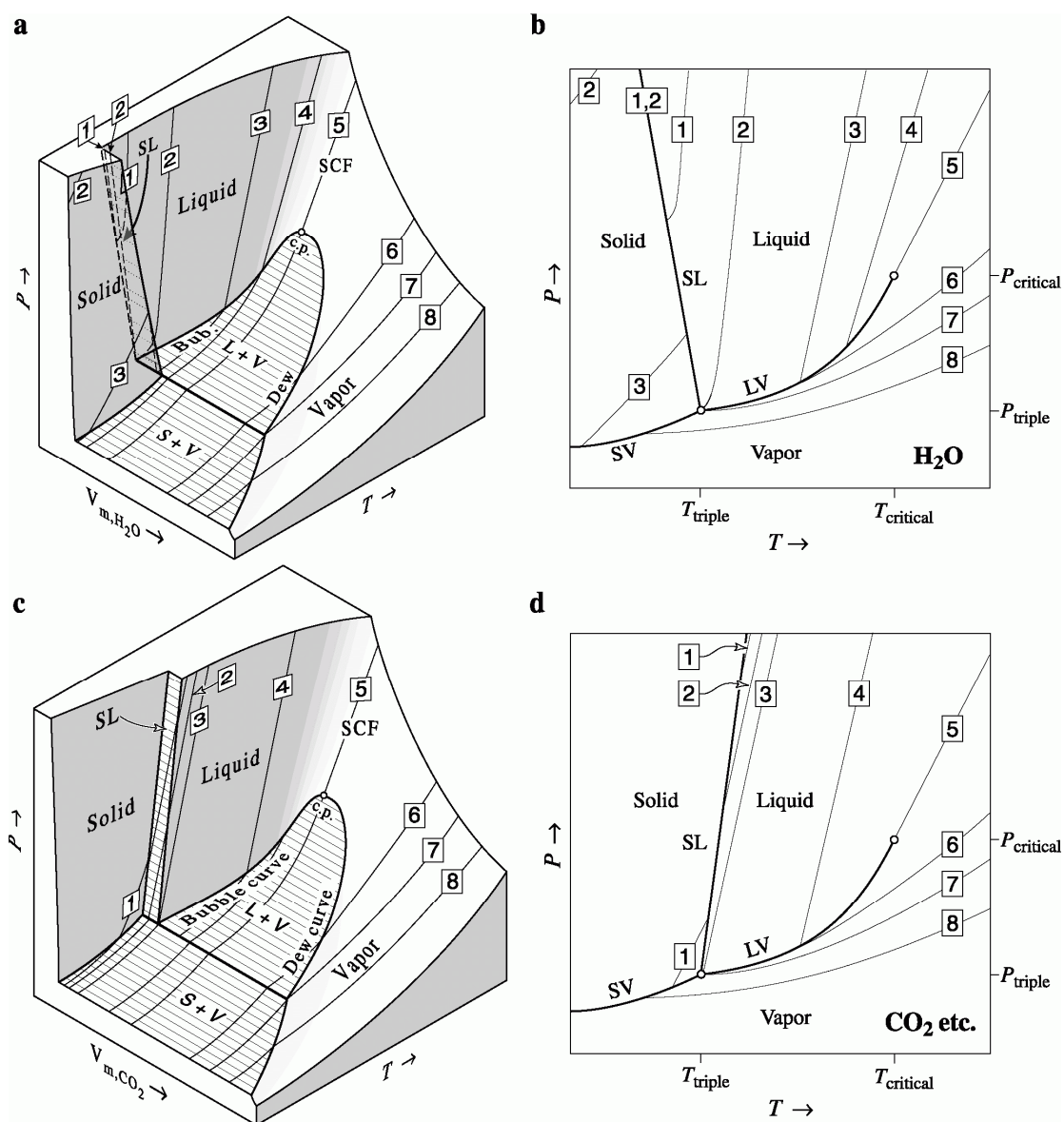


Figure 3.4, Qualitative phase topologies of unary systems, in which only one solid is considered. (a) Pressure-temperature-molar volume (P-T- V_m) perspective diagram for pure H_2O ; (b) P-T projection of Figure 3.4a for pure H_2O ; (c) P-T- V_m perspective diagram labeled for pure CO_2 ; (d) P-T projection of Fig. 3.4c (Diamond, 2003b)

Figure 3.4 illustrates different isochore topologies for H_2O and CO_2 within the p-T and p-T- V_m space (Diamond, 2003b).

The following equations of state have been used to calculate the molar Volume / density of the fluid inclusions. The equations of state for the calculation of the isochores have been chosen by the p-T limits given by Bakker (2003):

Table 3.1, Used equations of state for calculation of the molar Volume / density of the fluid inclusions

Fluid inclusion type	System	Salinity	Bulk properties			Isochor		
A1	H ₂ O – NaCl	Bodnar (1993)	Zhang (1987)	&	Franz	Zhang (1987)	&	Franz
A2	H ₂ O – NaCl	Bodnar (1993)	Zhang (1987)	&	Franz	Anderko & Pitzer (1993a, 1993b) Duan et al. (1995)	&	Franz
A3	H ₂ O – NaCl	Bodnar (1993)	Zhang (1987)	&	Franz	Zhang (1987)	&	Franz
A4	H ₂ O – NaCl	Bodnar (1993)	Zhang (1987)	&	Franz	Anderko & Pitzer (1993a, 1993b) Duan et al. (1995)	&	Franz
B1	H ₂ O – NaCl – CaCl ₂	Oakes et al. (1990)	Zhang (1987)	&	Franz	Zhang (1987)	&	Franz
B2	H ₂ O – NaCl – CaCl ₂	Oakes et al. (1990)	Zhang (1987)	&	Franz	Zhang (1987)	&	Franz
C	CO ₂	–	Duschek (1990)	et	al.	Span & Wagner (1996)		
D	H ₂ O – CO ₂	Duan et al. (1992)	Duan et al. (1996)			Anderko & Pitzer (1993a, 1993b) Duan et al. (1995)		

3.2.5) Raman spectroscopy

The Raman effect is described by the energy changes in a beam of light due to the inelastic collision with vibrating polyatomic molecules or molecular groups. This Raman scattering is a rather weak physical effect and therefore a monochromatic laser beam has to be used to study it. As mentioned before, the interaction of a laser beam with a sample will result in an energy change, more specifically the laser beam can lose (Stokes scattering) or gain energy (Anti-Stokes scattering). Due to the fact that there are always more molecules in lower energy states, the Stokes side of the spectrum is always more intense than the Anti-Stokes side (fig. 3.5). A Raman spectrum itself is a plot of the intensity of the scattering versus the change of the energy, which is expressed in wavenumbers relative to the source. The different peaks visible in the spectrum correspond to the specific energies of the vibration modes of the different molecular groups in the measured sample (Burke, 2001).

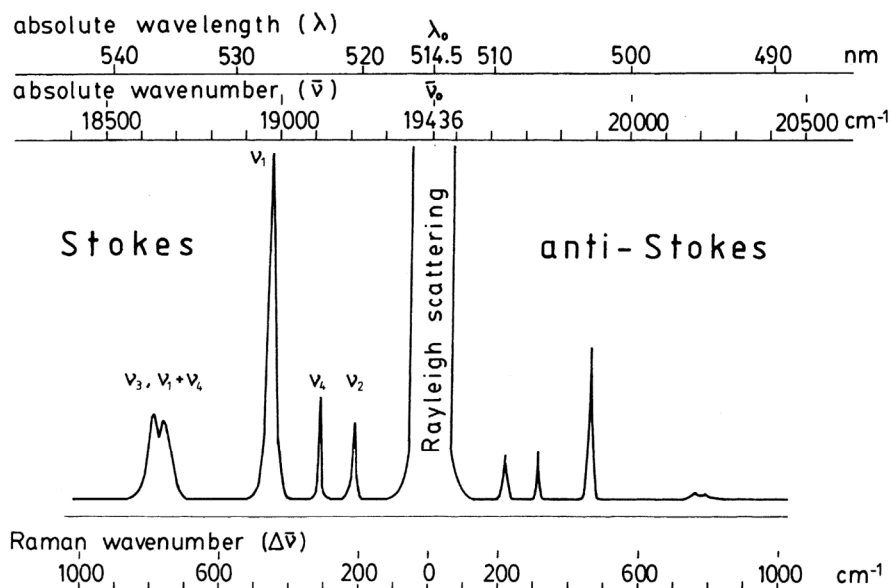


Figure 3.5, comparison of the Stokes and the Anti-Stokes scattering, from Burke (2001)

Raman measurements in this thesis have been performed with a LABRAM (ISA Jobin Yvon) spectrometer at the University of Leoben. A 100 mW frequency-doubled Nd – YAG Laser with a wavelength of 532 nm (green light) has been used, which is focused with a Olympus BX 60 microscope. The energy of the laser on the sample is around 1 - 2 mW and 100 mW at the source. The used internal standards were Si, calcite and diamond (Bakker et al., 2005).

3.3) Isotopic analyses

All isotope analyses of H and O have been performed at the Institute of Mineralogy and Geochemistry of the University of Lausanne.

Analyses of the hydrogen isotopic composition were carried out using high-temperature (1450°C) reduction methods with He-carrier gas and a TC-EA linked to a Delta Plus XL mass spectrometer from Thermo-Finnigan. Samples with sizes of 2 to 4 mg have been used according to a method adapted by Sharp et al. (2001).

The results are given in the standard δ -notation, expressed relative to VSMOW in permil (‰). The precision of the in-house kaolinite and G1 biotite standards for hydrogen isotope analyses was better than $\pm 2\text{‰}$ for the method used; all values were normalized using a value of -125‰ for the kaolinite standard and -65‰ for NBS-30 (Piribauer et al., 2011).

The oxygen isotope composition (^{16}O , ^{18}O) of the samples was measured using a method similar to that described by Sharp (1990) and Rumble and Hoering (1994), described in more detail in Kasemann et al. (2001). Between 0.5 to 2 mg of sample was loaded onto a small Pt-sample holder and pumped out to a vacuum of about 10^{-6} mbar. After prefluorination of the sample chamber overnight, the samples were heated with a CO_2 laser in 50 mbars of pure F_2 . Excess F_2 is separated from the O_2 produced by conversion to Cl_2 using KCl held at 150°C. The extracted O_2 is collected on a molecular sieve (5Å) and subsequently expanded into the inlet of a Finnigan MAT 253 isotope ratio mass spectrometer. Oxygen isotope compositions are given in the standard δ -notation, expressed relative to VSMOW in permil (‰). Replicate oxygen isotope analyses of the standard used (NBS-28 quartz; $n = 3$) have an average precision of $\pm 0.1\text{‰}$ for $\delta^{18}\text{O}$ (Piribauer et al., 2011).

The samples used for the analysis of the isotopic composition of fluid inclusions were hand-picked and cleaned. The fluids were extracted through heating and decrepitation in a vacuum extraction line. Released H_2O and CO_2 were trapped under vacuum in a liquid nitrogen-cooled U-tube, leaving the other gases in its vapour state. H_2O and CO_2 were separated cryogenically using an ethanol–liquid nitrogen slush trap at about -90°C , at this temperature CO_2 is released as a vapour. H_2O and CO_2 were then cryogenically transferred into small Pyrex® glass tubes for the transfer to the mass spectrometers (Kesler et al. 1997; Tarantola et al. 2007).

3.4) XRD analyses

For XRD analyses a Bruker D8-Advance Diffractometer from the Institute of Mineralogy and Economic Geology of the RWTH Aachen has been used. The X-Ray diffractometer is equipped with a Sol-X detector, a Vantec detector, a Cu-anode and an automatic sample charger.

The samples must be milled down with a McCrone mill to obtain a constant grain size distribution. Milling occurs together with ethanol, which cools down the grinded material and inhibits changes in the mineralogy during milling.

The evaluation of the analysis is done with the aid of EVA and Topas 4.2 software.

3.5) EMPA analyses

Electron microprobe analyses have been performed with a JEOL JXA-8900R electron microprobe from the Institute of mineralogy and economic geology of the RWTH Aachen. Polished thin sections have been used, which were coated with graphite in advance. The measurement points were logged with a point logger mounted on a Leica microscope. Zonation of the mineral grains could be determined with backscatter electron images, which show lighter colors as heavier the elements get.

An electron beam is focused (around 1 μm in diameter) on the polished sample, which generates element specific X-rays. Due to a comparison of these characteristic X-rays of the sample with a standard with known composition, a quantitative analysis can be obtained.

Two different methods can be used to obtain these information:

- Wavelength-dispersive analysis (limit of detection is around 0.005 mass%, material dependent)
- Energy-dispersive analysis (limit of detection is around 0.5 mass%)

5 different analysing crystals can be used at the Institute of Mineralogy and Economic Geology of the RWTH Aachen: LDEB, LDE1, LDE2, TAP, PET, LiF. All chemical elements between boron and uranium can be analysed.

4) Petrography and Geochemistry of the drill core

The uppermost 33 m of the drill core from the Outokumpu research borehole are made up of younger cover rocks comprising sand and silt. This is followed by a sequence of metasediments that mainly consist of biotite-muscovite schist, biotite schist, black schist, and biotite-rich gneisses. The metasediments are underlain by serpentinites, skarns, and black schist of the Outokumpu assemblage, which extent to a depth of 1,515 m. The base of the sequence (1,515m – 2,516m) is composed of amphibolite facies metasediments, that are locally intruded and crosscut by pegmatite dykes (Figure 4.1). Pegmatitic granite dominates at depth beyond 2,000m. In all lithologies, except the black schists, fluid inclusion-bearing quartz and carbonate veins can be observed.

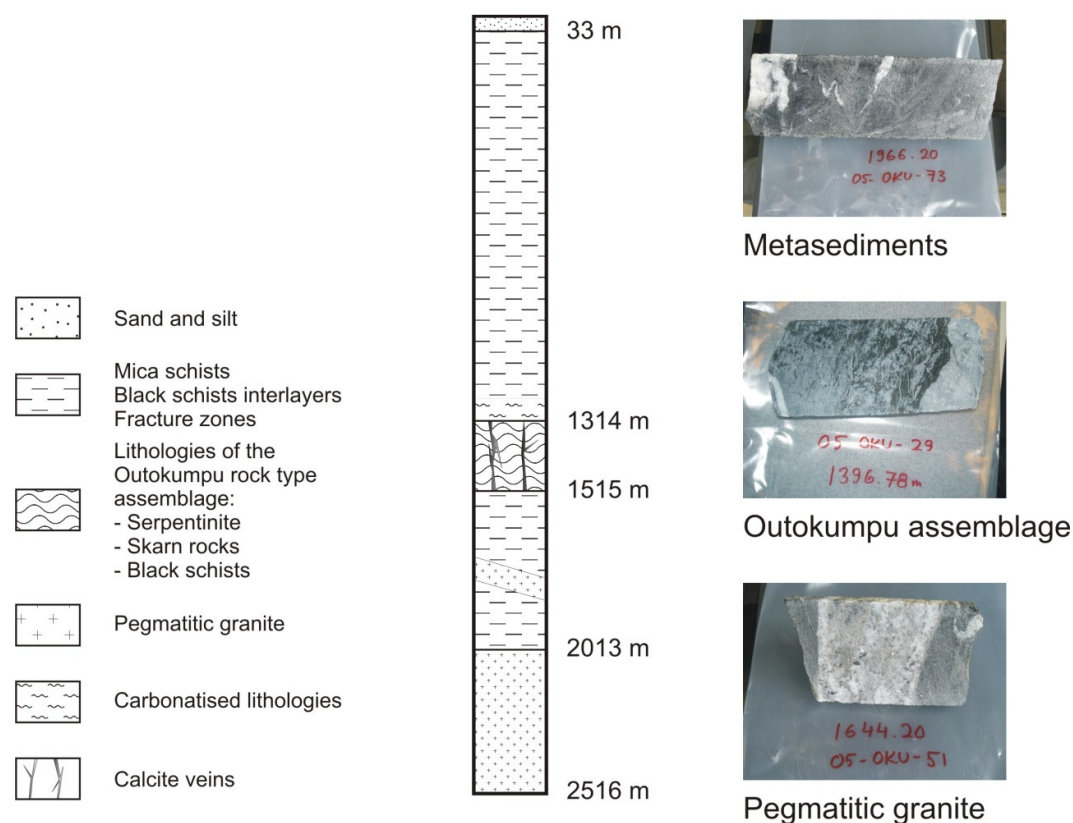


Figure 4.1, general sketch of the petrology of the Outokumpu deep drill hole

The abbreviations of the mineral names are according to Siivola and Schmid (2007). Qualitative mineral data were obtained by transmitted and reflected light microscopy and XRD analyses. Quantitative data were calculated using Rietveld technique. Major and trace element analyses were performed using XRF technique.

4.1) Petrography

Metasediments

The metasediments, which make up most of the drill core, consist mainly of monotonous biotite mica schists with biotite gneiss interlayer. Västi (2011) also distinguishes between chlorite-sericite schist, hornblende-epidote schist, and black schists, which occur in the vicinity of the Outokumpu rock assemblage (ORA).

The mineralogical composition measured by XRD is shown in figure 4.2. Mica schist, biotite mica schist, and biotite gneiss contain quartz, biotite, chlorite, feldspars, and muscovite as main components and accessory minerals like hematite, pyrrhotite, garnet and tourmaline (Figure 4.2). They are fine to medium grained and show a strained up to granoblastic fabric. The grain size ranges from <0.1 mm, for quartz, feldspar, chlorite, and the accessory minerals, up to 5 mm for biotite.

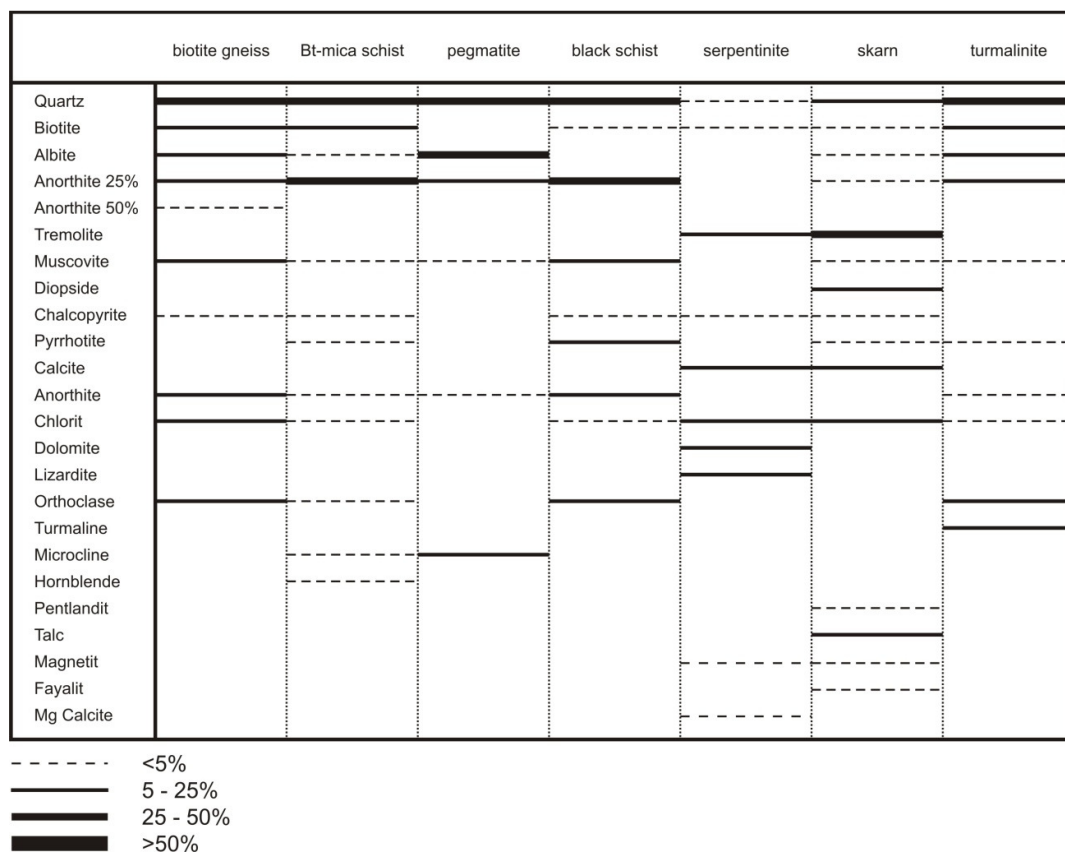


Figure 4.2, Mineralogical composition of the different lithologies measured with XRD

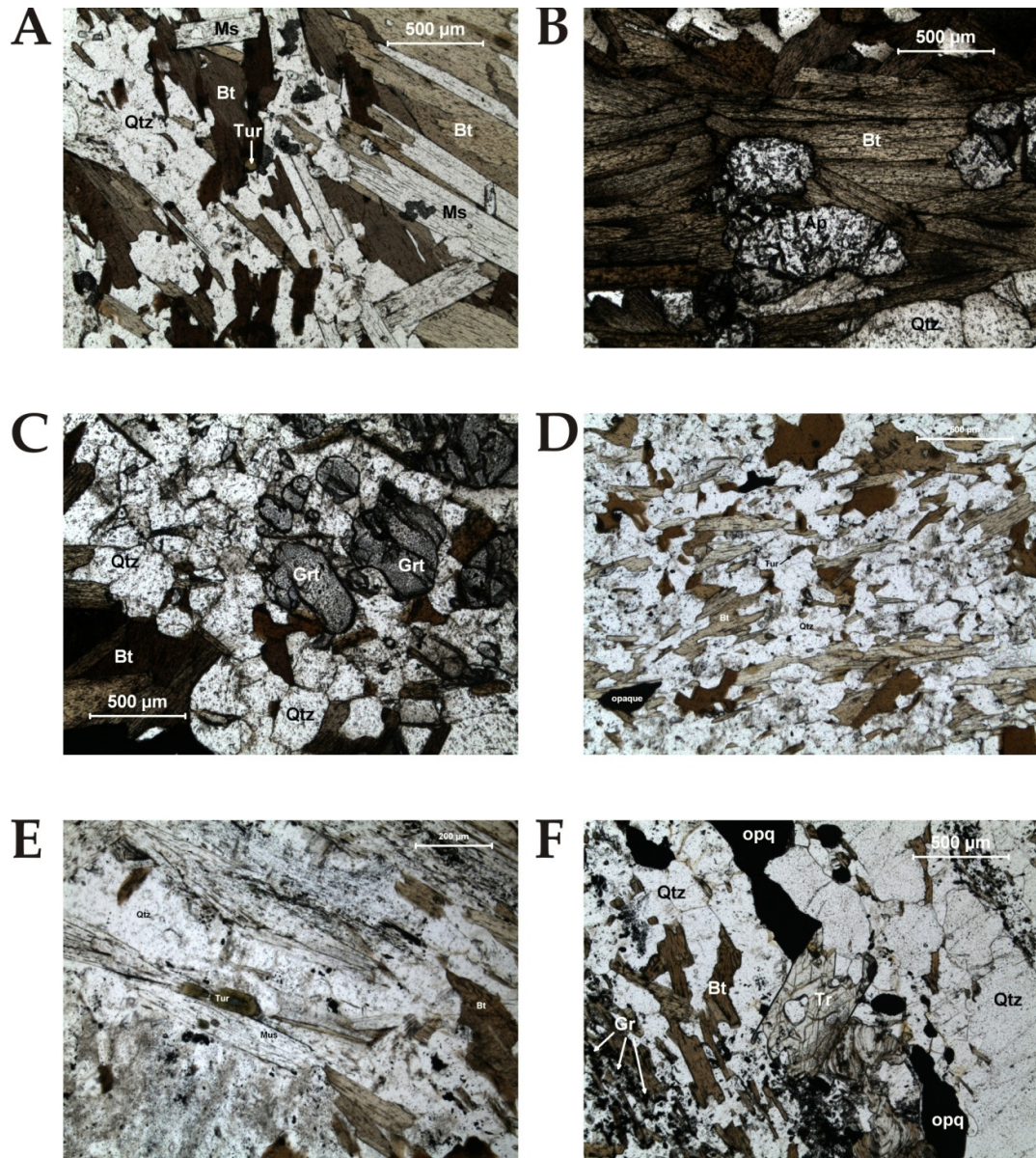


Figure 4.3, Microscope pictures of typical metasediments; mineral abbreviations according to Siivola & Schmid (2007); A) fine grained bt-mica schist with bt, qtz, plag, ms and tur; B) ap-bearing bt-mica gneiss; C) grt-bearing bt-mica schist; D) fine grained bt-mica schist, overview; E) ms-rich bt-mica schist; F) tr and gr-bearing bt-mica gneiss

Biotite defines bedding planes and/or foliation and is partly replaced by chlorite (Figure 4.3). Biotite mica schist shows a higher biotite content than biotite gneiss. The chemical composition of biotite shows intermediate annite - phlogopite composition (Figure 4.4), with Mg numbers between 0.45 and 0.61 and Al^{IV} of around 2.4. One sample shows a phlogopite-rich composition. The Ti content only shows a small increase with depth within the borehole. The F content is around 0.17 mass%. Cl is low and close to the limit of detection, <0.01 mass%.

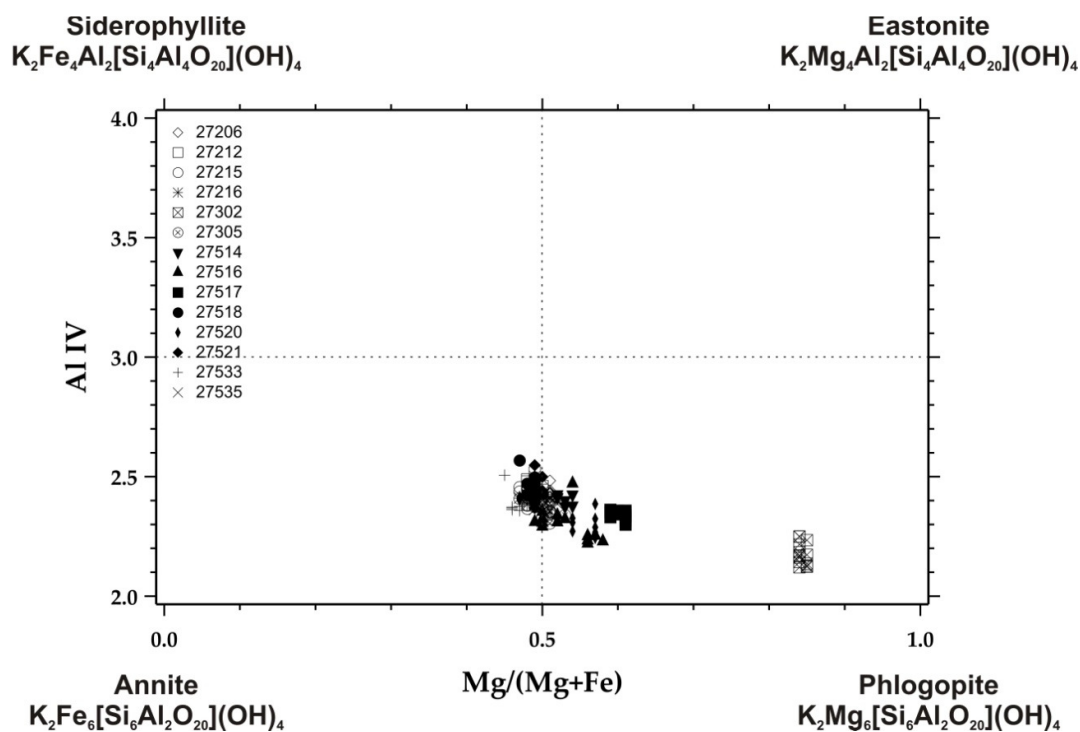


Figure 4.4, Biotite classification of the metasediments as a function of X_{Mg} and tetrahedral Al (Deer et al., 1992)

Fine-grained quartz, plagioclase, and alkali feldspar are orientated along bedding planes and/or foliation. Some quartz grains show undulous extinction and incipient recrystallisation. Plagioclase is rarely replaced by white mica and alkali feldspars show signs of incipient alteration. Plagioclase measurements show a high albite content and plot within the field of oligoclase and andesine, while some analyses can be addressed as labradorite (Figure 4.5). The potassium content is below 0.04 mass%. Potassic feldspars, with an orthoclase content of around 90 mol%, plot within the sanidine field.

The rare occurring garnets show almandine-rich compositions with rarely occurring Mn-rich rims. X_{alm} values are between 52 and 70 mol%. The amount of the other components is highly variable with X_{adr} between 0 and 6 mol%, X_{grs} between 0.5 and 29 mol%, X_{prp} between 4 and 11 mol%, and X_{sps} between 4.4 and 18 mol%. The chemical composition shows no correlation with depth within the borehole but X_{grs} and X_{prp} seem to correlate with the CaO and MgO content of the whole rock; due to the rare occurrence of garnet within the samples it was not possible to give a statistical statement. Mineral chemical analyses from Hölttä & Karttunen (2011) show a similar picture.

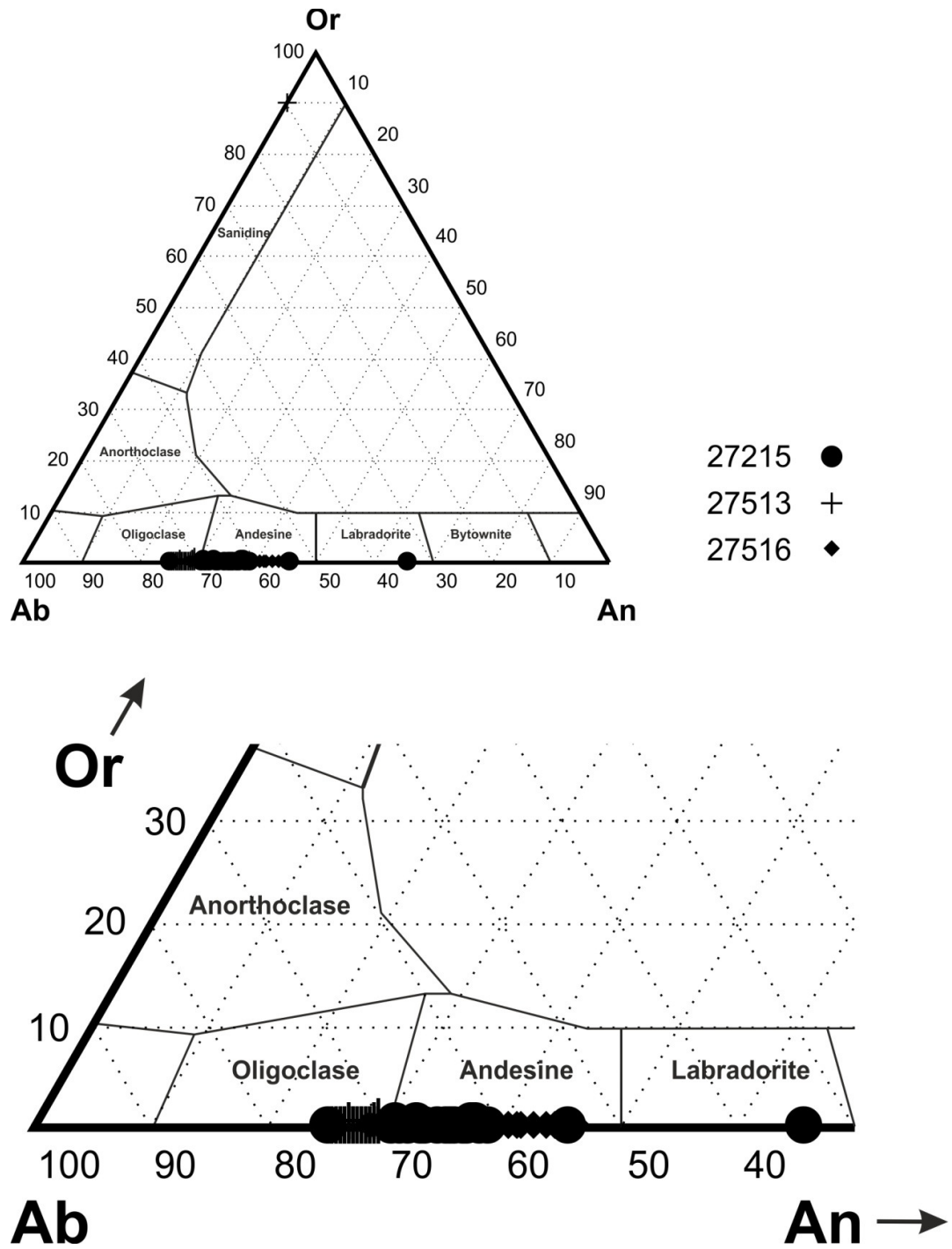


Figure 4.5, Ternary classification diagram Ab-An-Or for feldspars of the metasediments

Outokumpu assemblage

The mineralogy and texture of the ultramafic rocks of the Outokumpu assemblage show an amphibolite facies overprint (Peltonen et al., 2008). The samples studied are addressed as serpentinites and skarn rocks. Microscopically, serpentine, calcite, Mg-

chlorite and sericite can be distinguished (Figure 4.6). In most of the samples serpentine is replaced by carbonate phases, most likely calcite. This secondary carbonatization can also be observed within the skarn rocks and the metasediments, which are close by to the rocks of the Outokumpu assemblage (Figure 4.6). Because of the strong serpentinisation, the later carbonatization, and the metamorphic conditions, no relicts of the primary magmatic minerals could be identified. In addition, magnetite, pyrite, chalcopyrite, pentlandite, and graphite occur as opaque phases (Figure 4.7). The skarn rock mainly consists of diopside and tremolite, which are arranged in a herringbone pattern. Talc, carbonates, and opaque phases are also present.

The skarn rocks are often cut by calcite veins. The opaque phases, like pyrrhotite and chalcopyrite, replace the primary minerals. Pyrrhotite is intergrown with pentlandite. Both minerals are replacing a first generation of magnetite. A second magnetite generation is oriented at the rims of the pyrrhotite pentlandite grains. Detailed mineral analyses with XRD and Rietveld technique are shown in figure 4.2. The composition of the amphiboles and the pyroxenes within the skarn rocks is illustrated in figures 4.8 and 4.9.

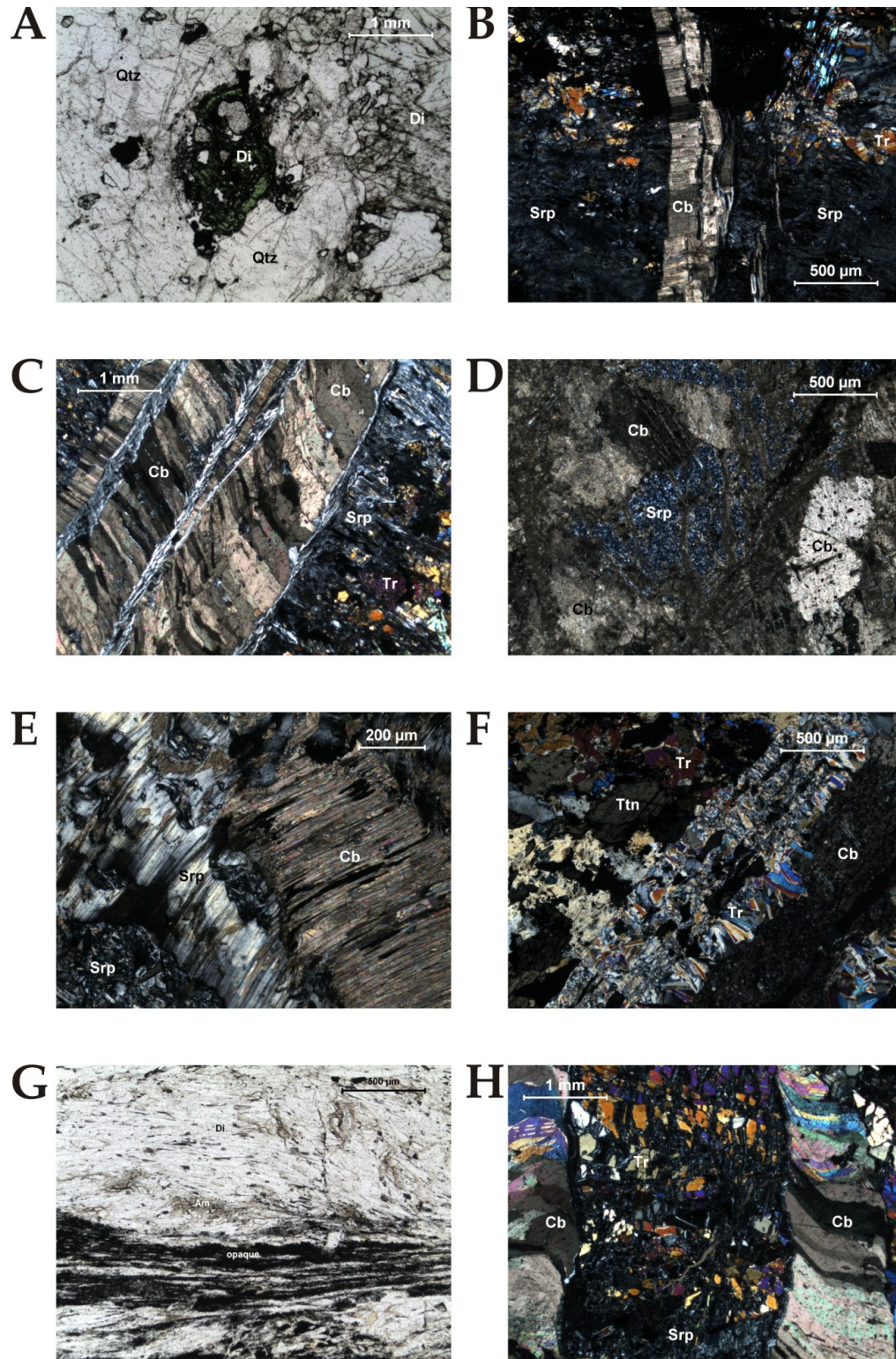


Figure 4.6, Microscope pictures of typical rocks of the Outokumpu assemblage; mineral abbreviations according to Siivola & Schmid (2007); A) Qtz-bearing di-rich skarn rock with cr-di in the centre; B) srp and tr-bearing meta-ultramafic rock with a cb-vein; C) srp and tr-bearing meta-ultramafic rock with a calcite vein replacing srp; D) srp replaced by cb; E) srp vein replaced by cb; F) tr-di skarn with ttn and cb; G) di and tr arranged in herringbone pattern with opaque phases; H) srp-bearing tr-di skarn penetrated by cd veins

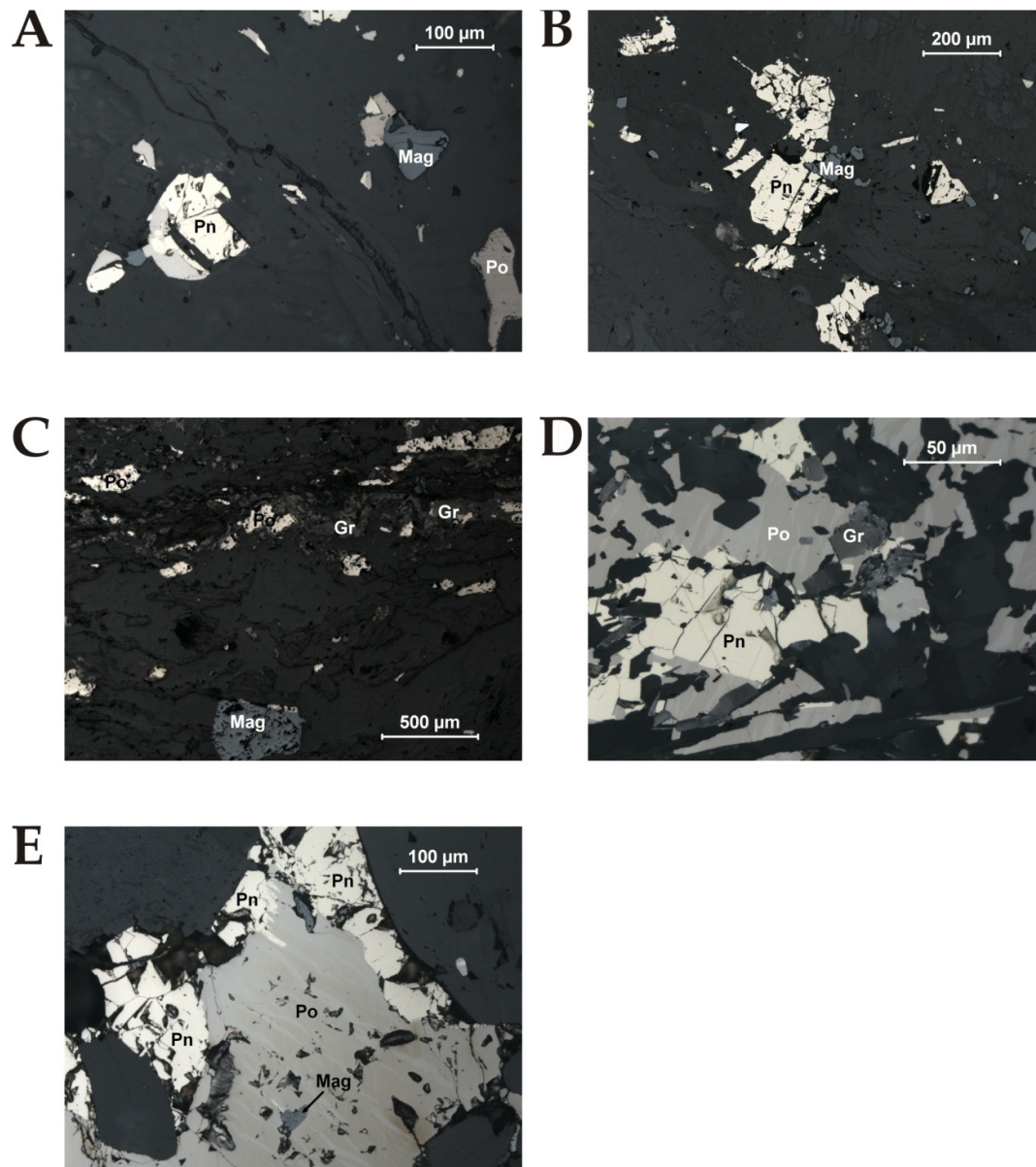


Figure 4.7, Microscope pictures of ore minerals within rocks of the Outokumpu assemblage; mineral abbreviations according to Siivola & Schmid (2007); A) pn and po with secondary mag; B) fine grained pn with mag; C) gr and po with “porous” primary mag; D) large areas of po-pn-gr; E) po-pn intergrowth with primary mag in the centre

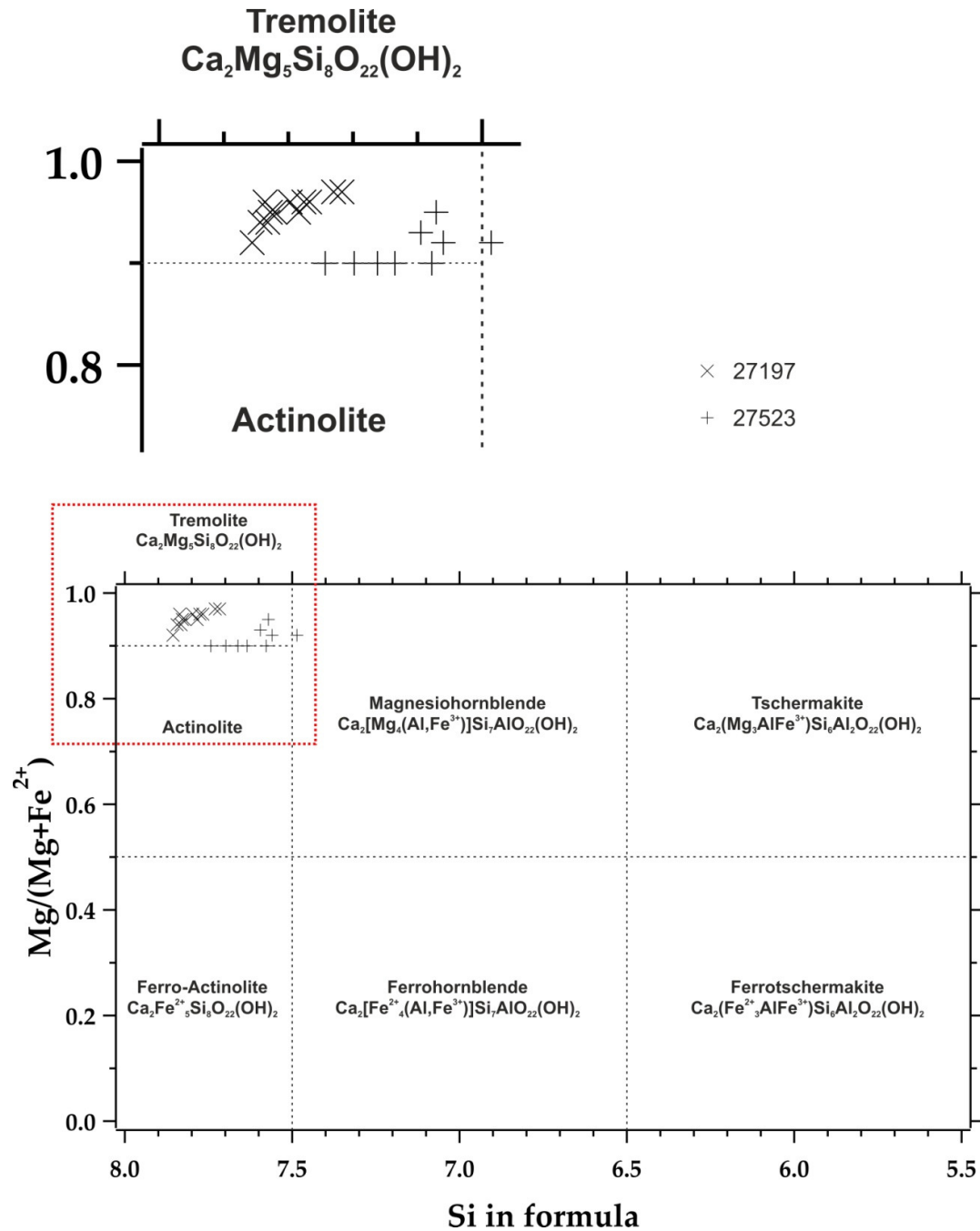


Figure 4.8, Amphibole classification diagram after Leake et al. (1997)

The amphiboles are calcic amphiboles and belong to the tremolite – ferro-actinolite series. They show a tremolite-rich composition with $X_{\text{Mg}} > 0.9$, close to magnesiohornblende and actinolite. Their Na content is below 0.23 mass%.

Pyroxene shows diopside composition with an elevated Cr content in some grains. One grain can be defined as Cr-diopside, which plots in the ternary enstatite-ferrosilite-wollastonite diagram, and is located in the augite field.

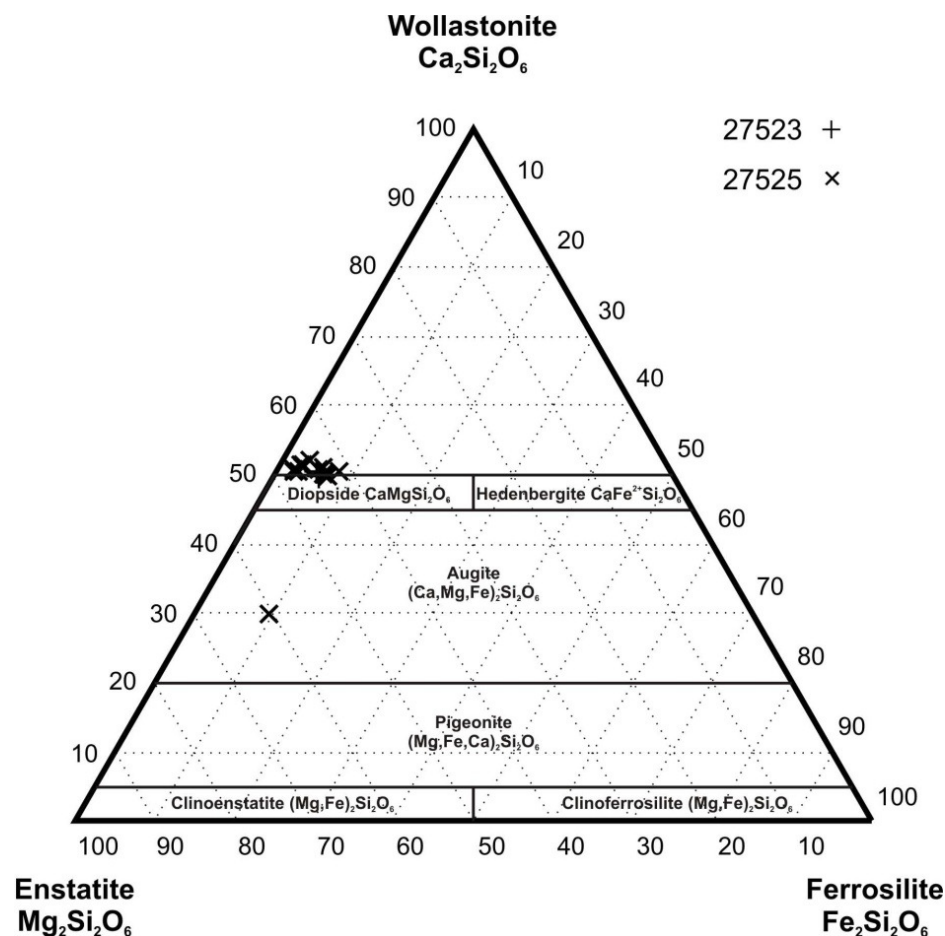


Figure 4.9, Pyroxene classification diagram (Morimoto, 1988)

Pegmatitic granite

The pegmatitic granites appear in the lower part of the drill hole, below the rocks of the Outokumpu assemblage. They occur as cross-cutting dykes within the metasediments with a thickness of a few cm up to massive lenses with a thickness of more than 100 m.

The pegmatites and pegmatitic granites consist of alkali feldspar, plagioclase, muscovite, quartz, and partly garnet. Apatite, epidote, and opaque phases are accessory constituents. Quartz shows partly undulous extinction and no grain size

reduction has been observed that would have been caused by recrystallization. The strip-shaped plagioclase shows beginning alteration and a myrmekitic intergrowth with quartz. Alkali feldspar is not as strongly altered as plagioclase and muscovite forms large crystals within the interstices (Figure 4.10).

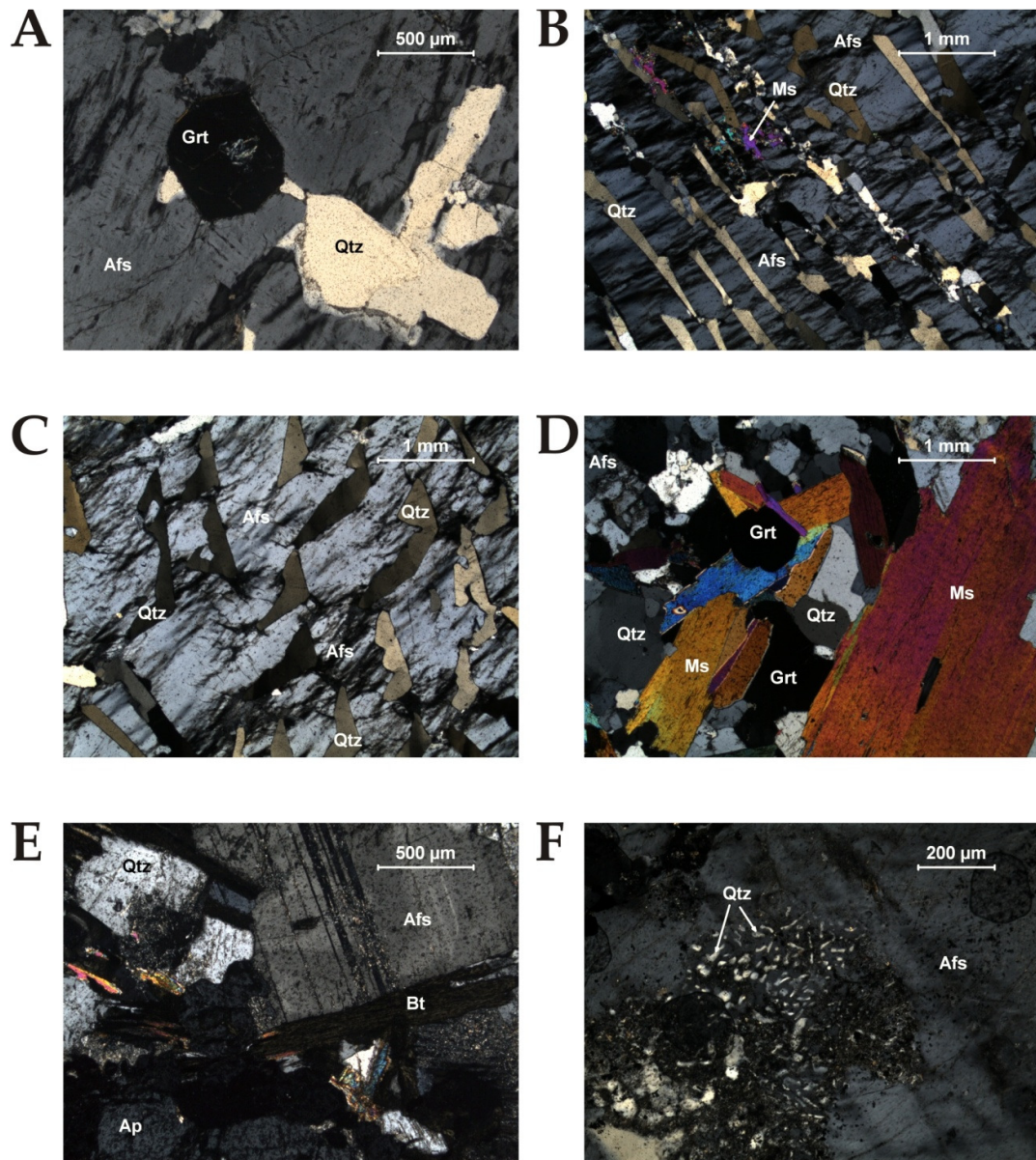


Figure 4.10, Microscope pictures of typical pegmatitic granites; mineral abbreviations according to Siivola & Schmid (2007); A) grt; B + C) graphic intergrowth of afs and qtz; D) ms-rich pegmatitic granite; E) ap and bt-bearing pegmatitic granite F) myrmekitic intergrowth between qtz and afs

Two different types of plagioclase can be distinguished with microprobe analyses (Figure 4.11). One type is defined by an albite rich composition ($X_{ab} = 95 - 99$). It occurs together with the K-feldspars and forms perthitic lamellae. A second albite rich type

($X_{ab} = 78 - 87$), which plots mainly in the oligoclase field, forms separate crystals. The amount of Fe, Mn, Mg, Ba is low, close to the detection limit. The plagioclase grains show no zonation. The anorthite content of the pegmatites is lower than in the metasediments.

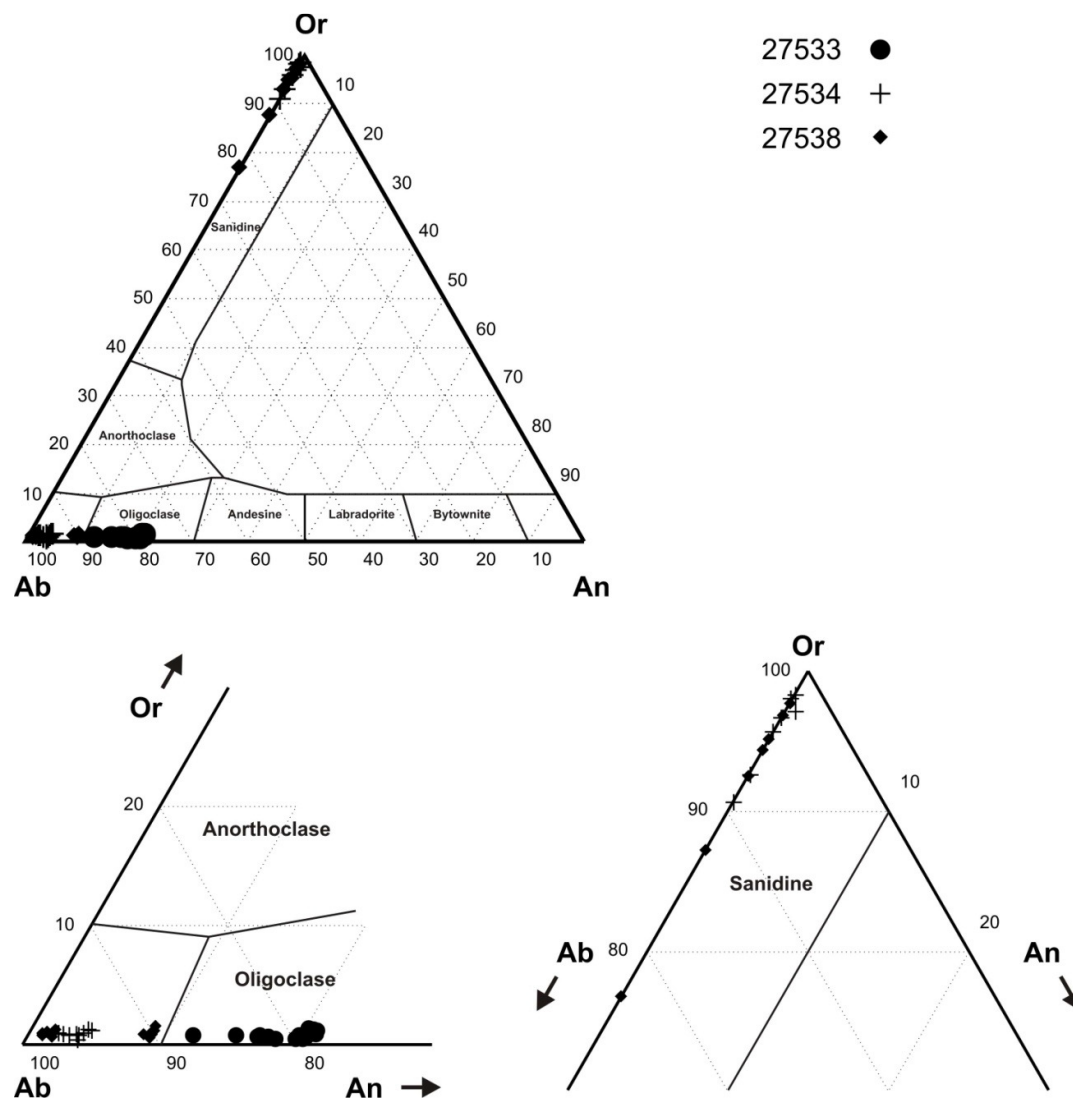


Figure 4.11, Ternary classification diagram Ab-An-Or for feldspars of the pegmatitic granite

The detected white micas can be classified as muscovite due to microprobe analyses (Figure 4.12). The only elevated elements are FeO with around 1.2 mass%, MgO with 0.5 mass%, Na₂O with 0.6 mass% and TiO₂ with 0.5 mass%. The F content is below 0.2 mass%. Other possible cations (Li, Cr, Cs, Rb, and Ba) are below the detection limit.

According to Hölttä & Kerttunen (2011), the rare occurring garnet clearly differs from the garnets within the metasediments. The garnets show almandine-spessartine-rich composition with low Mg and Ca content (Hölttä & Kerttunen, 2011).

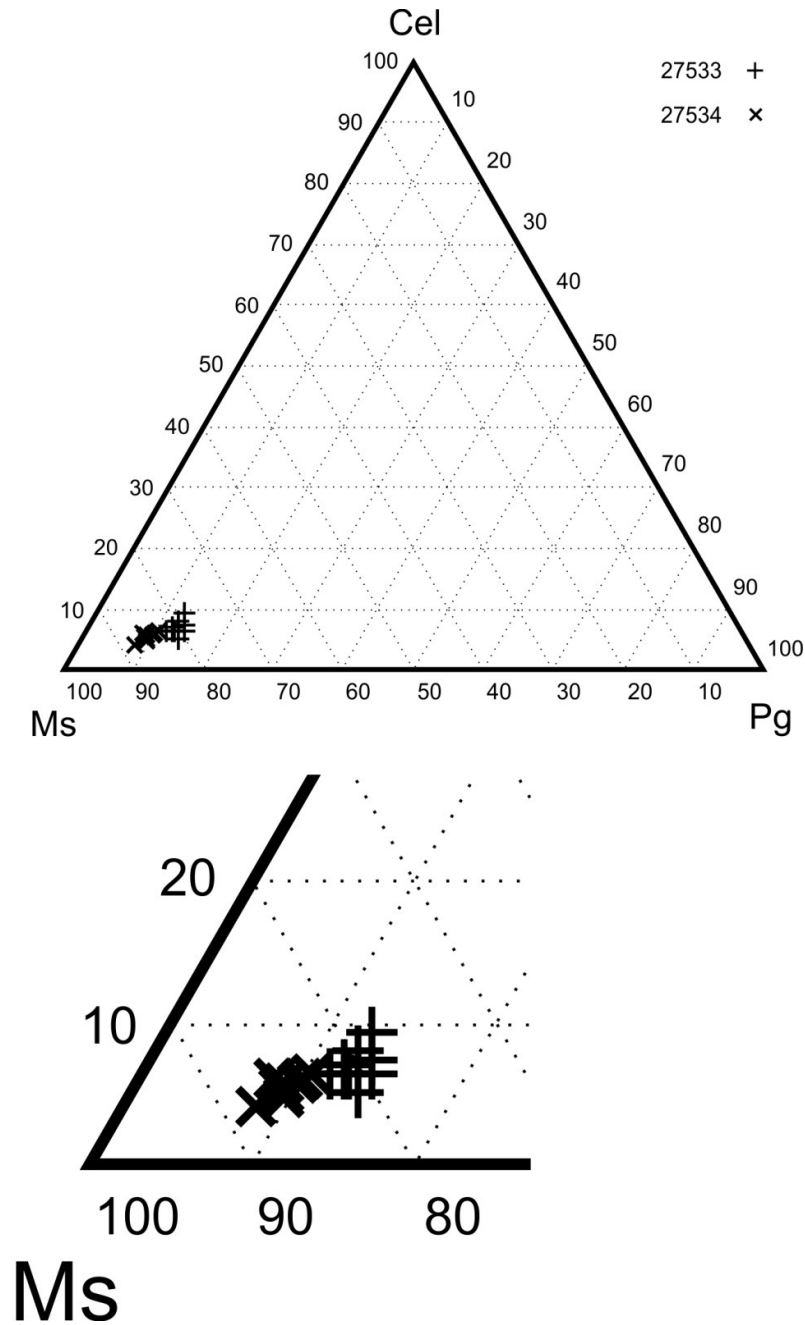


Figure 4.12, Ternary ms-cel-pg diagram for white micas of the pegmatitic granites

Additional Lithologies

In addition to these main lithologies, other, strongly carbonatized rock types and one sample, which have been identified as tourmalinite, was found (Figure 4.13).

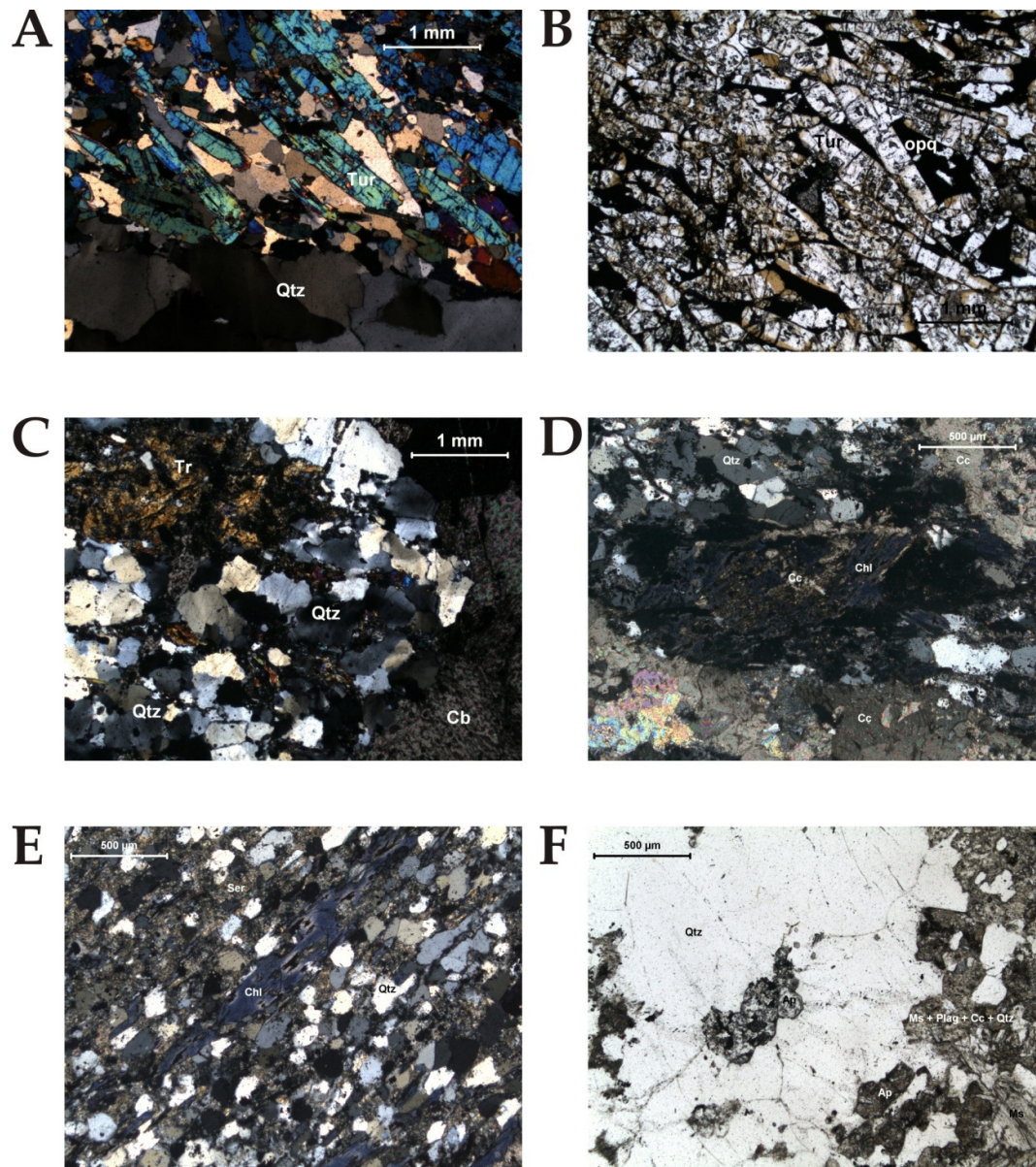


Figure 4.13, Microscope pictures of typical samples of the additional lithologies; mineral abbreviations according to Siivola & Schmid (2007); A + B) tourmalinite with qtz vein; C + D + E + F) strongly carbonatized metasediment with cb veins

The strong secondary carbonatization occurs within all lithologies except the pegmatitic granites. Metasediments show an increase in titanite and apatite, whereas nearly all biotite is completely transformed to chlorite, which is partly replaced by carbonate minerals. The chlorites within the carbonatized metasediments show blue to violet interference colors, which is typical for iron-rich varieties. Their FeO content is around 24 mass% and MgO around 15 mass%. Due to preparation issues it was not possible to measure chlorites within the rocks of the Outokumpu assemblage, but their brown interference colors suggest Mg-rich composition. Their TiO₂ content is (0.03 mass%) significantly below the original biotites.

4.2) Geochemistry

40 samples of all occurring lithologies were analyzed with XRF technique to determine the main and trace element composition. A detailed list of the samples can be found in the appendix.

The metasediments of the upper Kaleva are considered to be deep marine metaturbiditic greywackes with thick intercalations of black schists (Peltonen et al., 2008).

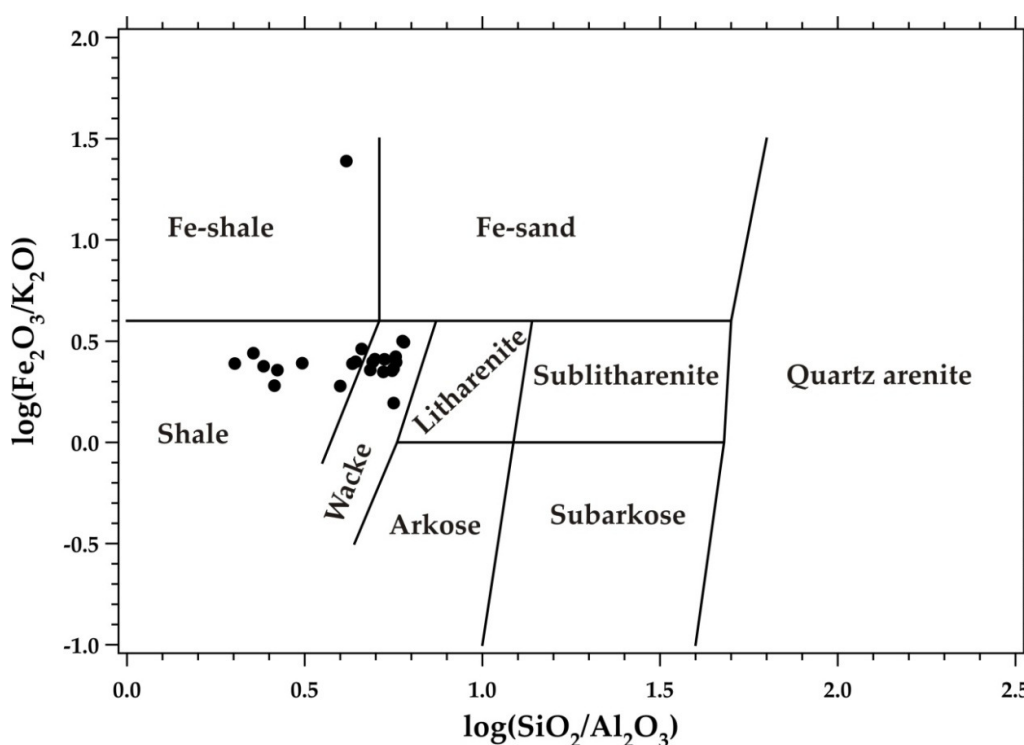
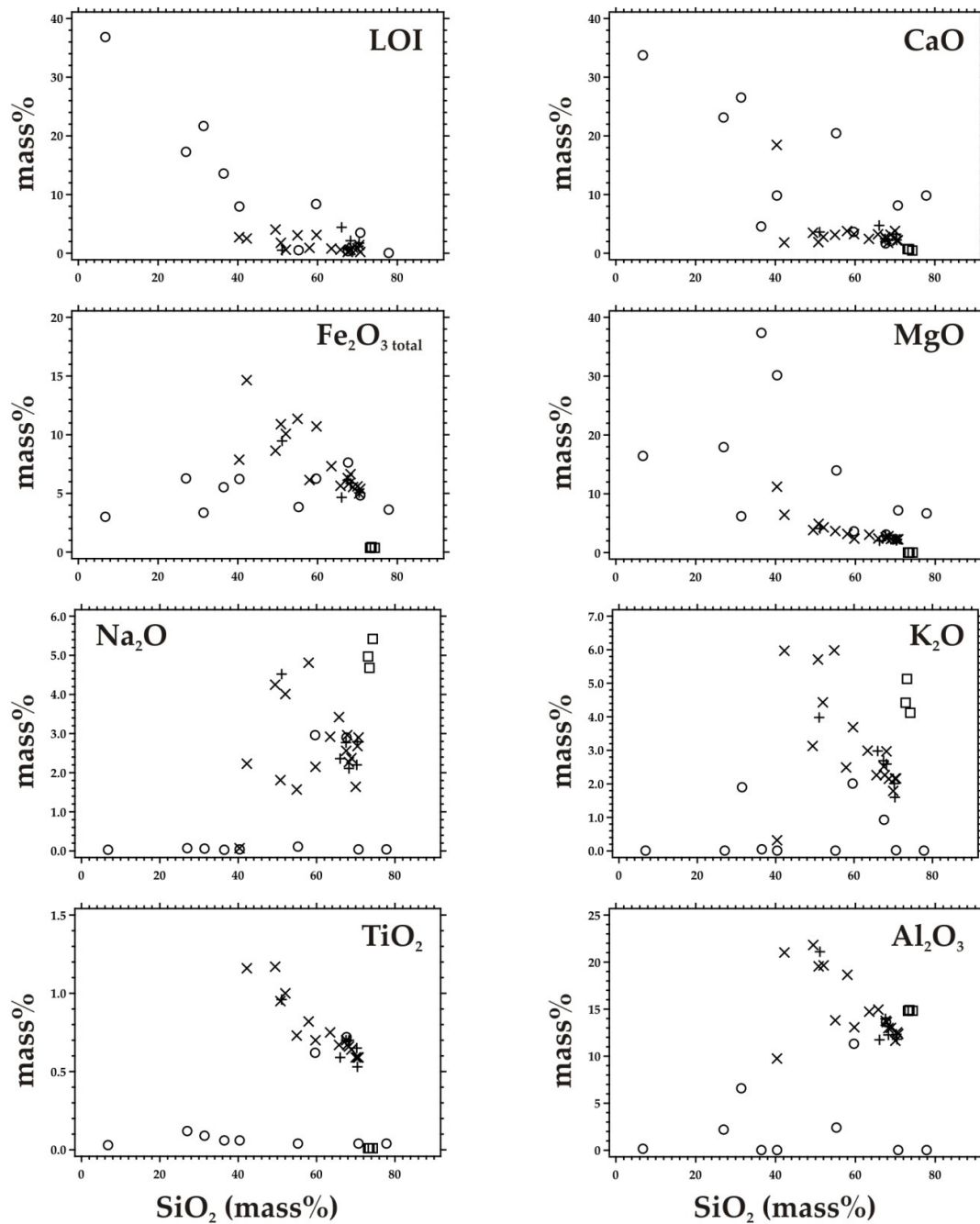


Figure 4.14, Metasediments plotted in the classification diagram of terrigenous sandstones and shales by Herron, 1988

Within the classification diagram after Herron (Figure 4.14), most of the biotite mica schist and biotite gneisses plot within the Wacke and the Shale field. The Shale is defined by a very low $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio, which can be observed in many mica schist samples.



- + Bt-Gneiss
- x Bt-Schist
- o ORA
- Peg

Figure 4.15, Harker variation diagrams from all occurring lithologies

The SiO_2 content of the biotite gneiss is in average higher than of the biotite mica schists. The values of the gneiss plot between 51 and 70 mass%, whereas the SiO_2 concentrations within the mica schist range from 40 to 70 mass%. Al_2O_3 , Fe_2O_3 , and TiO_2 show negative covariation with SiO_2 (Figure 4.15). Compared to the Outokumpu

rock assemblage (ORA), the metasediments are enriched in K_2O and Na_2O . Both elements show no covariation with SiO_2 . The carbonatized metasediments show a higher CaO and MgO content with the lowest SiO_2 concentrations. They are also depleted in K_2O , Na_2O and Al_2O_3 , whereas the elements show no sign of covariation.

The rocks of the Outokumpu assemblage are defined by low concentrations of Na_2O , K_2O , TiO_2 and Al_2O_3 . The SiO_2 content is highly variable between 6 mass% (serpentine) and 70 mass% (quartz rock, skarn rock) due to the different rock types present (serpentinites, skarn rocks, quartz rocks). They show enrichment in CaO and MgO compared to the other lithologies. Samples with higher MgO content often show depletion in CaO and vice versa. This can be explained by the fact that some samples show a stronger carbonatization than others. A negative covariation of the LOI, CaO and MgO against SiO_2 can be observed. Fe_2O_3 is constant between 3 and a maximum of 7 mass% (Figure 4.15).

As mentioned above, the granitic pegmatites occur in the lower part of the drill hole. Västi (2011) distinguishes tonalitic pegmatite granite, which can be subdivided into muscovite-rich and muscovite-poor types, and granodioritic pegmatite granite, based on the Streckeisen classification.

The SiO_2 content of the pegmatitic granites varies between 73 and 75 mass%. Other major elements, Na_2O , K_2O , and Al_2O_3 , show no variations in concentration (Figure 4.15). CaO , Fe_2O_3 , MgO , and TiO_2 show very low concentrations below 1 mass%. In the Na_2O versus K_2O diagram after Chappell and White (1974, 1992; Figure 4.16), the samples plot within the field of I-type granites, except some measurements of Västi (2011), which can be defined as S-type granites.

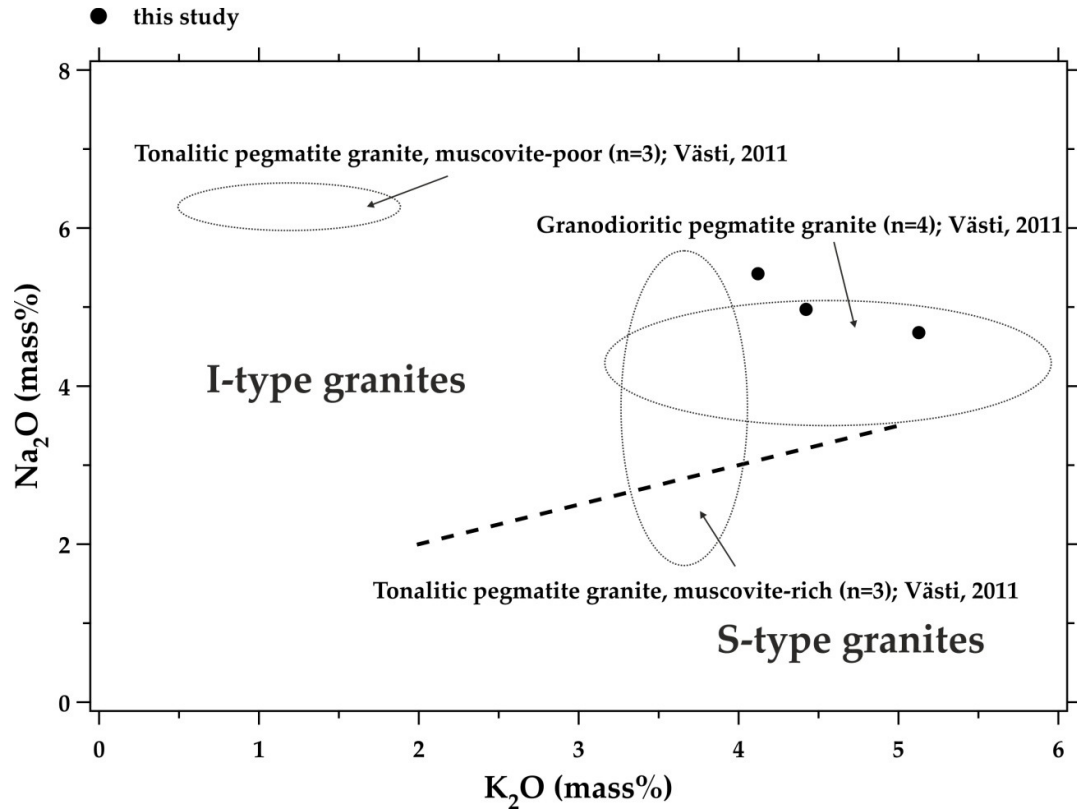


Figure 4.16, Granite classification after Chappell and White (1974; 1992)

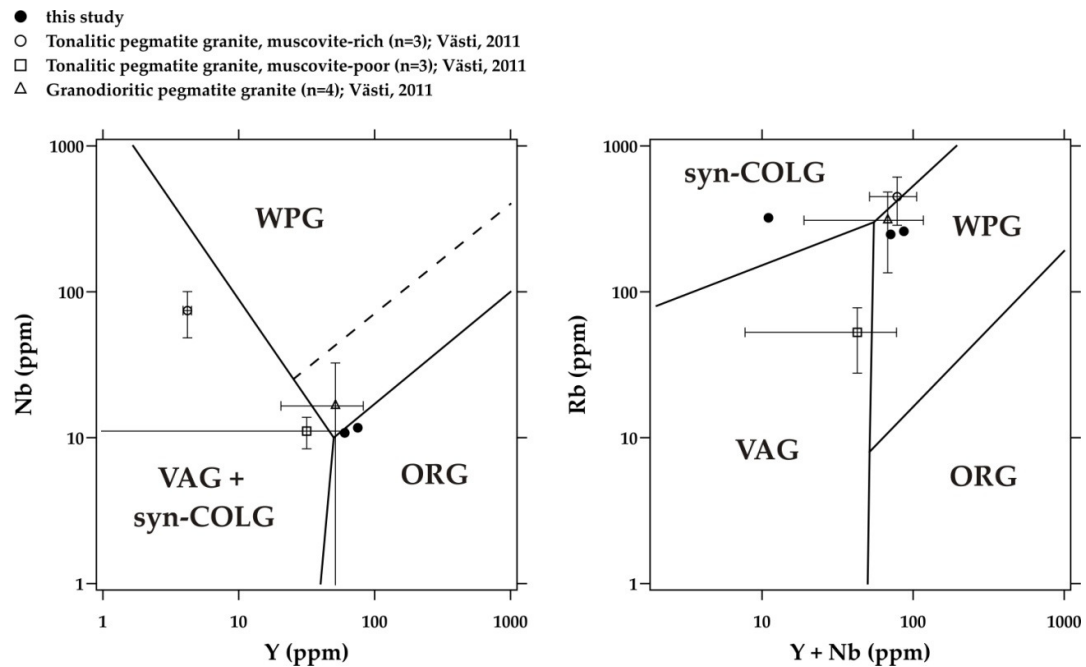


Figure 4.17, Nb – Y and Rb – (Y+Nb) discrimination diagram for the tectonic setting of granites after Pearce et al. (1984). Volcanic-arc granites (VAG), syn- collisional granites (syn-COLG), within-plate granites (WPG), and ocean-ridge granites (ORG)

According to Pearce et al. (1984), different granite types can be classified according to their tectonic setting.

- Ocean-ridge granites (ORG)
 - Granites associated with normal ocean ridges
 - Granites associated with anomalous oceanic ridges
 - Granites associated with back-arc basin ridges
 - Granites associated with fore-arc basin ridges
- Volcanic-arc granites (VAG)
 - Granites in oceanic arcs dominated by tholeiitic basalt
 - Granites in oceanic arcs dominated by calc-alkali basalt
 - Granites in active continental margins
- Within-plate granites (WPG)
 - Granites in intracontinent ring complexes
 - Granites in attenuated continental crust
 - Granites in oceanic islands
- Collisional granites (COLG)
 - Syn-tectonic granites associated with continent-continent collision
 - Post-tectonic granites associated continent-continent collision
 - Syn-tectonic granites associated with continent-arc collision

A clear classification cannot be done with the Nb – Y and Rb – (Y+Nb) discrimination diagram for the tectonic setting of granites as the samples plot not only in the WPG and syn-COLG field (Figure 4.17), some points can also be found in the ORG field. According to Rollinson (1993), post-orogenic granites cannot be distinguished from VAG type and syn-COLG type granites with these discrimination diagrams.

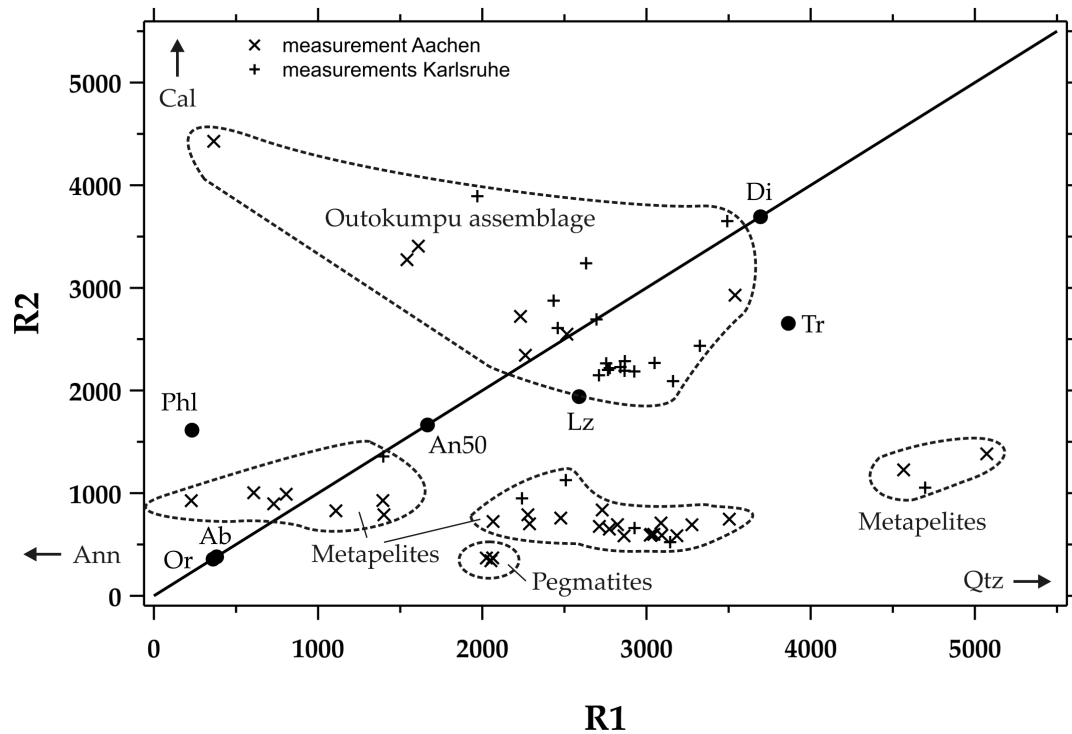


Figure 4.18, Multi-cation plot of major element composition of rocks of the Outokumpu drill hole according to de la Roche (1980); Ab = albite, An = anorthite, Ann = annite, Cal = calcite, Di = diopside, Lz = lizardite, Or = orthoclase, Phl = phlogopite, Qtz = quartz, Tr = tremolite (Siivola & Schmid, 2007); $R1 = 4Si - 11(Na + K) - 2(Fe + Ti)$, $R2 = 6Ca + 2Mg + Al$ (element in millimoles/100g). Measurements from the University of Karlsruhe by F. Dietzel (unpublished)

Major element characteristics of the lithologic units of the Outokumpu drill hole are displayed in Figure 4.18 and reflect the mineralogical composition. Metapelites show various abundances of biotite and quartz, whereas the Outokumpu assemblage tend to Ca- and Mg-rich compositions due to high modal abundance of lizardite, chlorite, calcite, tremolite, and diopside. The pegmatite samples analyzed have similar proportions of feldspars and quartz as major modal components, leading to a confined compositional space in Figure 4.18.

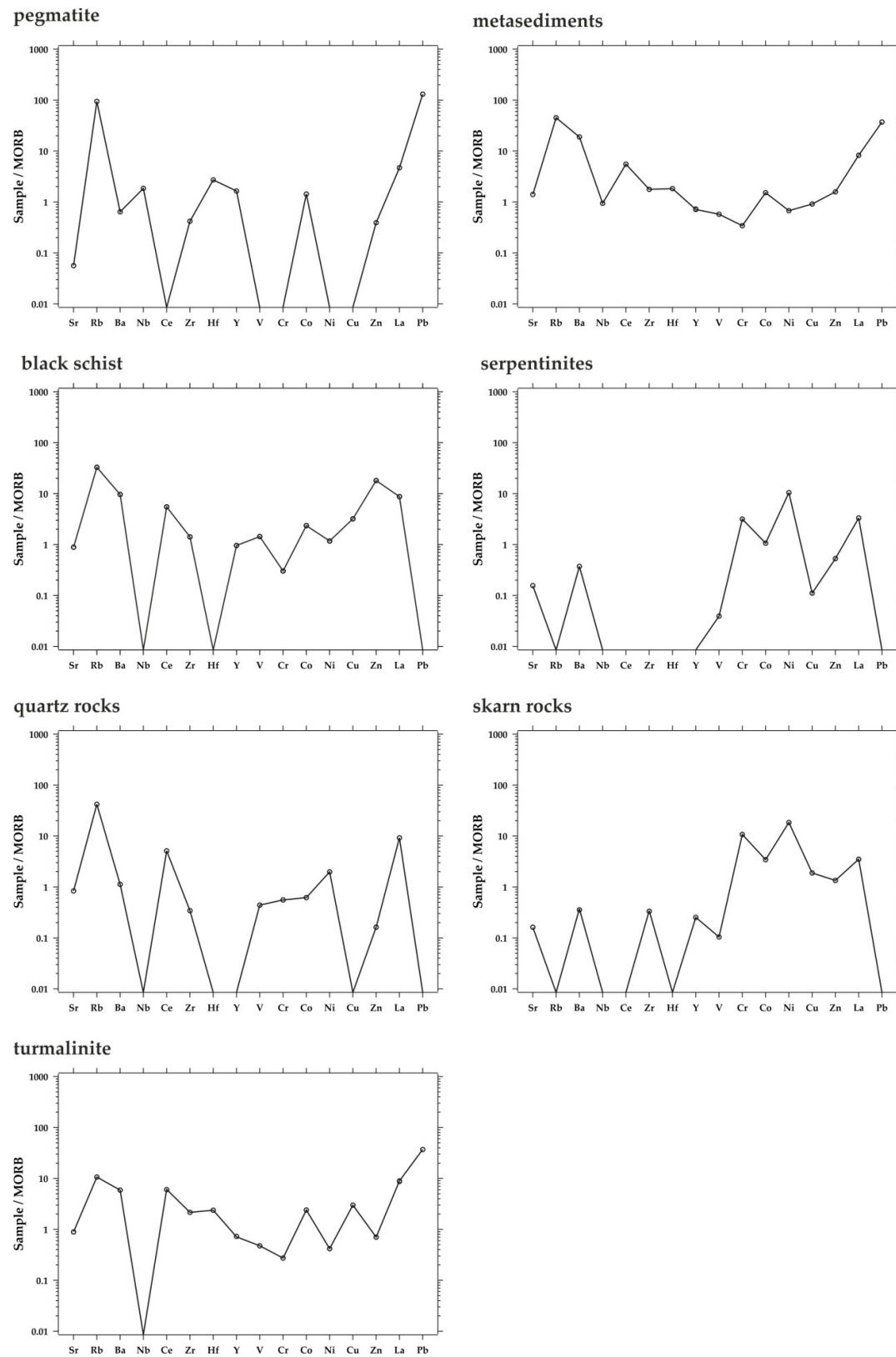


Figure 4.19, MORB normalized (MORB data from Kelemen et al., 2004) trace element data of the different lithologies

It is also possible to distinguish the different lithologies with trace element data. Figure 4.19 shows the MORB normalized (MORB data from Kelemen et al., 2004) trace element data of the different lithologies. The pegmatites are characterized by elevated Rb and Pb contents and depletion in Ce, V, Cr, Ni, and Cu. The lithologies within the Outokumpu rock assemblage (serpentinites, skarn rocks and quartz rocks) show strong enrichment in Cr and Ni. Co also shows higher concentrations, which are in the range of the other samples. The trace element pattern of the serpentinites and the skarn rocks are similar, whereas the quartz rocks show higher Rb and Ce concentrations. The metasediments, black schists, and the tourmalinite show similar patterns, except the Nb and Hf depletion of the black schists and the Nb depletion of the tourmalinite.

The value for the chemical index of alteration (CIA; Nesbitt & Young, 1982) reflects the main mineral composition of the sample. Unaltered albite, anorthite, and potassic feldspars show values of 50; the value for diopside is 0 (Nesbitt & Young, 1982). The values for granites and granodiorites are between 45 and 55 (Nesbitt & Young, 1982). Muscovite and illite range from 75 to 85, whereas kaolinite and chlorite show highest values close to 100 (Nesbitt & Young, 1982). Typical values for average shales range from 70 to 75.

The CIA shows values from 55 to 68 for metasediments, around 59 for the pegmatitic granites, and 0 to 20 for the rocks of the Outokumpu assemblage. Because there is no change of the CIA values against depth, it can be assumed that the source rocks show only weak to moderate alteration or weathering. The values are mainly controlled by the different mineralogy of the rock types. The rocks of the Outokumpu assemblage show lower values due to the high carbonate content, whereas the metasediments reflect the composition of the protolith, which are mainly greywackes and shales. Pegmatitic granites show no sign of alteration; only the muscovite content elevates the value above the predefined values of Nesbitt & Young (1982).

4.3) Thermobarometry

Various mineral and isotopic thermometers were applied to obtain an understanding on the formation temperatures of the lithologies occurring in the drill core. This data, together with the microthermometrical measurements of fluid inclusions enabled the construction of a P-T path.

Stable isotope thermometer

The isotope thermometer used is based on the exchange of oxygen isotopes between biotite and quartz. The formula from Bottinga and Javoy (1975) was applied to calculate the temperatures.

Bottinga and Javoy (1975) used a dataset on naturally occurring oxygen isotope fractionation among coexisting minerals in igneous and metamorphic rocks to formulate an expression for the temperature dependence of the isotopic disproportionation among the minerals quartz, feldspar, pyroxene, olivine, garnet, muscovite, biotite, amphibole, ilmenite and magnetite. This thermometer is valid for temperatures above 500 °C (Bottinga & Javoy, 1975).

This thermometer is based on the temperature dependence of the fractionation factor of oxygen. This fractionation factor can be described by

$$a(X,Y) = \left(\frac{O^{18}}{O^{16}}\right)_x / \left(\frac{O^{18}}{O^{16}}\right)_y$$

$(O^{18}/O^{16})_x$ is the atomic oxygen isotope ratio for the phase X, which is in isotopic exchange equilibrium with the phase Y, which is described by $(O^{18}/O^{16})_y$ (Bottinga & Javoy, 1975).

Isotopic ratios are usually expressed in the δ notation where:

$$\delta_X = \left[\frac{\left(\frac{O^{18}}{O^{16}} \right)_x}{\left(\frac{O^{18}}{O^{16}} \right)_{SMOW}} - 1 \right] \times 1000$$

The isotopic fractionation between two minerals X and Y is given by $\Delta(X,Y) = \delta_x - \delta_y$, which also can be expressed as $\Delta(X,Y) \approx 1000 \ln \alpha(X,Y)$ (Bottinga & Javoy, 1975).

Two different formulas of Bottinga and Javoy (1975) describe the temperature dependence of the fractionation factor of oxygen:

$$1000 \ln \alpha(X,Y) = B_{XY}/T^2 \quad (1)$$

$$1000 \ln \alpha(X,H) = A_{XH} + B_{XH}/T^2 \quad (2)$$

Where T is the absolute temperature in °C, B_{XY} , A_{XH} and B_{XH} (table 4.1) are constants and H refers to a hydroxyl bearing silicate. Equation (1) is used for nonhydrous silicates or magnetite, whereas for minerals containing hydroxyl groups, equation (2) is used.

Table 4.1, Coefficients for the fractionation equations (1) and (2) (Bottinga & Javoy, 1975)

X	A	B
Quartz	—	-1.594
Feldspar	—	1.040
Pyroxene	—	1.076
Olivine	—	2.316
Garnet	—	1.286
Muscovite	-0.60	0.606
Amphibole	-0.30	1.554
Biotite	-0.60	2.096
Ilmenite	—	3.696
Magnetite	—	3.976

Next to the exact definition of the constants it is very important that the isotopic composition of the measured minerals represents equilibrium conditions. For this reason it is suggested to measure the isotopic composition of a third phase Z and calculate the mineral temperature from the three mineral pairs X – Y, Y – Z and Z – X. If these three temperatures are the same, it can be assumed that the mineral phases are in isotopic equilibrium (Clayton & Epstein, 1961; Bottinga & Javoy, 1975).

Oxygen isotopes from biotite and from quartz have been measured at the University of Lausanne under the supervision of Prof. Dr. Vennemann. The results of the measurements are displayed in table 4.2.

Table 4.2, $\delta^{18}\text{O}$ values for biotite and quartz, measured at the University of Lausanne

Sample	Depth [m]	$\delta^{18}\text{O}$ quartz [‰]	$\delta^{18}\text{O}$ biotite [‰]
05-OKU-91	584.55	12.6	6.9
05-OKU-91	584.55	12.0	6.7
05-OKU-88	711.50	12.8	7.6
05-OKU-88	711.50	12.5	7.5
05-OKU-93	887.30	12.5	7.9
05-OKU-93	887.30	12.8	7.6
05-OKU-22	1379.60	12.1	6.5
05-OKU-22	1379.60	12.6	7.5

The temperatures calculated with equation (2) vary between 504 °C for sample 05-OKU-91 and 546 °C for sample 05-OKU-93. The deepest sample, i. e. 05-OKU-22, shows a somewhat lower temperature of 514 °C. This appears to be inconsistent with the calculated temperatures increase with depth and could lead to the assumption that the measured mineral pairs are not in isotopic equilibrium.

Ti in biotite

The Ti in biotite geothermometer from Henry et al. (2005) uses the Ti content of biotite as a geothermometer for graphitic, peraluminous metapelites that contain ilmenite or rutile and have equilibrated at roughly 4–6 kbar.

With the use of an extensive data set of natural biotite samples from different locations in combination with the petrogenetic grid of Spear et al. (1999), the

relationship between the Ti content, temperature, and $Mg/(Mg + Fe)$ value was calibrated empirically (Henry et al., 2005). The shape of the Ti-saturation surface shows an increase of the Ti concentration as a function of the temperature for a given $Mg/(Mg + Fe)$ value and a decrease of the Ti concentration for a given temperature with an increase in $Mg/(Mg + Fe)$ (Henry et al., 2005).

Ti is incorporated into biotite by at least two substitution mechanisms. In magnesian biotite, Ti primarily substitutes via a Ti-tschermaks substitution controlled by octahedral-tetrahedral layer misfit. However, at intermediate X_{Mg} , Ti-deprotonation substitution becomes the dominant mechanism for Ti incorporation, particularly at metamorphic grade above the staurolite zone where is significant reduction of activity of H_2O in the metamorphic fluid from graphite-bearing metapelites (Henry et al., 2005).

These substitution mechanisms can be described with the help of exchange vectors. Magnesium rich biotites ($X_{Mg} > 0.65$) incorporate Ti with $TiAl_2R_{-1}Si_{-2}$ where R is the sum of the divalent cations $Mg + Fe + Mn$. This substitution mechanism is due to the misfits of the octahedral and tetrahedral layers in magnesian biotites. The Ti concentration in intermediate biotites is consistent with the Ti-deprotonation $TiO_2R_{-1}(OH)_{-2}$ - exchange vector. This mechanism is largely controlled by the H_2O activity at higher metamorphic grades. An additional combination of the $TiO_2R_{-1}(OH)_{-2}$ and $RSiAl_{-2}$ exchange vector is described for low Al biotite, which causes an incorporation of significantly higher Ti concentrations relative to peraluminous biotite (Henry et al., 2005).

The Ti-saturation surface gives temperature information for biotites from peraluminous metapelites at low-to-medium pressures and is valid over a range of 480 to 800 °C with an estimated precision of ± 24 °C (Henry et al., 2005).

The temperature can be calculated with equation 3, which is an optimal surface fit for the Ti-saturation surface (Henry et al., 2005):

$$\ln(z) = a + bx^3 + cy^3 \quad (3)$$

where $x = T$ °C, $y = Mg/(Mg+Fe)$, and $z = Ti$ (apfu). The values for a, b, and c are parameters for the fit and are listed in table 4.3.

Table 4.3, Surface fit equation coefficients and statistical parameters

Coefficient	Value	Standard error	95% confidence limits
a	-2.3594	0.0141	-2.3870 to - 2.3317
b	$4.6482 \cdot 10^{-09}$	$5.1970 \cdot 10^{-11}$	$4.5461 \cdot 10^{-9}$ to $4.7503 \cdot 10^{-9}$
c	-1.7283	0.0584	-1.8432 to -1.6134

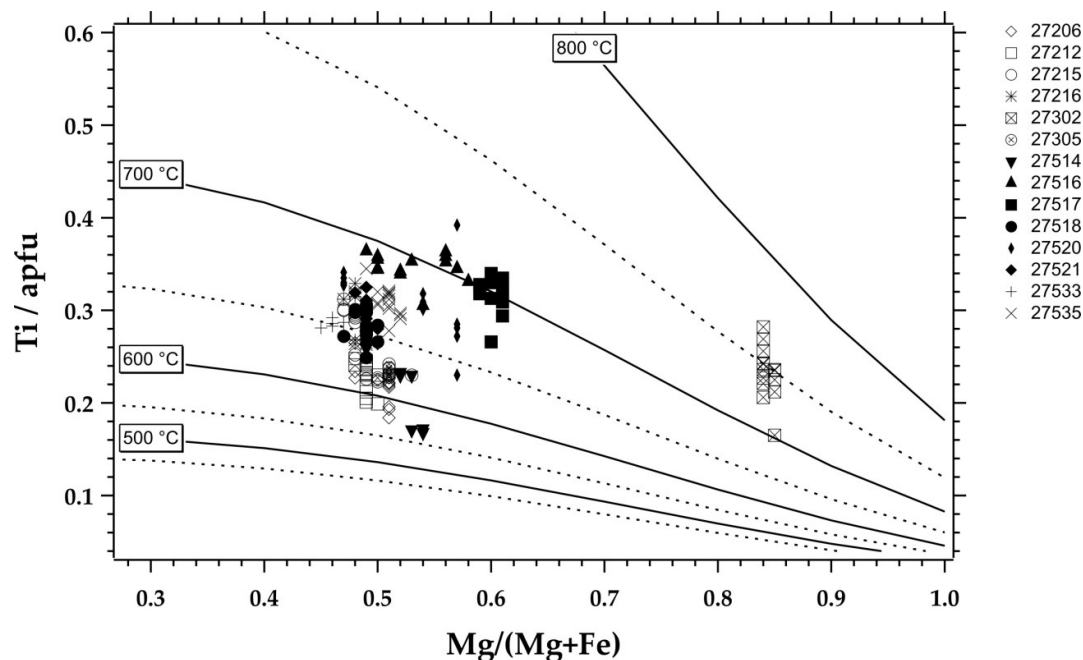


Figure 4.20, Ti in biotite geothermometer according to Henry et al. (2005)

The calculated temperatures plot mainly between 600 and 725 °C. The Mg rich samples show temperatures between 700 and 775 °C. The temperature difference of these two clusters, which show a similar Ti concentration, can be explained by different substitution mechanisms.

TitaniQ geothermometer - Ti in quartz

Ti has been measured in quartz with LA-ICP-MS technique. The Ti concentrations have been used to calculate a formation temperature of quartz with the formula of Wark & Watson (2006).

Wark and Watson (2006) describe the temperature dependence of the substitution of Ti in quartz in the form of a new geothermometer. Depending on the analytical technique, temperatures down to 400 °C can be calculated. The thermometer requires only the analysis of one phase. If rutile as a TiO_2 phase is present in equilibrium with

the quartz, precisions, which are usually better than ± 5 °C, can be achieved. If there is no rutile present the TiO_2 activity has to be estimated or has to be determined in some other way (Wark & Watson, 2006).

Trace elements within quartz can provide valuable clues to the crystallization conditions. Due to the fact that Ti occurs in relatively high concentrations within quartz (from 1 to over 100 ppm) and that it can substitute Si very easily without having to be charge balanced, it is an ideal element for geothermometry. Additionally the activity of Ti is fixed in many systems by the presence of a nearly pure TiO_2 phase, typically rutile (Wark & Watson, 2006).

The equilibrium constant for the exchange reaction between quartz and rutile in equilibrium are expressed as:

$$K = \frac{a_{\text{TiO}_2}^{\text{qtz}}}{a_{\text{TiO}_2}^{\text{rutile}}}$$

with a_{TiO_2} is the activity of TiO_2 in each phase. For pure rutile it can be assumed that a_{TiO_2} is equal to 1 so that $K = a_{\text{TiO}_2, \text{quartz}}$ (Wark & Watson, 2006).

Together with the relation of the equilibrium constant with the standard free energy and the Henrian behavior of a linear relation between the activity and the concentration, it is possible to formulate:

$$\exp \left[\frac{-\Delta G^0}{R \times T} \right] = \gamma \times X_{\text{TiO}_2}^{\text{qtz}}$$

where R is the gas constant, T is the absolute temperature, ΔG^0 is the free energy change, γ is the activity coefficient and X is the concentration of TiO_2 within quartz (Wark & Watson, 2006).

With a set of experiments Wark and Watson (2006) formulated the following equation for the temperature dependence of the Ti concentration in quartz:

$$T(^{\circ}\text{C}) = \frac{-3765}{\log(X_{\text{Ti}}^{\text{qtz}}) - 5.69} - 273$$

For rutile undersaturated rocks where $a_{\text{TiO}_2} < 1$ the following equation from Wark and Watson (2006) can be used to calculate the temperatures:

$$T(^{\circ}\text{C}) = \frac{-3765}{\log\left(\frac{X_{\text{Ti}}^{\text{qtz}}}{a_{\text{TiO}_2}}\right) - 5.69} - 273$$

The measured quartz samples contained no rutile, for this the a_{TiO_2} values have been estimated above 0.8 and 0.6 according to the study of Ghent and Stout (1984) (Wark and Watson, 2006; Thomas et al., 2010).

Wark and Watson (2006) already described a pressure effect on the TitaniQ calibration. A newer publication of Thomas et al. (2010) describes the temperature and pressure dependence on the solubility of Ti in quartz. Therefore it is possible to calculate Ti concentration dependent isopleths within the p-T space. The Ti solubility in quartz can be used as a thermobarometer when it is used in combination with another thermobarometer or other methods, which give an estimation of the p-T conditions of the quartz crystallization (Thomas et al., 2010).

Following equation, which was defined by Thomas et al. (2010) uses a least-squares method to fit Ti concentrations in quartz from all experiments; with this expression it is possible to calculate Ti concentration dependent isopleths within the p-T space:

$$RT \ln X_{\text{TiO}_2}^{\text{qtz}} = -60952 + 1.520 \times T(\text{K}) - 1741 \times p(\text{kbar}) + RT \ln a_{\text{TiO}_2}$$

The Ti concentrations have been measured with LA-ICP-MS. They differ between 8.26 and 13.40 ppm for sample 05-OKU-10, 3.60 and 16.20 ppm for sample 05-OKU-94, 8.07 and 20.49 ppm for sample 05-OKU-37 and between 2.49 and 3.91 ppm for sample 05-OKU-93. The calculated average temperatures and average isopleths for the p-T space are displayed in table 4.4.

The calculated temperatures differ between 466 and 575 °C for $a_{\text{TiO}_2} = 0.8$. Also the isopleths within the p-T space have been calculated with $a_{\text{TiO}_2} = 0.8$ (Figure 4.21). According to Thomas et al. (2010) the quartz could have formed at any p-T along the

respective isopleths. For the exact determination of the formation conditions additional information from other mineral thermometers are required.

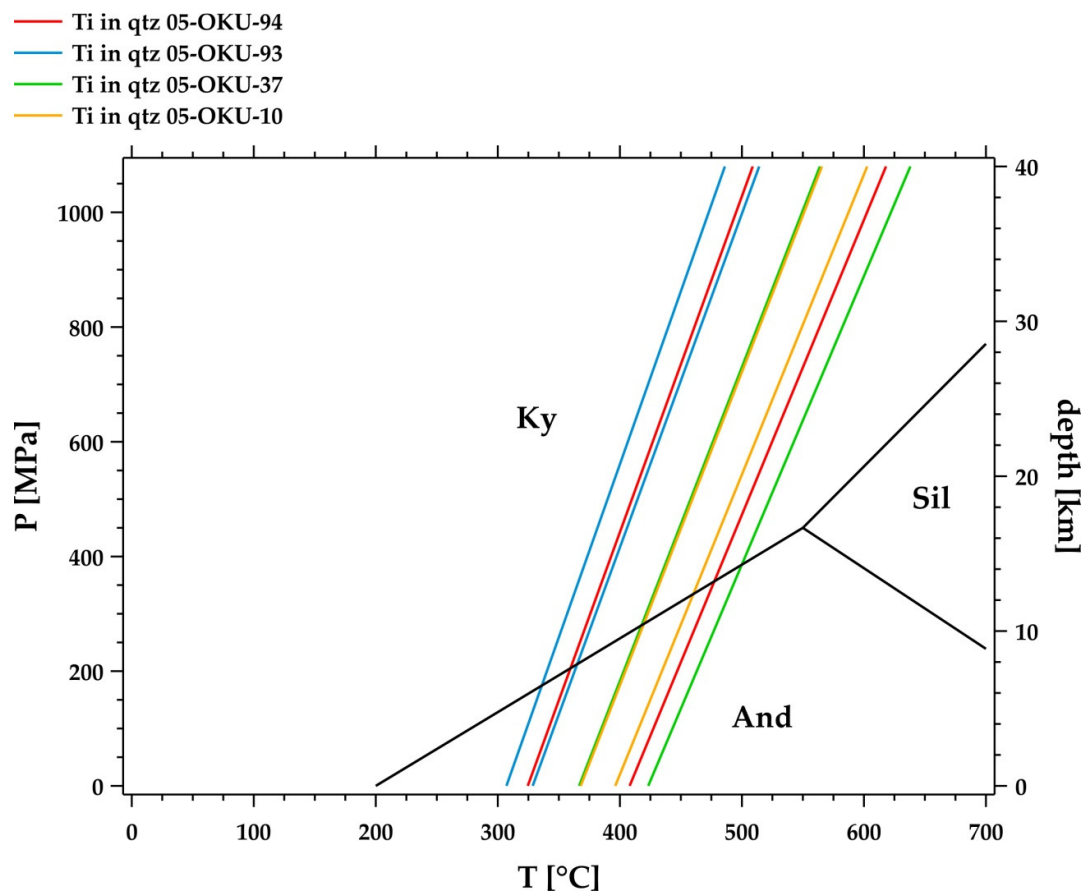
Table 4.4, Summary of the calculated temperatures and pressures

<i>Wark and Watson, 2006</i>							
sample	05-OKU-10	T average		sample	05-OKU-94	T average	
a _{TiO2}	X _{TiO2} [ppm]	T (°C)		a _{TiO2}	X _{TiO2} [ppm]	T (°C)	
0.20	10.83	678.46		0.20	9.90	669.17	
0.40	10.83	611.18		0.40	9.90	603.15	
0.60	10.83	576.05		0.60	9.90	568.65	
0.80	10.83	552.78		0.80	9.90	545.77	
<i>Thomas et al., 2010</i>							
T [°C]	a _{TiO2}	Ti [ppm]	P [MPa]	T [°C]	a _{TiO2}	Ti [ppm]	P [MPa]
0.00	0.80	10.83	-2044.53	0.00	0.80	9.90	-2032.82
100.00	0.80	10.83	-1511.32	100.00	0.80	9.90	-1495.32
200.00	0.80	10.83	-978.12	200.00	0.80	9.90	-957.83
300.00	0.80	10.83	-444.92	300.00	0.80	9.90	-420.34
400.00	0.80	10.83	88.29	400.00	0.80	9.90	117.15
500.00	0.80	10.83	621.49	500.00	0.80	9.90	654.64
600.00	0.80	10.83	1154.70	600.00	0.80	9.90	1192.14
700.00	0.80	10.83	1687.90	700.00	0.80	9.90	1729.63
<i>Wark and Watson, 2006</i>							
sample	05-OKU-37	T average		sample	05-OKU-93	T average	
a _{TiO2}	X _{TiO2} [ppm]	T (°C)		a _{TiO2}	X _{TiO2} [ppm]	T (°C)	
0.20	14.28	708.25		0.20	3.20	566.14	
0.40	14.28	636.85		0.40	3.20	513.36	
0.60	14.28	599.70		0.60	3.20	485.45	
0.80	14.28	575.13		0.80	3.20	466.83	
<i>Thomas et al., 2010</i>							
T [°C]	a _{TiO2}	Ti [ppm]	P [MPa]	T [°C]	a	Ti [ppm]	P [MPa]
0.00	0.80	14.28	-2080.60	0.00	0.80	3.20	-1885.49
100.00	0.80	14.28	-1560.60	100.00	0.80	3.20	-1294.06
200.00	0.80	14.28	-1040.61	200.00	0.80	3.20	-702.64
300.00	0.80	14.28	-520.61	300.00	0.80	3.20	-111.21
400.00	0.80	14.28	-0.61	400.00	0.80	3.20	480.22
500.00	0.80	14.28	519.39	500.00	0.80	3.20	1071.65
600.00	0.80	14.28	1039.38	600.00	0.80	3.20	1663.07
700.00	0.80	14.28	1559.38	700.00	0.80	3.20	2254.50

Additionally the limit of detection has been calculated for every measurement. The LOD (ppm) together with the concentration of Ti in the used standard are displayed in table 4.5.

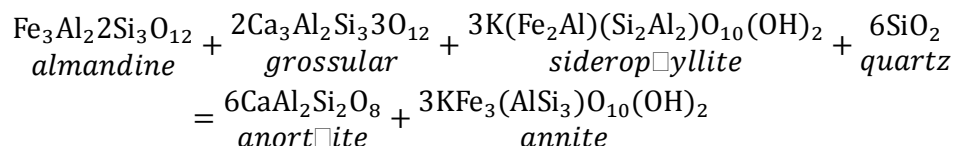
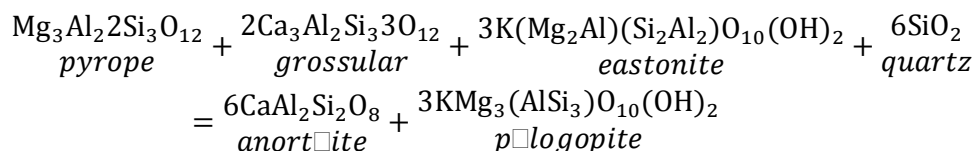
Table 4.5, Concentration of Ti in the used standard and the calculated LOD (ppm) for the different measurements

Nist614	conc. [ppm]	Sample	LOD, ppm
Ti47	3.40	05-OKU-10	3.11
		05-OKU-94	3.23
		05-OKU-37	2.68
		05-OKU-93	2.15

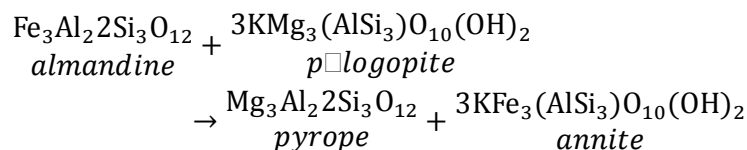
Figure 4.21, Isopleths for the temperature and pressure dependent substitution of Ti in quartz, calculated with the equation from Thomas et al. (2010) for $a_{\text{TiO}_2} = 0.8$ *Grt-Bt-Qtz-Plag*

Metamorphic temperatures and pressures have been additionally calculated with the GBPQ geobarometer for medium- to high grade metapelites according to Wu et al. (2004, 2006) and the garnet-biotite geothermometer according to Holdaway (2000).

The geobarometer is based on Fe- and Mg-model equilibria of following reactions (Höisch, 1990, 1991; Wu et al., 2004; 2006):



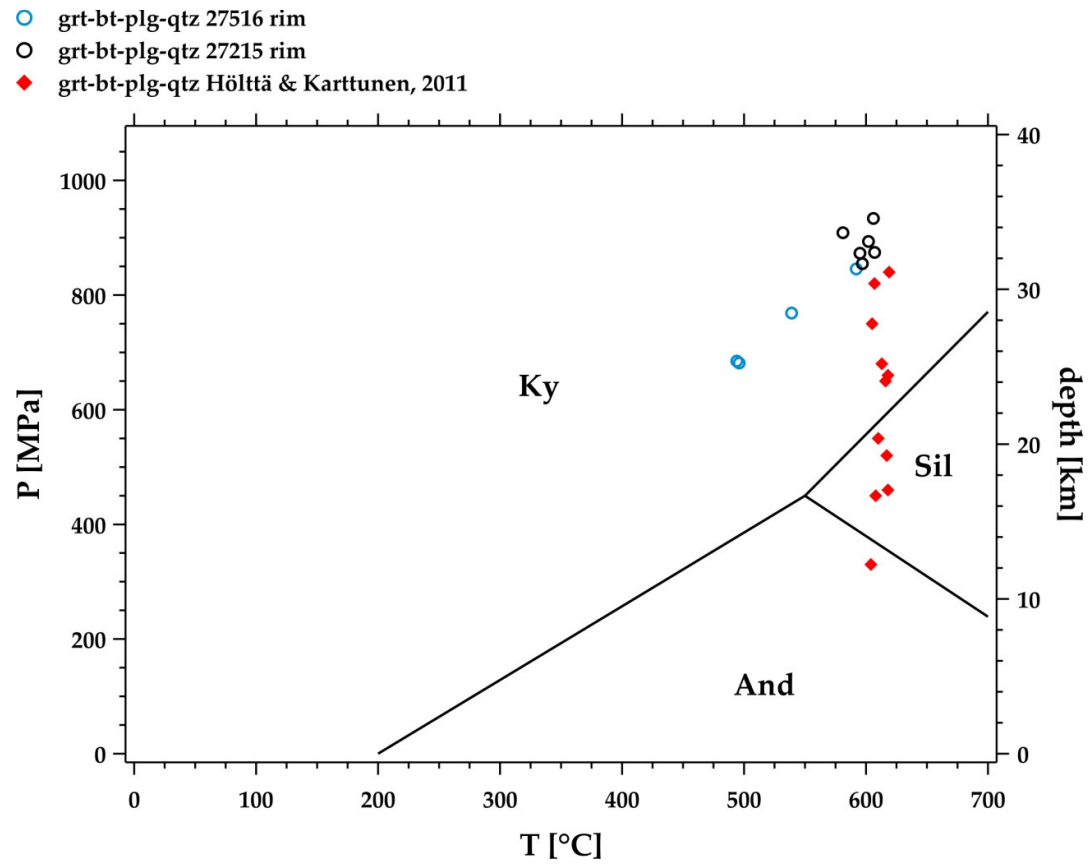
The garnet-biotite geothermometer is based on the cation exchange reaction



first investigated by Ferry and Spear (1978). For the temperature calculations the calibration from Holdaway (2000) has been used, that gives a thermodynamic correction for elevated Ca and Mn contents within garnet and Ti and Al contents within biotite.

Besides the measurements from this study also p-T values from Hölttä and Karttunen (2011) have been plotted in Figure. 4.22. Pressures and temperatures have been calculated using the Excel spreadsheet provided by Wu et al. (2004; 2006) and Holdaway (2000).

The calculated temperatures and pressures plot between 520 and 620 °C and between 700 and 900 MPa. The maximum pressures and temperatures are close to the maximum p-T conditions proposed by Hölttä and Karttunen (2011). However the isobaric cooling, which has been indicated by the study of Hölttä and Karttunen (2011), could not be confirmed by this study, due to too less garnet bearing samples.



Summary

Stable isotope measurements, Ti concentration in biotite, Ti concentration in quartz, the garnet-biotite geothermometer and the GBPQ geobarometer have been applied to get information about the formation conditions.

The different thermometers have been checked with respect to their applicability and consistency to these types of rocks. It has also been tried to use more than one thermometer for each sample. The calculated temperatures and pressures for all the applied methods and samples are presented in table 4.6.

Table 4.6, Summary of the mineral thermometer data

sample number	depth [m]	Ti in Quartz $T [^{\circ}\text{C}]$			
		$a \text{ TiO}_2 = 0.2$	$a \text{ TiO}_2 = 0.4$	$a \text{ TiO}_2 = 0.6$	$a \text{ TiO}_2 = 0.8$
	145.30				
	271.15				
	333.70				
	345.80				
05-Oku-10	464.10	676.89	609.79	574.76	551.55
05-Oku-91	584.55				
	620.80				
05-Oku-88	711.50				
05-Oku-95	794.80				
	803.70				
05-Oku-93	887.30	565.04	512.38	484.53	465.95
05-Oku-94	904.75	655.82	591.35	557.64	535.28
05-Oku-98	939.65				
	1042.60				
05-Oku-100	1087.95				
	1179.15				
	1212.55				
05-Oku-101	1218.20				
05-Oku-37	1262.40	702.34	631.65	594.86	570.53
05-Oku-38	1275.80				
05-Oku-40	1292.30				
05-Oku-42	1310.20				
	1537.25				
	1561.10				
05-Oku-51	1644.20				
05-Oku-55	1784.95				
	1885.15				
05-Oku-79	2247.60				
05-Oku-84	2340.30				

Table 4.6, continued

sample number	depth [m]	Isotopes	Ti in Biotite	Grt-Bt	<i>P</i> [MPa]	
		T [°C]	T [°C]	<i>T</i> [°C]		
	145.30			604.00	680.00	Hölttä & Karttunen, 2011
	271.15			567.67	766.67	Hölttä & Karttunen, 2011
	333.70			609.50	620.00	Hölttä & Karttunen, 2011
	345.80			600.00	663.33	Hölttä & Karttunen, 2011
05-Oku-10	464.10					
05-Oku-91	584.55	504.61				
	620.80			613.67	700.00	Hölttä & Karttunen, 2011
05-Oku-88	711.50	531.44	612.34			
05-Oku-95	794.80		614.87			
	803.70			621.50	525.00	Hölttä & Karttunen, 2011
05-Oku-93	887.30	545.94	646.56	597.00	894.20	
05-Oku-94	904.75					
05-Oku-98	939.65		654.80			
	1042.60			609.00	465.00	Hölttä & Karttunen, 2011
05-Oku-100	1087.95		746.58	520.00	729.10	
	1179.15			626.33	616.67	Hölttä & Karttunen, 2011
	1212.55			621.33	713.33	Hölttä & Karttunen, 2011
05-Oku-101	1218.20		621.18			
05-Oku-37	1262.40		662.76			
05-Oku-38	1275.80		692.84			
05-Oku-40	1292.30		685.78			
05-Oku-42	1310.20	514.36	660.58			
	1537.25			612.50	380.00	Hölttä & Karttunen, 2011
	1561.10			618.50	445.00	Hölttä & Karttunen, 2011
05-Oku-51	1644.20		674.34			
05-Oku-55	1784.95		663.38			
	1885.15			613.50	705.00	Hölttä & Karttunen, 2011
05-Oku-79	2247.60		664.24			
05-Oku-84	2340.30		669.62			

5) Fluid Inclusions

According to Diamond (2003a), a fluid inclusion is defined as any quantity of single- or multiphase fluid enclosed (included) within a crystalline or amorphous solid. Touret (2001) defines requirements for the interpretation, which must be made when measuring the inclusions and the molar volume on which the interpretation relies on:

- no variation of the volume of the cavity
- no leakage
- no reaction within the fluid system

This is the hypothesis that fluid inclusions should be regarded as closed systems with isochoric behavior (Touret, 2001; Bakker, 2011).

Fluid inclusions within metamorphic rocks occur either in veins or in rock forming minerals within the massive rock (Touret, 2001). Monomineralic veins often occur along major faults or shear zones and witness a great variety of different fluid pulses through time. Within metamorphic rocks it is therefore very important to identify a relative chronology of the occurring fluid inclusion assemblages and to compare the p-T estimates with p-T data from independent mineral thermometers from coexisting minerals (Touret, 2001). According to Touret (2001) and Roedder (1984), a number of difficulties are encountered when measuring and interpreting fluid inclusions within metamorphic rocks: small size, great number of inclusions, multiplicity of inclusion generations, possible fluid leakage or post-trapping changes.

According to Bakker (2011), fluid inclusions provide information about:

- Fluid composition
- Fluid density (molar volume)
- p-T conditions of fluid entrapment
- Temporal evolution

Different analytical methods have been used to gain information about the fluids: fluid inclusion petrography, microthermometrical measurements, LA-ICP-MS measurements of single fluid inclusions, ion chromatography (crush-leach) and stable isotope analyses of bulk composition. All calculations have been performed with the software from Bakker (2003). The used programs and equations of state are listed in table 3.1 (Chapter 3.2.4).

5.1) Fluid Inclusion Petrography and Microthermometry

Fluid inclusion (FI) measurements and petrography has been performed on different thick sections of quartz veins. The detailed sample list can be found in the appendix. The fluid inclusions within carbonate veins or single mineral grains within the massive rocks are too small to be measured by microthermometry. Due to the recrystallization of the quartz veins and the metamorphic overprint it is nearly impossible to define the different inclusion types with the typical nomenclature of primary, secondary, and pseudosecondary fluid inclusions. Fluid inclusions within the veins occur as intragranular trails (along grain boundaries; primary or pseudosecondary FI), on transgranular trails (crosscutting grain boundaries; secondary FI), in clusters (secondary FI) or as single isolated inclusions (primary FI).

The petrographic description of the fluid inclusions takes place at room temperature. The fluid inclusions observed in quartz veins contain up to three different phases: vapour phase (V), liquid phase (L), and sometimes a solid phase (S) as accidentally trapped crystals. Fluid inclusions within the carbonate veins are smaller than 5 μm and cannot be analysed with microthermometry.

Raman measurements were carried out on different fluid inclusions to determine the composition of the gaseous phase.

The different kinds of fluid inclusion, occurring in quartz veins, are displayed in figure 5.2.

Type A fluid inclusions (fig. 5.2, A, B, C, D) occur in all analysed samples. They always occur as 2 phase inclusions (L-V) and their size ranges between <2 and 40 μm . They sometimes show the presence of a solid phase as an accidentally trapped crystal. Their shape is irregular and depending of their homogenization temperature they exhibit a different filling degree. A detailed distinction and division into the 4 subtypes (A I, A II, A III and A IV) can only be made by microthermometry measurements.

Also the rare occurring type B fluid inclusions (fig. 5.2, E, F) show always 2 phases (L-V), and a size between 10 and 40 μm and a irregular shape. They can only be distinguished from type A fluid inclusions by microthermometry. They only occur in samples 1108, 1117 and 1137.

Type C fluid inclusions (fig. 5.2, G) show only 1 phase (L) at room temperature. They always occur together with inclusions of the type A III. Their size is around 10 μm and they show a regular uniform shape.

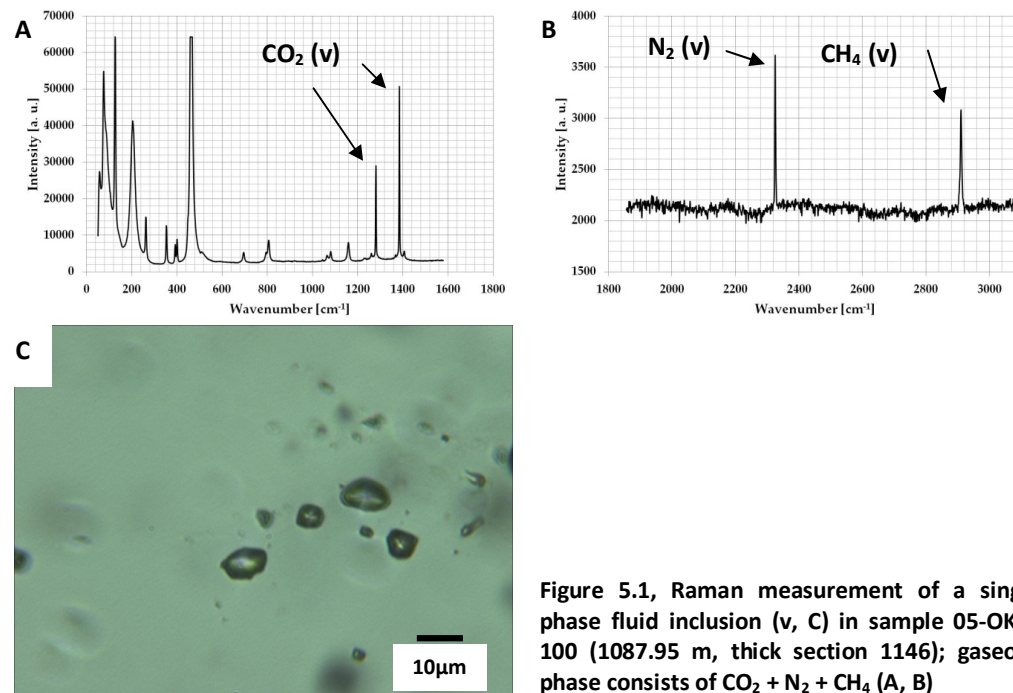


Figure 5.1, Raman measurement of a single phase fluid inclusion (v, C) in sample 05-OKU-100 (1087.95 m, thick section 1146); gaseous phase consists of CO_2 + N_2 + CH_4 (A, B)

Figure 5.25 shows measurements from a type C fluid inclusion. The melting temperature already indicated the presence of small amounts of another gas phase, which is proven by Raman spectroscopy. Next to CO_2 also N_2 and CH_4 could be observed.

Fluid inclusions from type D (fig. 5.2, H) could only be observed in one sample (1143). They occur as single isolated inclusions and show 2 phases (liquid H_2O and liquid CO_2) at room temperature. Like type C fluid inclusions their size is around 10 μm and they show a regular uniform shape.

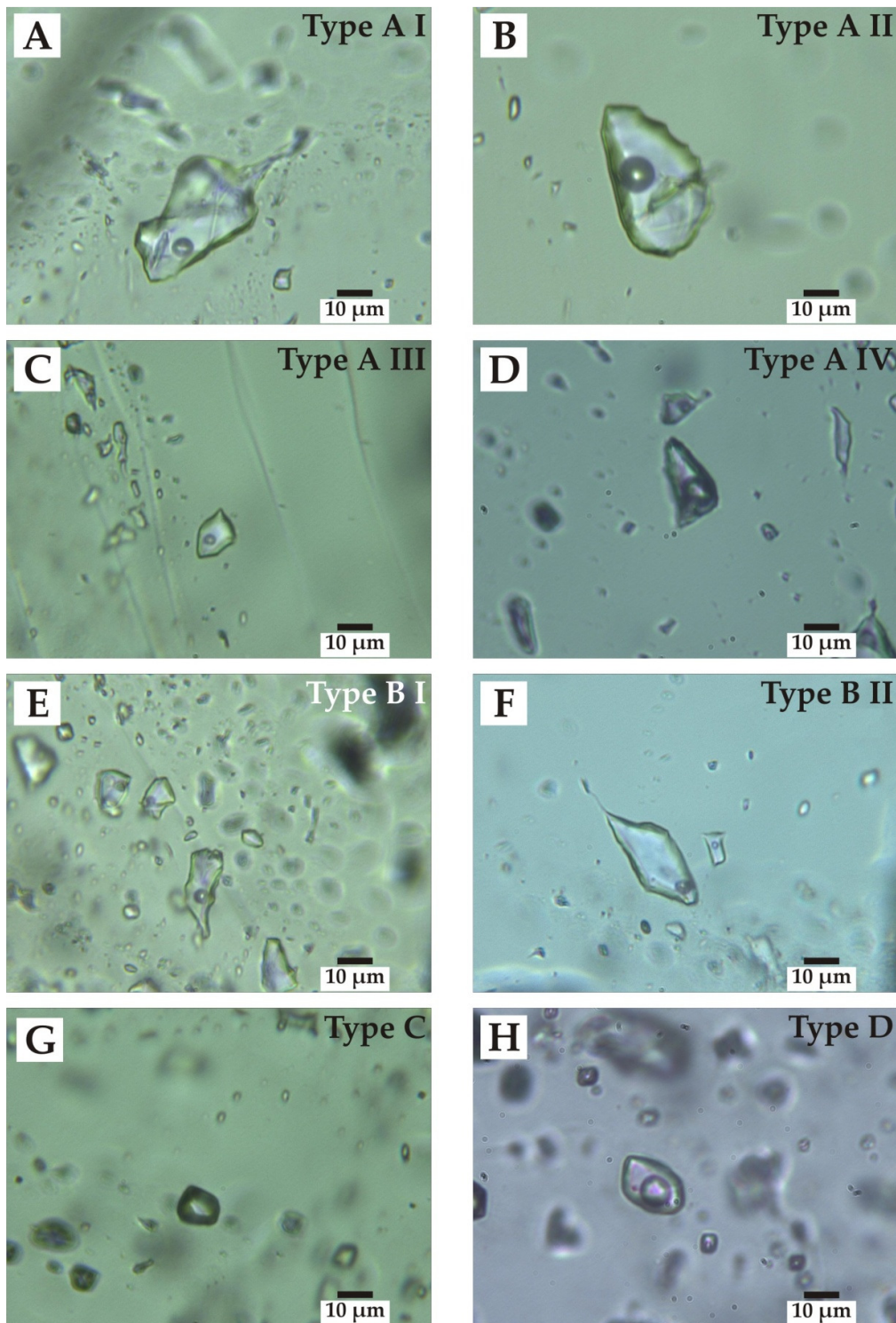


Figure 5.2, Different type of fluid inclusions, which can be distinguished within the quartz veins, based on their composition after microthermometrical measurements

Additional types of fluid inclusions, which are not displayed in figure 5.2 can only be distinguished with Raman spectroscopy. Following compositions could be distinguished by the aid of Raman spectroscopy: $\text{H}_2\text{O} (\text{l}) + \text{H}_2\text{O} (\text{v}) + \text{H}_2 (\text{v}) + \text{N}_2 (\text{v}) + \text{CH}_4 (\text{v})$, $\text{H}_2 (\text{v})$ with small amounts of H_2O at the rim and $\text{CH}_4 (\text{v}) + \text{H}_2\text{O} (\text{l}) \pm \text{N}_2 (\text{v}) \pm \text{C}_2\text{H}_6 (\text{v}) \pm \text{C}_3\text{H}_8 (\text{v})$.

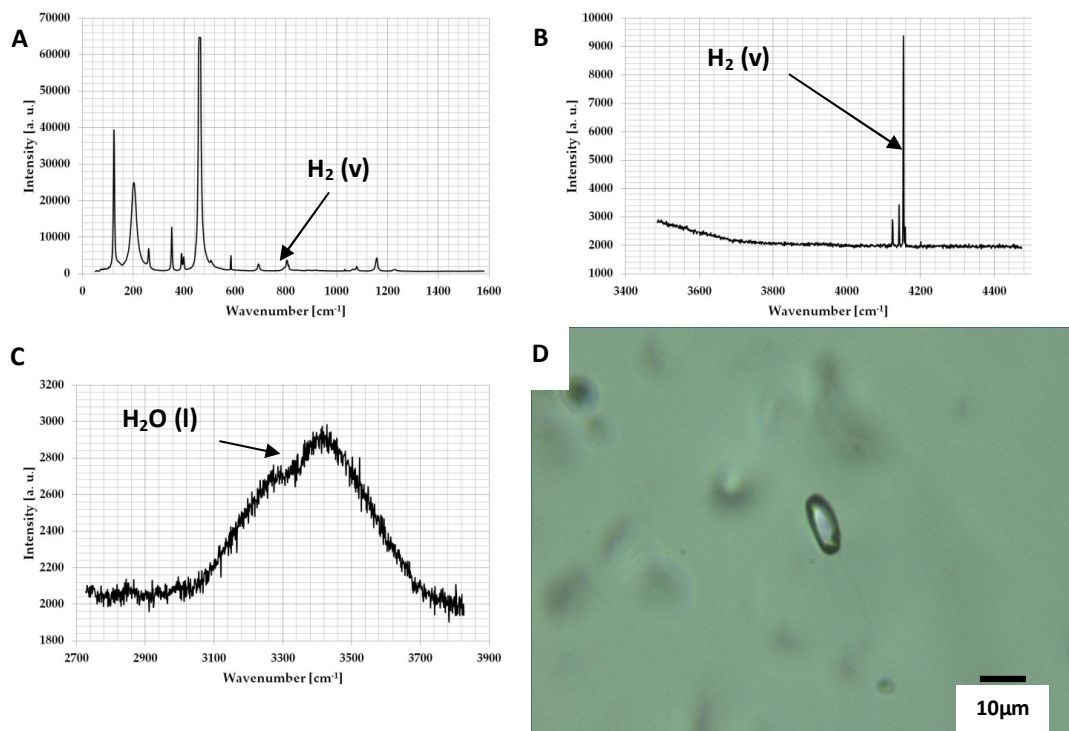


Figure 5.3, Raman measurement of a single phase fluid inclusion (v, D) in sample 05-OKU-62 (1845.50 m, thick section 1156); gaseous phase consists of H_2 (A, B); small amounts of H_2O were detected on the rim (C)

Figure 5.3 and 5.4 show two single phase fluid inclusions which cannot be distinguished from type C fluid inclusions by microscope. Raman measurements showed that the fluid inclusion displayed in figure 5.3 D consists of $\text{H}_2 (\text{v})$ with a not visible rim of $\text{H}_2\text{O} (\text{l})$. The type shown in figure 5.4 contains CH_4 as main constituent. Next to CH_4 also minor amounts of H_2 , C_2H_6 and C_3H_8 could be identified with RAMAN spectroscopy. These type of inclusions only occur close to the ORA.

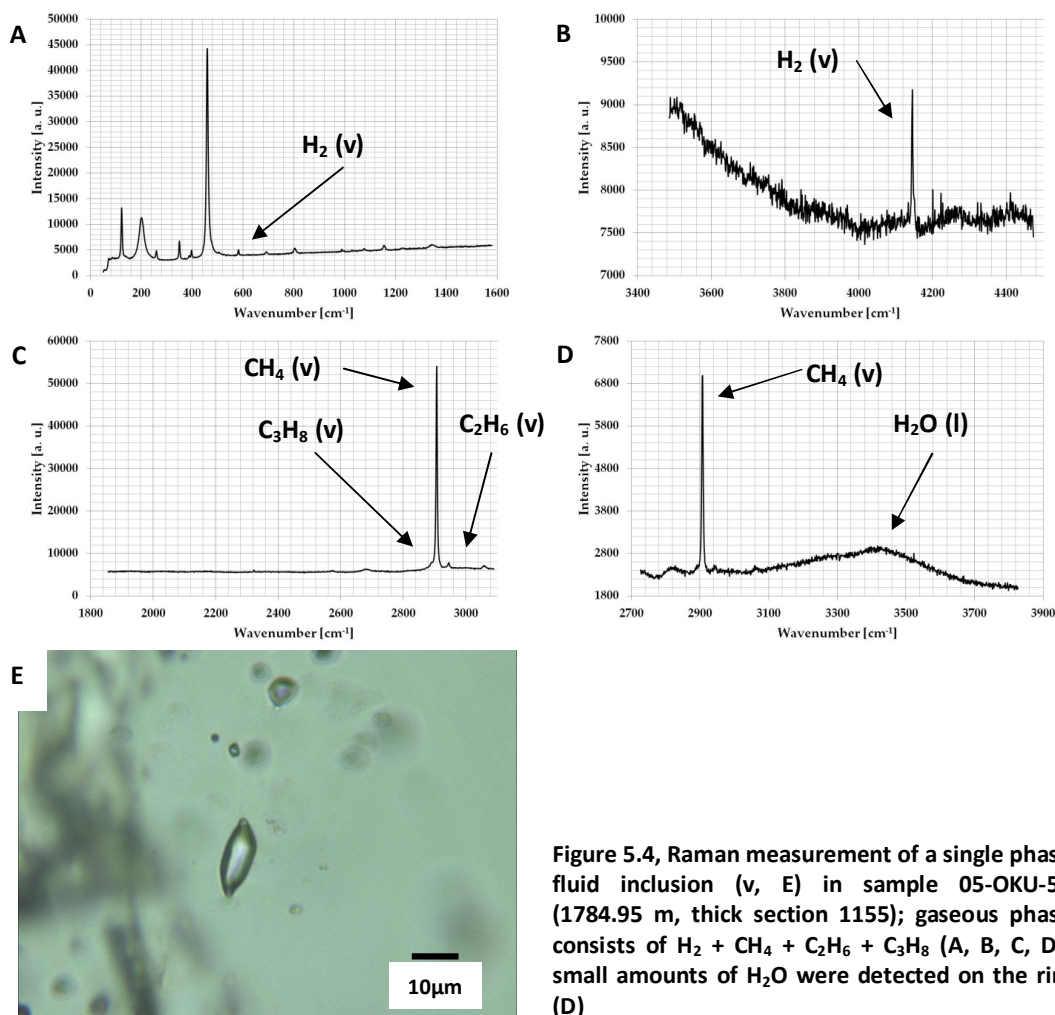


Figure 5.4, Raman measurement of a single phase fluid inclusion (v, E) in sample 05-OKU-55 (1784.95 m, thick section 1155); gaseous phase consists of H₂ + CH₄ + C₂H₆ + C₃H₈ (A, B, C, D); small amounts of H₂O were detected on the rim (D)

Every sample represents a different depth. They differ in the amount of fluid inclusions present, the fluid pulses present, and the relative timing of the fluid pulses. For this reason every sample is described separate.

Figure 5.5 shows sample 1138 (depth 464.10 m), a quartz vein crosscutting biotite mica schist. Different fluid inclusion-bearing areas have been marked and numbered. Areas A show large fluid inclusion clusters (or clouds), which are located along grain boundaries. These areas can be secondary and the measured data do not correspond to the peak metamorphic conditions. The Arabic numerals 1 to 14 show the location of larger isolated fluid inclusions, which can be considered primary. The Roman numerals I to IV denote intragranular fluid inclusion trails, which must be assumed pseudosecondary. The areas, which are marked with the letter B show the youngest fluid activity in this sample. These trails are crosscutting grain boundaries. Fluid inclusions at the intersection between intragranular trails and type B trails show also different volume fractions and seem to be influenced by the later transgranular trails

(fig. 5.3 A). These latest inclusions, only show a vapor phase, which can be addressed as vapor H_2O . No homogenisation temperatures could be measured from these inclusions. Additionally, some rare inclusions show the presence of an additional solid phase (fig. 5.3 B). Due to the fact that there is no proof that these inclusions form separate fluid inclusion assemblage, they are considered to be accidentally trapped and have no influence on the interpretation. Furthermore, it was not possible to determine the composition of the solid phase.

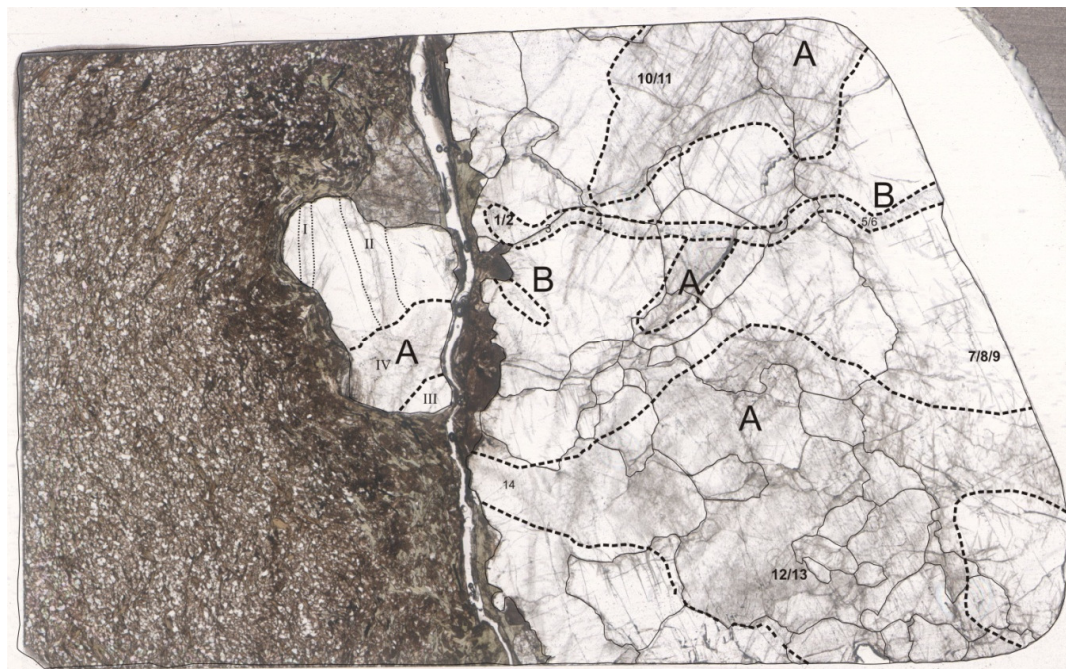


Figure 5.5, Sample 1138 (depth 464.10 m), different areas and points are explained in the text

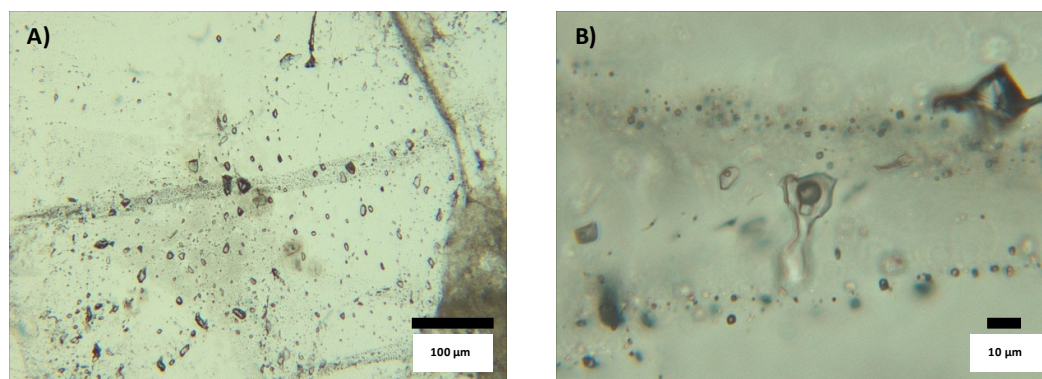


Figure 5.6, A) fluid inclusions at the intersection between intragranular trails and type B trails; B) Fluid inclusion with accidentally trapped solid phase

Microthermometrical measurements (for the histogram see Figure 5.7) show the occurrence of type A and type C fluid inclusions, whereas type A inclusions can be

divided into the A I, A II, and A III subgroups. Type A I fluid inclusions show $T_m(\text{ice})$ between -0.7 and -1.2 °C, which represents a salinity between 1.2 and 2.1 mass% NaCl. T_E is around -21 °C, so it can be assumed, that the only salt component present is NaCl. The $T_h(\text{LV} \rightarrow \text{L})$ is highly variable from 213.2 °C up to 360.5 °C. These inclusions occur on late transgranular trails and show necking down, which can explain the variable T_h . Within this sample they represent the second youngest fluid event present. Type A III and type C fluid inclusions occur together on the same intragranular trails. They are interpreted to show heterogeneous trapping, most likely due to unmixing due to retrograde boiling caused by pressure release (effervescence) (Roedder, 1984; Diamond, 1990). A III fluid inclusions show moderate salinity of around 13.9 mass% NaCl; their T_h is between 332.5 and 370.0 °C. At room temperature only liquid CO_2 is visible within type C fluid inclusions. Their $T_m(\text{CO}_2)$ is between -56.8 and -60.1 °C; homogenisation occurs into the liquid phase at temperatures between -20.6 and 10.7 °C. Type A II fluid inclusions form the maximum data points measured within this sample. They seem to be the oldest generation due to their occurrence on intragranular trails and as single isolated inclusions. Their T_h is between 118.4 °C and 227.5 °C with an average of 194.9 °C. The salinity is between 6.9 and 11.5 mass% NaCl.

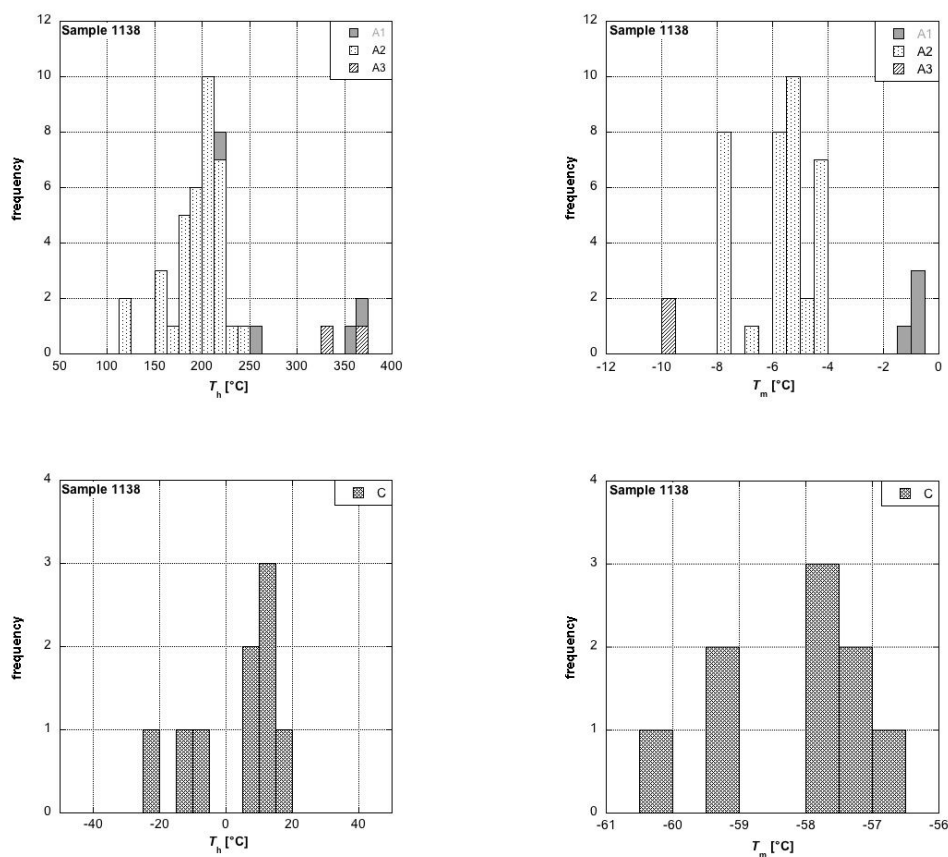


Figure 5.7, Histogram of T_h and T_m of sample 1138 (depth 464.10 m)

Sample 1117 (depth 584.55 m) is a biotite mica schist, with a deformed quartz lens. Fluid inclusions can occur as intragranular trails, transgranular, or single isolated inclusions. Biotite flakes occur within the vein. Other than in sample 1138, the latest stage is defined by one-phase H₂O (liquid,) fluid inclusions, which are crosscutting all other fluid inclusion assemblages, forming mixed inclusions at the intersection (fig. 5.8).

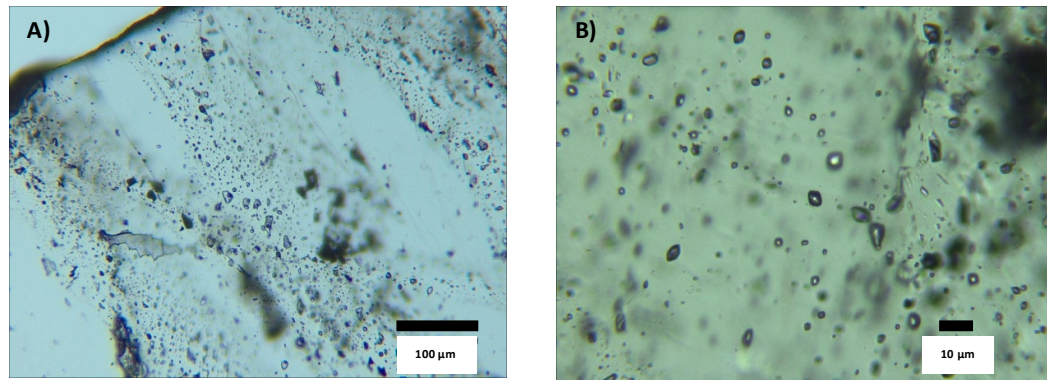


Figure 5.8, A) secondary fluid inclusions within sample 1117 (depth 584.55 m); B) type C fluid inclusions within sample 1117 (depth 584.55 m)

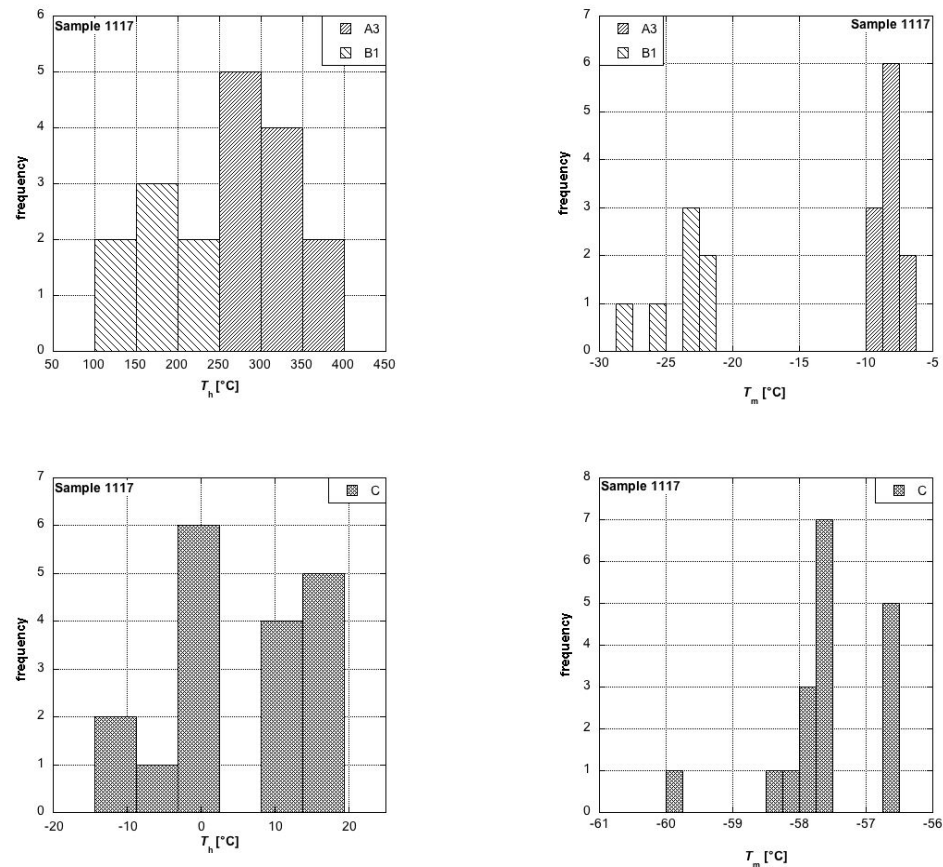


Figure 5.9, Histogram of T_h and T_m of sample 1117 (depth 584.55 m)

Most of the measured inclusions can be identified as type A III and type C inclusions, which can be found, similar to sample 1138, together (for the histogram see Figure 5.9). They occur as primary, single isolated inclusions same as on intragranular trails. $T_m(\text{ice})$ varies between -7.2 and -9.2 °C, which corresponds to a salinity between 10.7 and 13.1 mass% NaCl. The salinity is slightly higher than in type A III inclusions within sample 1138, which can also be caused by the presence of more data points. Their $T_h(\text{LV} \rightarrow \text{L})$ plots between 280 and 360 °C. Cogenetic type C inclusions (fig. 5.9) display $T_m(\text{CO}_2)$ between -56.6 and -59.8 °C and a $T_h(\text{LV} \rightarrow \text{L})$ between -2.5 and 18.6 °C. This sample shows also the first appearance of type B fluid inclusions. They represent the second latest fluid event within this sample and occur mainly as transgranular trails. This type is characterized by the appearance of a liquid phase at around -52 °C, which suggests the presence of CaCl_2 . It was not possible by optical microscopy to determine the exact nature of the melting phase (ice, hydrohalite, antarcticite) or, so the salinity calculations have been performed with the help of LA-ICP-MS, which is described in chapter 3.2.3. The measurement show a Na number ($\text{Na}/(\text{Na}+\text{Ca})$) of around 0.2, which corresponds, together with the $T_m(\text{final})$ between -21.7 and -27.6 °C, to a salinity of 4.4 to 4.9 mass% NaCl and 17.4 to 19.6 mass% CaCl_2 . $T_h(\text{LV} \rightarrow \text{L})$ occurs between 148.7 and 210 °C.

Sample 1137 (depth 711.50 m) was taken from a deformed quartz vein within a biotite mica schist. Strong tectonic deformation manifests itself in reduced grain size in some areas compared to other samples. All occurring fluid inclusions seem to have suffered post-trapping changes (fig. 5.10). Single isolated fluid inclusions are hard to find and the genetic classification is not always clear. All fluid inclusions within this sample are considered secondary or pseudosecondary.

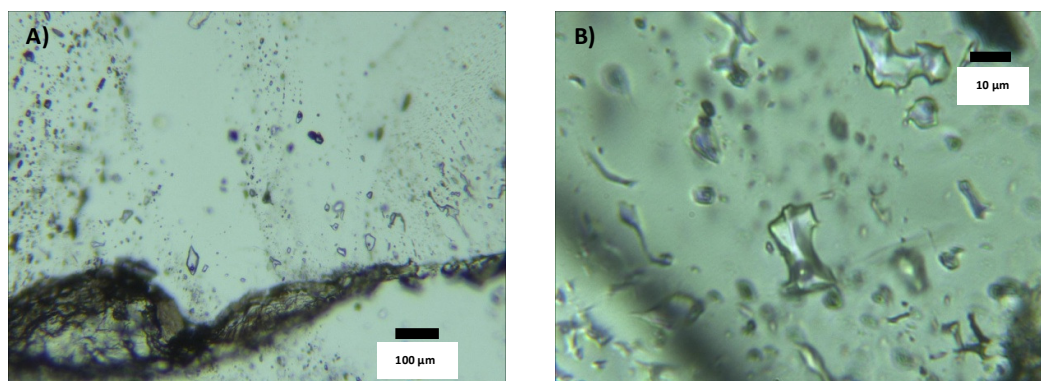


Figure 5.10, A) type B fluid inclusions within sample 1137 (depth 711.50 m); B) typical fluid inclusions within sample 1137 (depth 711.50 m)

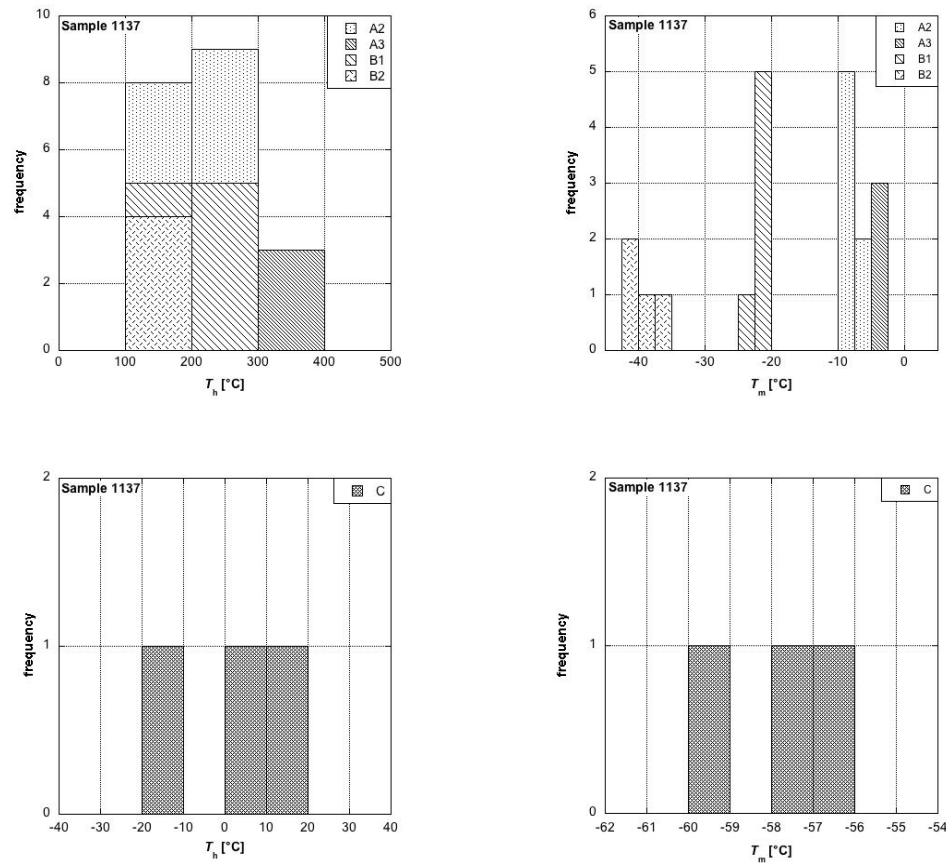


Figure 5.11, Histogram of T_h and T_m of sample 1137 (depth 711.50 m)

Two subgroups of type A inclusions could be identified with help of microthermometry (for the histogram see Figure 5.11). Type A II inclusions show salinities between 8.4 and 12.7 mass% NaCl. Their T_h (LV→L) is variable between 146.1 and 247.8 °C. This wide range could be a sign for post-trapping changes. No petrographic evidence for reequilibration, like a tridimensional set of smaller inclusions surrounding the original ones, could be found. The together with type C occurring type A III fluid inclusions show lower salinities, compared to the previous discussed samples, of around 6.4 up to 7.9 mass% NaCl. They show very high, nearly critical T_h (LV→L) between 340 and 386 °C. The melting temperature of the rarely occurring type C fluid inclusions varies between -56.9 and -59.3 °C; again CO₂ with small amounts of another gas component. Homogenisation occurs into the liquid phase between -17.3 and 10.5 °C. Due to differences in their salinity, two different type B inclusions (fig 5.11) could be distinguished with microthermometry. Both subgroups show the first appearance of a liquid phase at around -52 °C, but they differ in their final melting temperature. Type B I inclusions show final melting between -21.7 and -23.8 °C, in contrast to type B II with final melting temperatures between -37.2 and -42.4 °C. As mentioned before, the kind

of solid melting is unknown. Homogenisation temperatures are higher for type B I with 198.3 to 278.8 °C, than 111.4 to 174.5 °C for type B II.

Within sample 1118 (depth 887.30 m), only two types of fluid inclusions were measured (for the histogram see Figure 5.12). This sample was taken from a deformed quartz vein within biotite mica schist.

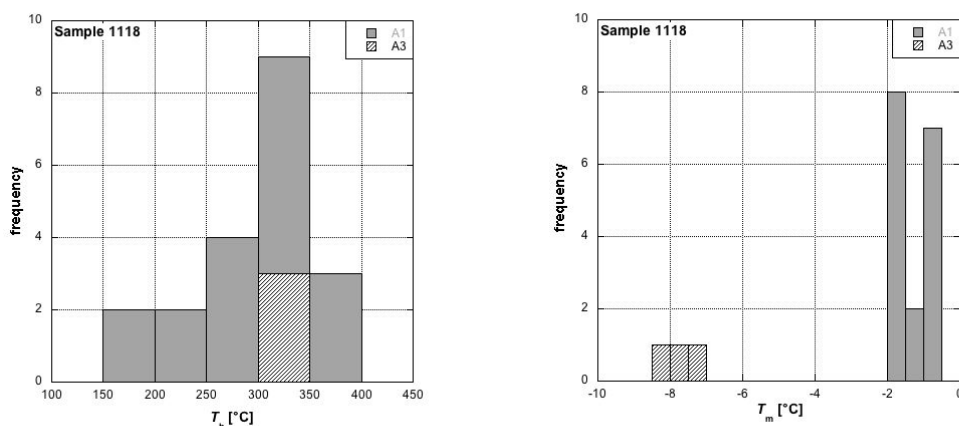


Figure 5.12, Histogram of T_h and T_m of sample 1118 (depth 887.30 m)

Most of the inclusions belong to type A I with $T_m(\text{ice})$ from -0.6 to -2.0 °C, which corresponds to a salinity between 1.1 and 3.4 mass% NaCl. Homogenisation temperatures are very variable between 157.5 and 391.4 °C; homogenisation occurs into the liquid phase. As mentioned before, this type of inclusions represents a relatively late fluid pulse. The inclusions show necking down, which is reflected in their variable volume fraction and influences the homogenisation temperature, in contrast to their constant low salinity. They also mainly occur in transgranular trails. The second subgroup, which can be found are type A III inclusions with salinities between 10.6 and 12.2 mass% NaCl and $T_h(\text{LV} \rightarrow \text{L})$ between 300.7 and 338.8 °C. No CO_2 -bearing type C inclusions could be found, which could be explained by the fact that the first inclusions measured in this sample show a very high homogenisation temperature and all occurring CO_2 -bearing inclusions decrepitated during the heating process.

Sample 1143 (depth 904.75 m, Figure 5.13; for the histogram see Figure 5.14) shows very special characteristics. It is a quartz vein within a biotite mica schist, containing cogenetic type A III and type C inclusions at the rim and type D inclusions in the core. The border could not be determined exactly but is suggested in figure 5.3.

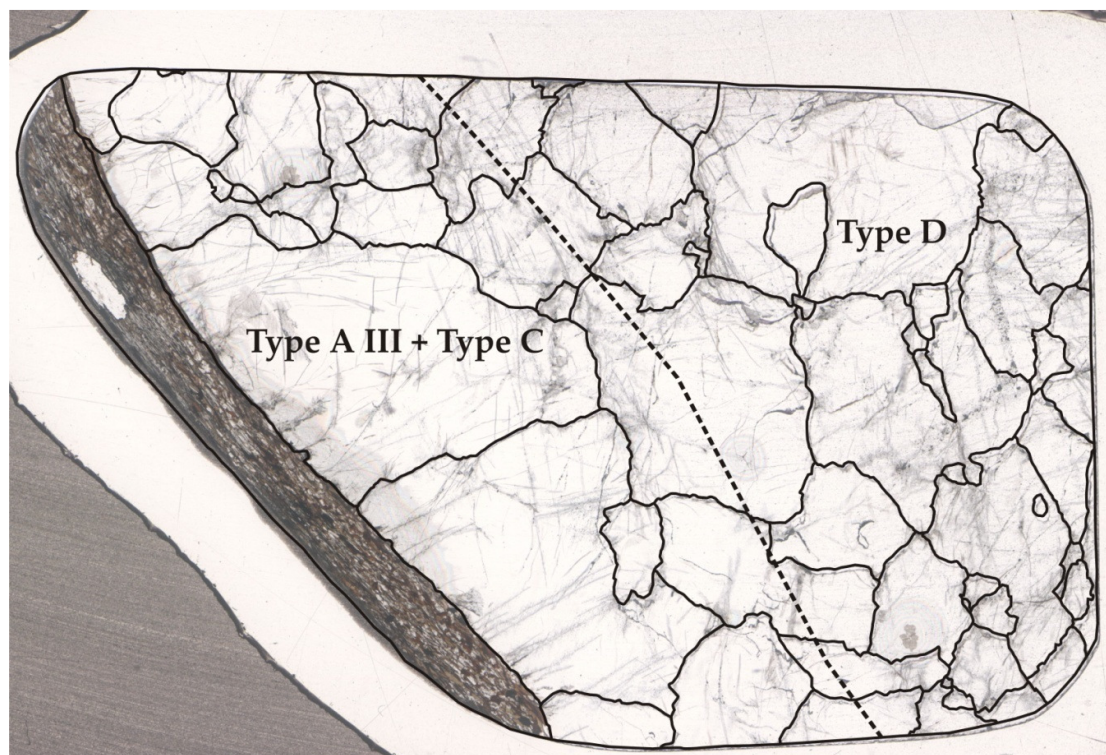


Figure 5.13, Sample 1143 (depth 904.75 m), different areas and points are explained in the text

Type A III inclusions occur as single isolated inclusions or within clusters, which are limited to one grain. Their melting temperature is between -5.4 and -6.3 °C, indicating salinities between 8.4 and 9.6 mass% NaCl; their $T_h(LV \rightarrow L)$ is between 289.8 and 330.0 °C. Type C inclusions, which occur together with type A III inclusions, show melting temperatures between -58.1 and -61.0 °C, which is the lowest temperature measured for this type. Homogenisation occurs into the liquid phase between -13.4 and 6.6 °C. Type D fluid inclusions show at room temperature two phases, liquid water and liquid CO_2 . Their melting temperatures are mainly below the ones of type C, between -57.9 and -62.5 °C, which indicates a higher amount of another gas component present. CO_2 homogenises into the liquid phase between 8.7 and 22.6 °C. Ice and clathrate melting temperatures also suggest the presence of an additional salt component within the H_2O , which is assumed to be NaCl. Total homogenisation could not be achieved due to decrepitation of the inclusions, which occurs above 300 °C.

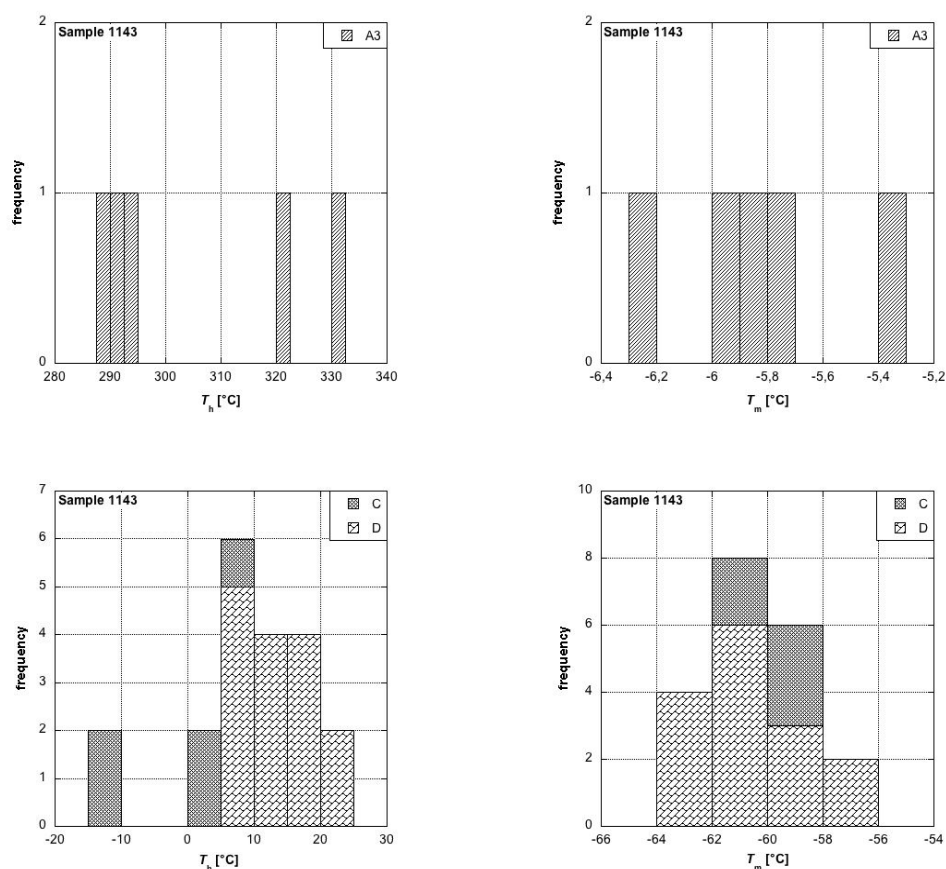


Figure 5.14, Histogram of T_h and T_m of sample 1143 (depth 904.75 m)

Samples 1109 and 1134 were taken at the same depth of 1262.4 m (for the histogram see Figure 5.15). They are part of a small, deformed quartz lens within a partly carbonatized biotite mica schist close to the rocks of the Outokumpu assemblage. As they are from the same quartz vein the results from both thick sections are combined. The encountered fluid inclusions can be divided into type A inclusions of the types A II, A III and A IV and CO_2 -bearing type C inclusions, which coexist together with type A III fluid. A II fluid inclusions occur as intragranular and transgranular trails. Their $T_m(\text{ice})$ varies between -6.0 and -7.0 °C, which corresponds to a salinity between 9.2 and 10.5 mass% NaCl. Melting of type A III occurs between -6.0 and -7.2 °C, $T_h(\text{LV} \rightarrow \text{L})$ is between 288.3 and 368.0 °C. Type A IV inclusions have higher salinities between 17.8 and 18.9 mass% NaCl with melting temperatures between -14.0 and -15.3 °C. They show very high $T_h(\text{LV} \rightarrow \text{L})$ of around 380 °C and are only found as isolated, single inclusions. The encountered type C fluid inclusions show melting temperatures between -58.7 and -60 °C and a homogenisation temperature ($\text{LV} \rightarrow \text{L}$) between -3.8 and 6.4 °C. They occur in intragranular clusters together with type A III inclusions.

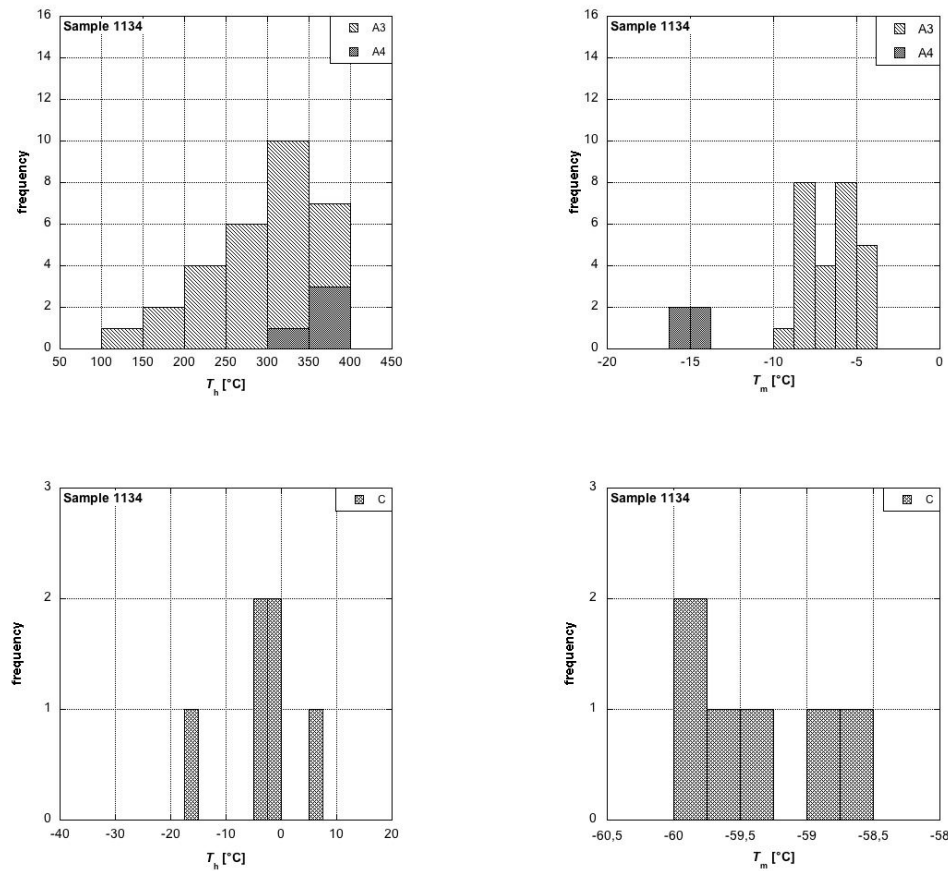


Figure 5.15, Histogram of T_h and T_m of samples 1109 and 1134 (depth 1262.40 m)

The last two samples were taken at a depth of 1321.10 m (1108) and 1325.15 m (1114) (Figure 5.16). They are from strong deformed quartz lenses within sulphide-rich quartz lenses of biotite mica schist. Due to the strong tectonic stress only a few data points could be obtained. Within sample 1108 type A IV, B I, and B II inclusions could be identified. Type A IV inclusions occur as isolated single inclusions with melting temperatures between -14.3 and -17.0 °C, which are consistent with other inclusions of this type found in other samples. $T_h(LV \rightarrow L)$ is around 370 °C. The three measured CaCl_2 bearing type B inclusions show melting temperatures of -23.3 and -29 °C for B I and -39.3 for type B II. Salinities are between 18.1 and 22.6 mass% CaCl_2 and 4.5 to 5.6 mass% NaCl respectively. Homogenisation occurs into the liquid phase between 175.0 and 236.2 °C, with higher $T_h(LV \rightarrow L)$ for the B I fluid inclusions.

The inclusions found within sample 1114 only consist of type A I and type A III. No CaCl_2 and CO_2 -bearing inclusions could be measured. The low saline type A I inclusions show melting temperatures between -0.4 and 2.1 °C, with a highly variable $T_h(LV \rightarrow L)$ between 155.0 and 290.3 °C due to post-trapping changes. The melting temperatures

measured for type A III inclusions plot at a close range between -5.8 and 6.7 °C. Homogenisation occurs into the liquid phase between 280.3 and 352.3 °C.

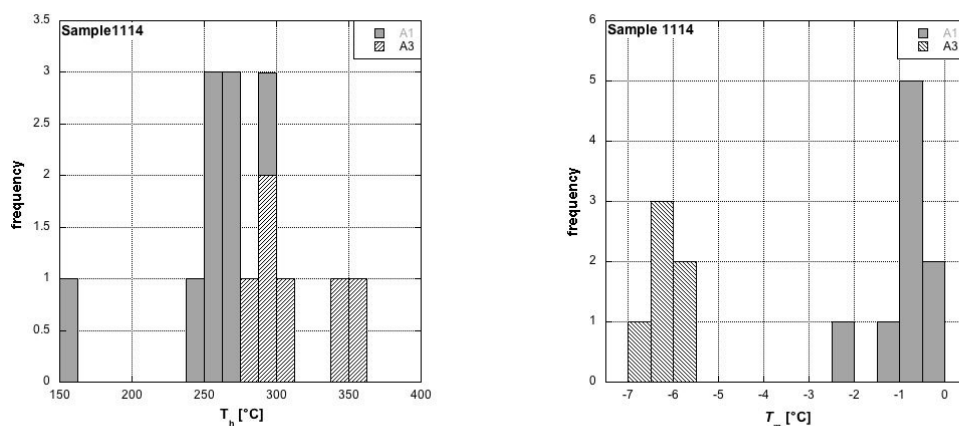


Figure 5.16, Histogram of T_h and T_m of sample 1114 (depth 1325.15 m)

Four different main types of fluid inclusions can be distinguished within the quartz veins, based on their composition after microthermometrical measurements (Table 5.1):

Table 5.1, Different type of fluid inclusions, which can be distinguished within the quartz veins, based on their composition after microthermometrical measurements

1	Type A	→ $H_2O - NaCl$
1.1	Type A I	
1.2	Type A II	
1.3	Type A III	
1.4	Type A IV	
2	Type B	→ $H_2O - CaCl_2 - NaCl$
2.1	Type B I	
2.2	Type B II	
3	Type C	→ CO_2
4	Type D	→ $H_2O - CO_2$

The differences in the melting and the homogenization temperature are also visible in figures 5.17 and 5.18. The different types form clear defined clusters in the diagrams. Also the strong variation of the T_h of type A I fluid inclusions are visible.

The type C and type D fluid inclusions show a rather broad scatter in the T_m versus T_h diagram. Type D fluid inclusions show a slightly lower T_m and a slightly higher T_h .

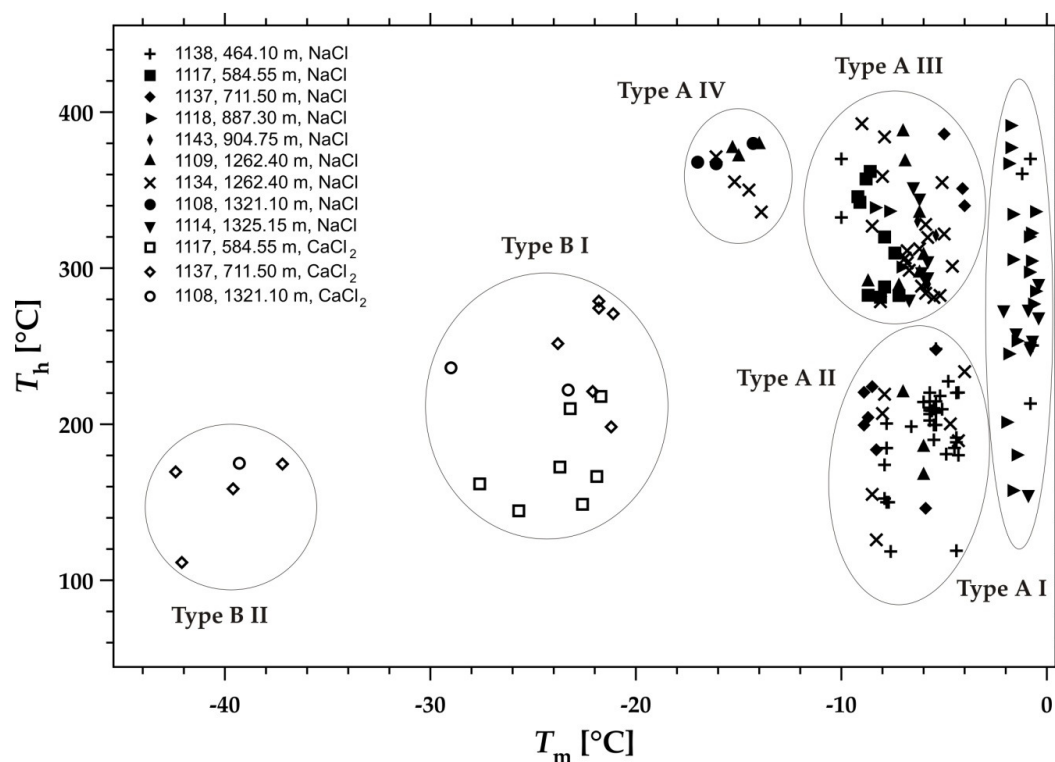


Figure 5.17, T_h vs. T_m plot of aqueous fluid inclusions measured in quartz veins of the drill core

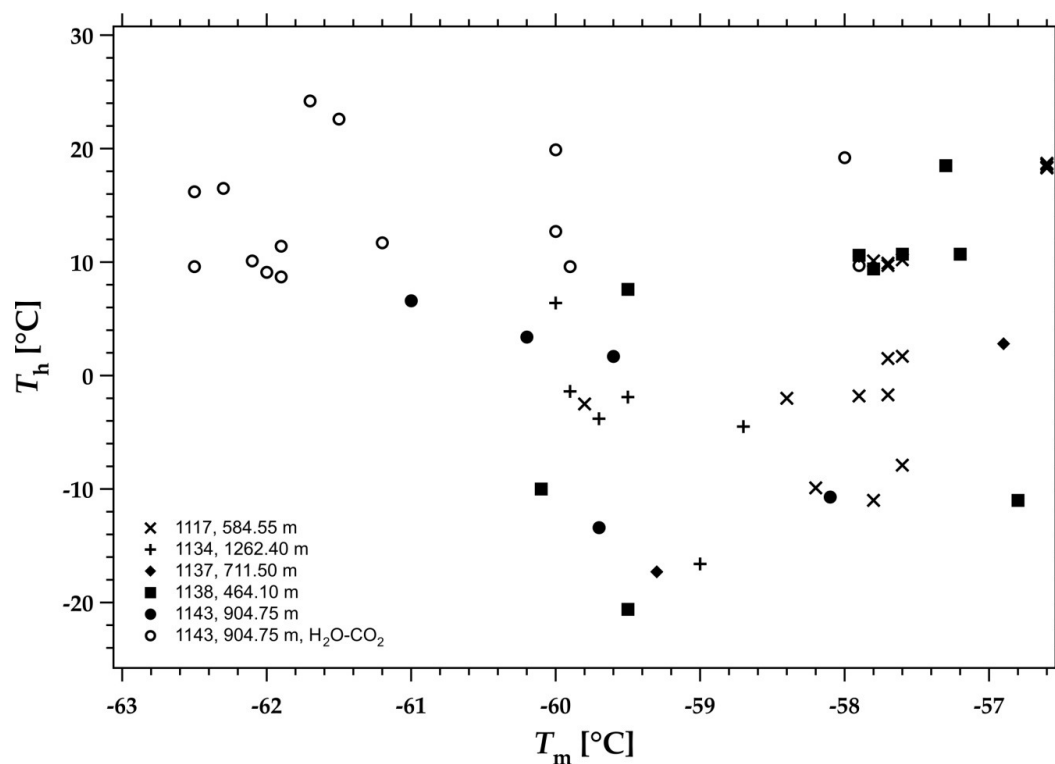


Figure 5.18, T_h vs. T_m plot of CO_2 bearing fluid inclusions measured in quartz veins of the drill core

Type A and type B fluid inclusions can be divided into different subgroups depending on their T_m and T_h (total).

Type A fluid inclusions show a melting temperature (T_m) between -2 and -22°C, which corresponds to a salinity of 2 – 22 mass% NaCl eq. The size of the inclusions range from <2 μm to 40 μm . The homogenisation temperatures (T_h (LV→L)) of the type A fluid inclusions plot between 100 and 400 °C (Figure 5.17, Table 5.2, Figure 5.19).

Table 5.2, Summary of microthermometrical measurements of type A fluid inclusions

		A1			
		Average	Standard deviation	min	max
T_m (Ice)	[°C]	-0.94	0.54	-2.10	-0.40
T_h	[°C]	252.52	38.98	155.00	290.30
P_h	[MPa]	4.32	1.72	0.90	7.10
Salinity [mass%]	NaCl	1.63	0.91	0.70	3.55
		A2			
		Average	Standard deviation	min	max
T_m (Ice)	[°C]	-6.19	1.48	-8.90	-4.00
T_h	[°C]	195.19	29.42	118.40	248.30
P_h	[MPa]	1.36	0.68	0.50	3.50
Salinity [mass%]	NaCl	9.39	1.90	6.45	12.73

Table 5.2 continued

		A3			
		Average	Standard deviation	min	max
T_m (Ice)	[°C]	-6.9	1.4	-10.0	-4.0
T_h	[°C]	320.1	32.3	278.5	392.6
P_h	[MPa]	11.5	5.2	5.9	25.2
Salinity [mass%]	NaCl	10.3	1.8	6.4	13.9
		A4			
		Average	Standard deviation	min	max
T_m (Ice)	[°C]	-15.14	1.02	-17.00	-13.90
T_h	[°C]	365.46	14.14	336.00	380.00
P_h	[MPa]	19.00	2.86	13.30	22.10
Salinity [mass%]	NaCl	18.73	0.83	17.70	20.22

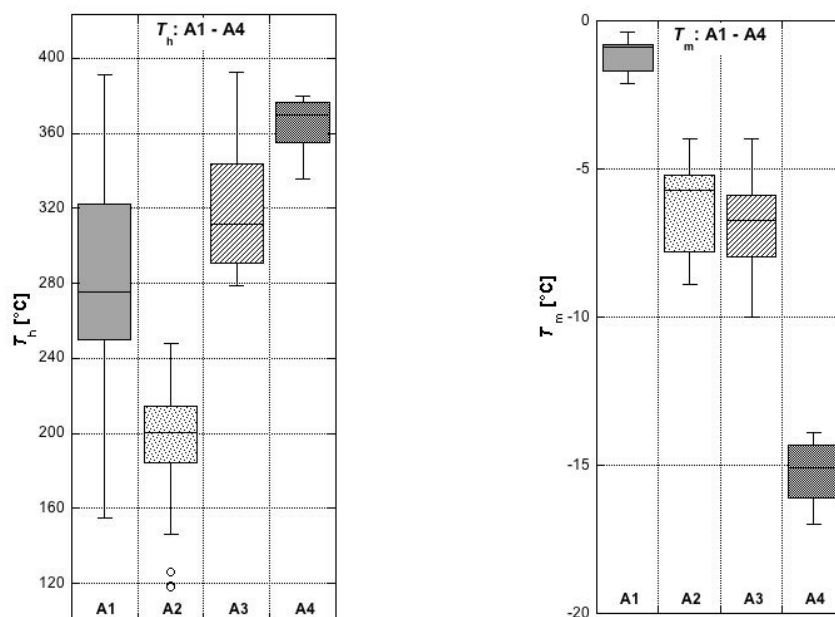


Figure 5.19, Boxplots of microthermometrical measurements of type A fluid inclusions

Type B fluid inclusions have an apparent lower eutectic melting (T_E) than type A fluid inclusions. T_E is around $-52\text{ }^{\circ}\text{C}$, which suggests the presence of CaCl_2 , in addition to NaCl . Final melting occurs between -45 and $-5\text{ }^{\circ}\text{C}$, which points to a variable salinity of the fluid inclusions next to a variable composition of the CaCl_2 -rich type (Figure 5.17, Table 5.3, Figure 5.20).

Table 5.3, Summary of microthermometrical measurements of type B fluid inclusions

		B1			
		Average	Standard deviation	min	max
T_m (Ice)	[$^{\circ}\text{C}$]	-23.37	2.35	-29.00	-21.10
T_m (Hydrate)	[$^{\circ}\text{C}$]	—	—	—	—
T_h (CO_2)	[$^{\circ}\text{C}$]	—	—	—	—
P_h (CO_2)	[MPa]	—	—	—	—
T_h	[$^{\circ}\text{C}$]	211.67	45.60	144.50	278.90
P_h	[MPa]	2.31	1.90	0.50	5.90
Salinity [mass%]	NaCl	4.52	0.21	4.30	5.00
	CaCl_2	18.05	0.85	17.20	20.00
		B2			
		Average	Standard deviation	min	max
T_m (Ice)	[$^{\circ}\text{C}$]	-40.12	2.16	-42.40	-37.20
T_m (Hydrate)	[$^{\circ}\text{C}$]	—	—	—	—
T_h (CO_2)	[$^{\circ}\text{C}$]	—	—	—	—
P_h (CO_2)	[MPa]	—	—	—	—
T_h	[$^{\circ}\text{C}$]	157.78	26.75	111.40	175.00
P_h	[MPa]	0.62	0.11	0.50	0.70
Salinity [mass%]	NaCl	5.74	0.57	5.20	6.70
	CaCl_2	22.58	0.93	21.30	23.80

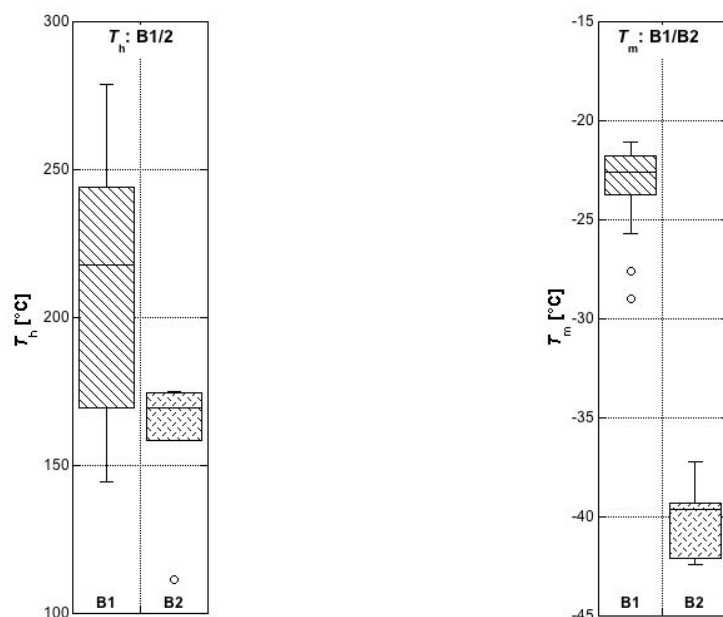


Figure 5.20, Boxplots of microthermometrical measurements of type B fluid inclusions

The CO₂ bearing type C inclusions are characterized by a $T_m(\text{CO}_2)$ between -57° and -60°C, which indicates the presence of small amounts of another gas phase, which has been identified as CH₄ and N₂ by RAMAN spectroscopy. They show different homogenisation temperatures $T_h(\text{CO}_2 \text{ LV} \rightarrow \text{L})$ between -11°C and +6°C. The homogenisation of the CO₂ occurs into the liquid phase (Figure 5.18, Table 5.4, Figure 5.21).

Table 5.4, Summary of microthermometrical measurements of type C fluid inclusions

		C				
		Average	Standard deviation	min	max	
T_m (Ice)	[°C]	-58.31	1.22	-61.00	-56.60	
T_m (Hydrate)	[°C]	—	—	—	—	
T_h (CO ₂)	[°C]	1.70	10.80	-20.60	18.70	
P_h (CO ₂)	[MPa]	3.58	1.20	0.90	5.60	
T_h	[°C]	—	—	—	—	
P_h	[MPa]	—	—	—	—	
Salinity [mass%]	NaCl	—	—	—	—	
	CaCl ₂	—	—	—	—	

The in one sample encountered type D fluid inclusions are assumed to be the oldest generation of fluid inclusions. They are two phase H₂O-CO₂ inclusions with small amounts of a salt component, most likely NaCl, which is suggested by $T_m(\text{ice})$ and $T_m(\text{clathrate})$. CO₂ melting occurs between -58 and -62 °C and is slightly lower than type C inclusions. The $T_h(\text{CO}_2 \text{ LV} \rightarrow \text{L})$ plots between 8.7 and 22.6 °C. No negative $T_h(\text{CO}_2$

LV→L) could be observed. Due to the high internal pressure at higher temperatures, all fluid inclusions decrepitated before reaching $T_h(\text{total})$. Further thermodynamic calculations have been performed with volume fraction estimation (Figure 5.18, Table 5.5, Figure 5.21).

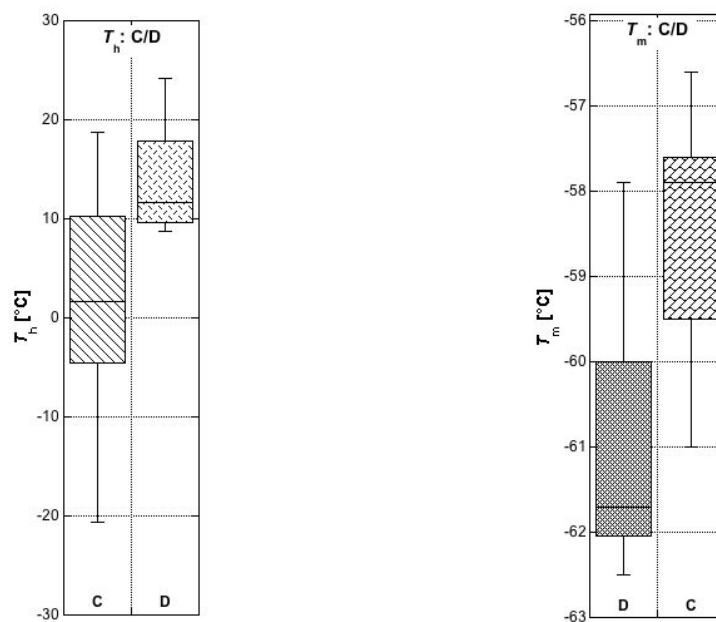


Figure 5.21, Boxplots of microthermometrical measurements of type C and D fluid inclusions

Table 5.5, Summary of microthermometrical measurements of type D fluid inclusions

		D			
		Average	Standard deviation	min	max
T_m (Ice)	[°C]	-60.79	1.74	-62.50	-57.30
T_m (Hydrate)	[°C]	7.96	0.69	7.00	9.30
T_h (CO ₂)	[°C]	14.36	5.21	8.70	24.20
P_h (CO ₂)	[MPa]	5.04	0.63	4.40	6.30
T_h	[°C]	—	—	—	—
P_h	[MPa]	—	—	—	—
Salinity [mass%]	NaCl	6.30	1.22	3.90	8.00
	CaCl ₂	—	—	—	—

5.2) LA-ICP-MS

In order to obtain detailed information about the relative element content of fluid inclusions LA-ICP-MS measurements have been performed, after the fluid inclusions have been measured with microthermometry. They were opened with the laser beam and the resulting signals have been evaluated. Figures 5.22 and 5.23 show LA-ICP-MS measurements from A II and B II fluid inclusions within sample 1137 (depth 584.55 m).

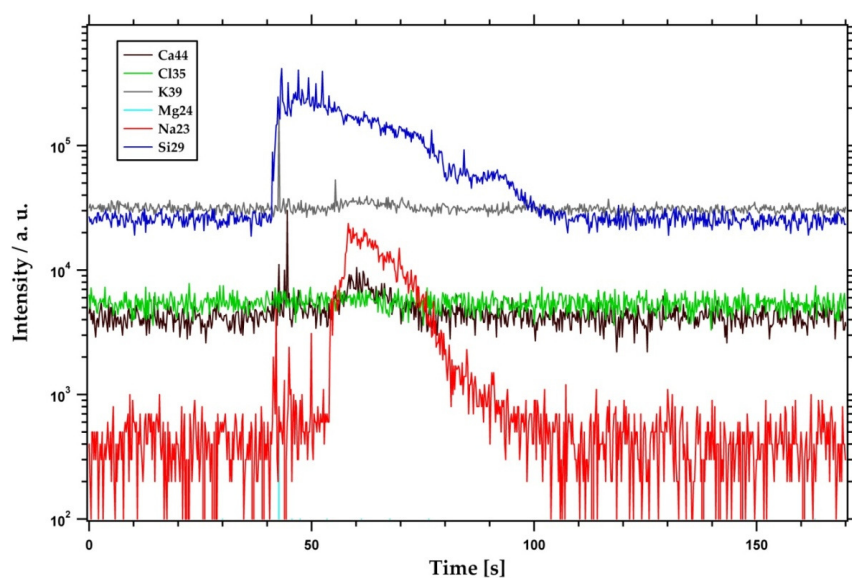


Figure 5.22 LA-ICP-MS signals of type A II fluid inclusions. Type A inclusions are characterized by a Na signal

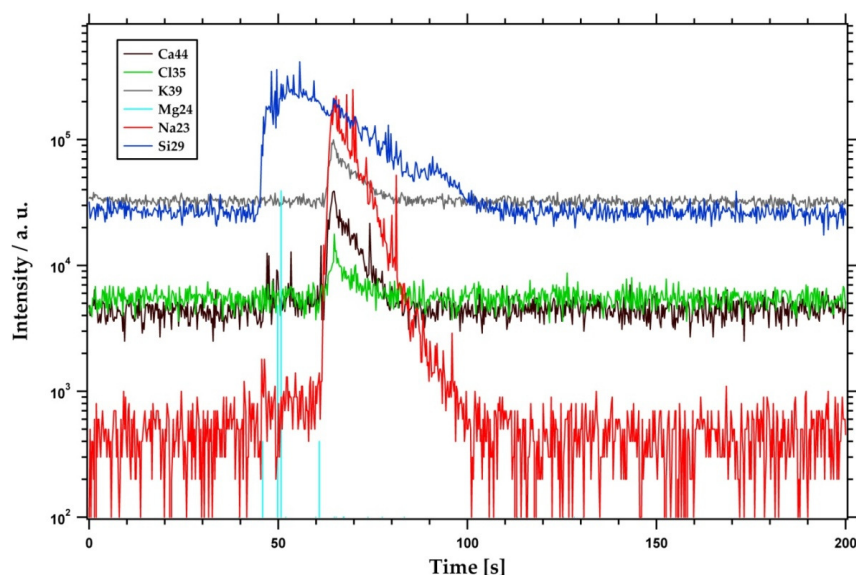


Figure 5.23, LA-ICP-MS signals of type B II fluid inclusions. Type B inclusions show a Ca signal next to Na

Table 5.6 displays the concentrations of the measurements, calculated with an external standard. Table 5.7 shows the element concentrations calculated with internal standards.

Table 5.6, Concentrations of the measurements, calculated with an external standard

	Si29	Cl35	Ca44	Mg24	K39	Na23	Na/(Na+Ca)
Nist612 1	341207.73	< 357.71	87592.47	50.34	< 97.60	105318.65	0.55
Nist612 2	331992.27	< 357.72	84007.53	49.66	< 97.60	101881.35	0.55
1137 1 (B II)	51510.73	< 357.73	2883.68	< 0.91	142.00	905.59	0.24
1137 2 (B II)	111281.58	< 357.74	3667.99	< 0.91	184.78	785.17	0.18
1137 3 (A II)	172776.83	< 357.75	< 1141.11	< 0.91	< 97.60	179.66	-
1137 4 (A II)	155144.24	< 357.76	< 1141.11	< 0.91	< 97.60	562.10	-
Nist612 4	364380.99	< 357.77	92887.07	54.75	< 97.60	111673.81	0.55
Nist612 5	335276.80	< 357.78	86251.69	50.17	< 97.60	104656.62	0.55

	Tm [°C]	mass% Ca	mass% Na	Ref.
Nist612 1	-	-	-	-
Nist612 2	-	-	-	-
1137 1 (B II)	-39.60	21.27	6.72	Oakes
1137 2 (B II)	-42.40	23.81	5.23	Oakes
1137 3 (A II)	-8.90	-	12.73	Bodnar
1137 4 (A II)	-8.70	-	12.51	Bodnar
Nist612 4	-	-	-	-
Nist612 5	-	-	-	-

Table 5.7, Element concentrations calculated with internal standards

Concentration in ppm

	int. Std (Na)	Si29	Cl35	Ca44	Mg24	K39	Na23
Nist612 1	103600.00	335639.71	< 357.71	86163.09	49.52	< 97.60	103600.00
Nist612 2	103600.00	337592.69	< 357.72	85424.66	50.50	< 97.60	103600.00
1137 1 (B II)	67200.00	3822413.16	< 357.73	213986.51	< 0.91	10537.63	67200.00
1137 2 (B II)	52300.00	7412487.86	< 357.74	244325.58	< 0.91	12307.98	52300.00
1137 3 (A II)	127300.00	122424347.21	< 357.75	< 1141.11	< 0.91	< 97.60	127300.00
1137 4 (A II)	125100.00	34528760.66	< 357.76	< 1141.11	< 0.91	< 97.60	125100.00
Nist612 4	103600.00	338036.93	< 357.77	86171.51	50.79	< 97.60	103600.00
Nist612 5	103600.00	331891.81	< 357.78	85380.89	49.66	< 97.60	103600.00

Concentration in mass%

	int. Std (Na)	Si	Cl	Ca	Mg	K	Na
Nist612 1	10.36	33.56	< 0.04	8.62	0.00	< 0.01	10.36
Nist612 2	10.36	33.76	< 0.04	8.54	0.01	< 0.01	10.36
1137 1 (B II)	6.72	382.24	< 0.04	21.40	< 0.01	1.05	6.72
1137 2 (B II)	5.23	741.25	< 0.04	24.43	< 0.01	1.23	5.23
1137 3 (A II)	12.73	12242.43	< 0.04	< 0.11	< 0.01	< 0.01	12.73
1137 4 (A II)	12.51	3452.88	< 0.04	< 0.11	< 0.01	< 0.01	12.51
Nist612 4	10.36	33.80	< 0.04	8.62	0.01	< 0.01	10.36
Nist612 5	10.36	33.19	< 0.04	8.54	0.00	< 0.01	10.36

In order to obtain exact quantitative data on the composition of a fluid inclusion, it is necessary to estimate, as accurate as possible, the concentration of the internal

standard. For fluid inclusions, which contain next to Na other major cations, it is important to consider these additional cations when calculating the Na concentration from the melting temperature of fluid inclusions. Gagnon et al. (2004) pointed out that the phase relationships exhibited by fluid inclusions are best interpreted using the system $\text{H}_2\text{O}-\text{NaCl}$ for Ca-free inclusions, and the system $\text{H}_2\text{O}-\text{NaCl}-\text{CaCl}_2$ for Ca-bearing inclusions. The Na concentration within Ca-free fluid inclusions can be calculated with the equation of Bodnar (1993). The salinity within Ca-bearing fluid inclusions can be calculated with the equations of Oakes et al. (1990) and the Ca:Na ratio measured from LA-ICP-MS analyses (Gagnon et al., 2004). A more recent publication about the phase relationships in the system $\text{H}_2\text{O}-\text{NaCl}-\text{CaCl}_2$ was published by Steele-MacInnis et al. (2011). The calculations were performed with the computer program AqSoVir developed by R. J. Bakker (<http://fluids.unileoben.ac.at>).

Table 5.8, Concentration of different elements within the Nist612 standard

Nist612	conc. [ppm]	conc. [mass%]
Si29	336600.00	33.66
Cl35	50.00	< 0.01
Ca44	85800.00	8.58
Mg24	50.00	< 0.01
K39	64.00	< 0.01
Na23	103600.00	10.36

With these measurements it has been shown that it is possible to use the LA-ICP-MS equipment of the Institute of Mineralogy and Economic Geology for the measurements of fluid inclusions. By the use of external and internal standards, the chemical composition could be determined.

Measurement of B II fluid inclusions show next to Na, elevated Ca concentrations, which is consistent with the microthermometrical measurements, where they show T_E at around -51°C . Only potassium is also present as cation. No other cations, next to Na, could be detected within type A II fluid inclusions.

Within type B II fluid inclusions Ca is the major cation with a concentration of around 21 to 24 mass%, followed by Na with a concentration between 5 and 6 mass% and potassium with around 1 mass%. Chlorine is within all measurements below the detection limit same as Mg.

5.3) Crush-Leach

Crush-leach analyses were performed at the University of Leoben under the supervision of Prof. Prochaska. The objective of this analysis was to compare the bulk fluid composition with the chemical composition of the groundwater to gather information if the groundwater could be derived from the fluid inclusions. The results of crush-leach analyses show cation ratios of Ca/Na (0.255 – 0.948 molar), K/Na (0.097 – 0.204 molar), Li/Na (0.001 – 0.085 molar), and Mg/Na (0.024 – 0.344 molar), which are partially higher than seawater (Ca/Na 0.022; K/Na 0.021; Li/Na >0.001; Mg/Na 0.113). The Li/Na ratio rises in the vicinity of the deeper pegmatites, which suggests an influence of magmatic water (chemical composition of seawater from Turekian, 1968). Only the composition of the fluid can be measured; no differentiation of different types can be made.

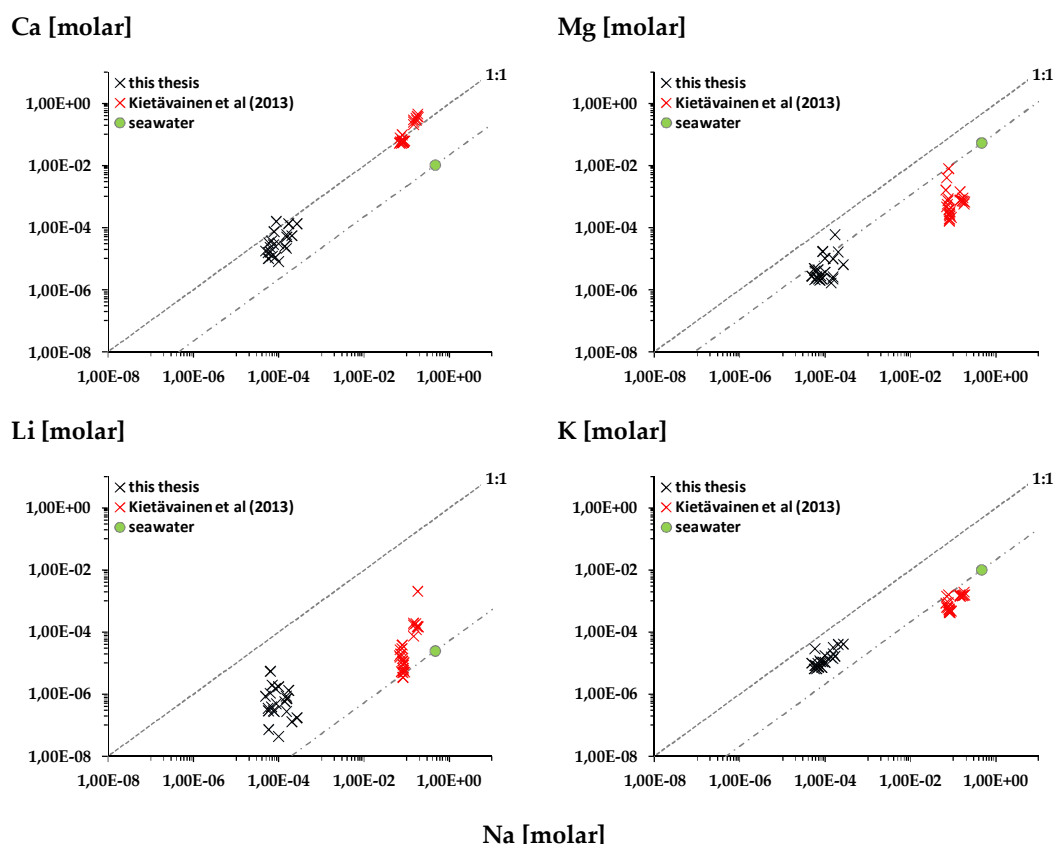


Figure 5.24, Different cations of fluid inclusion leachates and groundwater (Kietäväinen et al.) plotted against Na; chemical composition of seawater from Turekian, 1968

Figure 5.24 shows variation plots of the cations which were measured in the fluid inclusions and the groundwater. It is shown that all cations are enriched within the

fluid inclusions relative to seawater. The groundwater, measured by Kietavainen et al. (2013) is Ca dominated whereas the fluid inclusions are mainly Na dominated. Relative to seawater and the fluid inclusions, the groundwater values show a depletion in Mg and K.

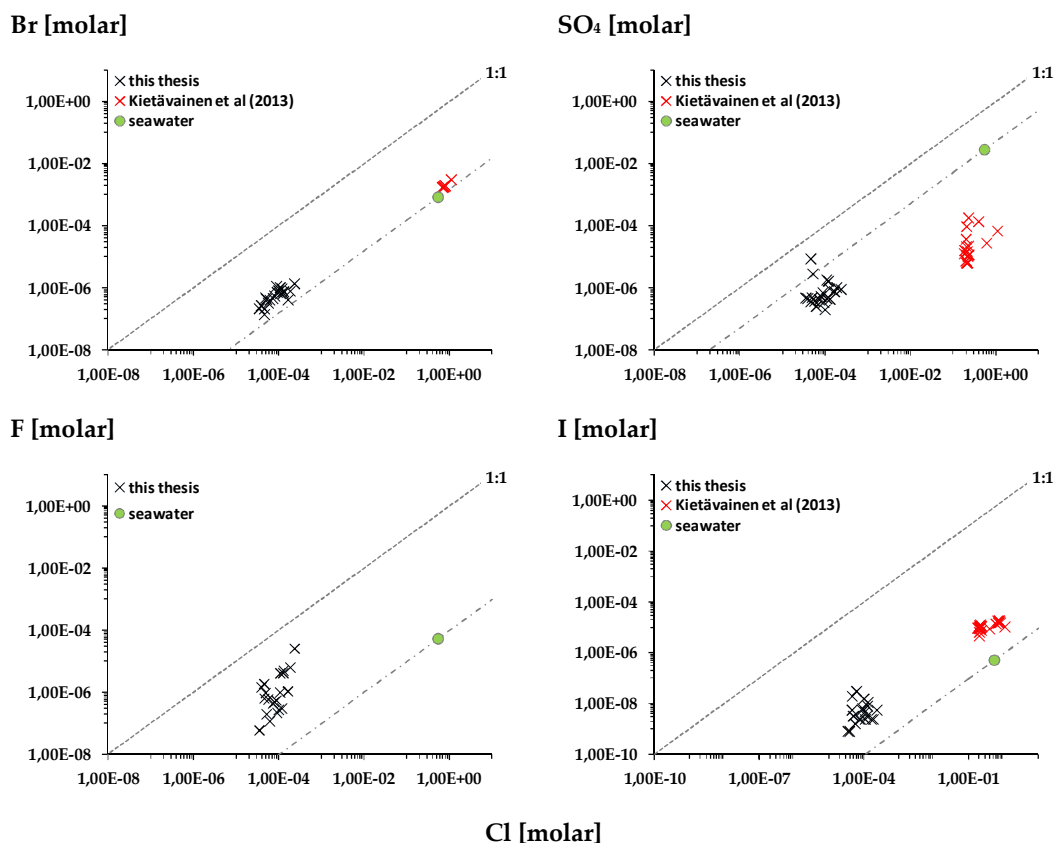


Figure 5.25, Different anions of fluid inclusion leachates and groundwater (Kietavainen et al.) plottet against Cl; chemical composition of seawater from Turekian, 1968

Also within the anion plot (Fig. 5.25) the differences between seawater, groundwater and fluid inclusions are visible with an enrichment of Br, F and I relative to seawater and a depletion of SO₄.

Within the Cl/Br-Na/Br diagram (Figure 5.26), most of the crush-leach samples differ significantly from the seawater evaporation trajectory (SET; Figure 5.26). They also plot mainly below the 1:1 line, indicating a change of the Cl/Br-Na/Br ratios during halite precipitation and halite dissolution. The molar Cl/Br ratios range from 100 to 400 and are significantly lower than seawater, implying a higher Br concentration than seawater. The molar Na/Br ratios are between 80 and 580 and are similar to seawater ratios.

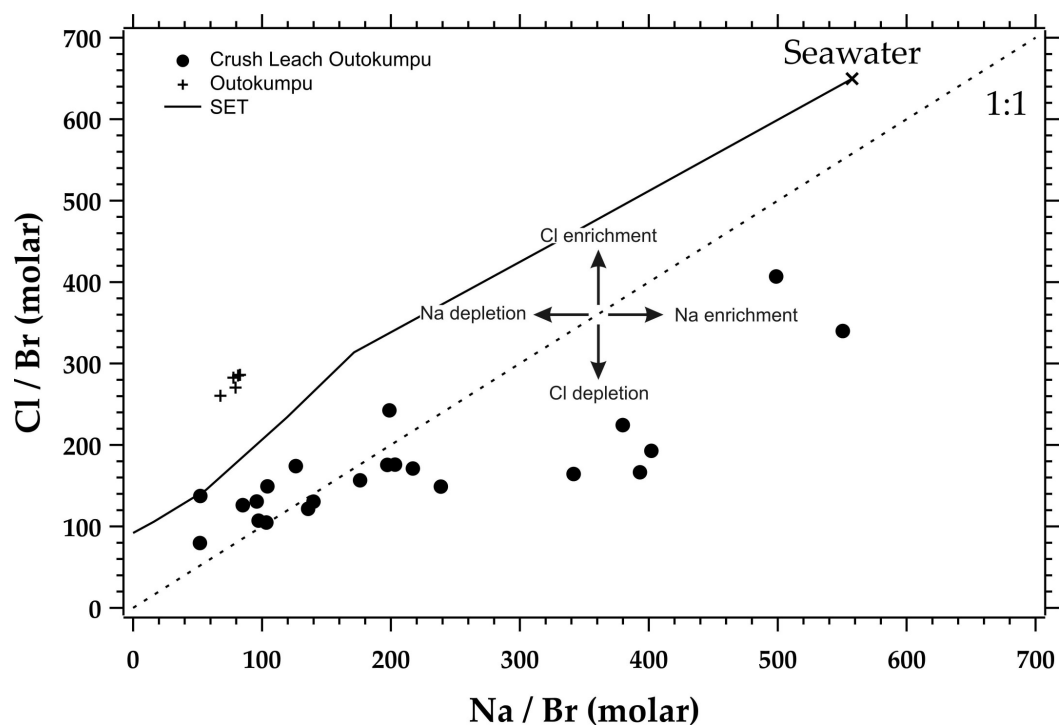


Figure 5.26, Na/Br vs. Cl/Br plot of fluid inclusion leachates from Outokumpu and groundwater values from Outokumpu (Nurmi et al., 1988); SET-seawater evaporation trajectory

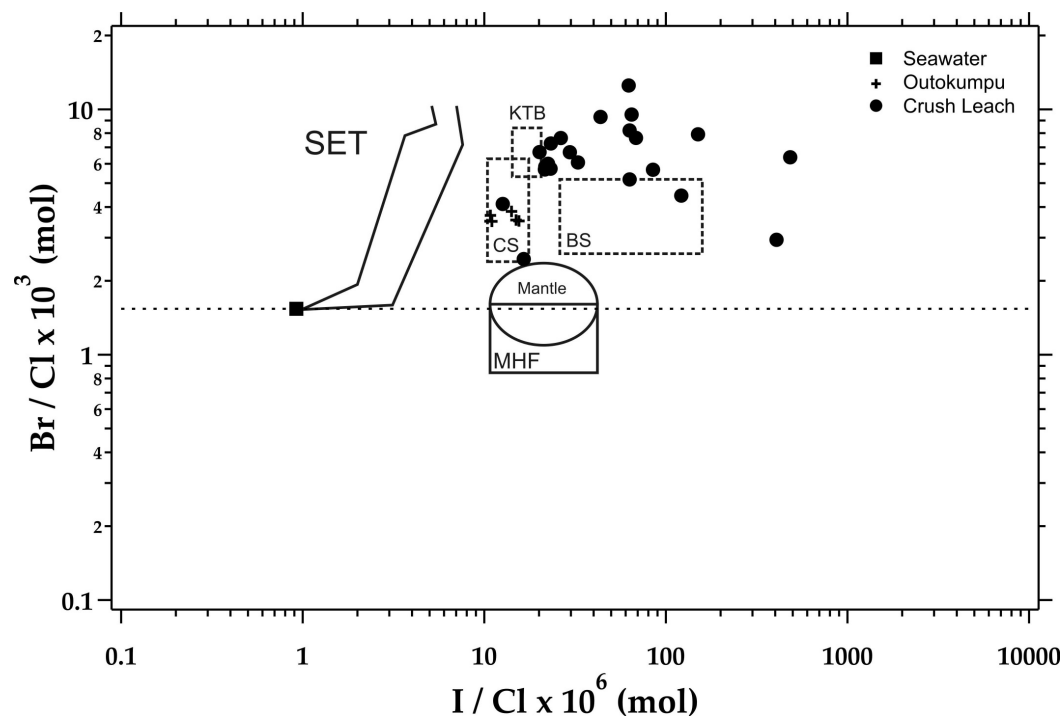


Figure 5.27, I/Cl vs. Br/Cl plot of fluid inclusion leachates from Outokumpu and groundwater values from Outokumpu (Nurmi et al. 1988). SET-seawater evaporation trajectory, MHF-uncontaminated magmatic hydrothermal fluids, CS-shield brines from the Canadian Shield, BS-shield brines from the Baltic Shield, KTB-deep saline fluids drilled by KTB borehole (Dolníček et al. 2009)

A comparison of the main anion ratios ($\text{Br/Cl} - \text{I/Cl}$) is shown in figure 5.27. Most fluid inclusion leachates exhibit higher Br/Cl ratios than brines from stable cratons (i. e. Canadian shield and Baltic shield). Most fluid inclusions leachates also plot away from the values of Outokumpu groundwater and, thus, cannot easily be assigned to any specific environment or geological setting.

5.4) Stable Isotopes

The O and H isotope analyses were carried out on 7 samples of handpicked biotite separates. Fluid inclusions of 18 handpicked quartz separates were released by thermal decrepitation and analyzed for H isotope composition. Due to the method no O isotopes could be measured within the fluid. Therefore the quartz residue was used for O isotope determination. The analyses were carried out in collaboration with Torsten Vennemann (University of Lausanne). A detailed description of the analytical method can be found in chapter 3. A summary of the stable isotopes results can be found in the appendix. The objective of this analysis was to compare the bulk fluid composition with the chemical composition of the groundwater to gather information if the groundwater could be derived from the fluid inclusions.

The $\delta^{18}\text{O}$ values within the fluid inclusions were calculated under the assumption of isotopic balance and equilibrium thermodynamics between the fluid phase and the host mineral (quartz, Hu & Clayton, 2003) at a temperature of 450 °C, as indicated by isotopic geothermometry. The δD values of the fluid inclusions show a broad scatter; however, all values plot in the field of metamorphic fluids. The isotopic composition of the groundwater at Outokumpu (Nurmi et al., 1988) is situated to the left of the meteoric water line (Figure 5.28).

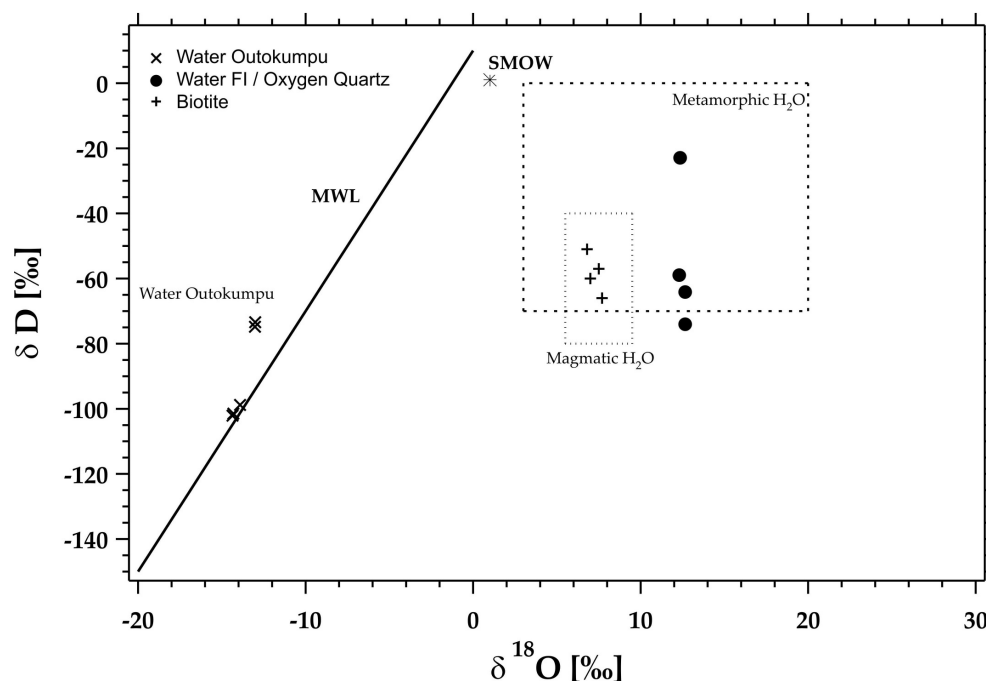


Figure 5.28, $\delta^{18}\text{O}$ vs. δD plot of fluid inclusions and biotites from Outokumpu, groundwater values from Outokumpu are from Nurmi et al., 1988

6) Discussion

Petrography and metamorphic conditions

Peltonen et al. (2008) gives a summary of the events, which have taken place in the process of the formation of the Outokumpu type ore deposits, which they consider to be polygenetic. Three main stages are described, which lead to the petrological characteristics, which can be observed today in the Outokumpu area (Peltonen et al., 2008):

1. Ultramafic ocean floor stage (1950 Ma)

Formation of a Cu rich proto ore within peridotites at the seafloor

2. Obduction stage (1900 Ma)

Low-T (100 – 200 °C) alteration of the peridotites (listwaenite-birbirite-type), formation of disseminated Ni sulphides

3. Regional deformation stage (1880 Ma)

Syntectonic remobilisation at metamorphic conditions of around 630 °C and 2 to 4 kbar

Hölttä & Karttunen (2011) used grt – bt thermometers, grt – bt – plg – qtz and grt – ms – plg – qtz geobarometers, thermocalc (Andersson et al., 2002) and fluid inclusions to reconstruct a p-T path. Their measurements and calculations indicate metamorphism at temperatures between 600 and 670 °C and pressures around 8 kbar (Hölttä & Karttunen, 2011). These results can be confirmed by this study. Temperatures were measured with different methods including Ti in biotite, Ti in quartz, isotopic exchange and grt – bt – plg – qtz geobarometer/geothermometer. The different methods gave temperatures between 500 and 750 °C. Fluid inclusions analysis and grt – bt – plg – qtz were used as geobarometers indicating pressures between 8 and 9 kbar for peak metamorphic conditions.

Additionally, fluid inclusions analyses showed different fluid pulses at different temperatures and pressures. Detailed petrographic studies allowed reconstruction of relative timing of these different pulses, which show a complex p – T history.

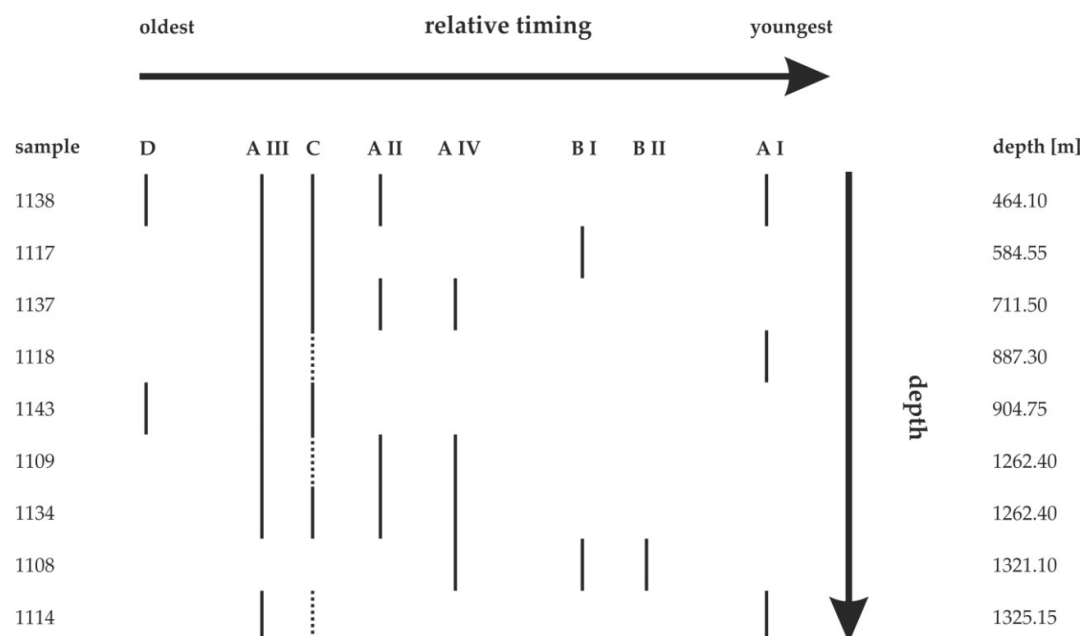


Figure 6.1, Relative timing of the different fluid pulses

Figure 6.1 shows all occurring fluid inclusion types as a function of their depth and relative timing according to petrographic evidence. The different fluid pulses are not only characterized by different petrographic features, they also show different homogenisation temperatures and compositions, which are described in chapter 5 (Fluid Inclusions).

Type D inclusions are typical for metamorphic fluids and represent an event close to peak metamorphic conditions.

Their $T_h(\text{CO}_2)$ vary between 8.7 and 24.2 °C with an average of 14.4 °C. Final melting of the clathrate occurs at around 8 °C, which indicates the presence of a salt. $T_m(\text{CO}_2)$ is around -60 °C which is an indication for the presence of other gases such as CH_4 or N_2 .

Type A III and cogenetic type C inclusions could represent a second metamorphic event as suggested by Hölttä & Karttunen (2011).

Type A III fluid inclusions are characterized by a salinity of about 10 eq. mass% NaCl and a $T_h(\text{total})$ in the range of 280 to 390 °C. The coexisting inclusions of the type C show a melting temperature of around -58 °C which shows the presence of another gaseous phase, most likely CH₄. CO₂ homogenisation temperatures plot between -20 and 20 °C with an average of 1.7 °C.

Fluid inclusions, which were assigned to type A II are probably related to this second event (Figure 6.1) and may show a stage of isobaric cooling.

Their melting temperature and salinity is similar to type A III inclusions with a lower T_h of around 200 °C.

Type A IV fluid inclusions show the highest salinity and cannot be exactly timed (Figure 6.1). It is suggested by the petrographic evidence that they represent an event, which is close to the second metamorphic event.

Ice melting temperatures are between -17 and -14 °C, total homogenisation occurs around 365 °C.

B I and B II inclusions are encountered close to rocks which show a listwaenite–birbirite type carbonate–silica alteration at margins of the ultramafic massifs. These rocks formed during a secondary carbonatization event, which is mentioned by Peltonen et al. (2008) and which took place after the peak metamorphism. Therefore these inclusions could be influenced by the alteration mineralogy, which was formed during the alteration.

They are characterized by the presence of CaCl₂ in addition to NaCl. They show low ice melting temperatures of -23 °C (B I) and -40 °C (B II). It is assumed that the final phase, which melted, was ice. Another possible phase would be a salt hydrate, which can only be determined by the use of combined microthermometry Raman method. The presence of CaCl₂ could also be demonstrated by the LA-ICP-MS measurements, which are described in chapter 5. B II inclusions show a slightly lower total homogenisation temperature (157 °C) than type B I (211 °C).

Discussion and conclusions

The latest generation of type A I inclusions forms a separate, low P-T event. They are related to the single-phase gaseous and pure liquid inclusions, which were formed most likely close to surface conditions. They occur mainly on transgranular trails and show a very variable filling degree.

The salinity is close to 2 eq. mass% NaCl. The total homogenisation temperature varies between 155 and 290 °C. The highly variable homogenisation temperature and filling degree can be explained by necking down, whereas some petrographic evidence features heterogeneous trapping.

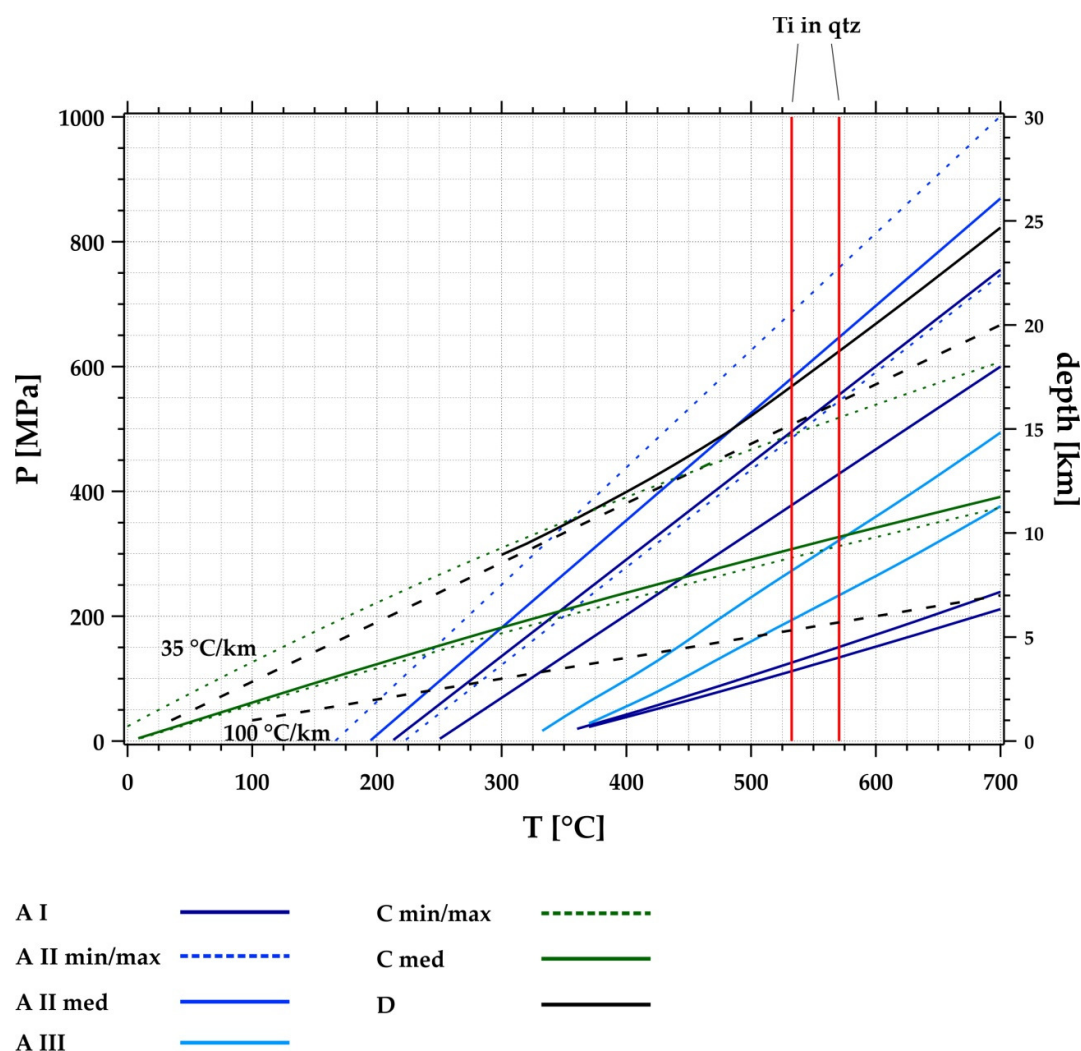


Figure 6.2, Calculated isochors from sample 1138 (depth 464.10 m); red lines mark the temperature obtained by the Ti in qtz thermometer after Wark & Watson (2006)

Sample 1138 (depth 464.10 m, Figure 6.2) is a quartz vein crosscutting biotite mica schist. Type A I, A II, A II, C and D inclusions were detected and analysed by petrographic investigations and microthermometrical measurements. The fluid

inclusions occur within clusters, intragranular trails, transgranular trails and as large isolated inclusions.

Some rare inclusions show the presence of an additional solid phase. Due to the fact that there is no proof that these inclusions belong to an own fluid inclusion assemblage, the solid phases are considered to be accidentally trapped and have no influence on the interpretation. Furthermore, it was not possible to determine the composition of the solid phase.

In addition to the microthermometrical measurements also Ti concentrations in quartz have been measured to obtain additional information about the formation temperatures. The calculated isochors are displayed in figure 6.2. During metamorphism the area was characterized by pressure conditions between 200 and 400 MPa (Koistinen, 1981; Korsman et al., 1999; Peltonen et al., 2008; Sääntti et al., 2006).

The isochors of type A III and type C inclusions shows an intersection at around 580 °C and 300 MPa, which corresponds to the peak metamorphic conditions described by various authors (Koistinen, 1981; Korsman et al., 1999; Peltonen et al., 2008; Sääntti et al., 2006). Due to this intersection, type A III and type C inclusions cannot be the result of heterogeneous trapping. Isochors, which are calculated from fluid inclusion assemblages, which are the result of heterogenic trapping do not intersect. The measured total homogenisation is the formation temperature. The coexisting type C and type A III inclusions could be the result of two different fluid pulses, which were entrapped at the same conditions.

The intersection of Type D fluid inclusions with the external geothermometer shows pressures between 600 and 650 MPa, which are significant higher than the published peak metamorphic conditions. In contrary they are lower than the maximum p-T conditions calculated by Hölttä & Karttunen (2011) and in this study with the help of the grt-bt-plg-qtz geobarometer and the grt-bt geothermometer, which shows temperatures between 600 and 670 °C and pressures at around 8 kbar.

Sample 1117 (depth 584.55 m, Figure 6.3) is a biotite mica schist with a deformed quartz lens. Type A III, C and B I fluid inclusions could be identified with microthermometrical measurements.

The intersection between the calculated isochores from the coexisting type C and type A III fluid inclusions show a temperature between 450 to 625 °C and pressures of around 225 MPa up to 450 MPa. The temperatures obtained from the oxygen isotope exchange thermometer after Bottinga and Javoy (1975) are with 505 °C in the range of the intersection of the calculated isochores.

B I fluid inclusions, which are considered to be related to a secondary carbonization event, are younger than the coexisting type A III and C fluid inclusions. Therefore lower p-T conditions of the entrapment are suggested, with formation conditions between 175 °C (T_h) and 300 °C (temperatures obtained from the isochor between the P_h (total) and 225 MPa).

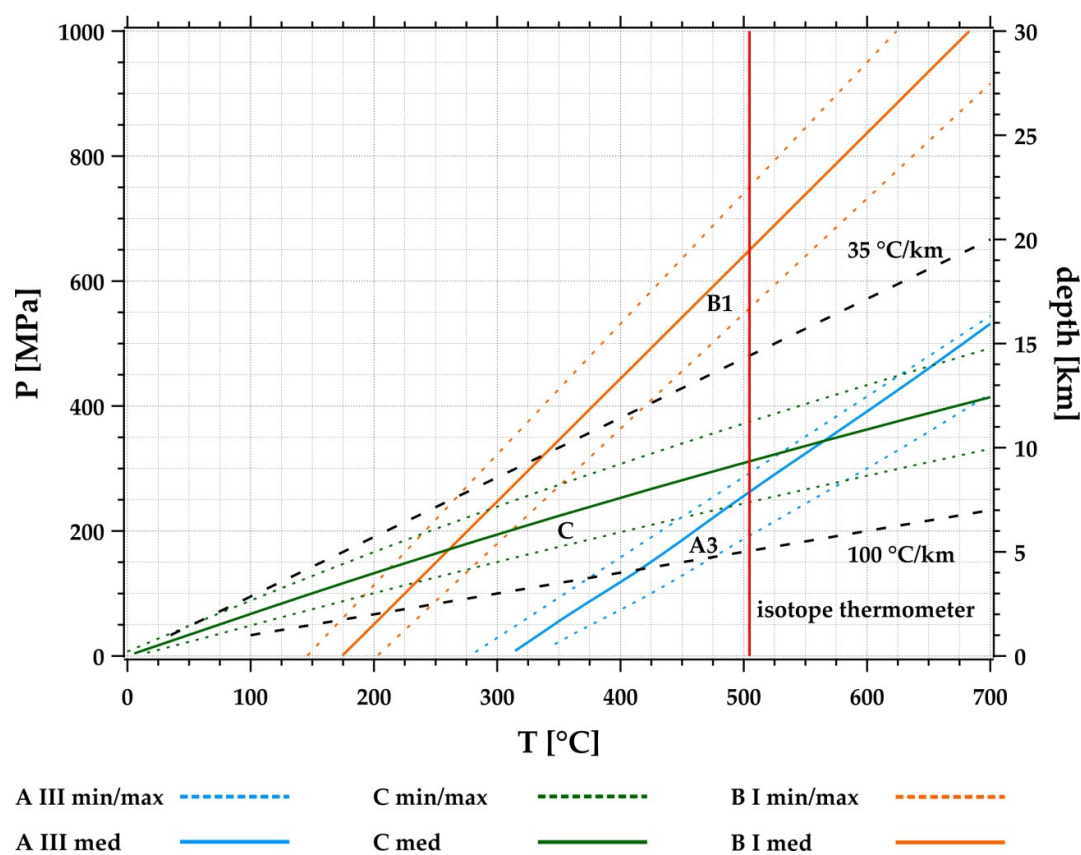


Figure 6.3, Calculated isochores from sample 1117 (depth 584.55 m); the red line marks the temperature obtained by the oxygen isotope exchange thermometer after Bottinga and Javoy (1975)

Sample 1137 (depth 584.55 m) was taken from a deformed quartz vein within a biotite mica schist. Strong tectonic deformation manifests itself in reduced grain size in some areas compared to other samples. All occurring fluid inclusions seem to have suffered post-trapping changes, which is indicated by microthermometrical measurements.

Single isolated fluid inclusions are hard to find and the genetic classification is not always clear. All fluid inclusions within this sample are considered secondary or pseudosecondary.

Two subgroups of type A inclusions and type C inclusions could be identified with help of microthermometry, the calculated isochores are displayed in figure 6.4. Type A III fluid inclusions and type C fluid inclusions show no intersection within the calculated temperature range. This may be caused by the fact that both of the inclusion types seem to have suffered post entrapment changes, which changed their composition and density.

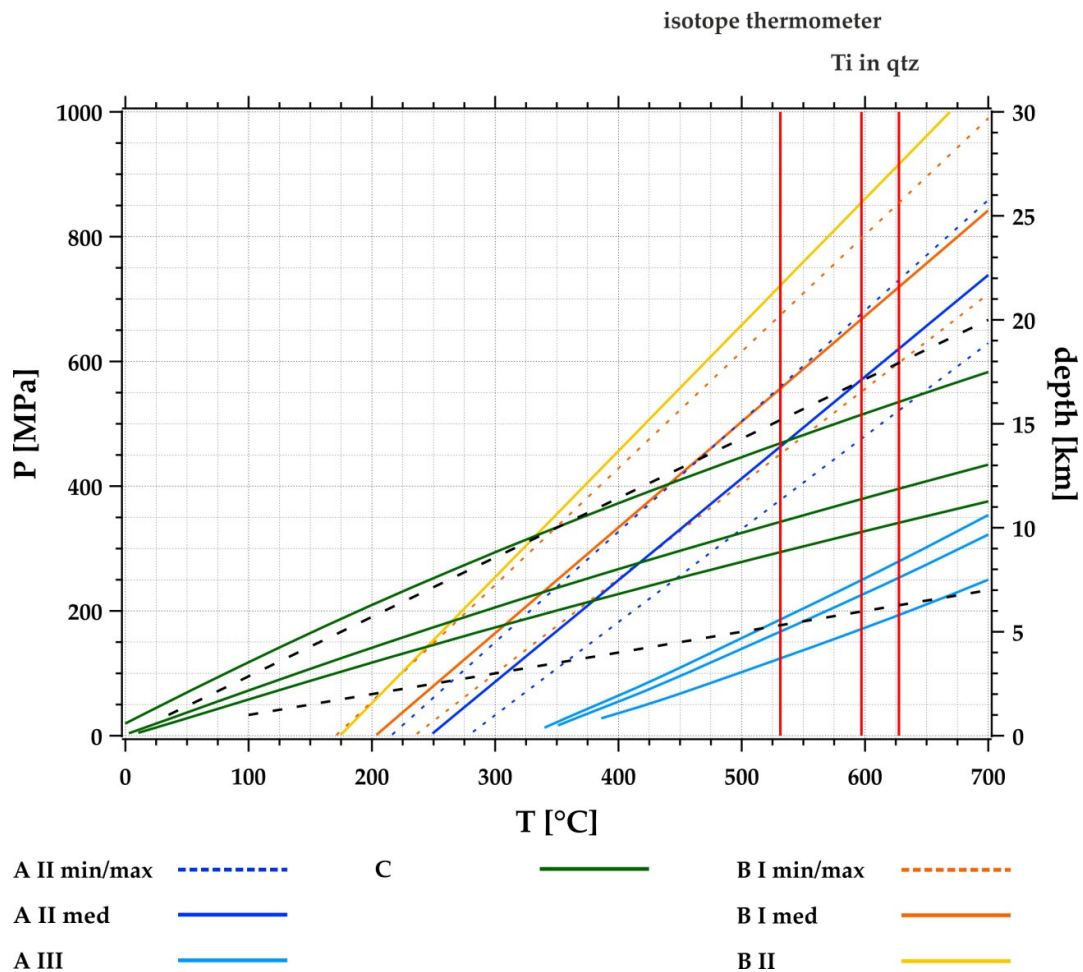


Figure 6.4, Calculated isochor for sample 1137 (depth 584.5 m); red lines mark the temperature obtained by the Ti in qtz thermometer after Wark & Watson (2006) and the temperature obtained by the oxygen isotope exchange thermometer after Bottinga and Javoy (1975)

Furthermore, two different mineral thermometers were applied at this sample to get additional information about the formation conditions. The calculated temperatures from the isotope exchange geothermometer plot at around 530 °C, Ti concentrations within biotite show a formation temperature of around 612 °C. Due to the very variable fluid history which is visible within the quartz it is possible that the measured minerals do not represent isotopic equilibrium conditions or that the phases were reequilibrated during the cooling history and the temperature refers to the secondary metamorphic event.

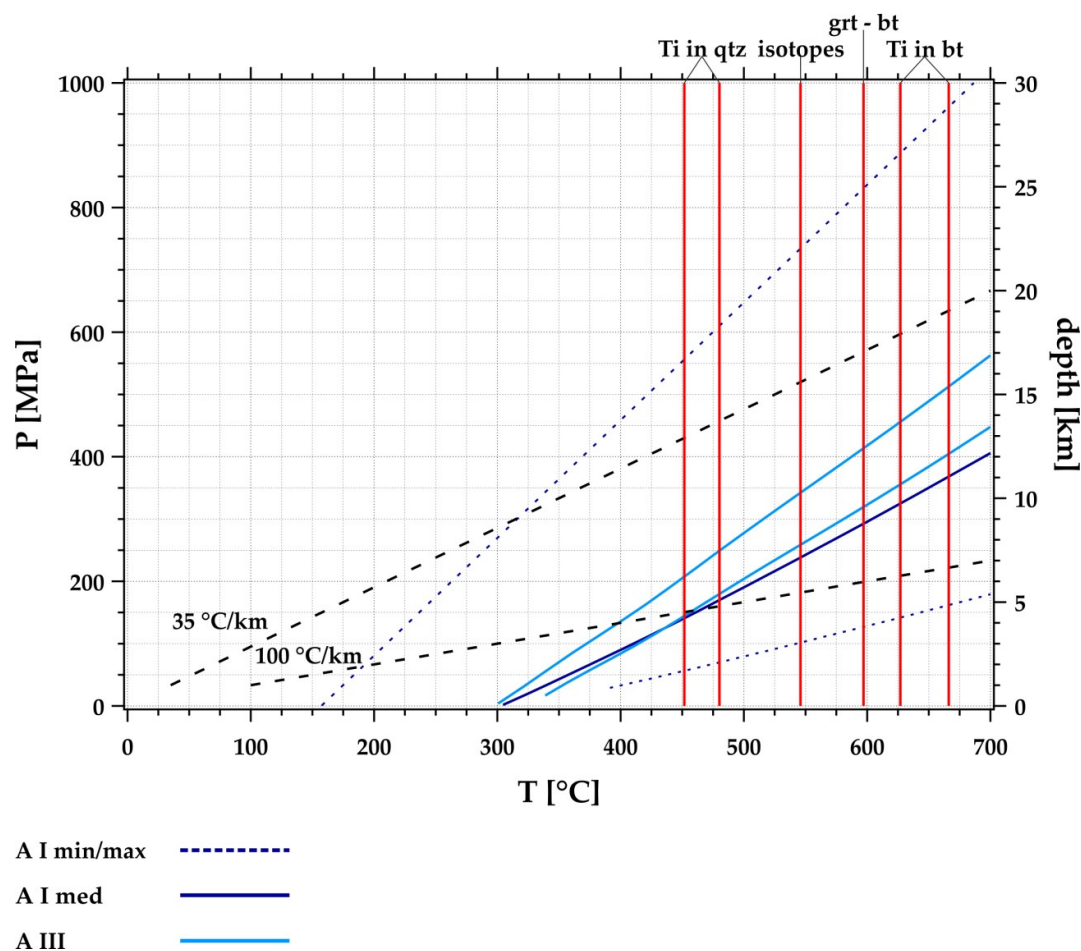


Figure 6.5, Calculated isochor for sample 1118 (depth 887.30 m); red lines mark the temperature obtained by the Ti in qtz thermometer after Wark & Watson (2006), the temperature obtained by the oxygen isotope exchange thermometer after Bottinga and Javoy (1975), the temperature obtained by Ti in Bt thermometer after Henry et al. (2005) and the temperature obtained by grt-bt thermometer after Holdaway (2000)

Only two types of fluid inclusions were encountered in sample 1118 (depth 887.30 m, Figure 6.5). Both types are H₂O-NaCl bearing inclusions from the type A III and A I. This time, no CO₂-bearing type C inclusions could be found, which could be explained by

the fact that the first inclusions measured in this sample show a very high homogenisation temperature and all occurring CO₂-bearing inclusions decrepitated during the heating process. Relicts of these inclusions were observed during the measurements.

Four different mineral thermometers were used to get additional information about the formation conditions: TitaniQ-Ti in quartz (Wark & Watson, 2006), Ti in biotite (Henry et al., 2005), isotope exchange (Bottinga & Javoy, 1975) and the grt-bt geothermometer (Holdaway, 2000). The intersection of the thermometers, which were measured with quartz and the isochors, show temperatures between 450 and 550 °C and pressures between 200 and 350 MPa. Grt-bt and Ti in biotite thermometers show higher temperatures of 600 to 675 °C, which are close to the temperatures of the metamorphic peak. The differences in the obtained temperatures can be explained by different formation temperatures of the quartz vein and the mica schist. Ti in quartz and the isotope exchange thermometer were measured in the quartz vein and the surrounding minerals (biotite), whereas the other thermometers were measured in minerals, occurring in the mica schist.

Samples 1109 and 1134 were taken at the same depth of 1262.4 m (Figure 6.6). They are part of a small, deformed quartz lens within partly carbonatized biotite mica schist close to the rocks of the Outokumpu assemblage. Following types of fluid inclusions were encountered during the measurement: fluid inclusions of the type A II, A III and A IV. Additional to these 2 phase L-V H₂O-NaCl inclusions also CO₂ bearing inclusions of the type C (L) were encountered. These inclusions occur together with fluid inclusions of the type AIII. The calculated isochors and additional applied thermometers are displayed in figure 6.7.

The isochors of type A III and A IV fluid inclusions plot very similar. The intersection of the isochors of type C and type A III inclusions show higher temperatures than in the other samples. They plot at around 550 °C to 650 °C and 350 to 450 MPa.

The TitaniQ geothermometer shows temperatures between 525 °C and 610 °C with an average of around 570 °C. Ti in biotite indicates higher temperatures with an average of around 662 °C.

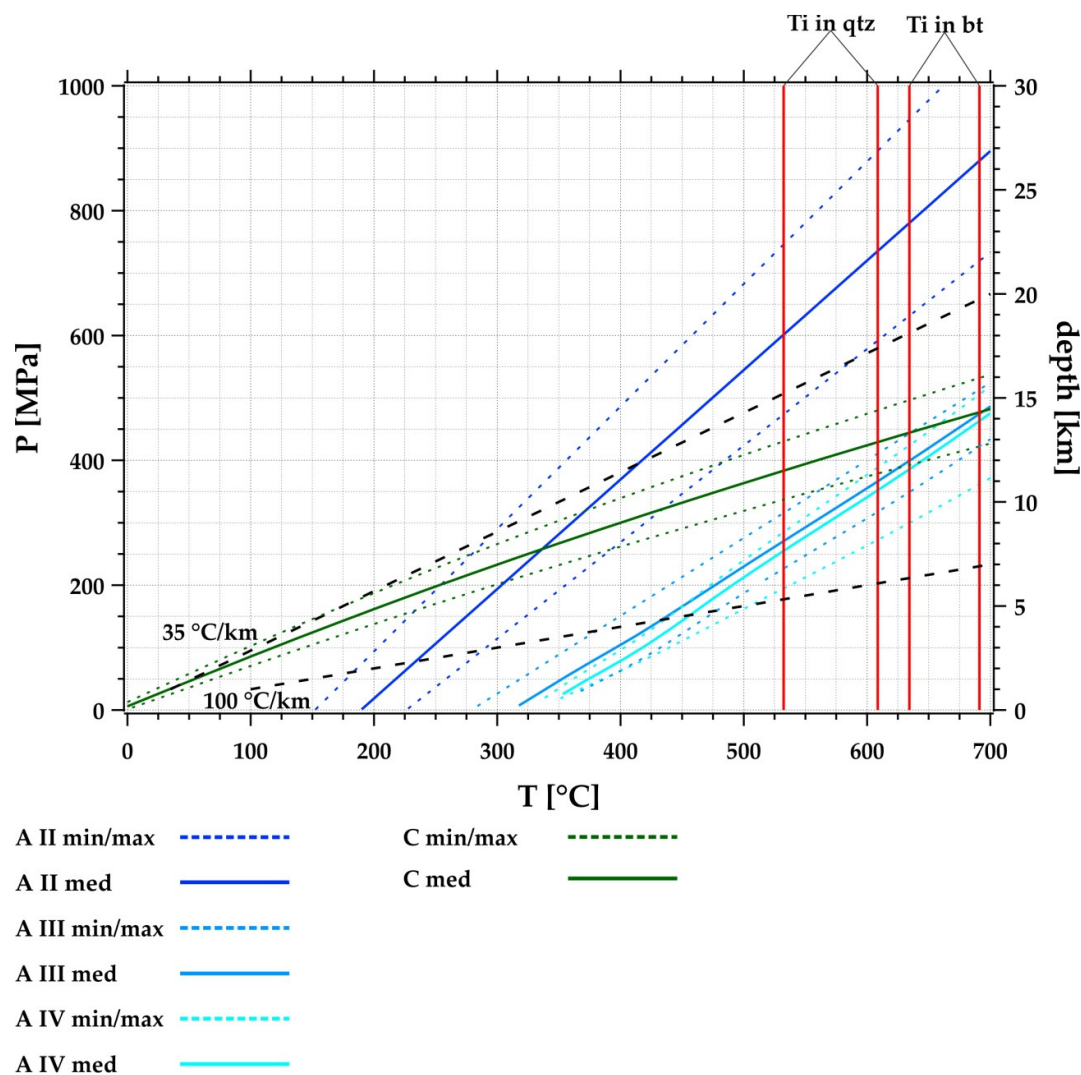
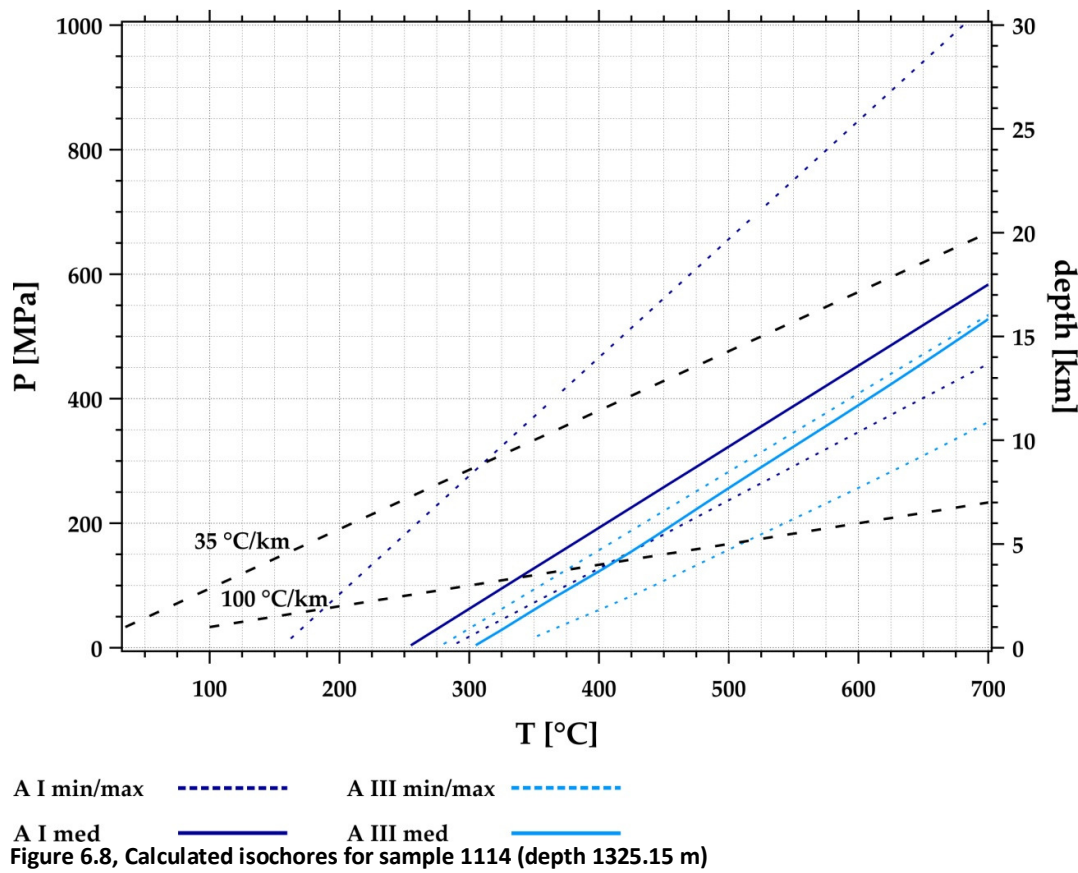
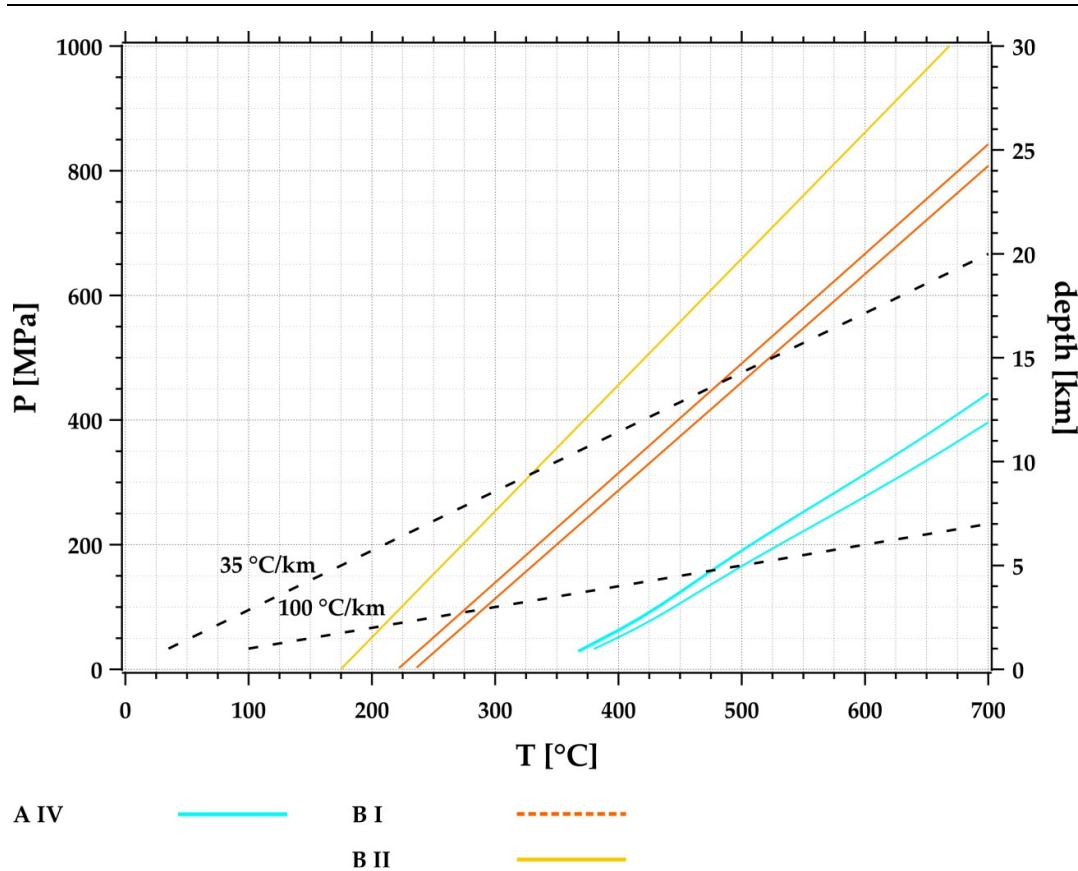


Figure 6.6, Calculated isochor for sample 1134 (depth 1262.4 m); red lines mark the temperature obtained by the Ti in Qtz thermometer after Wark & Watson (2006) and the temperature obtained by Ti in Bt thermometer after Henry et al. (2005)

The last two samples were taken at a depth of 1321.10 m (1108) and 1325.15 m (1114) (Figure 6.7 and 6.8). They are from strong deformed quartz lenses within sulfide-rich quartz lenses of biotite mica schist. Due to the strong tectonic stress, of which the samples have suffered, only few fluid inclusions are still present and only a few data points could be measured. Within sample 1108 type A IV, B I, and B II inclusions could be identified. Sample 1114 shows only the occurrence of type A I and type A III fluid inclusions. The calculated isochores are displayed in Figures 6.7 and 6.8.



In Figure 6.9 the dependency between the measured temperatures and depth is displayed; the temperatures increase with depth from around 550 °C up to 750 °C.

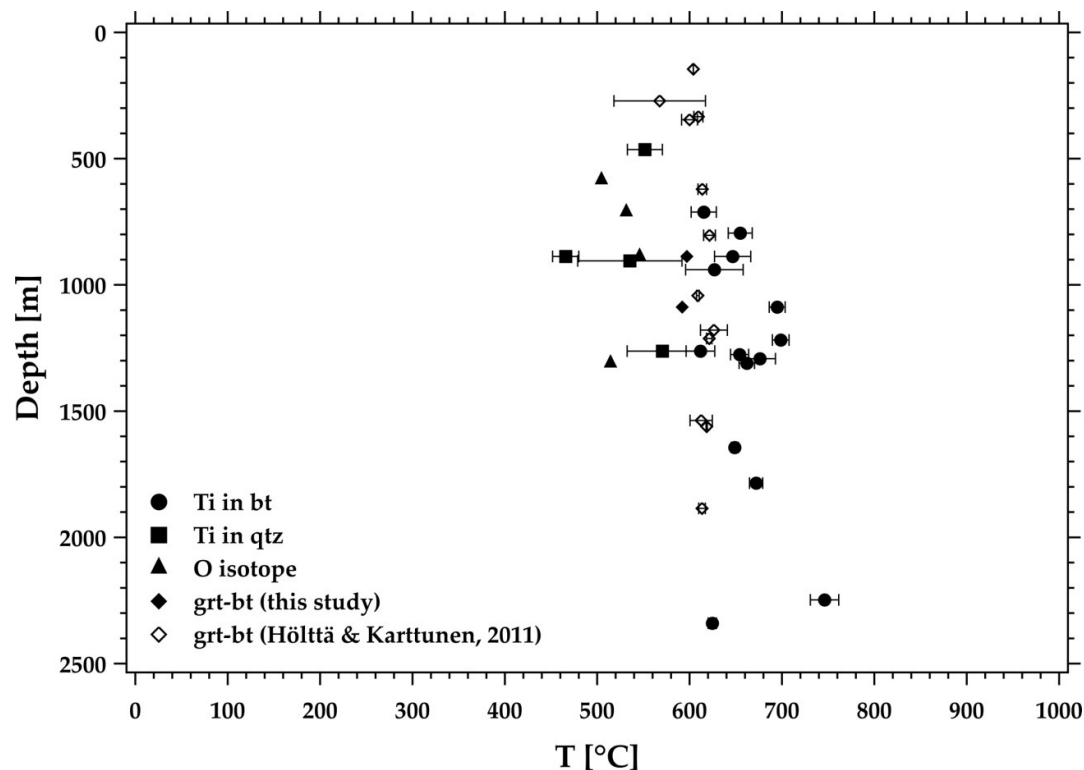


Figure 6.9, Formation temperatures of the lithologies versus the depth

Due to the fact that all temperatures, which were obtained by the ion exchange thermometer after Bottinga and Javoy (1975), were significant lower than the temperatures obtained by the other methods, it can be assumed that the second metamorphic event had an influence on the isotopic composition of the quartz and the biotite.

Temperatures from the TitaniQ geothermometer (Wark & Watson, 2006) show a variation between the core and the rim of the quartz veins. This also suggests a re-equilibration during a second event. The higher temperatures in the core are suggested to be related to the metamorphic peak and the formation of the quartz veins.

The temperatures obtained by the Ti in biotite (Henry et al., 2005) and the grt-bt geothermometer (Holdaway, 2000) are considered to be the temperatures of the metamorphic peak. The pressures, which were calculated with the grt-bt-plg-qtz geobarometer from Wu et al. (2004; 2006), plot at around 900 MPa.

The obtained p-T conditions plot close to the temperatures measured by Hölttä & Karttunen (2011). The calculated pressures from microthermometrical measurements (type D fluid inclusions) and the pressures calculated from the grt-bt-qtz-plag geobarometer plot above the pressures mentioned in the literature (Koistinen, 1981; Korsman et al., 1999; Peltonen et al., 2008; Sântti et al., 2006).

Groundwater salinity

The data on measured primary fluid inclusions reflect a complicated pattern. The distribution of salt species (NaCl and CaCl_2) and associated salinity of the fluid shows no correlation with depth. In some samples, CaCl_2 -dominated and NaCl-dominated fluid inclusions occur together. Type 2 fluid inclusions differ significantly in their salinity, but show similar T_h . NaCl-dominated type 1 fluid inclusions show not only a strong variation in T_m but also in T_h . No systematic correlation between the measured temperatures and depth can be inferred. The strong variability of the fluid characteristics of primary fluid inclusions shows the occurrence of more than one fluid pulse during the formation of the metamorphic quartz veins. Additional later fluid flux is evident in secondary fluid inclusion trails, which are too small to be measured (Piribauer et al., 2011).

Fluid inclusions may affect groundwater composition due to the preferential loss of H_2O of the fluid diffusion via microcracks (Bakker, 2009; Nordstrom et al., 1989c), therefore diluting the pore fluids. Based on their composition, type 1 and type 2 inclusions could have influenced groundwater chemistry. Considering an abundance of quartz veins of 1 to 2.2 vol%, and taking the average content of aqueous solution hosted by fluid inclusions of 0.2 $\mu\text{l/g}$ in vein quartz (Table 6.1), one can assume a total amount of 5–12 ml water per m^3 of rock.

Table 6.1, amount of fluid in quartz [$\mu\text{l/g}$] in different quartz veins within the drill core

Sample No.	05-OKU-10	05-OKU-91	05-OKU-88	05-OKU-93	05-OKU-94	05-OKU-98
Depth [m]	464.10	584.55	711.50	887.30	904.75	939.65
Fluid in quartz [$\mu\text{l/g}$]	0.40	0.30	0.16	0.16	0.19	0.12

Sample No.	05-OKU-99	05-OKU-100	05-OKU-101	05-OKU-38	05-OKU-39	05-OKU-40
Depth [m]	1052.90	1087.95	1218.20	1275.80	1276.30	1292.30
Fluid in quartz [$\mu\text{l/g}$]	0.46	0.13	0.20	0.40	0.10	0.08

Sample No.	05-OKU-42	05-OKU-13	05-OKU-22	05-OKU-55	05-OKU-70	05-OKU-81
Depth [m]	1310.20	1322.55	1379.60	1784.95	1941.65	2340.70
Fluid in quartz [$\mu\text{l/g}$]	0.13	0.18	0.25	0.08	0.05	0.22

Porosities in the different rock types were determined by Airo et al. (2011). The porosity increase slightly with depth (0.2 to 1 % for mica shists), which may be the result of stress release of the core during drilling and uplift (Airo et al., 2011). Serpentinities show the highest porosity with up to 4 – 6 % (Airo et al., 2011).

Contributions of fluid inclusions from other minerals than quartz and carbonate are possible. Fluid inclusions are also observed in Cr-diopside of the Outokumpu ores (Kinnunen, 1981; 1989). However, the volumetric abundance of fluid inclusions in the Outokumpu ores is lower than the abundance in quartz veins, and the inclusions are gas rich (Kinnunen, 1981). Consequently, they are considered as a less important fluid source relative to fluid inclusions in quartz veins (Piribauer et al., 2011).

The crush leach analyses compare the relative cation and anion ratios. The fluid inclusions data only partially follow the 1:1 line within the Cl/Br-Na/Br diagram (chapter 5). Most of the measurements plot to the left of this line, which can be interpreted as Na enrichment or Cl depletion. On the other hand, the Outokumpu groundwater measured by Nurmi et al. (1988) shows Na depletion, with a simultaneous enrichment of other cations, most likely Ca, and enrichment in Cl. While Br/Cl-I/Cl characteristics indicate that Outokumpu groundwater could be derived from a mixing of seawater and fluid inclusions water, the relatively high Na/Br ratios within fluid inclusions as well as the lack of a transgressive stage in the younger geological history in the Outokumpu region argue against simple mixing. In addition, Sr isotopic measurements performed by Smalley et al. (1988) and a recent compilation by Négrel

and Casanova (2005) also preclude a seawater input in the region of Outokumpu (Piribauer et al., 2011).

Relative to seawater (chemical composition of seawater from Turekian, 1968) the groundwater (Nurmi et al., 1988; Kitävainen et al., 2013) and the fluid inclusions are enriched in Ca, whereas both show a Mg depletion (figure 6.10). In contrast to the fluid inclusions Ca is the dominant cation within the groundwater.

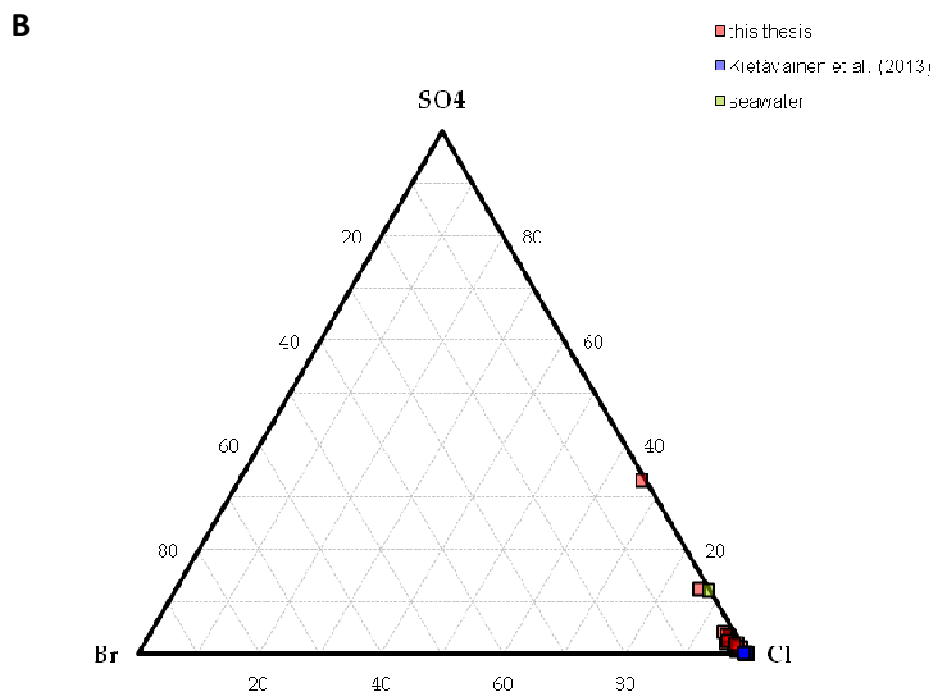
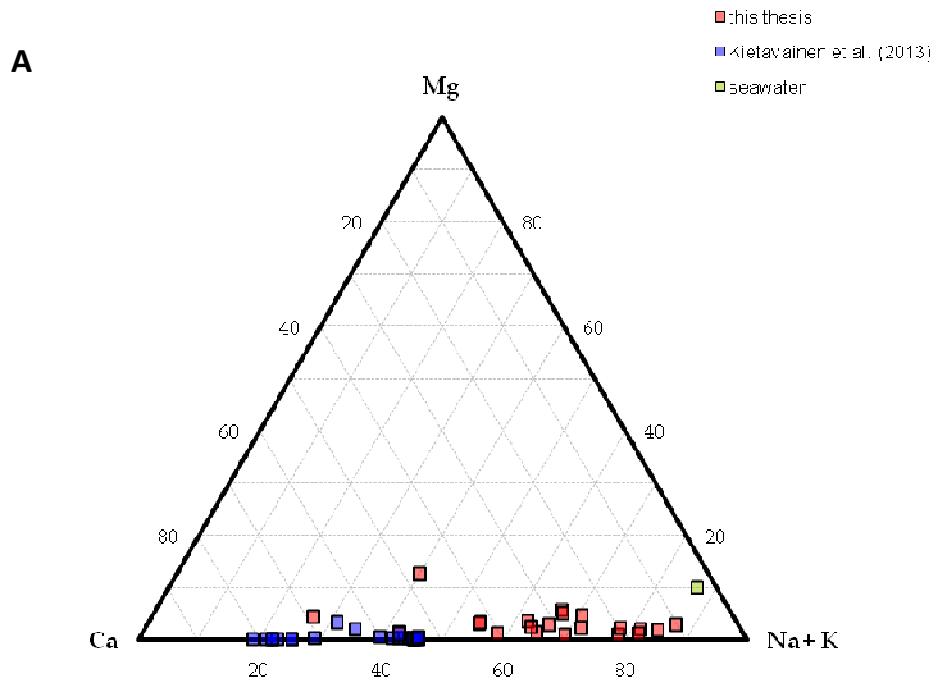


Figure 6.10, triangle plot of the different cations (A) and anions (B) groundwater (Kietävainen et al., 2013), fluid inclusions and seawater values (chemical composition of seawater from Turekian, 1968)

Also within the anion plot the differences between seawater (chemical composition of seawater from Turekian, 1968), groundwater (Nurmi et al., 1988; Kietävainen et al., 2013) and fluid inclusions are visible with an enrichment of Br relative to seawater and a depletion of SO_4 (figure 6.10).

The δD vs. depth diagram (figure 6.11) shows that the δD values of the fluid inclusions increase with depth. In contrast Kietävainen et al. (2013) observed that the most saline water, which occurs at the lower part of the drill hole, does not have the highest δD values. This data provides arguments against a simple mixing model and is more or less the result of different water sources and residence times which are combined with different processes of water rock interactions (Kietävainen et al., 2013).

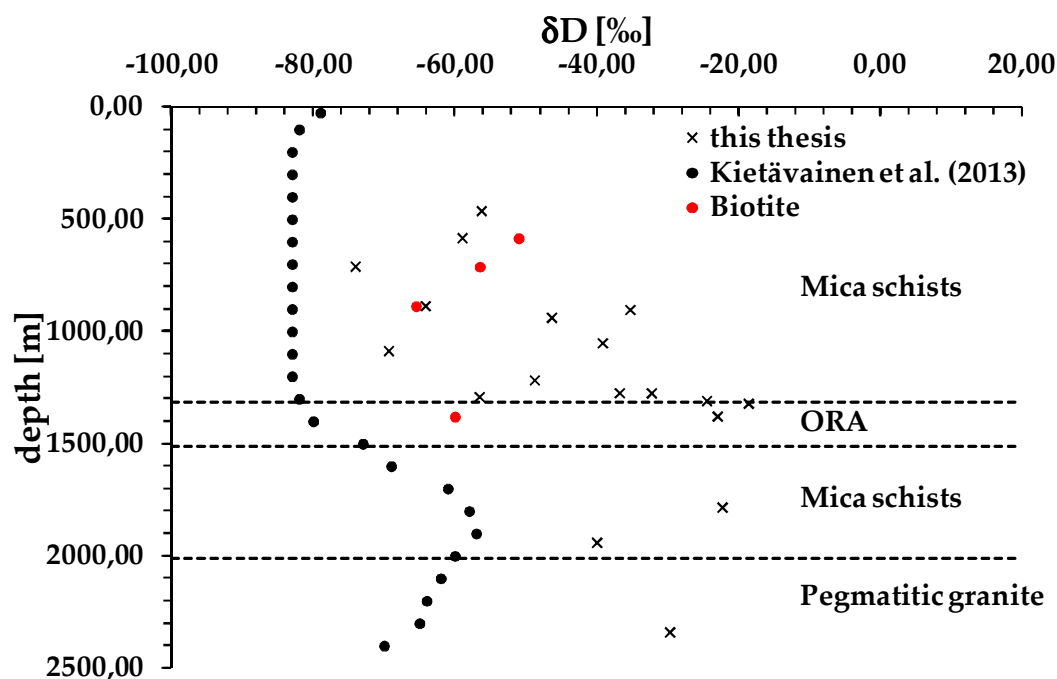


Figure 6.11, δD vs. depth, data from fluid inclusions and biotite compared to groundwater measurements from Kietävainen et al. (2013)

Kietävainen et al. (2013) lists 3 different processes which can explain the observed variations and the position of the groundwater left of the meteoric water line:

- Fractionation via silicate hydrolysis where the hydration of silicates is a possible process which is capable of shifting the isotopic composition of the

groundwater (Fritz and Frape, 1982; Kloppmann et al., 2002; Kietavainen et al., 2013). The hydration of feldspar for example leads an enrichment in ^2H and depleted in ^{18}O (e.g. Chacko et al., 2001; Clark and Fritz, 1997; Kloppmann et al., 2002; Kietavainen et al., 2013).

- Fractionation via formation of zeolites and/or calcite where the formation of zeolites and/or calcite leads to a depletion in ^{18}O (Karlsson and Clayton, 1990; Kietavainen et al., 2013) next to an increase in salinity due to the fixation of water within the newly formed mineral phases (Stober and Bucher, 2004; Bucher and Stober, 2010; Kietavainen et al., 2013)
- Fractionation between water and volatile phases (Kietavainen et al., 2013)

Next to the described cations and anions, also different dissolved gases like CH_4 , He, N_2 , C_2H_6 , CO_2 and H_2 were encountered within the groundwater. All of these gases, except He, were detected with Raman spectroscopy. The formation of these compounds can be explained by water-rock interaction and is a common feature in deep groundwater (Sleep et al., 2004; Kietavainen et al., 2013). Sleep et al. (2004) shows the possible reaction of H_2O with ultramafic rocks at moderate temperatures and pressures, hydrous Mg^{2+} and Fe^{2+} silicates and hydroxides are formed and some of the Fe^{2+} is oxidized to magnetite liberating gaseous and aqueous H_2 to the environment. The low temperature generation of hydrogen within mafic and ultramafic rocks is also described by Mayhew et al. (2013). These alteration products could therefore be preserved within fluid inclusions and also within the groundwater.

7) Summary and Conclusion

In order to obtain information about the metamorphic history and the fluid composition of the Outokumpu area, various samples from the Outokumpu Deep Drill Core have been analyzed regarding their composition, mineralogy and fluid history.

Detailed geochemical, mineralogical and petrographical analyses have been performed on the encountered lithologies which include metasediments, rocks of the Outokumpu rock assemblage (serpentinites, skarns and black schist) and pegmatitic granite.

The drill core is made up of metasediments that mainly consist of biotite-muscovite schist, biotite schist, black schist, and biotite-rich gneisses. The metasediments are underlain by serpentinites, skarns, and black schist of the Outokumpu assemblage, which are followed by a sequence of amphibolite facies metasediments, that are locally intruded and crosscut by pegmatite dykes. Pegmatitic granite dominates the lowest parts.

The metasediments consist of quartz, biotite, chlorite, feldspars, and muscovite as main paragenesis and accessory minerals like hematite, pyrrhotite, garnet and tourmaline.

The chemical composition of biotite shows intermediate annite - phlogopite composition, with Mg numbers between 0.45 and 0.61 and Al^{IV} of around 2.4. The Ti content only shows a small increase with depth within the borehole, which indicates an increase in the formation temperature.

Plagioclase composition show a high anorthite content and plot within the field of oligoclase and andesine, while some analyses can be addressed as labradorite. The potassium content is below 0.04 mass%. Potassic feldspars, with an orthoclase content of around 90 mol%, plot within the sanidine field.

The rare occurring garnets show almandine-rich compositions with rarely occurring Mn-rich rims. X_{alm} values are between 52 and 70 mol%. The amount of the other components is highly variable with X_{adr} between 0 and 6 mol%, X_{grs} between 0.5 and 29 mol%, X_{prp} between 4 and 11 mol%, and X_{sps} between 4.4 and 18 mol%. The chemical composition shows no correlation with depth within the borehole but X_{grs} and X_{prp} seem to correlate with the CaO and MgO content of the whole rock.

The SiO₂ content of the metasediments plots between 40 and 70 mass%. Al₂O₃, Fe₂O₃, and TiO₂ show negative covariation with SiO₂. Compared to the Outokumpu rock assemblage (ORA), the metasediments are enriched in K₂O and Na₂O. Both elements show no covariation with SiO₂. Within the classification diagram after Herron (1988, Figure 4.14), most of the biotite mica schist and biotite gneisses plot within the Wacke and the Shale field.

The rocks of the Outokumpu assemblage can be divided into serpentinites, skarns, and black schist. The serpentinites consist of serpentine, calcite, Mg-chlorite and sericite. Because of the strong serpentinitisation, the later carbonatization, and the metamorphic conditions, no relicts of the primary magmatic minerals could be identified. In addition, magnetite, pyrite, chalcopyrite, pentlandite, and graphite occur as opaque phases. The skarn rock mainly consists of diopside and tremolite, which are arranged in a herringbone pattern. Talc, carbonates, and opaque phases are also present.

The amphiboles belong to the tremolite – ferro-actinolite series (calcic amphiboles). They show a tremolite-rich composition with $X_{Mg} > 0.9$, close to magnesio-hornblende and actinolite. Their Na content is below 0.23 mass%.

Pyroxene shows diopside composition with an elevated Cr content in some grains. One grain can be defined as Cr-diopside, which plots in the ternary enstatite-ferrosilite-wollastonite diagram, and is located in the augite field.

The rocks of the Outokumpu assemblage are defined by low concentrations of Na₂O, K₂O, TiO₂ and Al₂O₃. The SiO₂ content is highly variable between 6 mass% (serpentinite) and 70 mass% (quartz rock, skarn rock). They show enrichment in CaO and/or MgO compared to the other lithologies. Samples with higher MgO content often show depletion in CaO and vice versa. This can be explained by the fact that some samples exhibit a stronger carbonatization than others. A negative covariation of the LOI, CaO and MgO against SiO₂ can be observed. Fe₂O₃ is nearly constant between 3 and a maximum of 7 mass%.

The pegmatites and pegmatitic granites consist of alkali feldspar, plagioclase, muscovite, quartz, and sometimes garnet. Apatite, epidote, and opaque phases occur as accessories.

Two different types of plagioclase can be distinguished with microprobe analyses (Figure 4.11). One type is defined by an albite rich composition ($X_{an} = 95 - 99$). It occurs together with the K-feldspars and forms perthitic lamellae. The anorthite rich type ($X_{an} = 78 - 87$), which plots mainly in the oligoclase field, forms separate crystals. The

amount of Fe, Mn, Mg, Ba is low, close to the detection limit of the electron microprobe. The plagioclase grains display no zonation on BSE images.

The SiO_2 content of the pegmatitic granites varies between 73 and 75 mass%. Other major elements, Na_2O , K_2O , and Al_2O_3 , show no variations in concentration. CaO , Fe_2O_3 , MgO , and TiO_2 show very low concentrations below 1 mass%. In the Na_2O versus K_2O diagram after Chappell and White (1974, 1992), the samples plot within the field of I-type granites.

In figure 7.1 shows the p-T path, which have been constructed from all the obtained data and fluid inclusion petrography is shown.

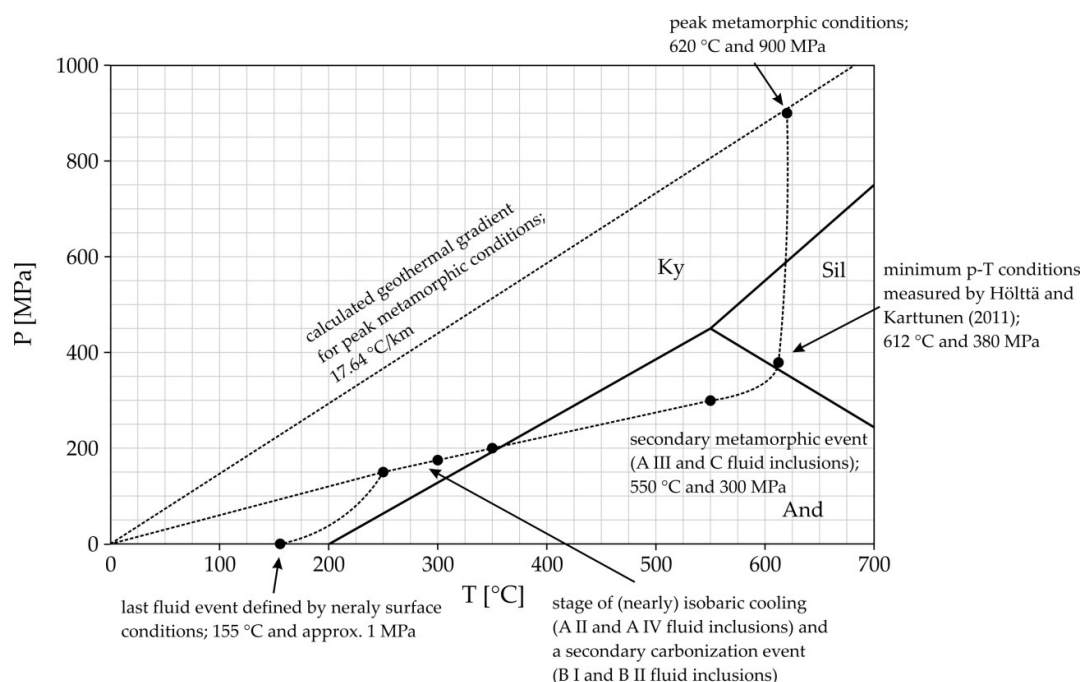


Figure 7.1, p-T path, been constructed from all the obtained data and fluid inclusion petrography

Grt-bt geothermometer (Holdaway, 2000) and grt-bt-plg-qtz geobarometer (Wu et al., 2004; 2006) indicate peak metamorphic conditions at around 620 °C and 900 MPa (data from this study and Hölttä and Karttunen, 2011). Hölttä and Karttunen (2011) found evidence for an isothermal decompression down to 612 °C and 380 MPa. Fluid inclusions of the types A II and C suggest a second metamorphic event, which is also proposed by Hölttä and Karttunen (2011) at ~550 °C and ~300 MPa. Additional fluid inclusion measurements show a picture of the cooling path, which is very shallow. The last event took place at near surface conditions.

The isotopic composition of fluid inclusions presented here (Fig. 5.28) and that of groundwater measured by Nurmi et al. (1988) differs significantly. Thus, fluid inclusions, which can be characterized as metamorphic water, are not assumed to have a significant effect on groundwater composition. Rather, groundwater appears to be derived from meteoric water, which composition changed due to fluid–rock interaction. This is indicated by the position of the Outokumpu stable isotopes groundwater data above the MWL (Fig. 5.28). Kietavainen et al. (2013) suggest water rock interaction, especially the hydration of silicate minerals and the formation of zeolites, as the main mechanism for the increased salinity and the isotopic composition. The processes which cause the isotopic evolution of the water are most likely the hydration of feldspars and the isotopic fractionation due to the formation of zeolites and/or calcite (Kietavainen et al., 2013).

Next to the isotopic composition, the elevated Br/Cl values point to brines generated during long-term water–rock interaction (Frape et al., 1984). This is supported by Smalley et al. (1988) and Kietavainen et al. (2013), who stated that the Sr concentration and Sr isotopes characteristics can be only explained by the breakdown of minerals such as feldspars. In addition, recent decrepitation of fluid inclusions as well as a recent tectonic process, responsible for decrepitation in areas not accessed by the Outokumpu drill core are not observed (Piribauer et al., 2011).

Despite the possibility of fluid inclusions losing their content by diffusion or microcracking (Bakker, 2009; Nordstrom et al., 1989c), the hypothesis, that fluid inclusions of rocks exposed in the Outokumpu well have influenced the salinity of the Outokumpu groundwater is not supported by the results obtained in this thesis (Piribauer et al., 2011).

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Table 1, sample list

No.	Sample No.	Thin Section	Fluid Section	Depth [m]	Macroscopic Description	XRF	Crush Leach	Microprobe	XRD	dH Fluid Inclusions	dO ¹⁸ quartz	dO ¹⁸ biotite	dH biotite
1	05-Oku-9	-	-	-	Bt-mica schist	-	-	-	-	-	-	-	-
2	05-Oku-10	27046	1113 1138	464.10	Bt-mica schist	-	X	-	-	X	-	-	-
3	05-Oku-87	-	-	537.40	qtz vein, no contact to host rock	-	-	-	-	-	-	-	-
4	05-Oku-85	-	-	537.55	Bt-mica schist with qtz lense and disseminated sulphides	X	-	-	X	-	-	-	-
5	05-Oku-86	-	-	539.20	Bt-mica schist with qtz lense, acicular minerals at the contact	-	-	-	-	-	-	-	-
6	05-Oku-91	27213 27214	1117	584.55	Bt-mica schist with qtz lense	X	X	-	X	X	X	X	X
7	05-Oku-92	-	-	593.10	Bt-mica schist with qtz vein, sulphides disseminated within the vein	-	-	-	-	-	-	-	-
8	05-Oku-90	-	-	689.80	Bt-gneiss with qtz lenses between the foliation	X	-	-	X	-	-	-	-
9	05-Oku-88	27211 27212	1112 1137	711.5	Bt-mica schist	X	X	X	X	X	X	X	X
10	05-Oku-96	-	-	752.05	Bt-gneiss with qtz lense	X	-	-	X	-	-	-	-
11	05-Oku-97	27219	-	758.50	Bt-gneiss	X	-	-	X	-	-	-	-
12	05-Oku-95	27216 27218 27217	1110 1135	794.80	partly carbonatised Bt-gneiss	X	-	X	X	-	-	-	-
13	05-Oku-89	-	-	842.50	qtz vein with a contact to a Bt-mica schist	-	-	-	-	-	-	-	-
14	05-Oku-93	27215	1118	887.30	Bt-mica schist with qtz lenses between the foliation and Bt rich layers	X	X	X	X	X	X	X	X
15	05-Oku-94	27513	1143	904.75	qtz vein with a contact to a Bt-mica schist	-	-	-	-	X	-	-	-
16	05-Oku-98	27514	1144	939.65	Bt-mica schist with qtz lenses and disseminated sulphides	X	X	X	X	X	-	-	-
17	05-Oku-99	27515	1145	1052.90	Bt-mica schist with qtz lense	X	-	X	X	X	-	-	-

Table 1 continued

No.	Sample No.	Thin Section	Fluid Section	Depth [m]	Macroscopic Description	XRF	Crush Leach	Microprobe	XRD	dH Fluid Inclusions	dO ¹⁸ quartz	dO ¹⁸ biotite	dH biotite
18	05-Oku-100	27516	1146	1087.95	Bt-gneiss with qtz lense and disseminated sulphides	X	-	X	X	X	-	-	-
19	05-Oku-101	27517	1147	1218.20	Bt-mica schist with qtz lenses and disseminated sulphides	X	-	X	X	X	-	-	-
20	05-Oku-37	27206 27207 27208 27209	1109 1134 1116 1111 1136	1262.4	partly carbonatised Bt-mica schist	-	X	X	X	-	-	-	-
21	05-Oku-38	27518	1148	1275.8	Bt-mica schist with qtz vein	X	-	X	X	X	-	-	-
22	05-Oku-39	27210 27519	1149	1276.3	Bt-mica schist with qtz vein	-	-	-		X	-	-	-
23	05-Oku-40	27520	-	1292.3	Bt-mica schist with qtz "veins" parallel to the foliation	X	X	X	X	X	-	-	-
24	05-Oku-41	-	-	1294.8	folded Bt-mica schist with qtz veins and disseminated sulphides	-	-	-	-	-	-	-	-
25	05-Oku-42	27521	1150	1310.2	Bt-mica schist with qtz lense	X	X	X	X	X	X	X	X
26	05-Oku-11	27182 27183 27184	-	1317.95	Skarn rock	X	-	-	X	-	-	-	-
27	05-Oku-12	27185 27186	1108 1133	1321.10	Bt-mics schiast with folded Bt layers	-	-	-	-	-	-	-	-
28	05-Oku-13	27522	1151	1322.55	dark massive fine grained rock with qtz lense	X	X	-	X	X	-	-	-
29	05-Oku-14	27187 27188 27189	-	1322.65	Bt-mica schist contact with skarn rock, rich in sulphides	-	-	-	-	-	-	-	-
30	05-Oku-15	27190 27191 27192	1114	1325.15	Bt-mica schist, rich in sulphides	-	-	-	-	-	-	-	-
31	05-Oku-16	27193 27194	-	1325.50	Bt-mica schist contact with skarn rock, rich in sulphides parallel to the foliation	-	-	-	-	-	-	-	-

Table 1 continued

No.	Sample No.	Thin Section	Fluid Section	Depth [m]	Macroscopic Description	XRF	Crush Leach	Microprobe	XRD	dH Fluid Inclusions	dO ¹⁸ quartz	dO ¹⁸ biotite	dH biotite
32	05-Oku-17	27195 27196	-	1330.40	Bt-mica schist contact with skarn rock with qtz veins, rich in sulphides parallel to the foliation and within the qtz veins	-	-	-	-	-	-	-	-
33	05-Oku-18	27523	-	1331.50	Skarn rock	X	-	X	X	-	-	-	-
34	05-Oku-19	27197 27198	1115	1360.15	Skarn rock	X	-	X	X	-	-	-	-
35	05-Oku-20	27524	1152	1374.90	dark massive fine grained rock with carbonate veins, Serpentinite	X	-	-	X	-	-	-	-
36	05-Oku-21	27199 27200	-	1375.00	Serpentinite, disseminated sulphides, fractures filled with carbonate	-	-	-	-	-	-	-	-
37	05-Oku-22	27201 27202	1119	1379.60	Skarn rock with qtz vein, sulphides at the contact and within the skarn rock	-	X	-	-	X	-	-	-
38	05-Oku-23	27525	-	1381.60	Skarn rock with qtz and carbonate veins, veins penetrate the foliation vertical, sulphides parallel to the foliation	X	-	X	X	-	-	-	-
39	05-Oku-24	27203 27204 27205	-	1385.40	Skarn rock with qtz and carbonate veins, rich in sulphides	-	-	-	-	-	-	-	-
40	05-Oku-25	-	-	1389.85	Skarn rock, amphiboles show herringbone pattern	-	-	-	-	-	-	-	-
41	05-Oku-26	27526	-	1395.20	dark massive fine grained rock with carbonates and serpentine veins, Serpentinite	X	-	-	X	-	-	-	-
42	05-Oku-27	-	-	1395.80	dark massive fine grained rock with carbonates and serpentine veins	-	-	-	-	-	-	-	-

Table 1 continued

No.	Sample No.	Thin Section	Fluid Section	Depth [m]	Macroscopic Description	XRF	Crush Leach	Microprobe	XRD	dH Fluid Inclusions	dO ¹⁸ quartz	dO ¹⁸ biotite	dH biotite
43	05-Oku-28	-	-	1396.40	dark massive fine grained rock with carbonates and serpentine veins	-	-	-	-	-	-	-	-
44	05-Oku-29	-	-	1396.58	dark massive fine grained rock with carbonates and serpentine veins	-	-	-	-	-	-	-	-
45	05-Oku-30	27527	-	1434.00	Serpentinite	X	-	X	X	-	-	-	-
46	05-Oku-31	-	-	1437.85	Serpentinite	-	-	-	-	-	-	-	-
47	05-Oku-32	-	-	1439.50	Serpentinite	-	-	-	-	-	-	-	-
48	05-Oku-33	27528	1153	1442.50	Skarn rock with carbonate veins	X	-	-	X	-	-	-	-
49	05-Oku-34	27529	-	1443.20	Quartzite rich in graphite	X	-	-	X	-	-	-	-
50	05-Oku-35	-	-	1444.50	Quartzite	-	-	-	-	-	-	-	-
51	05-Oku-36	-	-	1451.05	Bt-mica schist contact to qtz vein with sulphides parallel to the foliation	-	-	-	-	-	-	-	-
52	05-Oku-41	27530	-	1487.45	Skarn rock	X	-	X	X	-	-	-	-
53	05-Oku-42a	-	-	1493.30	black schist with qtz vein, rich in sulphides	-	X	-	-	-	-	-	-
54	05-Oku-43	27531	-	1505.55	black schist with qtz lenses and qtz veins, rich in sulphides	X	-	-	X	-	-	-	-
55	05-Oku-44	-	-	1539.75	Bt-mica schist with qtz vein	-	-	-	-	-	-	-	-
56	05-Oku-45	27532	1154	1561.90	Turmalinite	X	-	X	X	-	-	-	-
57	05-Oku-46	-	-	1595.90	Bt-mica schist with qtz vein	-	X	-	-	-	-	-	-
58	05-Oku-47	-	-	1602.00	Bt-mica schist with folded qtz veins and Bt rich layers	-	-	-	-	-	-	-	-
59	05-Oku-48	-	-	1602.40	Bt-mica schist with qtz lense	-	-	-	-	-	-	-	-
60	05-Oku-49	-	-	1630.55	Bt-mica schist with qtz vein	X	-	-	X	-	-	-	-
61	05-Oku-50	-	-	1639.50	Bt-mica schist with qtz lense	-	X	-	-	-	-	-	-
62	05-Oku-51	27533	-	1644.20	Bt-mica schist penetrated by a pegmatite dyke	-	-	X	-	-	-	-	-
63	05-Oku-52	-	-	1648.30	Bt-mica schist penetrated by a pegmatite dyke	-	-	-	-	-	-	-	-

Table 1 continued

No.	Sample No.	Thin Section	Fluid Section	Depth [m]	Macroscopic Description	XRF	Crush Leach	Microprobe	XRD	dH Fluid Inclusions	dO ¹⁸ quartz	dO ¹⁸ biotite	dH biotite
64	05-Oku-53	27534	-	1658.30	Pegmatite	X	-	X	X	-	-	-	-
65	05-Oku-54	-	-	1783.45	Bt-mica schist penetrated by a pegmatite dyke	-	-	-	-	-	-	-	-
66	05-Oku-55	27535	1155	1784.95	Bt-mica schist with qtz lense	X	X	X	X	X	-	-	-
67	05-Oku-56	-	-	1795.30	Bt-mica schist penetrated by a pegmatite dyke	-	-	-	-	-	-	-	-
68	05-Oku-57	-	-	1803.40	Bt-mica schist with qtz lense	-	X	-	-	-	-	-	-
69	05-Oku-58	-	-	1805.55	Bt-mica schist with qtz lense	-	-	-	-	-	-	-	-
70	05-Oku-59	27536	-	1814.60	Pegmatite	X	-	-	X	-	-	-	-
71	05-Oku-60	-	-	1830.50	Bt-mica schist with qtz lense	-	-	-	-	-	-	-	-
72	05-Oku-61	-	-	1831.95	Pegmatite	-	-	-	-	-	-	-	-
73	05-Oku-62	27537	1156	1845.50	Bt-mica schist black schist contact with qtz lenses and disseminated sulphides	X	X	-	X	-	-	-	-
74	05-Oku-63	27279 27280	-	1847.40	Pegmatite with sulphides and Bt- mica schist xenolithes	-	-	-	-	-	-	-	-
75	05-Oku-64	-	-	1874.90	Bt-mica schist penetrated by a pegmatite dyke	-	-	-	-	-	-	-	-
76	05-Oku-65	-	-	1875.65	Bt-mica schist with qtz lense	-	X	-	-	-	-	-	-
77	05-Oku-66	-	-	1885.20	Bt-mica schist with qtz lense	X	-	-	X	-	-	-	-
78	05-Oku-67	27281 27282 27283 27284 27285	-	1899.65	Bt-mica schist	-	-	-	-	-	-	-	-
79	05-Oku-68	-	-	1920.95	Bt-mica schist with qtz layers	X	X	-	X	-	-	-	-
80	05-Oku-69	27286	-	1935.85	Bt-mica schist penetrated by a pegmatite dyke	-	-	-	-	-	-	-	-
81	05-Oku-70	-	-	1941.65	Bt-mica schist with qtz vein	-	X	-	-	X	-	-	-
82	05-Oku-71	27287 27288 27289	-	1950.60	Bt-mica schist with qtz vein	-	-	-	-	-	-	-	-
83	05-Oku-72	27290 27291	-	1953.00	Bt-mica schist with qtz layers	-	-	-	-	-	-	-	-

Table 1 continued

No.	Sample No.	Thin Section	Fluid Section	Depth [m]	Macroscopic Description	XRF	Crush Leach	Microprobe	XRD	dH Fluid Inclusions	dO ¹⁸ quartz	dO ¹⁸ biotite	dH biotite
84	05-Oku-73	-	-	1966.20	folded Bt-mica schist with qtz veins and disseminated sulphides	X	-	-	X	-	-	-	-
85	05-Oku-74	-	-	1975.30	Bt-mica schist with qtz layers	-	-	-	-	-	-	-	-
86	05-Oku-75	27292	-	1980.35	Bt-mica schist with deformed qtz lenses	-	-	-	-	-	-	-	-
		27293											
		27294				-	X	-	-	-	-	-	-
		27295											
		27296											
		27297											
87	05-Oku-76	-	-	1993.45	Bt-mica schist with qtz layers	-	-	-	-	-	-	-	-
88	05-Oku-77	-	-	2007.30	Pegmatite	X	-	-	X	-	-	-	-
89	05-Oku-79	27302	-	2247.60	Bt-mica schist with qtz layers, idiomorph Phyrrotite within the qtz	X	-	X	X	-	-	-	-
		27303											
90	05-Oku-80	-	-	2258.85	Bt-mica schist with qtz vein, small amounts of muscovite visible	-	-	-	-	-	-	-	-
91	05-Oku-78	27298	-	2334.50	Bt-mica schist with folded qtz veins and Bt rich layers	-	X	-	-	-	-	-	-
		27299											
		27300											
		27301											
92	05-Oku-84	27305	-	2340.30	Bt-gneiss	-	-	-	-	-	-	-	-
		27306				X	-	X	X	-	-	-	-
		27307											
93	05-Oku-81	-	-	2340.70	Bt-mica schist with qtz vein	-	X	-	-	X	-	-	-
94	05-Oku-82	27304	-	2439.20	Pegmatite	X	-	-	X	-	-	-	-
95	05-Oku-83	-	-	2470.20	Bt-mica schist with qtz layers	-	-	-	-	-	-	-	-

Table 2, Pyroxene analysis, numbers of ions on the basis of 60

Sample	27523-1-2	27523-1-3	27523-2-3	27525-1	27525-1-2	27525-1-3	27525-1-4	27525-2	27525-2-2	27525-2-3
SiO ₂	53.565	53.724	53.685	54.526	53.272	54.292	53.833	54.094	53.546	54.730
TiO ₂	0.040	0.015	0.083	0.017	0.049	0.000	0.000	0.006	0.000	0.000
Al ₂ O ₃	0.656	0.620	0.631	0.237	3.680	0.283	0.455	0.570	0.293	0.601
FeO	3.387	3.245	3.613	1.913	5.275	1.583	4.198	1.880	4.458	1.486
Fe ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Cr ₂ O ₃	0.018	0.000	0.019	0.442	1.612	0.311	0.368	0.184	0.258	0.088
MnO	0.249	0.232	0.211	0.096	0.147	0.120	0.141	0.131	0.215	0.121
NiO	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
MgO	16.555	16.639	16.604	16.691	19.337	17.555	15.911	16.641	15.975	17.263
CaO	25.715	25.847	25.720	25.825	13.217	25.835	25.403	25.685	25.498	25.696
Na ₂ O	0.031	0.020	0.073	0.209	0.352	0.150	0.134	0.185	0.100	0.152
K ₂ O	0.002	0.009	0.015	0.024	0.102	0.017	0.000	0.000	0.000	0.000
Total	100.218	100.351	100.654	99.980	97.043	100.146	100.443	99.376	100.343	100.137
Si	1.953	1.955	1.949	1.986	1.987	1.966	1.967	1.980	1.959	1.983
Al	0.028	0.027	0.027	0.010	0.013	0.012	0.020	0.020	0.013	0.017
Sum Si + Al	1.981	1.982	1.976	1.996	2.000	1.978	1.987	2.000	1.972	2.000
Al	0.000	0.000	0.000	0.000	0.148	0.000	0.000	0.005	0.000	0.008
Ti	0.001	0.000	0.002	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Fe ³⁺	0.047	0.046	0.052	0.016	0.000	0.000	0.032	0.023	0.041	0.017
Fe ²⁺	0.038	0.034	0.034	0.038	0.000	0.043	0.083	0.035	0.067	0.028
Cr	0.001	0.000	0.001	0.013	0.047	0.009	0.011	0.005	0.007	0.003
Mg	0.900	0.903	0.899	0.906	0.803	0.948	0.867	0.908	0.871	0.932
Ni	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mn	0.008	0.007	0.006	0.003	0.005	0.004	0.004	0.004	0.007	0.004
Ca	1.004	1.008	1.000	1.008	0.528	1.002	0.994	1.007	0.999	0.997
Na	0.002	0.001	0.005	0.015	0.025	0.011	0.009	0.013	0.007	0.011
K	0.000	0.000	0.001	0.001	0.005	0.001	0.000	0.000	0.000	0.000
Sum	2.001	1.999	2.000	2.000	1.562	2.018	2.000	2.000	1.999	2.000
Atomic percentages										
Mg	46.154	46.246	46.329	46.363	60.658	47.345	44.489	46.471	44.799	47.532
âFe	2.320	2.123	2.094	2.081	9.545	2.579	4.462	1.978	3.810	1.619
Ca	51.525	51.631	51.578	51.556	29.798	50.076	51.049	51.551	51.391	50.849

Table 2 continued

Sample	27525-2-4	27525-3	27525-3-2	27525-3-3	27525-3-4	27525-4	27525-4-2	27525-4-3
SiO ₂	53.335	54.053	54.453	53.224	53.688	54.300	53.302	53.527
TiO ₂	0.031	0.000	0.032	0.000	0.000	0.000	0.010	0.000
Al ₂ O ₃	0.521	0.804	0.568	0.443	1.620	0.595	0.421	0.471
FeO	3.761	1.631	1.843	5.004	2.000	2.320	3.732	3.213
Fe ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Cr ₂ O ₃	0.559	0.146	0.246	0.464	0.258	0.682	0.422	0.539
MnO	0.186	0.109	0.091	0.258	0.086	0.076	0.144	0.135
NiO	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
MgO	16.153	16.755	17.502	15.177	16.463	16.135	15.926	15.993
CaO	25.456	25.798	26.102	25.301	25.210	25.850	25.791	25.437
Na ₂ O	0.189	0.197	0.131	0.170	0.375	0.204	0.122	0.181
K ₂ O	0.000	0.010	0.000	0.000	0.000	0.001	0.000	0.005
Total	100.191	99.503	100.968	100.041	99.700	100.163	99.870	99.501
Si	1.949	1.973	1.958	1.961	1.955	1.980	1.956	1.969
Al	0.022	0.027	0.024	0.019	0.045	0.020	0.018	0.020
Σ Si + Al	1.971	2.000	1.982	1.980	2.000	2.000	1.974	1.989
Al	0.000	0.008	0.000	0.000	0.025	0.006	0.000	0.000
Ti	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Fe ³⁺	0.046	0.029	0.000	0.038	0.039	0.009	0.040	0.029
Fe ²⁺	0.041	0.020	0.054	0.096	0.022	0.062	0.049	0.059
Cr	0.016	0.004	0.007	0.013	0.007	0.020	0.012	0.016
Mg	0.880	0.912	0.938	0.834	0.894	0.877	0.871	0.877
Ni	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mn	0.006	0.003	0.003	0.008	0.003	0.002	0.004	0.004
Ca	0.997	1.009	1.005	0.999	0.984	1.010	1.014	1.002
Na	0.013	0.014	0.009	0.012	0.026	0.014	0.009	0.013
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Σ	2.000	1.999	2.017	2.000	2.000	2.000	1.999	2.000
Atomic percentages								
Mg	45.755	46.892	46.863	43.041	46.980	44.952	44.933	45.142
ΣFe	2.421	1.217	2.907	5.391	1.315	3.289	2.770	3.256
Ca	51.824	51.891	50.230	51.568	51.705	51.759	52.297	51.602

Table 3, Pyroxene analysis, numbers of ions on the basis of 6O, summary

n = 18	average	median	standard deviation	minimum	maximum
SiO ₂	53.84	53.71	0.47	53.22	54.73
TiO ₂	0.02	0.00	0.02	0.00	0.08
Al ₂ O ₃	0.75	0.57	0.79	0.24	3.68
FeO	3.03	3.23	1.23	1.49	5.28
Fe ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.
Cr ₂ O ₃	0.37	0.28	0.37	0.00	1.61
MnO	0.15	0.14	0.06	0.08	0.26
NiO	n. a.	n. a.	n. a.	n. a.	n. a.
MgO	16.63	16.58	0.90	15.18	19.34
CaO	24.97	25.71	2.94	13.22	26.10
Na ₂ O	0.17	0.16	0.09	0.02	0.38
K ₂ O	0.01	0.00	0.02	0.00	0.10
Total	99.92	100.14	0.83	97.04	100.97
Si	1.97	1.96	0.01	1.95	1.99
Al	0.02	0.02	0.01	0.01	0.05
Σ Si + Al	1.99	1.98	0.01	1.97	2.00
Al	0.01	0.00	0.03	0.00	0.15
Ti	0.00	0.00	0.00	0.00	0.00
Fe ³⁺	0.03	0.03	0.02	0.00	0.05
Fe ²⁺	0.04	0.04	0.02	0.00	0.10
Cr	0.01	0.01	0.01	0.00	0.05
Mg	0.89	0.90	0.04	0.80	0.95
Ni	n. a.	n. a.	n. a.	n. a.	n. a.
Mn	0.00	0.00	0.00	0.00	0.01
Ca	0.98	1.00	0.11	0.53	1.01
Na	0.01	0.01	0.01	0.00	0.03
K	0.00	0.00	0.00	0.00	0.01
Σ	1.98	2.00	0.10	1.56	2.02
Atomic percentages					
Mg	46.72	46.29	3.66	43.04	60.66
ΣFe	3.07	2.50	1.94	1.22	9.55
Ca	50.22	51.56	5.13	29.80	52.30

Table 4, Amphibole analysis, numbers of ions on the basis of 23(O, OH, F, Cl)

Sample	27197-1	27197-1-2	27197-1-3	27197-2	27197-2-2	27197-2-3	27197-3	27197-3-2	27197-3-3	27197-4	27197-4-2
SiO ₂	56.410	55.978	56.273	56.184	56.725	56.929	56.864	56.742	56.580	56.420	55.505
TiO ₂	0.027	0.039	0.007	0.000	0.001	0.051	0.021	0.000	0.005	0.021	0.014
Al ₂ O ₃	1.404	1.459	1.293	0.742	0.957	0.953	0.963	1.088	0.939	1.158	1.315
FeO	3.347	3.414	3.615	3.779	3.590	3.310	3.721	3.655	3.336	3.792	3.938
Cr ₂ O ₃	0.335	0.086	0.093	0.154	0.201	0.144	0.068	0.051	0.087	0.162	0.291
MnO	0.057	0.027	0.038	0.050	0.017	0.032	0.047	0.045	0.080	0.032	0.050
MgO	22.239	22.569	22.405	21.994	22.554	22.598	22.306	22.260	22.431	21.686	22.073
CaO	13.249	13.499	13.241	13.259	13.434	13.065	13.369	13.295	13.484	13.225	13.025
Na ₂ O	0.180	0.172	0.177	0.102	0.148	0.096	0.139	0.143	0.143	0.115	0.159
K ₂ O	0.056	0.022	0.029	0.010	0.024	0.011	0.016	0.013	0.020	0.009	0.037
F	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Cl	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	97.304	97.265	97.171	96.274	97.651	97.189	97.514	97.292	97.105	96.620	96.407
O=FeCl	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
CTotal	97.304	97.265	97.171	96.274	97.651	97.189	97.514	97.292	97.105	96.620	96.407
Si	7.784	7.717	7.767	7.844	7.797	7.836	7.832	7.828	7.821	7.856	7.730
Al	0.216	0.237	0.210	0.122	0.155	0.149	0.156	0.169	0.153	0.144	0.216
Fe ³⁺	0.000	0.046	0.023	0.034	0.048	0.015	0.011	0.002	0.026	0.000	0.054
Σ T	8.000	8.000	8.000	8.000	8.000	8.000	7.999	7.999	8.000	8.000	8.000
Al	0.012	0.000	0.000	0.000	0.000	0.006	0.000	0.008	0.000	0.046	0.000
Cr	0.037	0.009	0.010	0.017	0.022	0.016	0.007	0.006	0.009	0.018	0.032
Fe ³⁺	0.148	0.222	0.214	0.127	0.160	0.182	0.145	0.155	0.130	0.072	0.246
Ti	0.003	0.004	0.001	0.000	0.000	0.005	0.002	0.000	0.001	0.002	0.001
Mg	4.575	4.638	4.610	4.578	4.622	4.637	4.580	4.578	4.622	4.501	4.583
Fe ²⁺	0.223	0.125	0.163	0.275	0.195	0.152	0.263	0.251	0.230	0.358	0.135
Mn	0.003	0.002	0.002	0.003	0.001	0.002	0.003	0.003	0.008	0.002	0.003
Σ C	5.001	5.000	5.000	5.000	5.000	5.000	5.000	5.001	5.000	4.999	5.000
Fe ²⁺	0.016	0.001	0.017	0.005	0.009	0.032	0.010	0.014	0.000	0.011	0.023
Mn	0.003	0.002	0.002	0.003	0.001	0.002	0.003	0.003	0.001	0.002	0.003
Ca	1.959	1.994	1.958	1.983	1.978	1.927	1.973	1.965	1.997	1.973	1.943
Na	0.022	0.003	0.022	0.009	0.012	0.013	0.014	0.019	0.002	0.014	0.021
Σ B	2.000	2.000	2.000	2.000	2.000	1.974	2.000	2.000	2.000	2.000	1.991
Na	0.026	0.043	0.025	0.019	0.028	0.013	0.023	0.020	0.037	0.017	0.022
K	0.010	0.004	0.005	0.002	0.004	0.002	0.003	0.002	0.004	0.002	0.007
Σ A	0.036	0.047	0.030	0.021	0.032	0.015	0.026	0.022	0.041	0.019	0.029
Σ cat	15.036	15.047	15.030	15.020	15.032	14.988	15.025	15.022	15.040	15.018	15.019
Cl	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
F	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Σ oxygen	23.000	23.000	23.000	23.000	23.000	23.000	23.000	23.000	23.000	23.000	23.000

Table 4 continued

Sample	27197-4-3	27523-1	27523-1-4	27523-2	27523-2-2	27523-2-4	27523-3	27523-3-3	27523-4	27523-4-3
SiO ₂	56.325	55.594	53.591	55.051	54.710	55.038	53.926	54.508	54.787	54.229
TiO ₂	0.000	0.065	0.162	0.021	0.100	0.061	0.077	0.091	0.043	0.065
Al ₂ O ₃	1.042	2.601	4.226	3.164	3.996	3.247	4.159	3.178	3.548	3.165
FeO	3.754	4.022	4.172	3.994	4.004	4.276	4.090	4.166	4.319	4.033
Cr ₂ O ₃	0.140	0.009	0.009	0.000	0.044	0.000	0.000	0.006	0.004	0.040
MnO	0.051	0.206	0.195	0.233	0.192	0.180	0.176	0.154	0.206	0.172
MgO	22.437	20.861	20.545	20.504	20.867	20.647	20.126	21.012	20.456	21.160
CaO	13.258	13.383	13.535	13.500	13.379	13.329	13.384	13.482	13.394	13.394
Na ₂ O	0.161	0.247	0.417	0.278	0.405	0.347	0.455	0.289	0.347	0.288
K ₂ O	0.015	0.062	0.169	0.083	0.088	0.077	0.108	0.083	0.048	0.072
F	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Cl	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	97.183	97.050	97.021	96.828	97.785	97.202	96.501	96.969	97.152	96.618
O=F=Cl	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
CTotal	97.183	97.050	97.021	96.828	97.785	97.202	96.501	96.969	97.152	96.618
Si	7.776	7.743	7.486	7.698	7.560	7.662	7.578	7.595	7.635	7.571
Al	0.169	0.257	0.514	0.302	0.440	0.338	0.422	0.405	0.365	0.429
Fe ³⁺	0.054	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sum T	7.999	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	0.000	0.169	0.181	0.219	0.210	0.195	0.267	0.116	0.218	0.092
Cr	0.015	0.001	0.001	0.000	0.005	0.000	0.000	0.001	0.000	0.004
Fe ³⁺	0.204	0.002	0.127	0.001	0.101	0.035	0.002	0.163	0.036	0.224
Ti	0.000	0.007	0.017	0.002	0.010	0.006	0.008	0.010	0.005	0.007
Mg	4.618	4.331	4.278	4.274	4.298	4.285	4.216	4.364	4.250	4.404
Fe ²⁺	0.159	0.467	0.360	0.466	0.362	0.463	0.479	0.322	0.468	0.247
Mn	0.003	0.023	0.023	0.028	0.014	0.016	0.021	0.018	0.024	0.020
Sum C	4.999	4.831	4.806	4.771	4.790	4.805	4.726	4.878	4.783	4.998
Fe ²⁺	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mn	0.003	0.001	0.000	0.000	0.009	0.005	0.000	0.000	0.000	0.000
Ca	1.961	1.997	2.000	2.000	1.981	1.988	2.000	2.000	2.000	2.000
Na	0.021	0.002	0.000	0.000	0.010	0.006	0.000	0.000	0.000	0.000
Sum B	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	0.022	0.065	0.113	0.075	0.098	0.087	0.124	0.078	0.094	0.078
K	0.003	0.011	0.030	0.015	0.016	0.014	0.019	0.015	0.009	0.013
Sum A	0.025	0.076	0.143	0.090	0.114	0.101	0.143	0.093	0.103	0.091
Sum cat	15.025	15.076	15.157	15.102	15.114	15.101	15.152	15.100	15.102	15.093
Cl	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
F	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Sum oxygen	23.000	23.002	23.000	23.018	23.000	23.000	23.012	23.000	23.000	23.000

Table 5, Amphibole analysis, numbers of ions on the basis of 23(O, OH, F, Cl), summary

n = 21	average	median	standard deviation	minimum	maximum
SiO ₂	55.64	55.98	1.04	53.59	56.93
TiO ₂	0.05	0.04	0.04	0.00	0.16
Al ₂ O ₃	2.12	1.40	1.26	0.74	4.23
FeO	3.83	3.79	0.31	3.31	4.32
Cr ₂ O ₃	0.11	0.09	0.10	0.00	0.34
MnO	0.11	0.06	0.08	0.02	0.23
MgO	21.61	21.99	0.86	20.13	22.60
CaO	13.34	13.38	0.14	13.03	13.54
Na ₂ O	0.23	0.18	0.11	0.10	0.46
K ₂ O	0.05	0.04	0.04	0.01	0.17
F	n. a.	n. a.	n. a.	n. a.	n. a.
Cl	n. a.	n. a.	n. a.	n. a.	n. a.
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.
Total	97.05	97.15	0.39	96.27	97.79
O=F=Cl	n. a.	n. a.	n. a.	n. a.	n. a.
CTotal	97.05	97.15	0.39	96.27	97.79
Si	7.72	7.74	0.11	7.49	7.86
Al	0.27	0.22	0.12	0.12	0.51
Fe ³⁺	0.03	0.03	0.02	0.00	0.05
Σ T	8.00	8.00	0.00	8.00	8.00
Al	0.13	0.17	0.09	0.01	0.27
Cr	0.01	0.01	0.01	0.00	0.04
Fe ³⁺	0.13	0.15	0.08	0.00	0.25
Ti	0.00	0.00	0.00	0.00	0.02
Mg	4.47	4.58	0.16	4.22	4.64
Fe ²⁺	0.29	0.26	0.12	0.13	0.48
Mn	0.01	0.00	0.01	0.00	0.03
Σ C	4.92	5.00	0.10	4.73	5.00
Fe ²⁺	0.01	0.01	0.01	0.00	0.03
Mn	0.00	0.00	0.00	0.00	0.01
Ca	1.98	1.98	0.02	1.93	2.00
Na	0.01	0.01	0.01	0.00	0.02
Σ B	2.00	2.00	0.01	1.97	2.00
Na	0.05	0.04	0.04	0.01	0.12
K	0.01	0.01	0.01	0.00	0.03
Σ A	0.06	0.04	0.04	0.02	0.14
Σ cat	15.06	15.04	0.05	14.99	15.16
Cl	n. a.	n. a.	n. a.	n. a.	n. a.
F	n. a.	n. a.	n. a.	n. a.	n. a.
Σ oxygen	23.00	23.00	0.00	23.00	23.02

Table 6, Zoisite analysis, numbers of ions on the basis of 130

Sample	27305-2	27305-2-1	27305-2-2	27305-4	27305-4-1	27305-4-2	27520-4-3
SiO ₂	43.090	43.074	42.560	42.481	42.522	41.611	43.074
TiO ₂	0.104	0.294	0.188	0.256	0.390	0.538	0.285
Al ₂ O ₃	24.330	24.170	23.762	24.382	23.749	23.592	24.265
Cr ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Fe ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
FeO	0.827	1.465	2.686	1.186	2.246	3.911	1.686
MnO	0.016	0.046	0.045	0.036	0.010	0.061	0.023
MgO	0.261	0.557	1.148	0.360	0.920	1.960	0.861
CaO	27.000	26.327	25.037	26.829	25.356	23.429	25.779
Na ₂ O	0.011	0.016	0.039	0.020	0.036	0.013	0.009
K ₂ O	0.003	0.024	0.032	0.014	0.017	0.202	0.129
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Total	95.642	95.973	95.497	95.564	95.246	95.317	96.111
Si	3.379	3.372	3.361	3.344	3.362	3.308	3.367
Al IV	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sum Si+Al	3.379	3.372	3.361	3.344	3.362	3.308	3.367
Al VI	2.247	2.228	2.210	2.260	2.211	2.209	2.234
Ti	0.006	0.017	0.011	0.015	0.023	0.032	0.017
Cr	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Fe ³⁺	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Mg	0.031	0.065	0.135	0.042	0.108	0.232	0.100
Fe ²⁺	0.054	0.096	0.177	0.078	0.149	0.260	0.110
Mn	0.001	0.003	0.003	0.002	0.001	0.004	0.002
Na	0.002	0.002	0.006	0.003	0.006	0.002	0.001
Ca	2.269	2.208	2.118	2.263	2.148	1.996	2.159
K	—	0.002	0.003	0.001	0.002	0.020	0.013
Sum	4.610	4.621	4.663	4.664	4.648	4.755	4.636
OH	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.

Table 7, Zoisite analysis, numbers of ions on the basis of 13O, summary

n = 7	average	median	standard deviation	minimum	maximum
SiO ₂	42.63	42.56	0.53	41.61	43.09
TiO ₂	0.29	0.29	0.14	0.10	0.54
Al ₂ O ₃	24.04	24.17	0.32	23.59	24.38
Cr ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.
Fe ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.
FeO	2.00	1.69	1.05	0.83	3.91
MnO	0.03	0.04	0.02	0.01	0.06
MgO	0.87	0.86	0.58	0.26	1.96
CaO	25.68	25.78	1.23	23.43	27.00
Na ₂ O	0.02	0.02	0.01	0.01	0.04
K ₂ O	0.06	0.02	0.08	0.00	0.20
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.
Total	95.62	95.56	0.32	95.25	96.11
Si	3.36	3.36	0.02	3.31	3.38
Al IV	0.00	0.00	0.00	0.00	0.00
Σ Si+Al	3.36	3.36	0.02	3.31	3.38
Al VI	2.23	2.23	0.02	2.21	2.26
Ti	0.02	0.02	0.01	0.01	0.03
Cr	n. a.	n. a.	n. a.	n. a.	n. a.
Fe ³⁺	n. a.	n. a.	n. a.	n. a.	n. a.
Mg	0.10	0.10	0.07	0.03	0.23
Fe ²⁺	0.13	0.11	0.07	0.05	0.26
Mn	0.00	0.00	0.00	0.00	0.00
Na	0.00	0.00	0.00	0.00	0.01
Ca	2.17	2.16	0.09	2.00	2.27
K	0.01	0.00	0.01	0.00	0.02
Σ	4.66	4.65	0.05	4.61	4.76
OH	n. a.	n. a.	n. a.	n. a.	n. a.

Table 8, Biotite analysis, numbers of ions on the basis of 24(O, OH, F, Cl)

Sample	27206-1	27206-1-2	27206-1-3	27206-2	27206-2-2	27206-2-3	27206-3	27206-3-2	27206-3-3	27206-4
SiO ₂	35.429	35.349	35.470	35.218	35.011	35.416	35.577	35.093	35.422	35.584
TiO ₂	1.634	1.653	1.550	1.846	1.851	1.893	1.840	1.875	1.861	1.955
Al ₂ O ₃	20.298	20.168	19.664	20.083	19.968	19.691	20.332	20.374	19.983	20.044
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	17.892	17.957	18.013	17.920	17.691	18.100	17.818	18.103	18.018	17.856
MnO	0.188	0.194	0.166	0.201	0.169	0.121	0.168	0.185	0.139	0.167
MgO	10.370	10.484	10.709	10.297	10.362	10.199	10.235	10.512	10.332	10.414
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.022	0.005	0.001	—	0.009	—	—	0.014	—	0.031
Na ₂ O	0.164	0.231	0.118	0.181	0.204	0.148	0.131	0.130	0.180	0.189
K ₂ O	9.794	9.587	9.672	9.942	9.411	9.766	9.659	9.657	9.694	9.545
F	0.180	0.269	0.273	0.293	0.294	0.102	0.154	0.229	0.277	—
Cl	0.020	0.016	—	—	0.016	0.034	0.003	0.008	0.010	0.020
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	95.991	95.913	95.636	95.981	94.986	95.470	95.917	96.180	95.916	95.805
O≡F≡Cl	0.080	0.120	0.110	0.120	0.130	0.050	0.070	0.100	0.120	0.000
Total	96.071	96.033	95.746	96.101	95.116	95.520	95.987	96.280	96.036	95.805
Si	5.573	5.569	5.607	5.558	5.565	5.606	5.587	5.517	5.583	5.588
Al IV	2.427	2.431	2.393	2.442	2.435	2.394	2.413	2.483	2.417	2.412
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.333	1.311	1.268	1.290	1.302	1.276	1.347	1.289	1.292	1.295
Ti	0.193	0.196	0.184	0.219	0.221	0.225	0.217	0.222	0.221	0.231
Fe ²⁺	2.354	2.366	2.381	2.365	2.351	2.396	2.340	2.380	2.375	2.345
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.025	0.026	0.022	0.027	0.023	0.016	0.022	0.025	0.019	0.022
Mg	2.432	2.462	2.524	2.422	2.455	2.406	2.396	2.464	2.428	2.438
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.004	0.001	—	—	0.002	—	—	0.002	—	0.005
Na	0.050	0.071	0.036	0.055	0.063	0.045	0.040	0.040	0.055	0.058
K	1.965	1.927	1.951	2.002	1.908	1.972	1.935	1.937	1.949	1.912
Sum	8.356	8.360	8.366	8.380	8.325	8.336	8.297	8.359	8.339	8.306
F	0.179	0.268	0.273	0.292	0.296	0.102	0.153	0.228	0.276	—
Cl	0.011	0.009	—	—	0.009	0.018	0.002	0.004	0.005	0.011
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.190	0.277	0.273	0.292	0.305	0.120	0.155	0.232	0.281	0.011
Fe/(Fe+Mg)	0.490	0.490	0.490	0.490	0.490	0.500	0.490	0.490	0.490	0.490
Mg/(Fe+Mg)	0.510	0.510	0.510	0.510	0.510	0.500	0.510	0.510	0.510	0.510

Table 8 continued

Sample	27212-3	27212-3-2	27212-3-3	27212-3-4	27212-4	27212-4-2	27212-4-3	27212-5	27212-5-2	27212-5-3
SiO ₂	35.195	35.545	35.641	35.309	35.231	35.478	35.580	35.487	35.392	35.618
TiO ₂	2.103	2.044	2.048	2.013	1.812	2.054	1.956	1.750	1.858	1.700
Al ₂ O ₃	20.881	20.563	20.791	20.918	21.120	20.649	20.547	21.300	21.139	21.201
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	18.376	18.630	18.638	18.380	18.793	18.227	18.293	18.519	18.408	18.249
MnO	0.189	0.161	0.169	0.183	0.195	0.178	0.180	0.146	0.174	0.183
MgO	9.694	10.093	10.012	9.888	10.272	9.968	10.164	9.929	9.926	10.053
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.033	0.003	0.044	0.041	0.011	0.046	0.021	0.009	0.006	0.033
Na ₂ O	0.154	0.112	0.206	0.242	0.151	0.242	0.260	0.228	0.323	0.193
K ₂ O	9.414	9.612	9.174	9.172	9.284	9.334	9.428	9.483	9.373	9.354
F	0.089	0.038	0.166	0.186	0.092	0.129	0.069	—	0.133	0.081
Cl	0.006	0.013	—	0.016	—	—	0.008	—	0.009	0.007
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	96.134	96.814	96.889	96.348	96.961	96.305	96.506	96.851	96.741	96.672
O≡F≡Cl	0.040	0.020	0.070	0.080	0.040	0.050	0.030	0.000	0.060	0.040
Total	96.174	96.834	96.959	96.428	97.001	96.355	96.536	96.851	96.801	96.712
Si	5.520	5.541	5.543	5.523	5.482	5.549	5.555	5.516	5.515	5.540
Al IV	2.480	2.459	2.457	2.477	2.518	2.451	2.445	2.484	2.485	2.460
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.377	1.316	1.351	1.377	1.352	1.352	1.333	1.415	1.394	1.423
Ti	0.248	0.240	0.240	0.237	0.212	0.242	0.230	0.205	0.218	0.199
Fe ²⁺	2.410	2.429	2.424	2.405	2.446	2.384	2.388	2.407	2.399	2.374
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.025	0.021	0.022	0.024	0.026	0.024	0.024	0.019	0.023	0.024
Mg	2.267	2.346	2.321	2.306	2.383	2.324	2.365	2.301	2.306	2.331
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.006	0.001	0.007	0.007	0.002	0.008	0.004	0.001	0.001	0.005
Na	0.047	0.034	0.062	0.073	0.046	0.073	0.079	0.069	0.098	0.058
K	1.884	1.912	1.820	1.830	1.843	1.862	1.878	1.881	1.863	1.856
Sum	8.264	8.299	8.247	8.259	8.310	8.269	8.301	8.298	8.302	8.270
F	0.088	0.037	0.163	0.184	0.091	0.128	0.068	—	0.131	0.080
Cl	0.003	0.007	—	0.008	—	—	0.004	—	0.005	0.004
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.091	0.044	0.163	0.192	0.091	0.128	0.072	0.000	0.136	0.084
Fe/(Fe+Mg)	0.520	0.510	0.510	0.510	0.510	0.510	0.500	0.510	0.510	0.500
Mg/(Fe+Mg)	0.480	0.490	0.490	0.490	0.490	0.490	0.500	0.490	0.490	0.500

Table 8 continued

Sample	27206-4-2	27206-4-3	27206-5	27206-5-2	27206-5-3	27212-1	27212-1-2	27212-2	27212-2-2	27212-2-3
SiO ₂	35.793	35.572	35.423	35.255	35.283	35.526	35.265	35.614	35.605	35.221
TiO ₂	1.938	1.925	1.915	1.973	2.229	2.006	2.083	1.957	1.974	2.050
Al ₂ O ₃	19.840	20.419	20.289	20.208	19.880	20.414	20.427	20.725	20.428	20.844
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	18.065	17.814	18.821	18.622	18.837	18.570	18.748	18.549	18.384	18.654
MnO	0.149	0.187	0.219	0.232	0.235	0.184	0.187	0.162	0.170	0.223
MgO	10.395	10.298	9.642	9.589	9.637	10.092	10.023	10.019	10.029	9.832
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.003	0.009	—	0.028	0.016	—	0.013	0.062	0.029	0.031
Na ₂ O	0.142	0.190	0.153	0.178	0.254	0.072	0.160	0.218	0.159	0.253
K ₂ O	9.669	9.621	9.660	9.651	9.539	9.628	9.241	9.121	9.608	9.234
F	0.240	0.293	0.136	0.133	0.006	0.138	0.036	0.090	—	0.059
Cl	0.029	0.020	0.018	0.055	0.020	—	—	0.006	0.005	—
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	96.263	96.348	96.276	95.924	95.936	96.630	96.183	96.523	96.391	96.401
O≡F≡Cl	0.110	0.130	0.060	0.070	0.010	0.060	0.020	0.040	0.000	0.020
Total	96.373	96.478	96.336	95.994	95.946	96.690	96.203	96.563	96.391	96.421
Si	5.615	5.570	5.572	5.568	5.568	5.554	5.532	5.553	5.568	5.511
Al IV	2.385	2.430	2.428	2.432	2.432	2.446	2.468	2.447	2.432	2.489
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.280	1.335	1.331	1.326	1.263	1.313	1.305	1.359	1.330	1.352
Ti	0.229	0.227	0.227	0.234	0.265	0.236	0.246	0.230	0.232	0.241
Fe ²⁺	2.370	2.333	2.476	2.460	2.486	2.428	2.459	2.419	2.404	2.441
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.020	0.025	0.029	0.031	0.031	0.024	0.025	0.021	0.023	0.030
Mg	2.431	2.404	2.261	2.258	2.267	2.352	2.344	2.329	2.338	2.293
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.001	0.002	—	0.005	0.003	—	0.002	0.010	0.005	0.005
Na	0.043	0.058	0.047	0.055	0.078	0.022	0.049	0.066	0.048	0.077
K	1.935	1.922	1.939	1.944	1.921	1.920	1.849	1.814	1.917	1.843
Sum	8.309	8.306	8.310	8.313	8.314	8.295	8.279	8.248	8.297	8.282
F	0.238	0.290	0.135	0.133	0.006	0.136	0.036	0.089	—	0.058
Cl	0.015	0.011	0.010	0.029	0.011	—	—	0.003	0.003	—
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.253	0.301	0.145	0.162	0.017	0.136	0.036	0.092	0.003	0.058
Fe/(Fe+Mg)	0.490	0.490	0.520	0.520	0.520	0.510	0.510	0.510	0.510	0.520
Mg/(Fe+Mg)	0.510	0.510	0.480	0.480	0.480	0.490	0.490	0.490	0.490	0.480

Table 8 continued

Sample	27212-6	27215-1	27215-1-2	27215-2	27215-2	27215-2-2	27215-2-3	27215-3	27215-3-2	27215-3-3
SiO ₂	35.782	35.721	35.299	35.777	35.042	34.532	35.115	35.573	35.558	35.525
TiO ₂	1.716	2.503	2.473	2.513	2.477	2.420	2.113	2.117	2.548	2.656
Al ₂ O ₃	21.032	18.853	19.231	18.724	18.520	18.580	18.687	19.991	19.235	19.601
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	18.146	19.630	19.763	19.550	19.040	19.292	20.464	19.897	19.915	19.910
MnO	0.151	0.196	0.139	0.137	0.190	0.188	0.140	0.180	0.200	0.168
MgO	9.823	10.056	10.408	10.132	9.897	9.931	10.677	10.174	9.713	9.872
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.032	0.242	0.188	0.208	0.092	0.149	0.115	0.001	0.015	0.011
Na ₂ O	0.241	0.282	0.171	0.206	0.174	0.139	0.155	0.162	0.129	0.153
K ₂ O	9.296	8.700	8.875	8.796	9.090	8.693	8.563	9.221	9.170	9.396
F	0.025	0.155	0.268	0.105	0.095	0.033	0.282	0.182	0.211	0.169
Cl	0.021	0.077	0.024	0.056	0.072	0.028	0.041	0.013	0.040	0.037
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	96.265	96.415	96.839	96.204	94.689	93.985	96.352	97.511	96.734	97.498
O≡F≡Cl	0.020	0.080	0.120	0.060	0.060	0.020	0.130	0.080	0.100	0.080
Total	96.285	96.495	96.959	96.264	94.749	94.005	96.482	97.591	96.834	97.578
Si	5.580	5.620	5.541	5.634	5.618	5.574	5.557	5.540	5.592	5.544
Al IV	2.420	2.380	2.459	2.366	2.382	2.426	2.443	2.460	2.408	2.456
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.443	1.113	1.096	1.107	1.115	1.106	1.040	1.207	1.154	1.147
Ti	0.201	0.296	0.292	0.298	0.299	0.294	0.252	0.248	0.301	0.312
Fe ²⁺	2.367	2.583	2.595	2.575	2.553	2.604	2.708	2.592	2.619	2.599
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.020	0.026	0.018	0.018	0.026	0.026	0.019	0.024	0.027	0.022
Mg	2.284	2.358	2.436	2.379	2.365	2.390	2.519	2.362	2.277	2.297
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.005	0.041	0.032	0.035	0.016	0.026	0.019	—	0.003	0.002
Na	0.073	0.086	0.052	0.063	0.054	0.044	0.048	0.049	0.039	0.046
K	1.849	1.746	1.777	1.767	1.859	1.790	1.729	1.832	1.840	1.871
Sum	8.242	8.249	8.298	8.242	8.287	8.280	8.334	8.314	8.260	8.296
F	0.025	0.154	0.266	0.105	0.096	0.034	0.282	0.179	0.210	0.167
Cl	0.011	0.041	0.013	0.030	0.039	0.015	0.022	0.007	0.021	0.020
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.036	0.195	0.279	0.135	0.135	0.049	0.304	0.186	0.231	0.187
Fe/(Fe+Mg)	0.510	0.520	0.520	0.520	0.520	0.520	0.520	0.520	0.530	0.530
Mg/(Fe+Mg)	0.490	0.480	0.480	0.480	0.480	0.480	0.480	0.480	0.470	0.470

Table 8 continued

Sample	27215-4	27215-4-2	27215-4-3	27215-5	27215-5-2	27215-5-3	27216-1	27216-1-2	27216-1-3	27216-2
SiO ₂	35.323	35.954	35.382	35.726	35.514	35.852	35.574	35.521	35.517	35.685
TiO ₂	2.530	2.514	2.437	1.907	1.881	1.907	2.229	2.256	2.272	2.281
Al ₂ O ₃	19.367	19.898	19.679	19.495	19.734	19.617	19.080	19.280	19.477	19.626
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	19.651	19.825	19.630	18.793	18.787	18.627	19.286	18.868	18.669	18.588
MnO	0.128	0.152	0.149	0.151	0.150	0.192	0.207	0.227	0.265	0.248
MgO	9.952	10.191	10.051	10.318	10.386	10.362	10.099	9.899	10.166	10.087
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.096	—	0.056	0.001	0.002	—	0.052	0.004	0.101	0.018
Na ₂ O	0.130	0.102	0.159	0.181	0.149	0.164	0.124	0.166	0.186	0.119
K ₂ O	9.002	9.454	9.043	9.137	9.294	9.209	9.510	9.464	9.235	9.368
F	0.204	—	0.106	0.093	0.200	0.087	0.043	0.123	0.105	0.263
Cl	0.066	0.020	0.030	0.019	0.027	0.034	0.024	0.012	0.006	0.026
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	96.449	98.110	96.722	95.821	96.124	96.051	96.228	95.820	95.999	96.309
O≡F≡Cl	0.100	0.000	0.050	0.040	0.090	0.040	0.020	0.050	0.050	0.120
Total	96.549	98.110	96.772	95.861	96.214	96.091	96.248	95.870	96.049	96.429
Si	5.563	5.553	5.546	5.627	5.589	5.629	5.610	5.617	5.593	5.606
Al IV	2.437	2.447	2.454	2.373	2.411	2.371	2.390	2.383	2.407	2.394
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.155	1.172	1.179	1.243	1.246	1.256	1.154	1.207	1.205	1.237
Ti	0.300	0.292	0.287	0.226	0.223	0.225	0.264	0.268	0.269	0.270
Fe ²⁺	2.588	2.561	2.573	2.475	2.473	2.446	2.544	2.495	2.458	2.442
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.017	0.020	0.020	0.020	0.020	0.026	0.028	0.030	0.035	0.033
Mg	2.336	2.347	2.349	2.423	2.437	2.425	2.374	2.333	2.386	2.362
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.016	—	0.009	—	—	—	0.009	0.001	0.017	0.003
Na	0.040	0.031	0.048	0.055	0.045	0.050	0.038	0.051	0.057	0.036
K	1.809	1.863	1.808	1.836	1.866	1.845	1.913	1.909	1.855	1.877
Sum	8.261	8.286	8.273	8.278	8.310	8.273	8.324	8.294	8.282	8.260
F	0.203	—	0.105	0.093	0.199	0.086	0.043	0.123	0.105	0.261
Cl	0.035	0.010	0.016	0.010	0.014	0.018	0.013	0.006	0.003	0.014
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.238	0.010	0.121	0.103	0.213	0.104	0.056	0.129	0.108	0.275
Fe/(Fe+Mg)	0.530	0.520	0.520	0.510	0.500	0.500	0.520	0.520	0.510	0.510
Mg/(Fe+Mg)	0.470	0.480	0.480	0.490	0.500	0.500	0.480	0.480	0.490	0.490

Table 8 continued

Sample	27216-2-2	27216-2-3	27216-3	27216-3-2	27216-3-3	27216-4	27216-4-2	27216-4-3	27216-5	27216-5-2
SiO ₂	35.588	35.817	35.527	35.492	35.262	35.615	35.629	35.609	35.728	35.859
TiO ₂	2.323	2.353	2.290	2.211	2.226	2.646	2.524	2.671	2.714	2.709
Al ₂ O ₃	19.269	19.377	19.628	19.443	19.589	19.360	19.558	19.328	19.422	19.633
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	18.560	18.429	18.611	18.592	18.385	19.353	19.061	18.919	19.056	18.789
MnO	0.243	0.233	0.260	0.273	0.253	0.233	0.194	0.242	0.236	0.236
MgO	10.076	10.028	10.028	10.057	10.025	9.764	9.925	9.929	9.877	9.796
BaO	—	—	—	—	—	—	—	—	—	—
CaO	—	—	—	—	0.002	0.119	0.020	0.044	0.034	0.025
Na ₂ O	0.177	0.128	0.123	0.123	0.141	0.143	0.140	0.196	0.170	0.127
K ₂ O	9.364	9.430	9.420	9.419	9.395	9.290	9.693	9.555	9.376	9.585
F	—	0.111	0.148	0.171	0.087	0.087	0.168	0.129	0.040	0.065
Cl	0.015	0.003	0.004	0.011	0.008	0.028	0.003	0.008	0.008	0.012
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	95.615	95.909	96.039	95.792	95.373	96.638	96.915	96.630	96.661	96.836
O≡F≡Cl	0.000	0.050	0.060	0.070	0.040	0.040	0.070	0.060	0.020	0.030
Total	95.615	95.959	96.099	95.862	95.413	96.678	96.985	96.690	96.681	96.866
Si	5.620	5.637	5.594	5.607	5.586	5.589	5.579	5.588	5.593	5.600
Al IV	2.380	2.363	2.406	2.393	2.414	2.411	2.421	2.412	2.407	2.400
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.204	1.229	1.234	1.224	1.241	1.167	1.186	1.160	1.174	1.210
Ti	0.276	0.279	0.271	0.263	0.265	0.312	0.297	0.315	0.320	0.318
Fe ²⁺	2.451	2.426	2.451	2.456	2.436	2.540	2.496	2.483	2.495	2.454
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.033	0.031	0.035	0.037	0.034	0.031	0.026	0.032	0.031	0.031
Mg	2.372	2.353	2.354	2.369	2.368	2.284	2.317	2.323	2.305	2.280
Ba	—	—	—	—	—	—	—	—	—	—
Ca	—	—	—	—	—	0.020	0.003	0.007	0.006	0.004
Na	0.054	0.039	0.038	0.038	0.043	0.044	0.043	0.060	0.052	0.038
K	1.887	1.893	1.892	1.898	1.899	1.860	1.936	1.913	1.872	1.909
Sum	8.277	8.250	8.275	8.285	8.286	8.258	8.304	8.293	8.255	8.244
F	—	0.110	0.147	0.171	0.087	0.086	0.166	0.128	0.040	0.064
Cl	0.008	0.002	0.002	0.006	0.004	0.015	0.002	0.004	0.004	0.006
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.008	0.112	0.149	0.177	0.091	0.101	0.168	0.132	0.044	0.070
Fe/(Fe+Mg)	0.510	0.510	0.510	0.510	0.510	0.530	0.520	0.520	0.520	0.520
Mg/(Fe+Mg)	0.490	0.490	0.490	0.490	0.490	0.470	0.480	0.480	0.480	0.480

Table 8 continued

Sample	27216-5-3	27302-1	27302-1-1	27302-1-2	27302-2	27302-2-1	27302-2-2	27302-3	27302-3-1	27302-3-2
SiO ₂	35.737	38.584	38.908	38.696	38.652	38.817	39.111	39.476	38.089	38.501
TiO ₂	2.806	1.811	2.147	1.454	2.105	1.958	2.018	2.106	2.373	2.123
Al ₂ O ₃	19.456	17.121	16.964	17.244	17.506	17.360	17.561	17.277	17.340	16.983
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	19.265	6.677	6.623	6.590	6.691	6.725	6.635	6.537	7.059	6.804
MnO	0.261	0.212	0.224	0.196	0.212	0.203	0.181	0.232	0.222	0.212
MgO	9.854	20.329	20.026	20.647	20.828	20.347	20.064	19.924	20.261	19.829
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.037	0.051	0.058	0.030	—	0.036	0.013	0.021	0.378	0.033
Na ₂ O	0.149	0.068	0.102	0.053	0.080	0.081	0.094	0.111	0.122	0.151
K ₂ O	9.562	9.204	9.426	9.619	9.181	9.389	9.437	9.846	8.011	9.407
F	0.109	0.366	0.512	0.736	0.640	0.558	0.558	0.526	0.274	0.540
Cl	0.003	—	0.008	0.013	0.007	0.017	—	0.011	0.009	0.006
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	97.239	94.423	94.998	95.278	95.902	95.491	95.672	96.067	94.138	94.589
O≡F≡Cl	0.050	0.150	0.220	0.310	0.270	0.240	0.230	0.220	0.120	0.230
Total	97.289	94.573	95.218	95.588	96.172	95.731	95.902	96.287	94.258	94.819
Si	5.576	5.830	5.857	5.827	5.766	5.816	5.839	5.879	5.751	5.832
Al IV	2.424	2.170	2.143	2.173	2.234	2.184	2.161	2.121	2.249	2.168
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.151	0.876	0.864	0.885	0.841	0.879	0.927	0.909	0.834	0.862
Ti	0.329	0.206	0.243	0.165	0.236	0.221	0.227	0.236	0.269	0.242
Fe ²⁺	2.514	0.844	0.834	0.830	0.835	0.843	0.828	0.814	0.891	0.862
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.034	0.027	0.029	0.025	0.027	0.026	0.023	0.029	0.028	0.027
Mg	2.292	4.579	4.494	4.635	4.632	4.545	4.466	4.423	4.560	4.478
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.006	0.008	0.009	0.005	—	0.006	0.002	0.003	0.061	0.005
Na	0.045	0.020	0.030	0.015	0.023	0.024	0.027	0.032	0.036	0.044
K	1.903	1.774	1.810	1.848	1.747	1.795	1.798	1.871	1.543	1.818
Sum	8.274	8.334	8.313	8.408	8.341	8.339	8.298	8.317	8.222	8.338
F	0.108	0.350	0.487	0.701	0.604	0.529	0.527	0.495	0.262	0.517
Cl	0.002	—	0.004	0.007	0.004	0.009	—	0.006	0.005	0.003
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.110	0.350	0.491	0.708	0.608	0.538	0.527	0.501	0.267	0.520
Fe/(Fe+Mg)	0.520	0.160	0.160	0.150	0.150	0.160	0.160	0.160	0.160	0.160
Mg/(Fe+Mg)	0.480	0.840	0.840	0.850	0.850	0.840	0.840	0.840	0.840	0.840

Table 8 continued

Sample	27302-4	27302-4-1	27302-4-2	27302-5	27302-5-1	27302-5-2	27305-1	27305-1-1	27305-1-2	27305-3
SiO ₂	37.875	38.259	34.017	39.221	39.685	39.409	36.008	36.139	35.036	35.859
TiO ₂	2.240	2.480	2.335	2.000	2.113	1.898	2.015	2.058	1.971	1.951
Al ₂ O ₃	17.265	16.998	17.902	17.295	17.422	17.398	19.352	19.338	18.696	19.054
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	6.929	6.830	9.610	6.280	6.446	6.531	18.289	18.243	18.745	18.183
MnO	0.172	0.246	0.310	0.232	0.220	0.201	0.267	0.213	0.281	0.239
MgO	20.458	20.197	21.883	19.871	20.035	20.204	10.553	10.467	10.840	10.817
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.105	0.403	0.757	0.014	0.058	0.038	0.050	0.016	0.104	0.033
Na ₂ O	0.083	0.111	0.042	0.124	0.089	0.076	0.115	0.155	0.116	0.086
K ₂ O	8.169	8.237	3.228	9.995	9.960	9.856	9.537	9.602	8.732	9.512
F	0.646	0.611	0.482	0.404	0.589	0.426	0.091	0.218	0.253	0.221
Cl	—	0.034	—	0.003	—	0.002	0.011	0.024	0.032	0.021
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	93.942	94.406	90.566	95.439	96.617	96.039	96.288	96.473	94.806	95.976
O≡F≡Cl	0.270	0.260	0.200	0.170	0.250	0.180	0.040	0.100	0.110	0.100
Total	94.212	94.666	90.766	95.609	96.867	96.219	96.328	96.573	94.916	96.076
Si	5.750	5.784	5.321	5.872	5.877	5.863	5.643	5.658	5.597	5.646
Al IV	2.250	2.216	2.679	2.128	2.123	2.137	2.357	2.342	2.403	2.354
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	0.837	0.810	0.619	0.922	0.916	0.911	1.214	1.224	1.115	1.179
Ti	0.256	0.282	0.275	0.225	0.235	0.212	0.238	0.242	0.237	0.231
Fe ²⁺	0.880	0.864	1.257	0.786	0.798	0.813	2.397	2.389	2.504	2.394
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.022	0.032	0.041	0.029	0.028	0.025	0.035	0.028	0.038	0.032
Mg	4.630	4.552	5.103	4.435	4.423	4.481	2.465	2.443	2.582	2.539
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.017	0.065	0.127	0.002	0.009	0.006	0.008	0.003	0.018	0.006
Na	0.024	0.033	0.013	0.036	0.026	0.022	0.035	0.047	0.036	0.026
K	1.582	1.589	0.644	1.909	1.882	1.871	1.907	1.918	1.780	1.911
Sum	8.248	8.227	8.079	8.344	8.317	8.341	8.299	8.294	8.310	8.318
F	0.620	0.584	0.477	0.383	0.552	0.401	0.090	0.216	0.256	0.220
Cl	—	0.017	—	0.002	—	0.001	0.006	0.013	0.017	0.011
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.620	0.601	0.477	0.385	0.552	0.402	0.096	0.229	0.273	0.231
Fe/(Fe+Mg)	0.160	0.160	0.200	0.150	0.150	0.150	0.490	0.490	0.490	0.490
Mg/(Fe+Mg)	0.840	0.840	0.800	0.850	0.850	0.850	0.510	0.510	0.510	0.510

Table 8 continued

Sample	27305-3-1	27305-3-2	27305-5	27305-5-1	27305-5-2	27514-1	27514-1-2	27514-2	27514-2-2	27514-2-3
SiO ₂	36.281	36.123	35.741	35.698	36.047	36.093	36.280	35.791	35.728	35.655
TiO ₂	1.932	1.962	1.933	1.899	1.951	1.460	1.473	1.981	1.962	1.427
Al ₂ O ₃	18.730	18.800	19.038	18.951	19.199	20.179	20.209	20.123	20.130	20.154
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	18.580	18.426	18.398	18.413	17.517	17.350	17.568	17.544	17.815	17.452
MnO	0.255	0.270	0.209	0.270	0.228	0.111	0.141	0.168	0.153	0.164
MgO	10.636	10.826	10.551	10.338	10.969	11.181	11.356	10.856	10.840	11.399
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.025	0.016	—	—	—	0.018	0.028	0.006	0.016	0.074
Na ₂ O	0.084	0.087	0.093	0.017	0.049	0.158	0.132	0.153	0.111	0.158
K ₂ O	9.750	9.496	9.512	9.412	9.763	9.569	9.464	9.504	9.575	9.490
F	0.152	0.428	0.038	0.084	0.192	0.122	0.146	0.144	0.119	0.020
Cl	0.017	0.020	0.011	0.011	0.019	0.008	0.016	0.010	0.016	0.013
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	96.442	96.454	95.524	95.093	95.934	96.249	96.813	96.280	96.465	96.006
O≡F≡Cl	0.070	0.180	0.020	0.040	0.090	0.050	0.070	0.060	0.050	0.010
Total	96.512	96.634	95.544	95.133	96.024	96.299	96.883	96.340	96.515	96.016
Si	5.695	5.676	5.650	5.669	5.661	5.624	5.621	5.586	5.574	5.575
Al IV	2.305	2.324	2.350	2.331	2.339	2.376	2.379	2.414	2.426	2.425
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.157	1.155	1.194	1.213	1.212	1.327	1.308	1.285	1.273	1.286
Ti	0.228	0.232	0.230	0.227	0.230	0.171	0.172	0.233	0.230	0.168
Fe ²⁺	2.439	2.421	2.432	2.446	2.301	2.261	2.276	2.290	2.324	2.282
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.034	0.036	0.028	0.036	0.030	0.015	0.019	0.022	0.020	0.022
Mg	2.489	2.536	2.486	2.448	2.568	2.597	2.623	2.526	2.521	2.657
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.004	0.003	—	—	—	0.003	0.005	0.001	0.003	0.012
Na	0.026	0.027	0.029	0.005	0.015	0.048	0.040	0.046	0.034	0.048
K	1.952	1.904	1.918	1.907	1.956	1.902	1.871	1.892	1.906	1.893
Sum	8.329	8.314	8.317	8.282	8.312	8.324	8.314	8.295	8.311	8.368
F	0.151	0.425	0.038	0.084	0.191	0.120	0.143	0.142	0.117	0.020
Cl	0.009	0.011	0.006	0.006	0.010	0.004	0.008	0.005	0.008	0.007
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.160	0.436	0.044	0.090	0.201	0.124	0.151	0.147	0.125	0.027
Fe/(Fe+Mg)	0.490	0.490	0.490	0.500	0.470	0.470	0.460	0.480	0.480	0.460
Mg/(Fe+Mg)	0.510	0.510	0.510	0.500	0.530	0.530	0.540	0.520	0.520	0.540

Table 8 continued

Sample	27514-2-3	27514-3	27514-3-2	27514-3-3	27514-4	27514-4-2	27514-4-3	27514-5	27514-5-2	27514-5-3
SiO ₂	35.805	35.391	35.533	35.477	35.799	35.142	35.813	35.744	35.839	35.676
TiO ₂	1.957	2.195	2.308	2.321	2.240	2.348	2.333	2.326	2.210	2.344
Al ₂ O ₃	20.161	19.666	19.588	19.712	19.790	19.578	19.924	19.760	19.935	19.905
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	17.175	18.664	18.791	18.948	18.513	18.627	18.772	18.746	18.843	18.554
MnO	0.139	0.178	0.171	0.181	0.188	0.171	0.156	0.157	0.178	0.207
MgO	10.859	10.110	10.246	10.059	10.052	10.154	10.173	10.209	10.281	10.183
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.030	0.009	0.011	0.027	—	0.022	0.011	0.051	—	—
Na ₂ O	0.134	0.149	0.152	0.156	0.171	0.082	0.182	0.194	0.127	0.141
K ₂ O	9.486	9.336	9.200	9.332	9.302	9.203	9.433	9.149	9.520	9.579
F	0.356	0.170	0.155	0.049	0.110	0.056	0.104	0.158	0.012	0.163
Cl	0.015	0.017	0.032	0.020	0.012	0.018	0.022	0.013	0.010	0.021
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	96.117	95.885	96.187	96.282	96.177	95.401	96.923	96.507	96.955	96.773
O≡F≡Cl	0.150	0.080	0.070	0.030	0.050	0.030	0.050	0.070	0.010	0.070
Total	96.267	95.965	96.257	96.312	96.227	95.431	96.973	96.577	96.965	96.843
Si	5.599	5.583	5.585	5.572	5.613	5.564	5.582	5.591	5.581	5.575
Al IV	2.401	2.417	2.415	2.428	2.387	2.436	2.418	2.409	2.419	2.425
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.312	1.237	1.211	1.218	1.267	1.214	1.239	1.231	1.237	1.238
Ti	0.230	0.260	0.273	0.274	0.264	0.280	0.274	0.274	0.259	0.276
Fe ²⁺	2.246	2.462	2.470	2.489	2.428	2.466	2.447	2.452	2.454	2.425
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.018	0.024	0.023	0.024	0.025	0.023	0.021	0.021	0.023	0.027
Mg	2.531	2.378	2.401	2.355	2.350	2.397	2.364	2.381	2.387	2.372
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.005	0.002	0.002	0.005	—	0.004	0.002	0.009	—	—
Na	0.041	0.046	0.046	0.048	0.052	0.025	0.055	0.059	0.038	0.043
K	1.892	1.879	1.845	1.870	1.861	1.859	1.876	1.826	1.891	1.909
Sum	8.275	8.288	8.271	8.283	8.247	8.268	8.278	8.253	8.289	8.290
F	0.352	0.170	0.154	0.049	0.109	0.056	0.103	0.156	0.012	0.161
Cl	0.008	0.009	0.017	0.011	0.006	0.010	0.012	0.007	0.005	0.011
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.360	0.179	0.171	0.060	0.115	0.066	0.115	0.163	0.017	0.172
Fe/(Fe+Mg)	0.470	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510
Mg/(Fe+Mg)	0.530	0.490	0.490	0.490	0.490	0.490	0.490	0.490	0.490	0.490

Table 8 continued

Sample	27516-1	27516-1-2	27516-1-3	27516-2	27516-2-2	27516-2-3	27516-3	27516-3-3	27516-4	27516-4-2
SiO ₂	37.021	36.805	36.845	36.174	34.251	36.621	36.228	36.291	35.924	36.237
TiO ₂	2.999	3.039	3.095	2.889	2.513	2.791	3.002	3.087	2.886	2.994
Al ₂ O ₃	17.105	16.969	17.001	16.728	17.167	16.681	17.659	17.622	17.620	17.531
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	16.877	17.084	16.948	16.638	19.436	16.516	18.823	19.350	18.457	18.195
MnO	0.231	0.252	0.250	0.268	0.213	0.237	0.258	0.301	0.284	0.239
MgO	12.053	12.073	12.338	12.260	12.806	12.630	10.712	10.507	11.261	11.472
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.013	0.032	0.022	0.027	0.038	0.030	—	0.013	0.043	0.067
Na ₂ O	0.077	0.046	0.090	0.060	0.049	0.117	0.057	0.093	0.115	0.183
K ₂ O	9.630	9.443	9.595	9.383	6.619	9.448	9.685	9.576	9.364	9.448
F	0.238	0.307	0.257	0.199	0.343	0.122	0.167	0.307	0.222	0.132
Cl	—	—	0.037	0.009	0.017	0.013	0.009	0.005	0.010	0.026
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	96.244	96.050	96.478	94.635	93.452	95.206	96.600	97.152	96.186	96.524
O≡F≡Cl	0.100	0.130	0.120	0.090	0.150	0.050	0.070	0.130	0.100	0.060
Total	96.344	96.180	96.598	94.725	93.602	95.256	96.670	97.282	96.286	96.584
Si	5.780	5.767	5.749	5.747	5.529	5.771	5.693	5.690	5.662	5.678
Al IV	2.220	2.233	2.251	2.253	2.471	2.229	2.307	2.310	2.338	2.322
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	0.925	0.898	0.873	0.877	0.793	0.867	0.961	0.944	0.932	0.913
Ti	0.352	0.358	0.363	0.345	0.305	0.331	0.355	0.364	0.342	0.353
Fe ²⁺	2.204	2.239	2.211	2.211	2.624	2.177	2.474	2.537	2.433	2.384
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.031	0.033	0.033	0.036	0.029	0.032	0.034	0.040	0.038	0.032
Mg	2.805	2.820	2.870	2.904	3.082	2.967	2.509	2.456	2.646	2.680
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.002	0.005	0.004	0.005	0.007	0.005	—	0.002	0.007	0.011
Na	0.023	0.014	0.027	0.018	0.015	0.036	0.017	0.028	0.035	0.056
K	1.918	1.888	1.910	1.902	1.363	1.899	1.942	1.915	1.883	1.889
Sum	8.260	8.255	8.291	8.298	8.218	8.314	8.292	8.286	8.316	8.318
F	0.235	0.304	0.254	0.200	0.350	0.122	0.166	0.304	0.221	0.131
Cl	—	—	0.020	0.005	0.009	0.007	0.005	0.003	0.005	0.014
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.235	0.304	0.274	0.205	0.359	0.129	0.171	0.307	0.226	0.145
Fe/(Fe+Mg)	0.440	0.440	0.440	0.430	0.460	0.420	0.500	0.510	0.480	0.470
Mg/(Fe+Mg)	0.560	0.560	0.560	0.570	0.540	0.580	0.500	0.490	0.520	0.530

Table 8 continued

Sample	27516-4-3	27516-5	27516-5	27516-6	27517-1	27517-1-2	27517-1-3	27517-2	27517-2-2	27517-2-3
SiO ₂	36.252	35.853	35.922	36.349	36.137	36.411	36.601	36.360	36.302	36.343
TiO ₂	2.874	2.887	2.921	3.030	2.747	2.814	2.288	2.712	2.776	2.680
Al ₂ O ₃	17.631	17.615	17.833	17.596	18.756	18.881	19.117	18.433	18.482	18.884
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	18.242	19.005	18.971	18.806	15.346	15.295	15.248	15.311	15.585	15.155
MnO	0.226	0.218	0.241	0.232	0.175	0.172	0.160	0.171	0.172	0.183
MgO	11.243	10.661	10.823	10.695	12.546	12.550	12.989	12.572	12.744	12.676
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.041	0.080	—	0.048	—	0.009	0.051	0.039	—	0.021
Na ₂ O	0.112	0.149	0.142	0.077	0.073	0.050	0.084	0.137	0.073	0.059
K ₂ O	9.626	9.232	9.716	9.533	9.561	9.624	9.601	9.753	9.592	9.770
F	0.331	0.316	0.229	0.149	0.232	0.126	0.337	0.263	0.251	0.303
Cl	0.021	0.022	0.010	0.020	0.016	0.010	0.035	0.016	0.012	0.012
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	96.599	96.038	96.808	96.535	95.589	95.942	96.511	95.767	95.989	96.086
O≡F≡Cl	0.140	0.140	0.100	0.070	0.100	0.060	0.150	0.110	0.110	0.130
Total	96.739	96.178	96.908	96.605	95.689	96.002	96.661	95.877	96.099	96.216
Si	5.691	5.676	5.647	5.709	5.638	5.648	5.651	5.670	5.648	5.642
Al IV	2.309	2.324	2.353	2.291	2.362	2.352	2.349	2.330	2.352	2.358
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	0.951	0.960	0.948	0.964	1.084	1.097	1.127	1.055	1.034	1.095
Ti	0.339	0.344	0.345	0.358	0.322	0.328	0.266	0.318	0.325	0.313
Fe ²⁺	2.395	2.516	2.494	2.470	2.002	1.984	1.969	1.997	2.028	1.968
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.030	0.029	0.032	0.031	0.023	0.023	0.021	0.023	0.023	0.024
Mg	2.631	2.516	2.536	2.504	2.918	2.902	2.990	2.923	2.956	2.934
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.007	0.014	—	0.008	—	0.001	0.008	0.007	—	0.003
Na	0.034	0.046	0.043	0.023	0.022	0.015	0.025	0.041	0.022	0.018
K	1.928	1.864	1.949	1.910	1.903	1.904	1.891	1.940	1.904	1.935
Sum	8.315	8.289	8.347	8.268	8.274	8.254	8.297	8.304	8.292	8.290
F	0.329	0.316	0.228	0.148	0.229	0.124	0.329	0.259	0.247	0.298
Cl	0.011	0.012	0.005	0.011	0.008	0.005	0.018	0.008	0.006	0.006
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.340	0.328	0.233	0.159	0.237	0.129	0.347	0.267	0.253	0.304
Fe/(Fe+Mg)	0.480	0.500	0.500	0.500	0.410	0.410	0.400	0.410	0.410	0.400
Mg/(Fe+Mg)	0.520	0.500	0.500	0.500	0.590	0.590	0.600	0.590	0.590	0.600

Table 8 continued

Sample	27517-3	27517-3-2	27517-3-3	27517-4	27517-4-2	27517-4-3	27517-5	27517-5-2	27517-5-3	27518-1
SiO ₂	36.697	36.416	36.388	36.216	36.249	36.187	36.659	36.544	36.374	35.366
TiO ₂	2.525	2.736	2.692	2.804	2.794	2.895	2.874	2.650	2.636	2.558
Al ₂ O ₃	18.897	18.440	18.672	18.629	18.713	18.538	18.366	18.558	18.209	19.495
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	14.770	15.087	14.760	14.823	14.643	14.883	14.934	14.825	14.576	18.725
MnO	0.195	0.228	0.148	0.195	0.182	0.223	0.207	0.144	0.174	0.137
MgO	13.003	13.058	12.901	12.562	12.904	12.604	12.905	13.170	12.913	10.066
BaO	—	—	—	—	—	—	—	—	—	—
CaO	—	0.006	—	0.006	—	0.003	—	0.009	—	—
Na ₂ O	0.066	0.056	0.061	0.075	0.074	0.079	0.085	0.090	0.043	0.085
K ₂ O	9.760	9.851	9.759	9.817	9.848	9.751	9.729	9.868	9.709	9.196
F	0.337	0.389	0.101	0.299	0.178	0.339	0.195	0.314	0.230	0.194
Cl	—	0.009	0.027	0.016	0.010	0.001	0.029	0.020	0.013	0.009
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	96.250	96.276	95.509	95.442	95.595	95.503	95.983	96.192	94.877	95.831
O≡F≡Cl	0.140	0.170	0.050	0.130	0.080	0.140	0.090	0.140	0.100	0.080
Total	96.390	96.446	95.559	95.572	95.675	95.643	96.073	96.332	94.977	95.911
Si	5.672	5.653	5.661	5.658	5.642	5.653	5.685	5.662	5.701	5.580
Al IV	2.328	2.347	2.339	2.342	2.358	2.347	2.315	2.338	2.299	2.420
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.112	1.024	1.082	1.085	1.072	1.063	1.039	1.048	1.062	1.202
Ti	0.294	0.319	0.315	0.330	0.327	0.340	0.335	0.309	0.311	0.304
Fe ²⁺	1.909	1.958	1.921	1.937	1.906	1.944	1.937	1.921	1.911	2.471
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.026	0.030	0.020	0.026	0.024	0.030	0.027	0.019	0.023	0.018
Mg	2.996	3.022	2.992	2.926	2.994	2.935	2.984	3.042	3.017	2.367
Ba	—	—	—	—	—	—	—	—	—	—
Ca	—	0.001	—	0.001	—	0.001	—	0.001	—	—
Na	0.020	0.017	0.018	0.023	0.022	0.024	0.026	0.027	0.013	0.026
K	1.925	1.951	1.937	1.957	1.955	1.943	1.925	1.951	1.941	1.851
Sum	8.282	8.322	8.285	8.285	8.300	8.280	8.273	8.318	8.278	8.239
F	0.329	0.382	0.099	0.295	0.175	0.335	0.191	0.308	0.228	0.194
Cl	—	0.005	0.014	0.008	0.005	0.001	0.015	0.011	0.007	0.005
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.329	0.387	0.113	0.303	0.180	0.336	0.206	0.319	0.235	0.199
Fe/(Fe+Mg)	0.390	0.390	0.390	0.400	0.390	0.400	0.390	0.390	0.390	0.510
Mg/(Fe+Mg)	0.610	0.610	0.610	0.600	0.610	0.600	0.610	0.610	0.610	0.490

Table 8 continued

Sample	27518-1-2	27518-1-3	27518-2	27518-2-2	27518-2-3	27518-3	27518-3-2	27518-3-3	27518-4	27518-4-2
SiO ₂	35.247	34.205	35.221	34.968	33.665	35.111	35.059	35.161	35.427	35.177
TiO ₂	2.544	2.056	2.498	2.502	2.242	2.382	2.578	2.527	2.387	2.326
Al ₂ O ₃	20.279	19.648	19.358	19.556	19.562	19.170	19.433	19.199	19.829	19.366
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	18.550	19.796	18.849	19.416	20.861	18.869	18.998	18.958	18.756	18.744
MnO	0.098	0.111	0.111	0.105	0.087	0.165	0.155	0.153	0.160	0.114
MgO	10.010	10.594	9.960	10.241	10.320	10.399	10.362	9.968	10.121	10.144
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.036	0.160	0.041	0.055	0.098	0.031	0.032	0.013	0.056	0.005
Na ₂ O	0.066	0.082	0.105	0.090	0.106	0.093	0.088	0.124	0.131	0.045
K ₂ O	9.062	6.322	9.271	8.546	6.501	8.837	9.088	9.332	9.251	9.012
F	0.144	0.003	0.131	0.444	0.234	0.075	0.173	0.083	0.194	0.204
Cl	0.005	0.008	0.003	0.018	0.022	0.001	0.013	0.011	0.006	0.029
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	96.041	92.985	95.548	95.941	93.698	95.133	95.979	95.529	96.318	95.166
O≡F≡Cl	0.060	0.000	0.060	0.190	0.100	0.030	0.080	0.040	0.080	0.090
Total	96.101	92.985	95.608	96.131	93.798	95.163	96.059	95.569	96.398	95.256
Si	5.531	5.503	5.579	5.529	5.432	5.574	5.533	5.577	5.562	5.588
Al IV	2.469	2.497	2.421	2.471	2.568	2.426	2.467	2.423	2.438	2.412
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.278	1.225	1.190	1.170	1.149	1.158	1.145	1.163	1.228	1.211
Ti	0.300	0.249	0.298	0.298	0.272	0.284	0.306	0.301	0.282	0.278
Fe ²⁺	2.434	2.663	2.497	2.567	2.815	2.505	2.507	2.515	2.463	2.490
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.013	0.015	0.015	0.014	0.012	0.022	0.021	0.021	0.021	0.015
Mg	2.341	2.541	2.352	2.414	2.482	2.461	2.438	2.357	2.369	2.402
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.006	0.028	0.007	0.009	0.017	0.005	0.005	0.002	0.009	0.001
Na	0.020	0.026	0.032	0.028	0.033	0.029	0.027	0.038	0.040	0.014
K	1.814	1.297	1.874	1.724	1.338	1.790	1.830	1.888	1.853	1.826
Sum	8.206	8.044	8.265	8.224	8.118	8.254	8.279	8.285	8.265	8.237
F	0.143	0.003	0.131	0.444	0.239	0.075	0.173	0.083	0.193	0.205
Cl	0.003	0.004	0.002	0.010	0.012	0.001	0.007	0.006	0.003	0.016
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.146	0.007	0.133	0.454	0.251	0.076	0.180	0.089	0.196	0.221
Fe/(Fe+Mg)	0.510	0.510	0.510	0.520	0.530	0.500	0.510	0.520	0.510	0.510
Mg/(Fe+Mg)	0.490	0.490	0.490	0.480	0.470	0.500	0.490	0.480	0.490	0.490

Table 8 continued

Sample	27518-4-3	27518-5	27518-5-2	27518-5-3	27520-1	27520-1-2	27520-1-3	27520-2	27520-2-2	27520-2-3
SiO ₂	35.389	35.592	35.306	35.349	35.494	35.605	35.284	35.568	35.625	35.518
TiO ₂	2.332	2.312	2.308	2.242	2.831	2.884	2.770	2.789	2.779	2.762
Al ₂ O ₃	19.614	19.661	19.727	19.663	19.220	19.178	19.201	19.274	19.215	19.161
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	18.560	18.490	18.557	18.626	19.229	19.310	19.337	19.288	19.361	19.429
MnO	0.147	0.121	0.117	0.154	0.206	0.202	0.215	0.223	0.167	0.174
MgO	10.054	10.112	10.101	10.294	9.630	9.629	9.524	9.571	9.693	9.604
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.017	0.010	0.015	0.009	0.018	0.026	0.048	0.033	0.050	0.017
Na ₂ O	0.106	0.123	0.107	0.105	0.084	0.077	0.108	0.113	0.128	0.096
K ₂ O	9.340	9.282	9.365	9.380	9.516	9.566	9.256	9.567	9.436	9.665
F	0.114	0.036	0.172	0.114	0.185	0.185	0.096	0.288	0.233	0.202
Cl	0.021	0.005	0.002	0.003	0.021	0.008	0.013	—	0.009	—
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	95.694	95.744	95.777	95.939	96.434	96.670	95.852	96.714	96.696	96.628
O≡F≡Cl	0.050	0.020	0.070	0.050	0.080	0.080	0.040	0.120	0.100	0.090
Total	95.744	95.764	95.847	95.989	96.514	96.750	95.892	96.834	96.796	96.718
Si	5.587	5.602	5.572	5.569	5.591	5.596	5.585	5.594	5.597	5.593
Al IV	2.413	2.398	2.428	2.431	2.409	2.404	2.415	2.406	2.403	2.407
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.234	1.247	1.238	1.217	1.156	1.146	1.164	1.164	1.152	1.146
Ti	0.277	0.274	0.274	0.266	0.335	0.341	0.330	0.330	0.328	0.327
Fe ²⁺	2.451	2.434	2.449	2.454	2.533	2.538	2.560	2.537	2.544	2.559
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.020	0.016	0.016	0.021	0.027	0.027	0.029	0.030	0.022	0.023
Mg	2.366	2.373	2.376	2.418	2.261	2.256	2.247	2.244	2.270	2.255
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.003	0.002	0.003	0.002	0.003	0.004	0.008	0.006	0.008	0.003
Na	0.032	0.038	0.033	0.032	0.026	0.023	0.033	0.034	0.039	0.029
K	1.881	1.864	1.886	1.885	1.912	1.918	1.869	1.919	1.891	1.942
Sum	8.264	8.248	8.275	8.295	8.253	8.253	8.240	8.264	8.254	8.284
F	0.114	0.036	0.172	0.114	0.184	0.184	0.096	0.286	0.232	0.201
Cl	0.011	0.003	0.001	0.002	0.011	0.004	0.007	—	0.005	—
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.125	0.039	0.173	0.116	0.195	0.188	0.103	0.286	0.237	0.201
Fe/(Fe+Mg)	0.510	0.510	0.510	0.500	0.530	0.530	0.530	0.530	0.530	0.530
Mg/(Fe+Mg)	0.490	0.490	0.490	0.500	0.470	0.470	0.470	0.470	0.470	0.470

Table 8 continued

Sample	27520-3	27520-3-2	27520-3-3	27520-4	27520-4-2	27520-5	27520-5-2	27520-5-3	27521-1	27521-1-2
SiO ₂	36.382	35.222	36.776	36.406	36.815	36.331	36.381	36.627	35.538	35.652
TiO ₂	2.319	3.267	2.398	1.946	2.422	2.556	2.711	2.629	2.610	2.546
Al ₂ O ₃	17.832	17.510	17.506	17.416	16.987	17.770	17.907	17.600	20.306	20.411
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	17.149	16.552	16.841	17.504	17.418	17.912	17.875	17.994	18.177	18.377
MnO	0.180	0.176	0.160	0.170	0.209	0.226	0.223	0.186	0.126	0.153
MgO	12.929	12.103	12.730	13.157	12.742	11.731	11.782	11.682	9.704	9.803
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.019	2.428	0.016	0.039	0.029	0.013	0.025	0.020	0.015	0.083
Na ₂ O	0.069	0.112	0.097	0.044	0.051	0.050	0.094	0.030	0.167	0.201
K ₂ O	9.075	5.078	9.589	8.751	9.355	9.652	9.636	9.485	9.512	9.196
F	0.288	0.198	0.432	0.269	0.382	0.175	0.378	0.376	0.205	0.035
Cl	0.009	—	—	—	0.003	—	0.001	0.013	0.021	0.022
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	96.251	92.646	96.545	95.702	96.413	96.416	97.013	96.642	96.381	96.479
O≡F≡Cl	0.120	0.080	0.180	0.110	0.160	0.070	0.160	0.160	0.090	0.020
Total	96.371	92.726	96.725	95.812	96.573	96.486	97.173	96.802	96.471	96.499
Si	5.676	5.614	5.733	5.712	5.756	5.692	5.674	5.729	5.563	5.560
Al IV	2.324	2.386	2.267	2.288	2.244	2.308	2.326	2.271	2.437	2.440
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	0.952	0.901	0.947	0.930	0.884	0.971	0.963	0.971	1.306	1.308
Ti	0.272	0.392	0.281	0.230	0.285	0.301	0.318	0.309	0.307	0.299
Fe ²⁺	2.237	2.206	2.196	2.297	2.278	2.347	2.331	2.354	2.380	2.397
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.024	0.024	0.021	0.023	0.028	0.030	0.029	0.025	0.017	0.020
Mg	3.007	2.876	2.958	3.077	2.970	2.740	2.739	2.724	2.265	2.279
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.003	0.415	0.003	0.007	0.005	0.002	0.004	0.003	0.003	0.014
Na	0.021	0.035	0.029	0.013	0.015	0.015	0.028	0.009	0.051	0.061
K	1.806	1.033	1.907	1.752	1.866	1.929	1.917	1.893	1.900	1.830
Sum	8.322	7.882	8.342	8.329	8.331	8.335	8.329	8.288	8.229	8.208
F	0.284	0.200	0.426	0.267	0.378	0.173	0.373	0.372	0.203	0.035
Cl	0.005	—	—	—	0.002	—	0.001	0.007	0.011	0.012
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.289	0.200	0.426	0.267	0.380	0.173	0.374	0.379	0.214	0.047
Fe/(Fe+Mg)	0.430	0.430	0.430	0.430	0.430	0.460	0.460	0.460	0.510	0.510
Mg/(Fe+Mg)	0.570	0.570	0.570	0.570	0.570	0.540	0.540	0.540	0.490	0.490

Table 8 continued

Sample	27521-1-3	27521-2	27521-2-2	27521-2-3	27521-3	27521-3-2	27521-3-3	27521-4	27521-4-2	27521-4-3
SiO ₂	34.461	35.541	35.553	35.011	35.121	35.467	35.542	35.381	35.403	34.874
TiO ₂	2.405	2.648	2.536	2.392	2.373	2.238	2.424	2.561	2.460	2.483
Al ₂ O ₃	20.412	20.474	20.190	20.339	20.550	20.324	20.212	20.352	20.191	19.954
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	18.977	18.332	18.609	18.887	18.291	18.216	18.190	18.286	18.257	18.364
MnO	0.165	0.117	0.165	0.154	0.143	0.104	0.163	0.201	0.122	0.119
MgO	10.160	9.855	9.849	10.239	10.173	10.050	9.783	9.848	10.006	9.826
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.043	0.043	0.032	0.034	0.046	0.034	—	0.064	0.097	0.071
Na ₂ O	0.098	0.280	0.127	0.057	0.354	0.320	0.139	0.276	0.159	0.086
K ₂ O	8.541	8.900	9.128	8.736	8.946	9.178	9.585	8.906	8.970	9.066
F	0.171	—	0.075	0.147	0.202	0.184	0.290	0.239	0.015	0.204
Cl	0.018	0.005	0.012	0.018	0.014	0.011	0.014	0.022	0.004	0.012
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	95.451	96.195	96.276	96.014	96.213	96.126	96.342	96.136	95.684	95.059
O≡F≡Cl	0.080	0.000	0.030	0.070	0.090	0.080	0.130	0.110	0.010	0.090
Total	95.531	96.195	96.306	96.084	96.303	96.206	96.472	96.246	95.694	95.149
Si	5.452	5.546	5.563	5.499	5.501	5.559	5.574	5.545	5.559	5.539
Al IV	2.548	2.454	2.437	2.501	2.499	2.441	2.426	2.455	2.441	2.461
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.255	1.309	1.284	1.261	1.292	1.310	1.307	1.301	1.293	1.271
Ti	0.286	0.311	0.298	0.283	0.280	0.264	0.286	0.302	0.291	0.297
Fe ²⁺	2.511	2.392	2.435	2.481	2.396	2.388	2.386	2.397	2.397	2.439
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.022	0.015	0.022	0.020	0.019	0.014	0.022	0.027	0.016	0.016
Mg	2.396	2.293	2.297	2.397	2.376	2.348	2.287	2.301	2.342	2.326
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.007	0.007	0.005	0.006	0.008	0.006	—	0.011	0.016	0.012
Na	0.030	0.085	0.039	0.017	0.108	0.097	0.042	0.084	0.048	0.026
K	1.724	1.772	1.822	1.750	1.788	1.835	1.918	1.781	1.797	1.837
Sum	8.231	8.184	8.202	8.215	8.267	8.262	8.248	8.204	8.200	8.224
F	0.171	—	0.074	0.146	0.200	0.182	0.288	0.237	0.015	0.205
Cl	0.010	0.003	0.006	0.010	0.007	0.006	0.007	0.012	0.002	0.006
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.181	0.003	0.080	0.156	0.207	0.188	0.295	0.249	0.017	0.211
Fe/(Fe+Mg)	0.510	0.510	0.510	0.510	0.500	0.500	0.510	0.510	0.510	0.510
Mg/(Fe+Mg)	0.490	0.490	0.490	0.490	0.500	0.500	0.490	0.490	0.490	0.490

Table 8 continued

Sample	27521-5	27521-5-2	27521-5-3	27533-1	27533-1-2	27533-1-3	27533-5	27533-5-2	27533-5-3	27535-1
SiO ₂	35.283	35.541	35.608	35.993	35.780	35.605	35.742	34.220	35.598	35.880
TiO ₂	2.744	2.700	2.610	2.323	2.413	2.413	2.391	2.327	2.455	2.613
Al ₂ O ₃	19.927	20.017	19.692	19.621	19.411	19.436	19.415	18.808	19.114	19.822
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	18.289	18.657	18.060	19.176	19.507	18.921	19.573	21.248	19.477	17.696
MnO	0.154	0.136	0.150	0.347	0.337	0.342	0.360	0.327	0.397	0.238
MgO	9.784	9.564	9.563	9.456	9.365	9.519	9.277	9.774	9.322	9.932
BaO	—	—	—	—	—	—	—	—	—	—
CaO	0.065	0.043	0.066	—	0.008	0.001	0.017	0.038	0.020	0.094
Na ₂ O	0.291	0.163	0.267	0.166	0.071	0.099	0.180	0.059	0.129	0.166
K ₂ O	8.763	9.073	8.894	9.349	9.373	9.417	9.363	8.387	9.197	9.157
F	0.253	0.119	0.188	0.604	0.728	0.525	0.798	0.729	1.149	0.182
Cl	0.016	0.017	0.006	0.003	0.000	0.024	0.010	0.020	0.014	0.010
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	95.569	96.030	95.104	97.038	96.993	96.302	97.126	95.937	96.872	95.790
O≡F≡Cl	0.110	0.050	0.080	0.250	0.310	0.230	0.340	0.310	0.490	0.080
Total	95.679	96.080	95.184	97.288	97.303	96.532	97.466	96.247	97.362	95.870
Si	5.563	5.580	5.631	5.642	5.632	5.624	5.627	5.494	5.638	5.627
Al IV	2.437	2.420	2.369	2.358	2.368	2.376	2.373	2.506	2.362	2.373
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.263	1.281	1.298	1.264	1.230	1.239	1.227	1.050	1.203	1.288
Ti	0.325	0.319	0.310	0.274	0.286	0.287	0.283	0.281	0.292	0.308
Fe ²⁺	2.411	2.449	2.388	2.514	2.568	2.499	2.577	2.853	2.580	2.321
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.021	0.018	0.020	0.046	0.045	0.046	0.048	0.044	0.053	0.032
Mg	2.300	2.238	2.254	2.210	2.197	2.241	2.177	2.339	2.201	2.322
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.011	0.007	0.011	—	0.001	—	0.003	0.007	0.003	0.016
Na	0.089	0.050	0.082	0.050	0.022	0.030	0.055	0.018	0.040	0.050
K	1.763	1.817	1.794	1.870	1.882	1.898	1.881	1.718	1.858	1.832
Sum	8.183	8.179	8.157	8.228	8.231	8.240	8.251	8.310	8.230	8.169
F	0.252	0.118	0.188	0.599	0.725	0.524	0.795	0.740	1.151	0.181
Cl	0.009	0.009	0.003	0.002	—	0.013	0.005	0.011	0.008	0.005
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.261	0.127	0.191	0.601	0.725	0.537	0.800	0.751	1.159	0.186
Fe/(Fe+Mg)	0.510	0.520	0.510	0.530	0.540	0.530	0.540	0.550	0.540	0.500
Mg/(Fe+Mg)	0.490	0.480	0.490	0.470	0.460	0.470	0.460	0.450	0.460	0.500

Table 8 continued

Sample	27535-1-2	27535-1-3	27535-2	27535-2-2	27535-2-3	27535-3	27535-3-2	27535-3-3	27535-4	27535-4-2
SiO ₂	36.058	35.361	35.776	35.699	34.597	35.615	35.518	35.895	35.595	36.018
TiO ₂	2.614	2.702	2.638	2.686	2.886	2.694	2.703	2.715	2.556	2.593
Al ₂ O ₃	20.327	19.623	19.670	20.017	19.254	19.676	19.643	20.173	20.073	19.933
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	16.813	17.633	17.263	17.642	18.679	17.705	17.901	17.200	17.337	17.364
MnO	0.232	0.204	0.189	0.191	0.201	0.222	0.211	0.215	0.233	0.137
MgO	9.588	10.149	10.187	10.118	10.240	10.410	10.048	9.966	10.125	10.292
BaO	—	—	—	—	—	—	—	—	—	—
CaO	1.294	0.018	0.034	0.079	0.479	0.094	0.207	0.101	0.045	0.123
Na ₂ O	0.216	0.097	0.180	0.204	0.098	0.135	0.162	0.140	0.088	0.208
K ₂ O	8.798	9.496	9.443	9.148	8.535	8.998	8.742	9.241	9.350	9.113
F	0.182	0.258	0.200	0.141	0.104	0.178	0.166	0.121	0.061	0.330
Cl	0.012	0.003	0.003	0.005	0.028	0.019	0.004	0.008	0.024	0.012
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	96.134	95.544	95.583	95.930	95.101	95.746	95.305	95.775	95.487	96.123
O≡F≡Cl	0.080	0.110	0.080	0.060	0.050	0.080	0.070	0.050	0.030	0.140
Total	96.214	95.654	95.663	95.990	95.151	95.826	95.375	95.825	95.517	96.263
Si	5.613	5.582	5.624	5.587	5.500	5.589	5.598	5.612	5.591	5.624
Al IV	2.387	2.418	2.376	2.413	2.500	2.411	2.402	2.388	2.409	2.376
Sum Si+Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	1.339	1.230	1.265	1.277	1.104	1.225	1.244	1.326	1.304	1.289
Ti	0.306	0.321	0.312	0.316	0.345	0.318	0.320	0.319	0.302	0.305
Fe ²⁺	2.189	2.328	2.269	2.309	2.483	2.324	2.360	2.249	2.278	2.267
Cr	—	—	—	—	—	—	—	—	—	—
Mn	0.031	0.027	0.025	0.025	0.027	0.030	0.028	0.028	0.031	0.018
Mg	2.225	2.388	2.387	2.361	2.427	2.435	2.361	2.323	2.371	2.396
Ba	—	—	—	—	—	—	—	—	—	—
Ca	0.216	0.003	0.006	0.013	0.082	0.016	0.035	0.017	0.008	0.021
Na	0.065	0.030	0.055	0.062	0.030	0.041	0.050	0.042	0.027	0.063
K	1.747	1.912	1.894	1.827	1.731	1.801	1.758	1.843	1.874	1.815
Sum	8.118	8.239	8.213	8.190	8.229	8.190	8.156	8.147	8.195	8.174
F	0.179	0.258	0.199	0.140	0.105	0.177	0.165	0.120	0.061	0.326
Cl	0.006	0.002	0.002	0.003	0.015	0.010	0.002	0.004	0.013	0.006
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.185	0.260	0.201	0.143	0.120	0.187	0.167	0.124	0.074	0.332
Fe/(Fe+Mg)	0.500	0.490	0.490	0.490	0.510	0.490	0.500	0.490	0.490	0.490
Mg/(Fe+Mg)	0.500	0.510	0.510	0.510	0.490	0.510	0.500	0.510	0.510	0.510

Table 8 continued

Sample	27535-4-3	27535-5	27535-5-2	27535-5-3
SiO ₂	35.761	36.132	36.094	34.101
TiO ₂	2.521	2.525	2.484	2.390
Al ₂ O ₃	19.990	20.244	20.215	23.696
Cr ₂ O ₃	—	—	—	—
FeO	17.375	17.226	17.002	17.278
MnO	0.162	0.191	0.218	0.180
MgO	10.400	10.488	10.471	9.994
BaO	—	—	—	—
CaO	0.097	0.056	0.062	0.072
Na ₂ O	0.186	0.192	0.206	0.076
K ₂ O	9.083	9.280	9.279	8.813
F	0.103	0.188	0.038	0.063
Cl	0.005	0.016	0.013	—
H ₂ O	n. a.	n. a.	n. a.	n. a.
	95.683	96.538	96.082	96.663
O=F=Cl	0.040	0.080	0.020	0.030
Total	95.723	96.618	96.102	96.693
Si	5.599	5.606	5.614	5.265
Al IV	2.401	2.394	2.386	2.735
Sum Si+Al	8.000	8.000	8.000	8.000
Al VI	1.285	1.305	1.317	1.573
Ti	0.297	0.295	0.291	0.278
Fe ²⁺	2.275	2.235	2.212	2.231
Cr	—	—	—	—
Mn	0.021	0.025	0.029	0.024
Mg	2.427	2.426	2.428	2.300
Ba	—	—	—	—
Ca	0.016	0.009	0.010	0.012
Na	0.056	0.058	0.062	0.023
K	1.814	1.837	1.841	1.736
Sum	8.191	8.190	8.190	8.177
F	0.102	0.185	0.037	0.062
Cl	0.003	0.008	0.007	—
OH	—	—	—	—
Sum	0.105	0.193	0.044	0.062
Fe/(Fe+Mg)	0.480	0.480	0.480	0.490
Mg/(Fe+Mg)	0.520	0.520	0.520	0.510

Table 9, Biotite analysis, numbers of ions on the basis of 24(O, OH, F, Cl), summary

n = 179	average	median	standard deviation	minimum	maximum
SiO ₂	35.66	35.61	0.53	33.67	37.02
TiO ₂	2.37	2.41	0.37	1.43	3.27
Al ₂ O ₃	19.43	19.60	1.02	16.68	23.70
Cr ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.
FeO	18.18	18.43	1.24	14.58	21.25
MnO	0.19	0.18	0.05	0.09	0.40
MgO	10.55	10.17	0.99	9.28	13.17
BaO	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	0.07	0.03	0.23	0.00	2.43
Na ₂ O	0.14	0.13	0.06	0.02	0.35
K ₂ O	9.28	9.38	0.57	5.08	9.94
F	0.20	0.17	0.15	0.00	1.15
Cl	0.02	0.01	0.01	0.00	0.08
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.
	96.08	96.18	0.73	92.65	98.11
O≡F≡Cl	0.08	0.07	0.06	0.00	0.49
Total	96.16	96.25	0.74	92.73	98.11
Si	5.60	5.59	0.07	5.27	5.78
Al IV	2.40	2.41	0.07	2.22	2.74
Σ Si+Al	8.00	8.00	0.00	8.00	8.00
Al VI	1.19	1.22	0.13	0.79	1.57
Ti	0.28	0.29	0.04	0.17	0.39
Fe ²⁺	2.39	2.43	0.17	1.91	2.85
Cr	n. a.	n. a.	n. a.	n. a.	n. a.
Mn	0.03	0.02	0.01	0.01	0.05
Mg	2.47	2.39	0.23	2.18	3.08
Ba	n. a.	n. a.	n. a.	n. a.	n. a.
Ca	0.01	0.01	0.04	0.00	0.42
Na	0.04	0.04	0.02	0.01	0.11
K	1.86	1.88	0.11	1.03	2.00
Σ	8.27	8.28	0.06	7.88	8.38
F	0.20	0.17	0.15	0.00	1.15
Cl	0.01	0.01	0.01	0.00	0.04
OH	n. a.	n. a.	n. a.	n. a.	n. a.
Σ	0.20	0.18	0.15	0.00	1.16
Fe/(Fe+Mg)	0.49	0.51	0.04	0.39	0.55
Mg/(Fe+Mg)	0.51	0.49	0.04	0.45	0.61

Table 10, Biotite analysis from sample 05-OKU-70, numbers of ions on the basis of 24(O, OH, F, Cl), summary

n = 15	average	median	standard deviation	minimum	maximum
SiO ₂	38.49	38.70	1.34	34.02	39.69
TiO ₂	2.08	2.11	0.25	1.45	2.48
Al ₂ O ₃	17.31	17.30	0.25	16.96	17.90
Cr ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.
FeO	6.86	6.68	0.78	6.28	9.61
MnO	0.22	0.21	0.03	0.17	0.31
MgO	20.33	20.20	0.51	19.83	21.88
BaO	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	0.14	0.04	0.22	0.01	0.76
Na ₂ O	0.09	0.09	0.03	0.04	0.15
K ₂ O	8.86	9.41	1.69	3.23	10.00
F	0.52	0.54	0.12	0.27	0.74
Cl	0.01	0.01	0.01	0.00	0.03
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.
	94.90	95.28	1.44	90.57	96.62
O≡F≡Cl	0.22	0.23	0.05	0.12	0.31
Total	95.13	95.59	1.45	90.77	96.87
Si	5.79	5.83	0.14	5.32	5.88
Al IV	2.21	2.17	0.14	2.12	2.68
Σ Si+Al	8.00	8.00	0.00	8.00	8.00
Al VI	0.86	0.88	0.08	0.62	0.93
Ti	0.24	0.24	0.03	0.17	0.28
Fe ²⁺	0.87	0.84	0.11	0.79	1.26
Cr	n. a.	n. a.	n. a.	n. a.	0.00
Mn	0.03	0.03	0.00	0.02	0.04
Mg	4.56	4.55	0.17	4.42	5.10
Ba	n. a.	n. a.	n. a.	n. a.	n. a.
Ca	0.02	0.01	0.04	0.00	0.13
Na	0.03	0.03	0.01	0.01	0.04
K	1.70	1.80	0.31	0.64	1.91
Σ	8.30	8.32	0.08	8.08	8.41
F	0.50	0.52	0.11	0.26	0.70
Cl	0.01	0.00	0.00	0.00	0.02
OH	n. a.	n. a.	n. a.	n. a.	n. a.
Σ	0.50	0.52	0.11	0.27	0.71
Fe/(Fe+Mg)	0.16	0.16	0.01	0.15	0.20
Mg/(Fe+Mg)	0.84	0.84	0.01	0.80	0.85

Table 11, Muscovite analysis, numbers of ions on the basis of 24(O, OH, F, Cl)

Sample	27533-2	27533-2-2	27533-2-3	27533-3	27533-3-2	27533-3-3	27533-4	27533-4-2	27533-4-3	27534-1
SiO ₂	45.039	45.721	45.999	45.904	46.061	46.357	45.933	45.458	45.390	46.352
TiO ₂	0.757	0.826	0.744	0.759	0.713	0.985	0.759	0.819	0.767	0.008
Al ₂ O ₃	34.506	35.695	35.223	35.307	35.000	34.720	35.419	35.029	34.718	36.983
Fe ₂ O ₃	—	—	—	—	—	—	—	—	—	—
FeO	1.120	1.051	1.149	1.101	1.142	1.147	1.150	1.069	1.470	1.364
MnO	0.035	0.026	0.001	0.018	0.025	0.020	—	—	0.008	0.017
MgO	0.872	0.731	0.884	0.889	0.927	0.986	0.905	0.819	0.918	0.190
CaO	—	0.017	0.005	0.017	0.023	0.019	—	0.013	0.036	0.011
Na ₂ O	0.675	0.723	0.697	0.687	0.670	0.607	0.668	0.619	0.652	0.554
K ₂ O	9.796	10.047	10.213	10.278	10.137	10.093	9.960	10.082	10.055	10.626
F	0.060	0.232	0.122	0.200	0.128	0.145	0.073	0.026	0.073	0.285
Cl	0.071	—	—	0.004	0.007	—	0.011	0.016	—	—
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	92.931	95.069	95.037	95.164	94.833	95.079	94.878	93.950	94.087	96.390
O≡F≡Cl	0.040	0.100	0.050	0.090	0.060	0.060	0.030	0.010	0.030	0.120
Total	92.891	94.969	94.987	95.074	94.773	95.019	94.848	93.940	94.057	96.270
Si	6.139	6.099	6.138	6.125	6.157	6.178	6.126	6.126	6.126	6.111
Al IV	1.861	1.901	1.862	1.875	1.843	1.822	1.874	1.874	1.874	1.889
Sum Al+Si	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	3.678	3.707	3.673	3.673	3.667	3.627	3.689	3.685	3.644	3.853
Ti	0.078	0.083	0.075	0.076	0.072	0.099	0.076	0.083	0.078	0.001
Fe ³⁺	—	—	—	—	—	—	—	—	—	—
Fe ²⁺	0.128	0.117	0.128	0.123	0.128	0.128	0.128	0.120	0.166	0.150
Mn	0.004	0.003	—	0.002	0.003	0.002	—	—	0.001	0.002
Mg	0.177	0.145	0.176	0.177	0.185	0.196	0.180	0.165	0.185	0.037
Ca	—	0.002	0.001	0.002	0.003	0.003	—	0.002	0.005	0.002
Na	0.178	0.187	0.180	0.178	0.174	0.157	0.173	0.162	0.171	0.142
K	1.703	1.710	1.739	1.750	1.729	1.716	1.695	1.733	1.731	1.787
Sum cations	5.946	5.954	5.972	5.981	5.961	5.928	5.941	5.950	5.981	5.974
F	0.052	0.196	0.103	0.169	0.108	0.122	0.062	0.022	0.062	0.238
Cl	0.033	—	—	0.002	0.003	—	0.005	0.007	—	—
OH	—	—	—	—	—	—	—	—	—	—
Sum	0.085	0.196	0.103	0.171	0.111	0.122	0.067	0.029	0.062	0.238
Fe/(Fe+Mg)	0.420	0.450	0.420	0.410	0.410	0.400	0.420	0.420	0.470	0.800
Mg/(Fe+Mg)	0.580	0.550	0.580	0.590	0.590	0.600	0.580	0.580	0.530	0.200

Table 11 continued

Sample	27534-1-2	27534-1-3	27534-2	27534-2-2	27534-2-3	27534-3	27534-3-2	27534-3-3
SiO ₂	45.721	45.760	45.854	45.729	45.804	45.908	45.637	45.397
TiO ₂	0.019	—	0.021	—	—	0.015	0.029	—
Al ₂ O ₃	36.319	36.548	36.532	36.992	36.831	36.351	36.478	36.383
Fe ₂ O ₃	—	—	—	—	—	—	—	—
FeO	1.248	1.424	1.270	0.849	1.268	1.246	1.137	1.028
MnO	0.010	—	—	0.012	—	0.048	0.006	0.010
MgO	0.291	0.097	0.159	0.349	0.146	0.325	0.266	0.335
CaO	0.031	0.010	—	—	0.017	—	0.022	0.017
Na ₂ O	0.563	0.561	0.550	0.529	0.550	0.557	0.527	0.532
K ₂ O	10.449	10.599	10.412	10.796	10.602	10.722	10.607	10.482
F	0.276	0.226	0.169	0.156	0.156	0.287	0.442	0.428
Cl	—	0.001	0.007	—	0.028	0.002	—	0.027
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
	94.927	95.226	94.974	95.412	95.402	95.461	95.151	94.639
O=F=Cl	0.120	0.100	0.070	0.070	0.070	0.120	0.190	0.190
Total	94.807	95.126	94.904	95.342	95.332	95.341	94.961	94.449
Si	6.118	6.109	6.121	6.078	6.095	6.119	6.104	6.100
Al IV	1.882	1.891	1.879	1.922	1.905	1.881	1.896	1.900
Sum Al+Si	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al VI	3.841	3.855	3.864	3.869	3.867	3.825	3.850	3.858
Ti	0.002	—	0.002	—	—	0.002	0.003	—
Fe ³⁺	—	—	—	—	—	—	—	—
Fe ²⁺	0.140	0.159	0.142	0.094	0.141	0.139	0.127	0.116
Mn	0.001	—	—	0.001	—	0.005	0.001	0.001
Mg	0.058	0.019	0.032	0.069	0.029	0.065	0.053	0.067
Ca	0.004	0.001	—	—	0.002	—	0.003	0.002
Na	0.146	0.145	0.142	0.136	0.142	0.144	0.137	0.139
K	1.784	1.805	1.773	1.831	1.800	1.823	1.810	1.797
Sum cations	5.976	5.984	5.955	6.000	5.981	6.003	5.984	5.980
F	0.234	0.191	0.143	0.131	0.131	0.242	0.374	0.364
Cl	—	—	0.003	—	0.013	0.001	—	0.012
OH	—	—	—	—	—	—	—	—
Sum	0.234	0.191	0.146	0.131	0.144	0.243	0.374	0.376
Fe/(Fe+Mg)	0.710	0.890	0.820	0.580	0.830	0.680	0.710	0.630
Mg/(Fe+Mg)	0.290	0.110	0.180	0.420	0.170	0.320	0.290	0.370

Table 12, Muscovite analysis, numbers of ions on the basis of 24(O, OH, F, Cl), summary

n = 18	average	median	standard deviation	minimum	maximum
SiO ₂	45.78	45.78	0.33	45.04	46.36
TiO ₂	0.52	0.75	0.39	0.01	0.99
Al ₂ O ₃	35.84	36.01	0.85	34.51	36.99
Fe ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.
FeO	1.18	1.15	0.15	0.85	1.47
MnO	0.02	0.02	0.01	0.00	0.05
MgO	0.56	0.54	0.34	0.10	0.99
CaO	0.02	0.02	0.01	0.01	0.04
Na ₂ O	0.61	0.59	0.07	0.53	0.72
K ₂ O	10.33	10.35	0.29	9.80	10.80
F	0.19	0.16	0.12	0.03	0.44
Cl	0.02	0.01	0.02	0.00	0.07
H ₂ O	n. a.	n. a.	n. a.	n. a.	n. a.
Total	94.92	95.05	0.72	92.93	96.39
O≡F≡Cl	0.08	0.07	0.05	0.01	0.19
CTotal	94.84	94.97	0.70	92.89	96.27
Si	6.12	6.12	0.02	6.08	6.18
Al IV	1.88	1.88	0.02	1.82	1.92
Σ Al+Si	8.00	8.00	0.00	8.00	8.00
Al VI	3.76	3.77	0.10	3.63	3.87
Ti	0.05	0.08	0.04	0.00	0.10
Fe ³⁺	n. a.	n. a.	n. a.	n. a.	n. a.
Fe ²⁺	0.13	0.13	0.02	0.09	0.17
Mn	0.00	0.00	0.00	0.00	0.01
Mg	0.11	0.11	0.07	0.02	0.20
Ca	0.00	0.00	0.00	0.00	0.01
Na	0.16	0.15	0.02	0.14	0.19
K	1.76	1.76	0.04	1.70	1.83
Σ cations	5.97	5.98	0.02	5.93	6.00
F	0.16	0.14	0.10	0.02	0.37
Cl	0.01	0.01	0.01	0.00	0.03
OH	n. a.	n. a.	n. a.	n. a.	n. a.
Σ	0.17	0.15	0.10	0.03	0.38
Fe/(Fe+Mg)	0.58	0.53	0.18	0.40	0.89
Mg/(Fe+Mg)	0.42	0.48	0.18	0.11	0.60

Table 13, Chlorite analysis, numbers of ions on the basis of 36(O, OH, F, Cl)

Sample	27515-1	27515-1-2	27515-1-3
SiO ₂	24.936	24.672	24.640
TiO ₂	0.013	0.031	0.032
Al ₂ O ₃	23.418	23.317	23.695
Fe ₂ O ₃	–	–	–
FeO	23.901	24.083	24.468
MnO	0.398	0.369	0.361
MgO	15.382	15.275	15.239
CaO	0.002	0.016	0.029
Na ₂ O	0.012	0.017	0.010
K ₂ O	0.013	0.008	0.008
H ₂ O	n. a.	n. a.	n. a.
Total	88.075	87.788	88.482
Si	5.188	5.160	5.120
Al IV	2.812	2.840	2.880
Sum Si+Al	8.000	8.000	8.000
Al VI	2.926	2.903	2.918
Ti	0.002	0.005	0.005
Fe ³⁺	–	–	–
Fe ²⁺	4.159	4.212	4.252
Mn	0.070	0.065	0.064
Mg	4.771	4.762	4.720
Ca	–	0.004	0.006
Na	0.005	0.007	0.004
K	0.003	0.002	0.002
Sum	11.936	11.960	11.971
OH	–	–	–
Fe/(Fe+Mg)	0.470	0.470	0.470
Mg/(Fe+Mg)	0.530	0.530	0.530

Table 14, Garnet analysis, numbers of ions on the basis of 12O (FeO - Fe2O3 calculated after Droop, 1987)

Sample	27215-1	27215-1	27215-2	27215-2	27215-2-2	27215-2-3	27215-2-4	27215-3	27215-3	27215-4
SiO ₂	37.58	37.75	37.67	37.53	37.73	37.66	37.83	37.51	37.56	37.87
TiO ₂	0.02	0.02	0.02	0.01	0.01	—	0.01	0.03	—	0.05
Al ₂ O ₃	21.04	21.08	21.07	20.96	20.78	21.24	20.90	21.00	20.97	21.10
Cr ₂ O ₃	0.05	—	0.01	0.03	0.01	0.01	0.02	0.02	0.01	—
FeO	29.47	30.63	28.43	28.95	28.76	28.55	28.50	29.59	29.28	28.73
Fe ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
MnO	2.83	2.09	2.28	3.59	5.07	3.42	3.37	1.95	2.90	1.98
MgO	2.24	2.31	1.93	2.17	2.16	2.09	2.12	2.13	2.13	1.93
CaO	7.54	6.87	9.07	7.17	6.31	7.74	7.72	7.72	7.50	8.87
Na ₂ O	0.01	—	—	0.03	0.02	0.03	0.03	0.01	0.01	0.05
Total	100.77	100.76	100.49	100.43	100.85	100.74	100.50	99.96	100.35	100.58
FeOcalc	28.48	30.19	27.77	28.17	28.05	27.90	28.11	29.27	28.62	28.38
Fe ₂ O ₃ calc	1.10	0.48	0.74	0.87	0.79	0.73	0.43	0.36	0.73	0.39
Totalcalc	100.84	100.81	100.55	100.49	100.92	100.80	100.53	99.98	100.42	100.62
Si	2.98	3.00	2.99	2.99	3.00	2.99	3.01	3.00	2.99	3.00
Al	0.02	—	0.01	0.01	—	0.01	—	—	0.01	—
Sum Si+Al	3.00	3.00	3.00	3.00	3.00	3.00	3.01	3.00	3.00	3.00
Al VI	1.95	1.97	1.96	1.95	1.95	1.97	1.96	1.97	1.96	1.97
Fe ³⁺	0.07	0.03	0.04	0.05	0.05	0.04	0.03	0.02	0.04	0.02
Ti	—	—	—	—	—	—	—	—	—	—
Cr	—	—	—	—	—	—	—	—	—	—
Sum A	2.02	2.00	2.00	2.01	2.00	2.01	1.98	2.00	2.00	2.00
Fe ²⁺	1.89	2.00	1.84	1.88	1.87	1.85	1.87	1.96	1.91	1.88
Mg	0.26	0.27	0.23	0.26	0.26	0.25	0.25	0.25	0.25	0.23
Mn	0.19	0.14	0.15	0.24	0.34	0.23	0.23	0.13	0.20	0.13
Ca	0.64	0.58	0.77	0.61	0.54	0.66	0.66	0.66	0.64	0.75
Na	—	—	—	—	—	—	0.01	—	—	0.01
Sum B	2.99	3.00	3.00	2.99	3.00	2.99	3.01	3.00	3.00	3.00
Sum_cat	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Mol percentages										
Alm	63.26	66.74	61.51	62.71	62.11	61.91	62.10	65.11	63.63	62.64
Adr	3.27	1.44	2.21	2.59	2.36	2.16	1.30	1.07	2.18	1.15
Grs	18.05	18.01	23.51	17.75	15.51	19.82	20.49	20.86	19.16	23.92
Prp	8.86	9.12	7.64	8.62	8.52	8.26	8.36	8.44	8.43	7.59
Sps	6.37	4.69	5.11	8.09	11.37	7.69	7.53	4.40	6.54	4.43
Uvt	0.14	—	0.03	0.11	0.02	0.04	0.06	0.07	0.02	—

Table 14 continued

Sample	27215-4	27215-4	27215-5	27215-5	27215-5	27215-6	27216-3	27216-3-3	27513-1	27513-1-2
SiO ₂	37.65	37.84	37.82	37.74	37.75	37.76	37.30	37.49	36.25	37.16
TiO ₂	–	0.06	–	0.04	–	–	0.03	–	0.44	–
Al ₂ O ₃	21.02	21.04	21.20	21.06	21.37	21.19	20.99	21.00	20.48	21.01
Cr ₂ O ₃	0.01	0.03	–	–	0.02	0.01	0.06	0.02	0.02	–
FeO	29.79	28.06	28.71	27.93	28.76	28.13	28.30	28.43	30.08	30.92
Fe ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
MnO	2.12	2.53	3.65	2.89	3.65	2.89	3.27	3.19	6.07	6.75
MgO	2.28	1.83	2.09	1.98	2.23	2.12	1.82	1.93	2.77	2.38
CaO	7.40	9.36	7.48	8.87	7.04	8.54	8.22	8.06	3.35	2.44
Na ₂ O	–	0.01	0.03	0.02	0.03	0.01	0.03	0.04	0.03	0.02
Total	100.26	100.75	100.99	100.52	100.84	100.63	100.03	100.15	99.48	100.67
FeOcalc	29.41	27.55	28.15	27.33	28.42	27.56	27.49	27.76	28.32	30.24
Fe ₂ O ₃ calc	0.42	0.57	0.63	0.67	0.38	0.63	0.91	0.75	1.95	0.75
Totalcalc	100.29	100.78	101.05	100.58	100.85	100.69	100.06	100.21	99.66	100.75
Si	3.00	3.00	2.99	2.99	2.99	2.99	2.98	2.99	2.94	2.98
Al	–	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.06	0.02
Sum Si+Al	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Al VI	1.97	1.96	1.97	1.96	1.98	1.97	1.96	1.96	1.89	1.97
Fe ³⁺	0.03	0.03	0.04	0.04	0.02	0.04	0.06	0.05	0.12	0.05
Ti	–	–	–	–	–	–	–	–	0.03	–
Cr	–	–	–	–	–	–	–	–	–	–
Sum A	2.00	2.00	2.01	2.00	2.01	2.01	2.02	2.01	2.04	2.01
Fe ²⁺	1.96	1.82	1.86	1.81	1.88	1.83	1.84	1.85	1.92	2.03
Mg	0.27	0.22	0.25	0.23	0.26	0.25	0.22	0.23	0.34	0.29
Mn	0.14	0.17	0.25	0.19	0.25	0.19	0.22	0.22	0.42	0.46
Ca	0.63	0.79	0.63	0.75	0.60	0.72	0.70	0.69	0.29	0.21
Na	–	–	0.01	–	–	–	0.01	0.01	–	–
Sum B	3.01	3.00	2.99	3.00	2.99	3.00	2.98	2.99	2.96	2.99
Sum_cat	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Mol percentages										
Alm	65.21	60.71	62.23	60.46	62.93	60.95	61.57	61.92	64.71	67.99
Adr	1.26	1.71	1.86	2.00	1.12	1.87	2.70	2.24	5.85	2.26
Grs	19.75	24.63	19.32	23.12	18.77	22.28	20.72	20.72	3.90	4.76
Prp	9.01	7.18	8.25	7.82	8.79	8.35	7.25	7.67	11.30	9.54
Sps	4.75	5.64	8.18	6.47	8.18	6.47	7.43	7.20	14.05	15.37
Uvt	0.02	0.09	–	0.01	0.07	0.03	0.17	0.06	0.05	–

Table 14 continued

Sample	27513-1-3	27513-2	27513-2	27513-3	27513-3	27513-3	27513-4	27513-4	27513-4-2	27513-4-3
SiO ₂	37.03	37.42	37.11	37.32	36.72	37.51	37.36	37.33	37.18	37.12
TiO ₂	—	0.05	0.04	—	0.03	0.03	0.01	0.02	—	—
Al ₂ O ₃	20.57	20.75	20.83	20.67	20.76	20.94	20.75	20.74	20.69	20.88
Cr ₂ O ₃	0.03	—	0.06	0.03	0.04	0.02	0.03	—	0.01	0.04
FeO	31.15	26.90	28.75	30.37	31.03	30.20	31.15	30.88	30.89	31.05
Fe ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
MnO	7.59	5.93	5.94	7.14	7.79	7.43	7.50	7.58	7.48	7.04
MgO	2.15	1.72	1.98	2.14	2.31	2.60	2.36	2.45	2.42	2.51
CaO	1.59	7.62	5.34	2.69	1.61	1.55	1.73	1.38	1.80	2.04
Na ₂ O	0.02	0.01	0.01	0.01	0.03	0.02	0.01	0.02	—	0.01
Total	100.13	100.40	100.06	100.36	100.31	100.30	100.88	100.41	100.46	100.68
FeOcalc	30.72	26.00	28.05	30.16	29.82	30.20	30.70	30.83	30.34	30.21
Fe ₂ O ₃ calc	0.48	0.99	0.77	0.23	1.34	0.00	0.49	0.06	0.61	0.94
Totalcalc	100.15	100.50	100.08	100.36	100.40	100.28	100.91	100.41	100.52	100.73
Si	3.00	2.99	2.98	3.01	2.97	3.02	3.00	3.01	3.00	2.98
Al	—	0.01	0.02	—	0.03	—	—	—	—	0.02
Sum Si+Al	3.00	3.00	3.00	3.01	3.00	3.02	3.00	3.01	3.00	3.00
Al VI	1.96	1.94	1.96	1.96	1.94	1.99	1.96	1.97	1.96	1.96
Fe ³⁺	0.03	0.06	0.05	0.01	0.08	0.00	0.03	0.00	0.04	0.06
Ti	—	—	—	—	—	—	—	—	—	—
Cr	—	—	—	—	—	—	—	—	—	—
Sum A	1.99	2.00	2.01	1.98	2.03	1.99	1.99	1.98	2.00	2.02
Fe ²⁺	2.08	1.74	1.89	2.03	2.02	2.03	2.06	2.08	2.05	2.03
Mg	0.26	0.20	0.24	0.26	0.28	0.31	0.28	0.30	0.29	0.30
Mn	0.52	0.40	0.41	0.49	0.53	0.51	0.51	0.52	0.51	0.48
Ca	0.14	0.65	0.46	0.23	0.14	0.13	0.15	0.12	0.16	0.18
Na	—	—	—	—	—	—	—	—	—	—
Sum B	3.01	3.00	2.99	3.01	2.97	2.99	3.01	3.01	3.00	2.99
Sum_cat	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Mol percentages										
Alm	69.30	57.97	63.08	67.51	67.85	68.04	68.62	68.99	68.13	67.98
Adr	1.46	2.98	2.32	0.71	4.01	0.00	1.50	0.18	1.85	2.81
Grs	3.06	18.78	12.89	6.93	0.54	4.42	3.37	3.76	3.28	2.93
Prp	8.66	6.82	7.95	8.52	9.36	10.45	9.40	9.78	9.68	10.05
Sps	17.34	13.38	13.53	16.18	17.94	16.94	16.97	17.17	17.01	16.04
Uvt	0.09	—	0.17	0.08	0.14	0.06	0.08	—	0.03	0.14

Table 14 continued

Sample	27513-5	27513-5	27513-6	27516-1	27516-1-2	27516-1-3	27516-2	27516-2-2	27516-2-3	27516-3
SiO ₂	37.65	37.83	37.18	37.82	37.63	37.94	37.69	37.70	38.12	37.62
TiO ₂	0.13	0.04	0.02	0.15	0.10	0.03	0.10	0.11	0.08	0.06
Al ₂ O ₃	21.00	20.90	20.88	20.90	20.98	20.81	20.82	20.85	20.77	20.81
Cr ₂ O ₃	0.02	0.03	—	0.02	0.04	0.02	0.01	—	—	0.02
FeO	24.32	28.40	29.31	25.19	26.72	26.69	25.27	27.00	25.08	26.63
Fe ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
MnO	5.53	5.69	5.31	4.99	3.85	3.61	4.81	3.72	5.26	4.11
MgO	0.95	1.97	2.05	1.17	1.22	1.22	1.27	1.31	1.12	1.28
CaO	11.08	6.12	5.56	10.21	10.11	10.10	10.10	9.66	10.28	9.92
Na ₂ O	0.03	—	—	0.03	0.01	0.02	0.03	0.01	0.05	0.04
Total	100.70	100.98	100.31	100.47	100.66	100.45	100.10	100.36	100.78	100.49
FeOcalc	23.62	28.24	28.41	25.08	26.10	26.60	25.05	26.73	25.00	25.81
Fe ₂ O ₃ calc	0.78	0.19	1.00	0.12	0.69	0.11	0.25	0.30	0.09	0.92
Totalcalc	100.75	100.97	100.41	100.47	100.69	100.44	100.11	100.39	100.78	100.57
Si	2.99	3.01	2.98	3.01	2.99	3.02	3.01	3.00	3.02	2.99
Al	0.01	—	0.02	—	0.01	—	—	—	—	0.01
Sum Si+Al	3.00	3.01	3.00	3.01	3.00	3.02	3.01	3.00	3.02	3.00
Al VI	1.95	1.96	1.95	1.96	1.95	1.95	1.96	1.96	1.94	1.94
Fe ³⁺	0.05	0.01	0.06	0.01	0.04	0.01	0.02	0.02	0.01	0.06
Ti	0.01	—	—	0.01	0.01	—	0.01	0.01	0.01	—
Cr	—	—	—	—	—	—	—	—	—	—
Sum A	2.00	1.97	2.01	1.98	2.00	1.96	1.98	1.98	1.95	2.00
Fe ²⁺	1.57	1.88	1.90	1.67	1.73	1.77	1.67	1.78	1.66	1.72
Mg	0.11	0.23	0.25	0.14	0.15	0.14	0.15	0.16	0.13	0.15
Mn	0.37	0.38	0.36	0.34	0.26	0.24	0.33	0.25	0.35	0.28
Ca	0.94	0.52	0.48	0.87	0.86	0.86	0.86	0.82	0.87	0.85
Na	—	—	—	—	—	—	—	—	0.01	0.01
Sum B	3.00	3.02	2.99	3.02	3.00	3.02	3.02	3.02	3.03	3.00
Sum_cat	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Mol percentages										
Alm	52.30	62.25	63.75	55.27	57.80	58.56	55.43	59.08	54.79	57.29
Adr	2.32	0.56	2.99	0.37	2.07	0.32	0.76	0.92	0.26	2.75
Grs	29.04	16.64	12.98	28.41	26.50	28.09	27.83	26.43	28.63	25.40
Prp	3.74	7.76	8.22	4.60	4.83	4.78	5.02	5.17	4.40	5.04
Sps	12.40	12.70	12.06	11.15	8.64	8.05	10.78	8.33	11.67	9.24
Uvt	0.07	0.09	—	0.05	0.11	0.08	0.04	0.01	—	0.05

Table 14 continued

Sample	27516-3-2	27516-3-3	27516-4	27516-4-3
SiO ₂	37.47	37.76	37.37	37.97
TiO ₂	0.07	0.05	0.04	0.04
Al ₂ O ₃	20.70	20.86	20.93	21.08
Cr ₂ O ₃	0.03	0.01	—	0.02
FeO	26.29	27.38	27.06	25.62
Fe ₂ O ₃	n. a.	n. a.	n. a.	n. a.
MnO	4.04	3.04	3.06	4.91
MgO	1.65	1.70	1.58	2.09
CaO	9.63	9.60	9.59	8.95
Na ₂ O	0.03	0.02	0.01	0.04
Total	99.91	100.40	99.64	100.72
FeOcalc	25.48	26.81	26.57	25.15
Fe ₂ O ₃ calc	0.90	0.64	0.55	0.52
Totalcalc	99.96	100.46	99.69	100.75
Si	2.99	3.00	2.99	3.00
Al	0.01	—	0.01	—
Sum Si+Al	3.00	3.00	3.00	3.00
Al VI	1.94	1.95	1.97	1.96
Fe ³⁺	0.05	0.04	0.03	0.03
Ti	—	—	—	—
Cr	—	—	—	—
Sum A	2.00	1.99	2.00	2.00
Fe ²⁺	1.70	1.78	1.78	1.66
Mg	0.20	0.20	0.19	0.25
Mn	0.27	0.21	0.21	0.33
Ca	0.82	0.82	0.82	0.76
Na	—	—	—	0.01
Sum B	3.00	3.01	3.00	3.00
Sum_cat	8.00	8.00	8.00	8.00
Mol percentages				
Alm	56.75	59.25	59.32	55.38
Adr	2.71	1.91	1.65	1.55
Grs	24.67	25.24	25.78	23.64
Prp	6.53	6.68	6.29	8.23
Sps	9.10	6.81	6.91	10.96
Uvt	0.11	0.02	0.01	0.05

Table 15, Garnet analysis, numbers of ions on the basis of 12O (FeO - Fe₂O₃ calculated after Droop, 1987), summary

n = 44	average	median	standard deviation	minimum	maximum
SiO ₂	37.53	37.62	0.35	36.25	38.12
TiO ₂	0.06	0.04	0.08	0.01	0.44
Al ₂ O ₃	20.92	20.92	0.18	20.48	21.37
Cr ₂ O ₃	0.02	0.02	0.01	0.01	0.06
FeO	28.48	28.63	1.84	24.32	31.15
Fe ₂ O ₃	n. a.	n. a.	n. a.	n. a.	n. a.
MnO	4.54	3.94	1.83	1.95	7.79
MgO	1.95	2.09	0.44	0.95	2.77
CaO	6.94	7.67	3.01	1.38	11.08
Na ₂ O	0.02	0.02	0.01	0.01	0.05
Total	100.45	100.47	0.33	99.48	100.99
FeOcalc	27.93	28.08	1.81	23.62	30.83
Fe ₂ O ₃ calc	0.62	0.63	0.37	0.00	1.95
Totalcalc	100.49	100.51	0.33	99.66	101.05
Si	2.99	2.99	0.01	2.94	3.02
Al	0.02	0.01	0.01	0.01	0.06
Σ Si+Al	3.00	3.00	0.01	3.00	3.02
Al VI	1.96	1.96	0.01	1.89	1.99
Fe ³⁺	0.04	0.04	0.02	0.00	0.12
Ti	0.01	0.01	0.01	0.01	0.03
Cr	0.00	0.00	0.00	0.00	0.00
Σ A	2.00	2.00	0.02	1.95	2.04
Fe ²⁺	1.86	1.87	0.13	1.57	2.08
Mg	0.23	0.25	0.05	0.11	0.34
Mn	0.31	0.27	0.13	0.13	0.53
Ca	0.59	0.66	0.26	0.12	0.94
Na	0.01	0.01	0.00	0.01	0.01
Σ B	3.00	3.00	0.01	2.96	3.03
Σ cat	8.00	8.00	0.00	8.00	8.00
Mol percentages					
Alm	62.16	62.17	4.36	52.30	69.30
Adr	1.85	1.87	1.10	0.00	5.85
Grs	17.82	19.78	8.69	0.54	29.04
Prp	7.75	8.24	1.77	3.74	11.30
Sps	10.26	8.87	4.20	4.40	17.94
Uvt	0.07	0.06	0.05	0.01	0.17

Table 16, Feldspar analysis of pegmatites, numbers of ions on the basis of 32O

Sample	27533-pl1	27533-pl1-2	27533-pl1-3	27533-pl2	27533-pl2-2	27533-pl2-3	27533-pl3	27533-pl3-2	27533-pl3-3	27533-pl3-4
SiO ₂	63.758	64.628	63.471	64.672	64.941	64.026	63.157	63.253	63.672	63.955
TiO ₂	–	0.017	0.036	0.003	0.002	0.039	–	0.007	–	0.016
Al ₂ O ₃	23.010	22.585	23.168	22.528	21.122	23.281	23.429	22.788	22.457	23.427
FeO	0.029	0.010	0.002	0.010	–	–	0.004	0.015	0.034	–
MnO	0.016	0.018	–	–	0.021	0.006	–	0.027	0.018	0.003
MgO	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	3.641	3.501	4.362	3.257	2.463	4.113	4.195	4.354	4.139	4.264
Na ₂ O	9.352	9.360	9.015	9.960	9.797	9.193	9.002	8.968	9.161	9.150
K ₂ O	0.105	0.123	0.193	0.129	0.115	0.077	0.221	0.133	0.123	0.176
Total	99.911	100.242	100.247	100.559	98.461	100.735	100.008	99.545	99.604	100.991
Si	11.255	11.354	11.190	11.345	11.580	11.217	11.159	11.227	11.289	11.189
Al	4.784	4.673	4.810	4.654	4.435	4.803	4.875	4.763	4.689	4.827
Ti	–	0.002	0.005	–	–	0.005	–	0.001	–	0.002
Fe ²⁺	0.004	0.001	–	0.001	–	–	0.001	0.002	0.005	0.000
Mn	0.002	0.003	–	–	0.003	0.001	–	0.004	0.003	0.000
Mg	–	–	–	–	–	–	–	–	–	0.000
Ca	0.689	0.659	0.824	0.612	0.471	0.772	0.794	0.828	0.786	0.799
Na	3.201	3.189	3.082	3.388	3.387	3.123	3.084	3.086	3.149	3.104
K	0.024	0.028	0.043	0.029	0.026	0.017	0.050	0.030	0.028	0.039
Sum	19.959	19.909	19.954	20.029	19.902	19.938	19.963	19.941	19.949	19.960
Mol percentages										
Ab	81.800	82.300	78.000	84.100	87.200	79.800	78.500	78.200	79.500	78.700
An	17.600	17.000	20.900	15.200	12.100	19.700	20.200	21.000	19.800	20.300
Or	0.600	0.700	1.100	0.700	0.700	0.400	1.300	0.800	0.700	1.000

Table 16 continued

Sample	27533-pl3-5	27533-pl4	27533-pl4-2	27533-pl4-3	27533-pl5	27533-pl5-2	27533-pl5-3	27534-pl1	27534-pl1-2	27534-pl1-3
SiO ₂	64.599	63.057	63.660	63.438	63.718	63.604	63.708	66.788	68.195	67.770
TiO ₂	0.012	–	–	0.024	0.013	0.040	0.012	0.002	–	–
Al ₂ O ₃	22.822	23.323	23.434	23.435	23.056	23.450	23.380	19.659	20.373	20.386
FeO	0.013	0.031	–	0.030	–	–	–	0.011	–	0.003
MnO	–	0.036	–	0.008	0.008	0.005	–	0.041	–	0.015
MgO	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	3.529	4.225	4.372	4.227	3.813	4.255	4.242	0.473	0.545	0.648
Na ₂ O	9.614	9.116	9.183	9.178	9.440	9.103	9.086	11.306	11.237	10.999
K ₂ O	0.105	0.065	0.207	0.118	0.073	0.107	0.230	0.158	0.147	0.125
Total	100.694	99.853	100.856	100.458	100.121	100.564	100.658	98.438	100.497	99.946
Si	11.311	11.159	11.164	11.161	11.233	11.171	11.184	11.876	11.861	11.848
Al	4.706	4.861	4.840	4.856	4.787	4.851	4.834	4.117	4.173	4.197
Ti	0.002	–	–	0.003	0.002	0.005	0.002	–	–	–
Fe ²⁺	0.002	0.005	–	0.004	–	–	–	0.002	–	–
Mn	–	0.005	–	0.001	0.001	0.001	–	0.006	–	0.002
Mg	–	–	–	–	–	–	–	–	–	–
Ca	0.662	0.801	0.821	0.797	0.720	0.801	0.798	0.090	0.102	0.121
Na	3.264	3.128	3.123	3.131	3.227	3.100	3.093	3.898	3.790	3.729
K	0.023	0.015	0.046	0.026	0.016	0.024	0.052	0.036	0.033	0.028
Sum	19.970	19.974	19.994	19.979	19.986	19.953	19.963	20.025	19.959	19.925
Mol percentages										
Ab	82.700	79.300	78.300	79.200	81.400	79.000	78.400	96.900	96.600	96.200
An	16.800	20.300	20.600	20.200	18.200	20.400	20.200	2.200	2.600	3.100
Or	0.600	0.400	1.200	0.700	0.400	0.600	1.300	0.900	0.800	0.700

Table 16 continued

Sample	27534-pl1-4	27534-pl2-2	27534-pl2-3	27534-pl2-4	27534-pl3	27534-pl3-2	27534-pl3-3	27534-pl3-4	27534-pl4-2	27534-pl4-3
SiO ₂	64.883	64.883	65.273	64.563	66.772	67.605	67.802	65.186	67.976	65.004
TiO ₂	–	–	0.019	–	–	0.052	–	–	–	0.000
Al ₂ O ₃	18.905	18.735	18.937	18.626	20.476	20.355	20.592	18.838	20.598	18.810
FeO	0.004	–	0.008	–	0.004	0.017	0.016	–	–	0.013
MnO	–	0.023	–	0.024	–	–	–	–	0.014	0.026
MgO	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	0.019	0.000	0.008	0.140	0.880	0.941	0.847	0.021	0.832	0.000
Na ₂ O	0.374	0.231	0.829	0.260	11.018	10.975	11.125	0.192	11.309	0.486
K ₂ O	16.335	16.380	15.718	16.369	0.206	0.196	0.152	16.632	0.051	16.085
Total	100.520	100.252	100.792	99.982	99.356	100.141	100.534	100.869	100.780	100.424
Si	11.932	11.961	11.942	11.947	11.772	11.817	11.803	11.954	11.804	11.952
Al	4.094	4.067	4.080	4.059	4.251	4.190	4.222	4.068	4.212	4.073
Ti	–	–	0.003	–	–	0.007	–	–	–	0.000
Fe ²⁺	0.001	–	0.001	–	0.001	0.002	0.002	–	–	0.002
Mn	–	0.004	–	0.004	–	–	–	–	0.002	0.004
Mg	–	–	–	–	–	–	–	–	–	0.000
Ca	0.004	–	0.002	0.028	0.166	0.176	0.158	0.004	0.155	0.000
Na	0.133	0.083	0.294	0.093	3.766	3.720	3.755	0.068	3.808	0.173
K	3.832	3.852	3.669	3.864	0.046	0.044	0.034	3.891	0.011	3.773
Sum	19.996	19.967	19.991	19.995	20.002	19.956	19.974	19.985	19.992	19.977
Mol percentages										
Ab	3.400	2.100	7.400	2.300	94.700	94.400	95.100	1.700	95.800	4.400
An	0.100	–	0.100	0.700	4.200	4.500	4.000	0.100	3.900	0.000
Or	96.500	97.900	92.500	97.000	1.200	1.100	0.900	98.200	0.300	95.600

Table 16 continued

Sample	27534-pl5-2	27534-pl5-3	27534-pl5-4	27538-pl1	27538-pl1-2	27538-pl1-3	27538-pl1-4	27538-pl2	27538-pl2-2	27538-pl2-3
SiO ₂	68.269	66.758	65.509	67.657	68.154	68.446	65.226	65.214	65.399	65.080
TiO ₂	0.005	0.049	0.016	–	–	0.059	–	–	–	–
Al ₂ O ₃	20.559	20.292	18.879	19.325	20.161	19.883	18.946	18.765	19.014	18.801
FeO	0.009	–	–	0.014	0.031	0.020	0.028	0.019	0.029	–
MnO	0.004	0.017	–	–	0.003	0.013	0.014	–	–	–
MgO	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	0.798	0.774	0.021	0.272	0.371	0.225	0.000	0.000	0.005	0.000
Na ₂ O	11.187	11.277	1.036	11.198	11.073	11.294	1.395	2.625	0.851	0.351
K ₂ O	0.124	0.143	15.412	0.167	0.204	0.130	14.518	13.108	15.638	16.389
Total	100.955	99.310	100.873	98.633	99.997	100.070	100.127	99.731	100.936	100.621
Si	11.829	11.780	11.959	11.978	11.901	11.940	11.954	11.957	11.942	11.955
Al	4.195	4.217	4.059	4.029	4.146	4.085	4.089	4.052	4.089	4.067
Ti	0.001	0.007	0.002	–	–	0.008	–	–	–	–
Fe ²⁺	0.001	–	–	0.002	0.005	0.003	0.004	0.003	0.004	–
Mn	0.001	0.003	–	–	–	0.002	0.002	–	–	–
Mg	–	–	–	–	–	–	–	–	–	–
Ca	0.148	0.146	0.004	0.052	0.069	0.042	–	–	0.001	–
Na	3.758	3.859	0.367	3.844	3.749	3.820	0.496	0.933	0.301	0.125
K	0.027	0.032	3.589	0.038	0.045	0.029	3.394	3.066	3.643	3.841
Sum	19.960	20.044	19.980	19.943	19.915	19.929	19.939	20.011	19.980	19.988
Mol percentages										
Ab	95.600	95.600	9.300	97.700	97.000	98.200	12.800	23.300	7.600	3.200
An	3.800	3.600	0.100	1.300	1.800	1.100	–	–	–	–
Or	0.700	0.800	90.600	1.000	1.200	0.700	87.200	76.700	92.300	96.800

Table 16 continued

Sample	27538-pl3	27538-pl3-2	27538-pl3-3	27538-pl3-4	27538-pl4	27538-pl4-2	27538-pl4-3	27538-pl4-4	27538-pl5	27538-pl5-2
SiO ₂	65.831	66.564	65.040	66.610	65.694	66.018	66.886	65.126	67.784	68.740
TiO ₂	0.087	–	–	–	–	–	0.054	0.022	–	0.092
Al ₂ O ₃	21.259	20.710	17.508	19.876	21.298	20.353	21.272	18.558	19.775	20.172
FeO	–	0.001	–	0.021	–	–	0.036	–	0.027	0.000
MnO	0.005	–	–	0.020	0.018	0.001	–	–	–	0.000
MgO	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	1.892	1.905	0.012	1.875	1.876	1.764	1.878	0.009	0.368	0.215
Na ₂ O	10.496	10.515	0.629	10.414	10.505	10.486	10.445	0.253	11.265	11.313
K ₂ O	0.148	0.249	15.898	0.184	0.150	0.137	0.088	16.288	0.097	0.153
Total	99.718	99.944	99.087	99.000	99.541	98.759	100.659	100.256	99.316	100.685
Si	11.595	11.694	12.114	11.801	11.592	11.725	11.652	11.995	11.922	11.917
Al	4.410	4.285	3.840	4.147	4.426	4.257	4.364	4.025	4.096	4.118
Ti	0.012	–	–	–	–	–	0.007	0.003	–	0.012
Fe ²⁺	–	–	–	0.003	–	–	0.005	–	0.004	0.000
Mn	0.001	–	–	0.003	0.003	–	–	–	–	0.000
Mg	–	–	–	–	–	–	–	–	–	0.000
Ca	0.357	0.359	0.002	0.356	0.355	0.336	0.351	0.002	0.069	0.040
Na	3.585	3.582	0.227	3.577	3.594	3.611	3.528	0.090	3.842	3.803
K	0.033	0.056	3.778	0.042	0.034	0.031	0.020	3.827	0.022	0.034
Sum	19.993	19.976	19.961	19.929	20.004	19.960	19.927	19.942	19.955	19.924
Mol percentages										
Ab	90.200	89.600	5.700	90.000	90.200	90.800	90.500	2.300	97.700	98.100
An	9.000	9.000	0.000	9.000	8.900	8.400	9.000	0.100	1.800	1.000
Or	0.800	1.400	94.300	1.100	0.900	0.800	0.500	97.700	0.600	0.900

Table 16 continued

Sample	27538-pl5-3
SiO ₂	65.133
TiO ₂	0.031
Al ₂ O ₃	18.772
FeO	0.028
MnO	0.010
MgO	n. a.
CaO	0.000
Na ₂ O	0.547
K ₂ O	16.201
Total	100.722
Si	11.951
Al	4.056
Ti	0.004
Fe ²⁺	0.004
Mn	0.002
Mg	—
Ca	—
Na	0.195
K	3.792
Sum	20.004
	Mol percentages
Ab	4.900
An	—
Or	95.100

Table 17, Feldspar analysis of metasediments, numbers of ions on the basis of 320

Sample	27215-1	27215-2	27215-3	27215-4	27215-5	27215-6	27215-7	27215-8	27215-9	27215-10
SiO ₂	60.094	61.029	60.761	59.805	59.836	61.521	61.320	60.129	60.046	59.348
TiO ₂	–	–	–	0.043	0.011	–	0.023	–	0.029	–
Al ₂ O ₃	26.004	25.512	25.676	26.125	26.235	25.328	25.101	26.178	26.347	26.621
FeO	0.018	0.002	0.030	0.010	0.064	0.030	–	–	0.024	0.017
MnO	0.001	0.002	0.004	–	0.001	–	–	–	0.005	–
MgO	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	7.349	6.525	6.991	7.517	7.560	6.372	6.379	7.133	7.569	7.703
Na ₂ O	7.349	7.789	7.440	7.059	7.145	7.989	7.888	7.344	7.471	7.127
K ₂ O	0.123	0.113	0.128	0.141	0.079	0.154	0.078	0.100	0.065	0.179
Total	100.938	100.972	101.030	100.700	100.931	101.394	100.789	100.884	101.556	100.995
Si	10.609	10.743	10.699	10.581	10.566	10.786	10.806	10.609	10.549	10.489
Al	5.406	5.289	5.324	5.443	5.456	5.229	5.209	5.439	5.451	5.541
Ti	–	–	–	0.006	0.001	–	0.003	–	0.004	–
Fe ²⁺	0.003	–	0.004	0.001	0.009	0.004	–	–	0.004	0.003
Mn	–	–	0.001	–	–	–	–	–	0.001	–
Mg	–	–	–	–	–	–	–	–	–	–
Ca	1.390	1.231	1.319	1.425	1.430	1.197	1.204	1.348	1.425	1.459
Na	2.516	2.659	2.540	2.422	2.447	2.716	2.695	2.512	2.545	2.442
K	0.028	0.025	0.029	0.032	0.018	0.034	0.018	0.023	0.015	0.040
Sum	19.952	19.947	19.916	19.910	19.927	19.966	19.935	19.931	19.994	19.974
Mol percentages										
Ab	64.000	67.900	65.300	62.400	62.800	68.800	68.800	64.700	63.900	62.000
An	35.300	31.400	33.900	36.700	36.700	30.300	30.700	34.700	35.800	37.000
Or	0.700	0.600	0.700	0.800	0.500	0.900	0.500	0.600	0.400	1.000

Table 17 continued

Sample	27215-11	27215-12	27215-13	27215-14	27215-15	27215-16	27215-17	27215-18	27215-19	27215-20
SiO ₂	59.220	61.450	60.716	60.820	60.790	59.467	59.121	62.676	57.327	52.433
TiO ₂	–	–	0.007	0.042	0.029	0.023	–	0.018	0.001	0.062
Al ₂ O ₃	26.549	25.032	25.582	25.603	25.421	26.349	26.484	24.015	27.848	31.247
FeO	0.084	0.075	0.055	0.059	0.071	0.055	0.039	0.032	0.020	0.091
MnO	0.004	0.006	–	0.008	0.014	–	0.011	–	–	0.013
MgO	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	7.873	6.223	6.776	6.741	6.784	7.611	7.818	5.084	9.426	13.689
Na ₂ O	6.935	7.864	7.663	7.699	7.518	7.282	7.054	8.487	6.207	3.930
K ₂ O	0.097	0.099	0.106	0.135	0.080	0.073	0.097	0.122	0.066	0.065
Total	100.762	100.749	100.905	101.107	100.707	100.860	100.624	100.434	100.895	101.530
Si	10.488	10.829	10.706	10.705	10.732	10.521	10.488	11.043	10.187	9.383
Al	5.537	5.195	5.312	5.307	5.285	5.490	5.533	4.983	5.828	6.585
Ti	–	–	0.001	0.006	0.004	0.003	–	0.002	–	0.008
Fe ²⁺	0.012	0.011	0.008	0.009	0.010	0.008	0.006	0.005	0.003	0.014
Mn	0.001	0.001	–	0.001	0.002	–	0.002	–	–	0.002
Mg	–	–	–	–	–	–	–	–	–	–
Ca	1.494	1.175	1.280	1.271	1.283	1.443	1.486	0.960	1.795	2.625
Na	2.382	2.687	2.620	2.628	2.574	2.498	2.426	2.899	2.139	1.364
K	0.022	0.022	0.024	0.030	0.018	0.016	0.022	0.027	0.015	0.015
Sum	19.936	19.920	19.951	19.957	19.908	19.979	19.963	19.919	19.967	19.996
Mol percentages										
Ab	61.100	69.200	66.800	66.900	66.400	63.100	61.700	74.600	54.200	34.100
An	38.300	30.300	32.600	32.300	33.100	36.500	37.800	24.700	45.500	65.600
Or	0.600	0.600	0.600	0.800	0.500	0.400	0.600	0.700	0.400	0.400

Table 17 continued

Sample	27513-1	27513-2	27513-3	27513-4	27513-5	27513-6	27513-7	27513-8	27513-9	27513-10
SiO ₂	61.485	61.823	62.079	61.802	61.470	61.021	62.284	61.988	61.550	62.568
TiO ₂	–	0.045	0.020	0.022	–	–	–	–	–	–
Al ₂ O ₃	24.751	24.384	24.546	24.739	24.913	24.881	24.396	24.617	24.945	24.247
FeO	0.058	–	0.026	0.026	–	0.027	0.001	0.014	0.030	–
MnO	–	–	0.018	0.021	0.015	–	–	–	0.003	–
MgO	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	5.766	5.606	5.449	5.621	5.869	6.000	5.317	5.575	6.044	5.177
Na ₂ O	8.192	8.305	8.216	8.383	8.229	8.036	8.318	8.367	8.124	8.490
K ₂ O	0.083	0.105	0.095	0.102	0.108	0.189	0.075	0.114	0.133	0.086
Total	100.335	100.268	100.449	100.716	100.604	100.154	100.391	100.675	100.829	100.568
Si	10.873	10.933	10.945	10.888	10.847	10.824	10.980	10.919	10.841	11.010
Al	5.154	5.078	5.097	5.133	5.177	5.198	5.065	5.106	5.174	5.025
Ti	–	0.006	0.003	0.003	–	–	–	–	–	–
Fe ²⁺	0.009	–	0.004	0.004	–	0.004	–	0.002	0.004	–
Mn	–	–	0.003	0.003	0.002	–	–	–	–	–
Mg	–	–	–	–	–	–	–	–	–	–
Ca	1.092	1.062	1.029	1.061	1.110	1.140	1.004	1.052	1.141	0.976
Na	2.809	2.848	2.809	2.864	2.816	2.764	2.843	2.858	2.775	2.897
K	0.019	0.024	0.021	0.023	0.024	0.043	0.017	0.026	0.030	0.019
Sum	19.956	19.951	19.911	19.979	19.976	19.973	19.909	19.963	19.965	19.927
Mol percentages										
Ab	71.700	72.400	72.800	72.500	71.300	70.000	73.600	72.600	70.300	74.400
An	27.900	27.000	26.700	26.900	28.100	28.900	26.000	26.700	28.900	25.100
Or	0.500	0.600	0.500	0.600	0.600	1.100	0.400	0.700	0.800	0.500

Table 17 continued

Sample	27513-11	27513-12	27513-13	27513-14	27513-15	27513-16	27513-17	27513-19	27513-20	27516-1
SiO ₂	62.505	62.044	62.031	62.453	61.902	62.524	61.866	62.104	61.067	61.703
TiO ₂	0.009	–	0.031	0.037	–	0.034	0.033	0.005	0.004	–
Al ₂ O ₃	24.643	24.176	24.790	24.324	24.436	24.215	24.879	24.717	25.000	24.608
FeO	0.033	0.045	0.025	0.036	–	0.019	0.022	0.077	–	0.005
MnO	–	0.028	–	–	0.006	0.013	0.014	–	0.007	–
MgO	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	5.698	5.454	6.022	5.474	5.400	5.313	5.832	5.728	5.960	5.858
Na ₂ O	8.357	8.289	8.168	8.417	8.410	8.446	8.101	8.193	7.916	8.080
K ₂ O	0.128	0.142	0.106	0.109	0.120	0.079	0.122	0.119	0.105	0.128
Total	101.373	100.178	101.173	100.850	100.274	100.643	100.869	100.943	100.059	100.382
Si	10.935	10.977	10.882	10.975	10.942	11.001	10.878	10.911	10.827	10.902
Al	5.077	5.037	5.122	5.034	5.087	5.017	5.152	5.114	5.220	5.120
Ti	0.001	–	0.004	0.005	–	0.004	0.004	0.001	0.001	–
Fe ²⁺	0.005	0.007	0.004	0.005	–	0.003	0.003	0.011	–	0.001
Mn	–	0.004	–	–	0.001	0.002	0.002	–	0.001	–
Mg	–	–	–	–	–	–	–	–	–	–
Ca	1.068	1.034	1.132	1.031	1.023	1.002	1.099	1.078	1.132	1.109
Na	2.835	2.844	2.779	2.868	2.882	2.881	2.762	2.791	2.721	2.768
K	0.029	0.032	0.024	0.024	0.027	0.018	0.027	0.027	0.024	0.029
Sum	19.950	19.935	19.947	19.942	19.962	19.928	19.927	19.933	19.926	19.929
Mol percentages										
Ab	72.100	72.700	70.600	73.100	73.300	73.900	71.000	71.600	70.200	70.900
An	27.200	26.400	28.800	26.300	26.000	25.700	28.300	27.700	29.200	28.400
Or	0.700	0.800	0.600	0.600	0.700	0.500	0.700	0.700	0.600	0.700

Table 17 continued

Sample	27516-2	27516-3	27516-4	27516-5	27516-6	27516-7	27516-8	27516-9	27516-10	27516-11
SiO ₂	59.916	59.466	59.727	57.812	57.838	57.812	58.945	57.651	57.354	58.394
TiO ₂	0.045	–	0.012	–	–	–	–	0.048	0.012	0.001
Al ₂ O ₃	26.241	26.340	26.180	27.411	27.652	27.720	26.338	26.916	28.041	27.092
FeO	0.031	0.005	0.088	0.048	0.032	0.064	0.054	0.042	0.010	0.014
MnO	0.016	–	0.013	0.018	0.022	0.041	0.034	0.029	–	0.014
MgO	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	7.502	7.666	7.464	8.991	9.274	9.179	7.893	8.539	9.418	8.499
Na ₂ O	7.270	7.143	7.235	6.415	6.279	6.339	6.976	6.323	6.048	6.689
K ₂ O	0.148	0.120	0.084	0.087	0.045	0.095	0.109	0.108	0.114	0.127
Total	101.169	100.740	100.803	100.782	101.142	101.250	100.349	99.656	100.997	100.830
Si	10.563	10.529	10.564	10.274	10.244	10.234	10.489	10.342	10.177	10.359
Al	5.448	5.492	5.453	5.737	5.768	5.779	5.520	5.686	5.859	5.660
Ti	0.006	–	0.002	–	–	–	–	0.006	0.002	–
Fe ²⁺	0.005	0.001	0.013	0.007	0.005	0.009	0.008	0.006	0.001	0.002
Mn	0.002	–	0.002	0.003	0.003	0.006	0.005	0.004	–	0.002
Mg	–	–	–	–	–	–	–	–	–	–
Ca	1.417	1.454	1.415	1.712	1.760	1.741	1.505	1.641	1.790	1.615
Na	2.485	2.452	2.481	2.211	2.156	2.176	2.407	2.199	2.081	2.301
K	0.033	0.027	0.019	0.020	0.010	0.021	0.025	0.025	0.026	0.029
Sum	19.959	19.955	19.949	19.964	19.946	19.966	19.959	19.909	19.936	19.968
Mol percentages										
Ab	63.200	62.300	63.400	56.100	54.900	55.300	61.100	56.900	53.400	58.300
An	36.000	37.000	36.100	43.400	44.800	44.200	38.200	42.500	45.900	40.900
Or	0.800	0.700	0.500	0.500	0.300	0.500	0.600	0.600	0.700	0.700

Table 17 continued

Sample	27516-12	27516-13	27516-14	27516-15	27516-16	27516-17	27516-18	27516-19	27516-20
SiO ₂	60.349	59.164	61.679	58.882	58.582	58.577	61.877	59.450	59.198
TiO ₂	–	–	0.006	–	0.029	0.035	0.027	0.030	–
Al ₂ O ₃	25.689	26.375	25.030	26.569	26.975	27.034	24.568	25.920	26.247
FeO	0.035	0.009	0.027	0.037	0.075	0.065	0.053	0.004	0.037
MnO	–	–	–	0.023	0.007	0.013	–	0.000	0.036
MgO	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	6.873	7.920	6.157	8.140	8.478	8.389	6.065	7.760	8.035
Na ₂ O	7.527	6.830	7.989	6.627	6.650	6.754	7.979	7.086	7.020
K ₂ O	0.129	0.094	0.120	0.109	0.105	0.067	0.126	0.116	0.108
Total	100.602	100.392	101.008	100.387	100.901	100.934	100.695	100.366	100.681
Si	10.676	10.510	10.841	10.467	10.382	10.376	10.904	10.567	10.504
Al	5.352	5.518	5.181	5.562	5.630	5.639	5.098	5.425	5.484
Ti	–	–	0.001	–	0.004	0.005	0.004	0.004	–
Fe ²⁺	0.005	0.001	0.004	0.006	0.011	0.010	0.008	0.001	0.005
Mn	–	–	–	0.003	0.001	0.002	0.000	0.000	0.005
Mg	–	–	–	–	–	–	–	0.000	–
Ca	1.303	1.507	1.159	1.550	1.610	1.592	1.145	1.478	1.527
Na	2.582	2.353	2.723	2.284	2.285	2.320	2.726	2.442	2.415
K	0.029	0.021	0.027	0.025	0.024	0.015	0.028	0.026	0.024
Sum	19.947	19.910	19.936	19.897	19.947	19.959	19.913	19.943	19.964
Mol percentages									
Ab	66.000	60.600	69.700	59.200	58.300	59.100	69.900	61.900	60.900
An	33.300	38.800	29.600	40.200	41.100	40.500	29.400	37.500	38.500
Or	0.700	0.500	0.700	0.600	0.600	0.400	0.700	0.700	0.600

Table 18, Feldspar analysis of metasediments, numbers of ions on the basis of 32O, summary

n = 59	average	median	standard deviation	minimum	maximum
SiO ₂	60.32	60.76	1.85	52.43	62.68
TiO ₂	0.02	0.03	0.02	0.00	0.06
Al ₂ O ₃	25.76	25.60	1.28	24.02	31.25
FeO	0.04	0.03	0.02	0.00	0.09
MnO	0.01	0.01	0.01	0.00	0.04
MgO	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	7.03	6.78	1.51	5.08	13.69
Na ₂ O	7.48	7.53	0.84	3.93	8.49
K ₂ O	0.11	0.11	0.03	0.05	0.19
Total	100.75	100.78	0.36	99.66	101.56
Si	10.66	10.71	0.29	9.38	11.04
Al	5.36	5.31	0.29	4.98	6.59
Ti	0.00	0.00	0.00	0.00	0.01
Fe ²⁺	0.01	0.01	0.00	0.00	0.01
Mn	0.00	0.00	0.00	0.00	0.01
Mg	n. a.	n. a.	n. a.	n. a.	n. a.
Ca	1.33	1.28	0.29	0.96	2.63
Na	2.56	2.58	0.28	1.36	2.90
K	0.02	0.02	0.01	0.01	0.04
Σ	19.95	19.95	0.02	19.90	20.00
Mol percentages					
Ab	65.43	66.40	7.25	34.10	74.60
An	33.95	33.10	7.30	24.70	65.60
Or	0.62	0.60	0.15	0.30	1.10

Table 19, Feldspar analysis of pegmatites, numbers of ions on the basis of 32O (Anorthite rich), summary

n = 17	average	median	standard deviation	minimum	maximum
SiO₂	63.84	63.71	0.56	63.06	64.94
TiO₂	0.02	0.01	0.01	0.00	0.04
Al₂O₃	22.98	23.17	0.59	21.12	23.45
FeO	0.02	0.01	0.01	0.00	0.03
MnO	0.02	0.02	0.01	0.00	0.04
MgO	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	3.94	4.20	0.52	2.46	4.37
Na₂O	9.28	9.18	0.28	8.97	9.96
K₂O	0.14	0.12	0.05	0.07	0.23
Total	100.21	100.25	0.62	98.46	100.99
Si	11.25	11.22	0.11	11.16	11.58
Al	4.77	4.80	0.11	4.44	4.88
Ti	0.00	0.00	0.00	0.00	0.01
Fe²⁺	0.00	0.00	0.00	0.00	0.01
Mn	0.00	0.00	0.00	0.00	0.01
Mg	n. a.	n. a.	n. a.	n. a.	n. a.
Ca	0.74	0.79	0.10	0.47	0.83
Na	3.17	3.13	0.10	3.08	3.39
K	0.03	0.03	0.01	0.02	0.05
Sum	19.96	19.96	0.03	19.90	20.03
Mol percentages					
Ab	80.38	79.30	2.54	78.00	87.20
An	18.85	20.20	2.42	12.10	21.00
Or	0.78	0.70	0.30	0.40	1.30

Table 20, Feldspar analysis of pegmatites, numbers of ions on the basis of 32O (Albite), summary

n = 22	average	median	standard deviation	minimum	maximum
SiO ₂	67.12	67.25	1.08	65.04	68.74
TiO ₂	0.05	0.05	0.03	0.00	0.09
Al ₂ O ₃	20.17	20.35	0.84	17.51	21.30
FeO	0.02	0.02	0.01	0.00	0.04
MnO	0.01	0.01	0.01	0.00	0.04
MgO	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	0.88	0.79	0.67	0.01	1.91
Na ₂ O	10.01	11.05	3.13	0.19	11.31
K ₂ O	1.62	0.15	4.74	0.05	16.63
Total	99.83	99.95	0.77	98.44	100.96
Si	11.83	11.82	0.13	11.59	12.11
Al	4.18	4.19	0.13	3.84	4.43
Ti	0.01	0.01	0.00	0.00	0.01
Fe ²⁺	0.00	0.00	0.00	0.00	0.01
Mn	0.00	0.00	0.00	0.00	0.01
Mg	n. a.	n. a.	n. a.	n. a.	n. a.
Ca	0.17	0.15	0.13	0.00	0.36
Na	3.41	3.75	1.06	0.07	3.90
K	0.38	0.03	1.12	0.01	3.89
Sum	19.97	19.96	0.03	19.92	20.04
Mol percentages					
Ab	86.29	95.35	26.90	1.70	98.20
An	4.20	3.70	3.20	0.00	9.00
Or	9.54	0.90	28.07	0.30	98.20

Table 21, Feldspar analysis of pegamites, numbers of ions on the basis of 32O (potassic Feldspars), summary

n = 12	average	median	standard deviation	minimum	maximum
SiO ₂	65.11	65.13	0.25	64.56	65.51
TiO ₂	0.02	0.02	0.01	0.00	0.03
Al ₂ O ₃	18.81	18.81	0.13	18.56	19.01
FeO	0.02	0.02	0.01	0.00	0.03
MnO	0.02	0.02	0.01	0.01	0.03
MgO	n. a.	n. a.	n. a.	n. a.	n. a.
CaO	0.02	0.00	0.04	0.00	0.14
Na ₂ O	0.77	0.52	0.69	0.23	2.63
K ₂ O	15.70	16.14	0.99	13.11	16.39
Total	100.44	100.47	0.38	99.73	100.94
Si	11.95	11.95	0.02	11.93	12.00
Al	4.07	4.07	0.02	4.03	4.09
Ti	0.00	0.00	0.00	0.00	0.00
Fe ²⁺	0.00	0.00	0.00	0.00	0.00
Mn	0.00	0.00	0.00	0.00	0.00
Mg	n. a.	n. a.	n. a.	n. a.	n. a.
Ca	0.01	0.00	0.01	0.00	0.03
Na	0.27	0.18	0.24	0.08	0.93
K	3.68	3.78	0.24	3.07	3.86
Sum	19.98	19.98	0.02	19.94	20.01
Mol percentages					
Ab	6.92	4.65	6.12	2.10	23.30
An	0.18	0.10	0.26	0.00	0.70
Or	92.99	95.35	6.07	76.70	97.90

Table 22, Fluid inclusion data of the crush leach analysis

Sample No.	Depth [m]	Li [ppb]	Na [ppb]	K [ppb]	Mg [ppb]	Ca [ppb]	F [ppb]	Cl [ppb]	SO ₄ [ppb]	Br [ppb]	NO ₃ [ppb]	PO ₄ [ppb]	[ppb]
05-OKU-10	464.1	0.3	2270.7	411.5	88.9	319.2	4.1	3272.4	32.1	56.5	318.1	n.a.	0.8
05-OKU-91	584.55	1.2	6115.7	1600.3	155.6	5323.7	78.4	4527	89.2	52.9	910.6	n.a.	1
05-OKU-88	711.5	2.7	1545	375.9	106.1	1494.5	5.1	3538.9	18.6	63.2	675.7	n.a.	1.9
05-OKU-93	887.3	1.9	1791.2	424.9	67.6	2961.6	34.9	1632.9	820.1	16.4	275.5	n.a.	0.7
05-OKU-98	939.65	2	1716.9	459.2	49.1	1139.1	11.8	1635.7	33.5	10.8	363.6	n.a.	2.4
05-OKU-37	1262.4	0.9	4650.8	1552.4	399.7	2190.2	20	5853.6	71.1	32.4	702.6	n.a.	0.3
05-OKU-40	1292.3	1.9	3510.2	792.1	238.7	2358.9	8.3	2606.4	39.1	35.7	1828.7	n.a.	0.3
05-OKU-42	1310.2	0.5	1328.2	329.1	98.3	1273.5	3.7	1839.2	266.7	34	481.6	n.a.	0.4
05-OKU-13	1322.55	2	1319.6	1126.5	51.1	402.6	10.2	3138.6	65.7	88.6	733.2	n.a.	0.7
05-OKU-22	1379.6	9.2	3916.9	644.9	1423.7	5392.3	478.6	8351.5	84.4	108	1889	n.a.	0.7
05-OKU-42	1493.3	0.4	1474.7	333.6	109.2	1108.2	0.7	6013.1	70.3	98.5	295.7	22.4	0.5
05-OKU-46	1595.9	4	3184.4	609.7	39.9	1009.6	76.6	3874.7	42.3	51	1011	n.a.	0.3
05-OKU-50	1639.5	12	2259.8	683	249.2	1221.4	18.6	3845.4	169.3	80.8	439	n.a.	0.6
05-OKU-55	1784.95	10.4	1907.3	283.3	54.5	442.8	1.1	1246.2	44.4	16.9	425.6	n.a.	0.1
05-OKU-57	1803.4	13.5	1600.6	289.1	53.5	479.5	2.2	2196.9	23.9	31.6	375.1	n.a.	3.8
05-OKU-62	1845.5	2.4	1282.7	252.6	116.4	630.4	9.1	2839.6	50.2	42.8	481.5	20	0.3
05-OKU-65	1875.65	6	3451.8	542.9	54.4	851.2	92.7	4613.4	41	59.1	1584.7	n.a.	1.4
05-OKU-68	1920.95	7.4	1441.8	254	62.5	916.2	26.7	1389.5	43.2	21	739.8	n.a.	0.1
05-OKU-70	1941.65	5.9	1119	389	66.2	707	17.9	1754.3	46.2	37.7	305.7	n.a.	0.4
05-OKU-75	1980.35	3.4	2016.7	425.8	410.6	6301.8	5.6	4244.2	156.3	73.2	833.8	n.a.	0.4
05-OKU-78	2334.5	5	3525.2	1246.4	61.9	2014	117.6	6640.5	96.7	61.7	1602.5	n.a.	0.3
05-OKU-81	2340.7	37.4	1463.6	316.2	56.9	650.8	11.1	2012.7	35.7	25.8	314.1	n.a.	0.2

Table 23, Fluid Inclusion data from microthermometry

Type	Fluid Nr.	Depth [m]	T_e	T_m (Ice)	T_m (Hydrate)	T_h (CO2)	P_h (CO ₂)	T_h	P_h	Salinity [mass%]		Na/(Na+Ca)	Salinity calculation	
			[°C]	[°C]	[°C]	[°C]	[MPa]	[°C]	[MPa]	NaCl	CaCl ₂			
A4	1108-1	LV	~-21	-14.3	—	—	—	380.0	22.1	LV→L	18.0	—	1	Bodnar (1993)
A4	1108-2	LV	~-21	-17.0	—	—	—	368.0	19.4	LV→L	20.2	—	1	Bodnar (1993)
A4	1108-3	LV	~-21	-16.1	—	—	—	367.0	19.2	LV→L	19.5	—	1	Bodnar (1993)
B1	1108-4	LV	~-51	-29.0	—	—	—	236.2	2.7	LV→L	5.0	20.0	0.20	Oakes et al. (1990)
B2	1108-5	LV	~-51	-39.3	—	—	—	175.0	0.7	LV→L	5.6	22.6	0.20	Oakes et al. (1990)
B1	1108-6	LV	~-51	-23.3	—	—	—	222.0	2.0	LV→L	4.5	18.1	0.20	Oakes et al. (1990)
A3	1109-1	LV	~-21	-6.0	—	—	—	308.0	9.2	LV→L	9.2	—	1	Bodnar (1993)
A3	1109-2	LV	~-21	-6.9	—	—	—	368.0	19.4	LV→L	10.4	—	1	Bodnar (1993)
A4	1109-3	LV	~-21	-14.0	—	—	—	379.0	21.9	LV→L	17.8	—	1	Bodnar (1993)
A3	1109-4	LV	~-21	-6.2	—	—	—	296.7	7.8	LV→L	9.5	—	1	Bodnar (1993)
A3	1109-5	LV	~-21	-6.2	—	—	—	335.0	13.1	LV→L	9.5	—	1	Bodnar (1993)
A3	1109-6	LV	~-21	-7.0	—	—	—	387.2	23.8	LV→L	10.5	—	1	Bodnar (1993)
A3	1109-7	LV	~-21	-7.2	—	—	—	288.3	6.8	LV→L	10.7	—	1	Bodnar (1993)
A4	1109-8	LV	~-21	-15.3	—	—	—	376.5	21.3	LV→L	18.9	—	1	Bodnar (1993)
A4	1109-9	LV	~-21	-15.0	—	—	—	371.2	20.1	LV→L	18.6	—	1	Bodnar (1993)
A2	1109-10	LV	~-21	-7.0	—	—	—	220.0	2.0	LV→L	10.5	—	1	Bodnar (1993)
A2	1109-11	LV	~-21	-6.0	—	—	—	185.0	0.9	LV→L	9.2	—	1	Bodnar (1993)
A3	1109-12	LV	~-21	-8.7	—	—	—	291.0	7.1	LV→L	12.5	—	1	Bodnar (1993)
A2	1109-13	LV	~-21	-6.0	—	—	—	167.0	0.6	LV→L	9.2	—	1	Bodnar (1993)
A3	1114-1	LV	~-21	-6.7	—	—	—	280.3	6.0	LV→L	10.1	—	1	Bodnar (1993)
A3	1114-2	LV	~-21	-5.8	—	—	—	304.8	8.7	LV→L	8.9	—	1	Bodnar (1993)
A3	1114-3	LV	~-21	-5.8	—	—	—	294.5	7.5	LV→L	8.9	—	1	Bodnar (1993)
A3	1114-4	LV	~-21	-6.1	—	—	—	297.8	7.9	LV→L	9.3	—	1	Bodnar (1993)
A3	1114-5	LV	~-21	-6.5	—	—	—	352.3	16.2	LV→L	9.9	—	1	Bodnar (1993)
A3	1114-6	LV	~-21	-6.2	—	—	—	345.0	14.9	LV→L	9.5	—	1	Bodnar (1993)
A1	1114-7	LV	~-21	-0.4	—	—	—	268.9	5.0	LV→L	0.7	—	1	Bodnar (1993)
A1	1114-8	LV	~-21	-0.4	—	—	—	290.3	7.1	LV→L	0.7	—	1	Bodnar (1993)
A1	1114-9	LV	~-21	-2.1	—	—	—	273.4	5.4	LV→L	3.5	—	1	Bodnar (1993)
A1	1114-10	LV	~-21	-1.5	—	—	—	258.6	4.2	LV→L	2.6	—	1	Bodnar (1993)
A1	1114-11	LV	~-21	-0.9	—	—	—	273.8	5.4	LV→L	1.6	—	1	Bodnar (1993)
A1	1114-12	LV	~-21	-0.9	—	—	—	155.0	0.9	LV→L	1.6	—	1	Bodnar (1993)
A1	1114-13	LV	~-21	-0.8	—	—	—	248.7	3.5	LV→L	1.4	—	1	Bodnar (1993)
A1	1114-14	LV	~-21	-0.7	—	—	—	253.9	3.8	LV→L	1.2	—	1	Bodnar (1993)
A1	1114-15	LV	~-21	-0.8	—	—	—	250.1	3.6	LV→L	1.4	—	1	Bodnar (1993)
A3	1117-1	LV	~-21	-7.2	—	—	—	282.5	6.2	LV→L	10.7	—	1	Bodnar (1993)
A3	1117-2	LV	~-21	-7.4	—	—	—	309.7	9.4	LV→L	11.0	—	1	Bodnar (1993)

Table 23 continued

Type	Fluid Nr.	Bulk properties		Mole Fraction (total fluid inclusion)					Volume Fraction [at 20 °C]				EOS
		V_m [cm ³ /mol]	ρ [g/cm ³]	X_{H_2O}	X_{Na+}	X_{Ca2+}	X_{Cl-}	X_{CO_2}	ϕ_{liq}	ϕ_{vap}	ϕ_{aq}	ϕ_{CO_2}	
A4	1108-1	25.242	0.815	0.880	0.060	–	0.060	–	0.68	0.32	–	–	Zhang & Franz (1987)
A4	1108-2	24.531	0.854	0.864	0.068	–	0.068	–	0.69	0.31	–	–	Zhang & Franz (1987)
A4	1108-3	24.549	0.848	0.870	0.065	–	0.065	–	0.69	0.31	–	–	Zhang & Franz (1987)
B1	1108-4	20.725	1.072	0.867	0.014	0.035	0.084	–	0.81	0.19	–	–	Zhang & Franz (1987)
B2	1108-5	19.963	1.145	0.848	0.016	0.040	0.096	–	0.83	0.17	–	–	Zhang & Franz (1987)
B1	1108-6	20.543	1.058	0.880	0.012	0.032	0.076	–	0.82	0.18	–	–	Zhang & Franz (1987)
A3	1109-1	23.814	0.808	0.942	0.029	–	0.029	–	0.74	0.26	–	–	Zhang & Franz (1987)
A3	1109-2	26.980	0.719	0.934	0.033	–	0.033	–	0.65	0.35	–	–	Zhang & Franz (1987)
A4	1109-3	25.246	0.814	0.882	0.059	–	0.059	–	0.68	0.32	–	–	Zhang & Franz (1987)
A3	1109-4	23.271	0.828	0.940	0.030	–	0.030	–	0.75	0.25	–	–	Zhang & Franz (1987)
A3	1109-5	25.150	0.767	0.940	0.030	–	0.030	–	0.70	0.30	–	–	Zhang & Franz (1987)
A3	1109-6	28.477	0.682	0.932	0.034	–	0.034	–	0.61	0.39	–	–	Zhang & Franz (1987)
A3	1109-7	22.771	0.855	0.932	0.034	–	0.034	–	0.77	0.23	–	–	Zhang & Franz (1987)
A4	1109-8	24.970	0.830	0.874	0.063	–	0.063	–	0.68	0.32	–	–	Zhang & Franz (1987)
A4	1109-9	24.800	0.834	0.876	0.062	–	0.062	–	0.69	0.31	–	–	Zhang & Franz (1987)
A2	1109-10	20.904	0.929	0.932	0.034	–	0.034	–	0.84	0.16	–	–	Zhang & Franz (1987)
A2	1109-11	20.230	0.951	0.942	0.029	–	0.029	–	0.87	0.13	–	–	Zhang & Franz (1987)
A3	1109-12	22.672	0.870	0.920	0.040	–	0.040	–	0.77	0.23	–	–	Zhang & Franz (1987)
A2	1109-13	19.933	0.965	0.940	0.030	–	0.030	–	0.88	0.12	–	–	Zhang & Franz (1987)
A3	1114-1	22.564	0.858	0.936	0.032	–	0.032	–	0.78	0.22	–	–	Zhang & Franz (1987)
A3	1114-2	23.720	0.810	0.942	0.029	–	0.029	–	0.74	0.26	–	–	Zhang & Franz (1987)
A3	1114-3	23.268	0.825	0.942	0.029	–	0.029	–	0.75	0.25	–	–	Zhang & Franz (1987)
A3	1114-4	23.339	0.825	0.940	0.030	–	0.030	–	0.75	0.25	–	–	Zhang & Franz (1987)
A3	1114-5	26.092	0.741	0.936	0.032	–	0.032	–	0.67	0.33	–	–	Zhang & Franz (1987)
A3	1114-6	25.760	0.748	0.940	0.030	–	0.030	–	0.68	0.32	–	–	Zhang & Franz (1987)
A1	1114-7	23.733	0.763	0.996	0.002	–	0.002	–	0.76	0.24	–	–	Zhang & Franz (1987)
A1	1114-8	25.151	0.720	0.996	0.002	–	0.008	–	0.72	0.28	–	–	Zhang & Franz (1987)
A1	1114-9	23.327	0.782	0.978	0.011	–	0.011	–	0.76	0.24	–	–	Zhang & Franz (1987)
A1	1114-10	22.793	0.805	0.984	0.008	–	0.008	–	0.79	0.21	–	–	Zhang & Franz (1987)
A1	1114-11	23.805	0.765	0.990	0.005	–	0.005	–	0.75	0.25	–	–	Zhang & Franz (1987)
A1	1114-12	19.645	0.927	0.990	0.005	–	0.005	–	0.91	0.09	–	–	Zhang & Franz (1987)
A1	1114-13	22.534	0.807	0.992	0.004	–	0.004	–	0.80	0.20	–	–	Zhang & Franz (1987)
A1	1114-14	22.811	0.796	0.992	0.004	–	0.004	–	0.79	0.21	–	–	Zhang & Franz (1987)
A1	1114-15	22.599	0.805	0.992	0.004	–	0.004	–	0.79	0.21	–	–	Zhang & Franz (1987)
A3	1117-1	22.571	0.862	0.930	0.035	–	0.035	–	0.77	0.23	–	–	Zhang & Franz (1987)
A3	1117-2	23.553	0.828	0.930	0.035	–	0.035	–	0.74	0.26	–	–	Zhang & Franz (1987)

Table 23 continued

Type	Fluid Nr.	Depth [m]	T_e	T_m (Ice)	T_m (Hydrate)	T_h (CO2)	P_h (CO ₂)	T_h	P_h	Salinity [mass%]		Na/(Na+Ca)	Salinity calculation	
			[°C]	[°C]	[°C]	[°C]	[MPa]	[°C]	[MPa]	NaCl	CaCl ₂			
A3	1117-3	LV	~-21	-7.9	—	—	—	288.0	6.8	LV→L	11.6	—	1	Bodnar (1993)
A3	1117-4	LV	~-21	-7.9	—	—	—	288.0	6.8	LV→L	11.6	—	1	Bodnar (1993)
A3	1117-5	LV	~-21	-7.9	—	—	—	320.0	10.8	LV→L	11.6	—	1	Bodnar (1993)
A3	1117-6	LV	~-21	-8.6	—	—	—	362.0	18.1	LV→L	12.4	—	1	Bodnar (1993)
A3	1117-7	LV	~-21	-8.7	—	—	—	282.7	6.3	LV→L	12.5	—	1	Bodnar (1993)
A3	1117-8	LV	~-21	-8.1	—	—	—	281.4	6.1	LV→L	11.8	—	1	Bodnar (1993)
A3	1117-9	LV	~-21	-9.1	—	—	—	342.3	14.4	LV→L	13.0	—	1	Bodnar (1993)
A3	1117-10	LV	~-21	-8.8	—	—	—	357.2	17.2	LV→L	12.6	—	1	Bodnar (1993)
A3	1117-11	LV	~-21	-9.2	—	—	—	345.8	15.0	LV→L	13.1	—	1	Bodnar (1993)
B1	1117-12	LV	~-51	-21.7	—	—	—	217.8	1.9	LV→L	4.4	17.4	0.20	Oakes et al. (1990)
B1	1117-13	LV	~-51	-21.9	—	—	—	166.5	0.6	LV→L	4.4	17.5	0.20	Oakes et al. (1990)
B1	1117-14	LV	~-51	-22.6	—	—	—	148.7	0.5	LV→L	4.4	17.8	0.20	Oakes et al. (1990)
B1	1117-15	LV	~-51	-23.2	—	—	—	210.0	1.6	LV→L	4.5	18.0	0.20	Oakes et al. (1990)
B1	1117-16	LV	~-51	-23.7	—	—	—	172.5	0.7	LV→L	4.6	18.2	0.20	Oakes et al. (1990)
B1	1117-17	LV	~-51	-25.7	—	—	—	144.5	0.5	LV→L	4.7	18.9	0.20	Oakes et al. (1990)
B1	1117-18	LV	~-51	-27.6	—	—	—	161.8	0.6	LV→L	4.9	19.6	0.20	Oakes et al. (1990)
C	1117-19	L	—	-56.6	—	18.3	5.5	LV→L	—	—	—	—	—	—
C	1117-20	L	—	-56.6	—	18.4	5.5	LV→L	—	—	—	—	—	—
C	1117-21	L	—	-56.6	—	18.3	5.5	LV→L	—	—	—	—	—	—
C	1117-22	L	—	-56.6	—	18.7	5.6	LV→L	—	—	—	—	—	—
C	1117-23	L	—	-56.6	—	18.6	5.5	LV→L	—	—	—	—	—	—
C	1117-24	L	—	-57.6	—	1.7	3.6	LV→L	—	—	—	—	—	—
C	1117-25	L	—	-57.6	—	10.2	4.5	LV→L	—	—	—	—	—	—
C	1117-26	L	—	-57.6	—	-7.9	2.8	LV→L	—	—	—	—	—	—
C	1117-27	L	—	-57.7	—	1.5	3.6	LV→L	—	—	—	—	—	—
C	1117-28	L	—	-57.7	—	-1.7	3.3	LV→L	—	—	—	—	—	—
C	1117-29	L	—	-57.7	—	9.7	4.5	LV→L	—	—	—	—	—	—
C	1117-30	L	—	-57.7	—	9.9	4.5	LV→L	—	—	—	—	—	—
C	1117-31	L	—	-57.8	—	10.1	4.5	LV→L	—	—	—	—	—	—
C	1117-32	L	—	-57.8	—	-11.0	2.6	LV→L	—	—	—	—	—	—
C	1117-33	L	—	-57.9	—	-1.8	3.3	LV→L	—	—	—	—	—	—
C	1117-34	L	—	-58.2	—	-9.9	2.7	LV→L	—	—	—	—	—	—
C	1117-35	L	—	-58.4	—	-2.0	3.3	LV→L	—	—	—	—	—	—
C	1117-36	L	—	-59.8	—	-2.5	3.3	LV→L	—	—	—	—	—	—
A1	1118-1	LV	~-21	-0.6	—	—	—	285.2	6.5	LV→L	1.1	—	1	Bodnar (1993)
A1	1118-2	LV	~-21	-0.6	—	—	—	336.2	13.3	LV→L	1.1	—	1	Bodnar (1993)

Table 23 continued

Type	Fluid Nr.	Bulk properties		Mole Fraction (total fluid inclusion)					Volume Fraction [at 20 °C]				EOS
		V_m [cm ³ /mol]	ρ [g/cm ³]	X_{H_2O}	X_{Na+}	X_{Ca2+}	X_{Cl-}	X_{CO_2}	φ_{liq}	φ_{vap}	φ_{aq}	φ_{CO_2}	bulk properties
A3	1117-3	22.666	0.864	0.924	0.037	–	0.037	–	0.77	0.23	–	–	Zhang & Franz (1987)
A3	1117-4	22.666	0.864	0.924	0.037	–	0.037	–	0.77	0.23	–	–	Zhang & Franz (1987)
A3	1117-5	23.880	0.820	0.924	0.037	–	0.037	–	0.73	0.27	–	–	Zhang & Franz (1987)
A3	1117-6	25.787	0.764	0.920	0.040	–	0.040	–	0.67	0.33	–	–	Zhang & Franz (1987)
A3	1117-7	22.414	0.880	0.920	0.040	–	0.040	–	0.77	0.23	–	–	Zhang & Franz (1987)
A3	1117-8	22.431	0.845	0.924	0.038	–	0.038	–	0.78	0.22	–	–	Zhang & Franz (1987)
A3	1117-9	24.599	0.804	0.916	0.042	–	0.042	–	0.71	0.29	–	–	Zhang & Franz (1987)
A3	1117-10	25.443	0.776	0.918	0.041	–	0.041	–	0.68	0.32	–	–	Zhang & Franz (1987)
A3	1117-11	24.740	0.801	0.916	0.042	–	0.042	–	0.70	0.30	–	–	Zhang & Franz (1987)
B1	1117-12	20.486	1.054	0.884	0.013	0.030	0.073	–	0.83	0.17	–	–	Zhang & Franz (1987)
B1	1117-13	19.774	1.093	0.884	0.013	0.030	0.073	–	0.86	0.14	–	–	Zhang & Franz (1987)
B1	1117-14	19.572	1.108	0.881	0.013	0.031	0.075	–	0.86	0.14	–	–	Zhang & Franz (1987)
B1	1117-15	20.360	1.067	0.881	0.013	0.031	0.075	–	0.83	0.17	–	–	Zhang & Franz (1987)
B1	1117-16	19.858	1.097	0.878	0.013	0.032	0.077	–	0.85	0.15	–	–	Zhang & Franz (1987)
B1	1117-17	19.555	1.122	0.873	0.014	0.033	0.080	–	0.86	0.14	–	–	Zhang & Franz (1987)
B1	1117-18	19.758	1.119	0.870	0.014	0.034	0.082	–	0.85	0.15	–	–	Zhang & Franz (1987)
C	1117-19	55.648	0.791	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-20	55.717	0.790	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-21	55.648	0.791	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-22	55.929	0.789	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-23	55.858	0.788	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-24	47.990	0.917	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-25	51.196	0.860	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-26	45.283	0.972	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-27	47.926	0.918	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-28	46.947	0.937	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-29	50.977	0.863	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-30	51.064	0.862	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-31	51.152	0.860	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-32	44.544	0.988	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-33	46.918	0.938	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-34	44.800	0.982	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-35	46.860	0.939	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
C	1117-36	46.716	0.942	–	–	–	–	1.000	1.00	–	–	–	Duschek et al. (1990)
A1	1118-1	24.672	0.736	0.994	0.003	–	0.003	–	0.73	0.27	–	–	Zhang & Franz (1987)
A1	1118-2	29.383	0.618	0.994	0.003	–	0.003	–	0.61	0.39	–	–	Zhang & Franz (1987)

Table 23 continued

Type	Fluid Nr.	Depth [m]	T_e	T_m (Ice)	T_m (Hydrate)	T_h (CO2)	P_h (CO ₂)	T_h	P_h	Salinity [mass%]		Na/(Na+Ca)	Salinity calculation	
			[°C]	[°C]	[°C]	[°C]	[MPa]	[°C]	[MPa]	NaCl	CaCl ₂			
A1	1118-3	LV	~-21	-0.7	—	—	—	277.0	5.7	LV→L	1.2	—	1	Bodnar (1993)
A1	1118-4	LV	~-21	-0.8	—	—	—	322.5	11.2	LV→L	1.4	—	1	Bodnar (1993)
A1	1118-5	LV	~-21	-0.8	—	—	—	304.6	8.7	LV→L	1.4	—	1	Bodnar (1993)
A1	1118-6	LV	~-21	-0.9	—	—	—	320.1	10.8	LV→L	1.6	—	1	Bodnar (1993)
A1	1118-7	LV	~-21	-0.9	—	—	—	297.5	7.9	LV→L	1.6	—	1	Bodnar (1993)
A1	1118-8	LV	~-21	-1.5	—	—	—	253.4	3.8	LV→L	2.6	—	1	Bodnar (1993)
A1	1118-9	LV	~-21	-1.5	—	—	—	180.3	0.8	LV→L	2.6	—	1	Bodnar (1993)
A1	1118-10	LV	~-21	-1.7	—	—	—	305.5	8.8	LV→L	2.9	—	1	Bodnar (1993)
A1	1118-11	LV	~-21	-1.7	—	—	—	157.5	0.5	LV→L	2.9	—	1	Bodnar (1993)
A1	1118-12	LV	~-21	-1.7	—	—	—	334.5	13.0	LV→L	2.9	—	1	Bodnar (1993)
A1	1118-13	LV	~-21	-1.8	—	—	—	377.2	21.4	LV→L	3.1	—	1	Bodnar (1993)
A1	1118-14	LV	~-21	-1.8	—	—	—	391.4	24.9	LV→L	3.1	—	1	Bodnar (1993)
A1	1118-15	LV	~-21	-1.9	—	—	—	245.1	3.3	LV→L	3.2	—	1	Bodnar (1993)
A1	1118-16	LV	~-21	-1.9	—	—	—	367.1	19.2	LV→L	3.2	—	1	Bodnar (1993)
A1	1118-17	LV	~-21	-2.0	—	—	—	201.3	1.3	LV→L	3.4	—	1	Bodnar (1993)
A3	1118-18	LV	~-21	-7.1	—	—	—	300.7	8.2	LV→L	10.6	—	1	Bodnar (1993)
A3	1118-19	LV	~-21	-7.7	—	—	—	336.5	13.4	LV→L	11.3	—	1	Bodnar (1993)
A3	1118-20	LV	~-21	-8.4	—	—	—	338.8	13.8	LV→L	12.2	—	1	Bodnar (1993)
A3	1134-1	LV	~-21	-8.1	—	—	—	278.5	5.9	LV→L	11.8	—	1	Bodnar (1993)
A2	1134-2	LV	~-21	-8.5	—	—	—	155.0	0.5	LV→L	12.3	—	1	Bodnar (1993)
A2	1134-3	LV	~-21	-8.3	—	—	—	125.9	0.5	LV→L	12.0	—	1	Bodnar (1993)
A2	1134-4	LV	~-21	-8.0	—	—	—	206.9	1.5	LV→L	11.7	—	1	Bodnar (1993)
A2	1134-5	LV	~-21	-7.9	—	—	—	219.2	1.9	LV→L	11.6	—	1	Bodnar (1993)
A4	1134-6	LV	~-21	-14.5	—	—	—	350.1	15.8	LV→L	18.2	—	1	Bodnar (1993)
A4	1134-7	LV	~-21	-16.1	—	—	—	371.4	20.1	LV→L	19.5	—	1	Bodnar (1993)
A3	1134-8	LV	~-21	-9.0	—	—	—	392.6	25.2	LV→L	12.8	—	1	Bodnar (1993)
A3	1134-9	LV	~-21	-7.9	—	—	—	384.1	23.1	LV→L	11.6	—	1	Bodnar (1993)
A3	1134-10	LV	~-21	-8.0	—	—	—	358.8	17.5	LV→L	11.7	—	1	Bodnar (1993)
A3	1134-11	LV	~-21	-8.5	—	—	—	326.9	11.8	LV→L	12.3	—	1	Bodnar (1993)
A3	1134-12	LV	~-21	-6.9	—	—	—	306.5	9.0	LV→L	10.4	—	1	Bodnar (1993)
A3	1134-13	LV	~-21	-6.8	—	—	—	311.2	9.6	LV→L	10.2	—	1	Bodnar (1993)
A3	1134-14	LV	~-21	-6.7	—	—	—	298.6	8.0	LV→L	10.1	—	1	Bodnar (1993)
A3	1134-15	LV	~-21	-6.8	—	—	—	303.4	8.6	LV→L	10.2	—	1	Bodnar (1993)
C	1134-16	L	—	-59.9	—	-1.4	3.4	LV→L	—	—	—	—	—	—
C	1134-17	L	—	-58.7	—	-4.5	3.1	LV→L	—	—	—	—	—	—
C	1134-18	L	—	-59.5	—	-1.9	3.3	LV→L	—	—	—	—	—	—

Type	Fluid Nr.	Bulk properties		Mole Fraction (total fluid inclusion)					Volume Fraction [at 20 °C]				EOS
		V_m [cm ³ /mol]	ρ [g/cm ³]	x_{H_2O}	x_{Na+}	x_{Ca2+}	x_{Cl-}	x_{CO_2}	φ_{liq}	φ_{vap}	φ_{aq}	φ_{CO_2}	bulk properties
A1	1118-3	24.087	0.754	0.992	0.004	—	0.004	—	0.75	0.25	—	—	Zhang & Franz (1987)
A1	1118-4	27.633	0.658	0.992	0.004	—	0.004	—	0.65	0.35	—	—	Zhang & Franz (1987)
A1	1118-5	26.001	0.700	0.992	0.004	—	0.004	—	0.69	0.31	—	—	Zhang & Franz (1987)
A1	1118-6	27.303	0.667	0.990	0.005	—	0.005	—	0.66	0.34	—	—	Zhang & Franz (1987)
A1	1118-7	25.377	0.718	0.990	0.005	—	0.005	—	0.71	0.29	—	—	Zhang & Franz (1987)
A1	1118-8	22.555	0.813	0.984	0.008	—	0.008	—	0.79	0.21	—	—	Zhang & Franz (1987)
A1	1118-9	20.173	0.909	0.984	0.008	—	0.008	—	0.89	0.11	—	—	Zhang & Franz (1987)
A1	1118-10	25.475	0.722	0.982	0.009	—	0.009	—	0.70	0.30	—	—	Zhang & Franz (1987)
A1	1118-11	19.698	0.933	0.982	0.009	—	0.009	—	0.91	0.09	—	—	Zhang & Franz (1987)
A1	1118-12	27.989	0.657	0.982	0.009	—	0.009	—	0.64	0.36	—	—	Zhang & Franz (1987)
A1	1118-13	33.581	0.548	0.980	0.010	—	0.010	—	0.53	0.47	—	—	Zhang & Franz (1987)
A1	1118-14	36.364	0.506	0.980	0.010	—	0.010	—	0.49	0.51	—	—	Zhang & Franz (1987)
A1	1118-15	22.110	0.833	0.980	0.010	—	0.010	—	0.81	0.19	—	—	Zhang & Franz (1987)
A1	1118-16	31.771	0.580	0.980	0.010	—	0.010	—	0.56	0.44	—	—	Zhang & Franz (1987)
A1	1118-17	20.668	0.893	0.978	0.011	—	0.011	—	0.86	0.14	—	—	Zhang & Franz (1987)
A3	1118-18	23.250	0.836	0.932	0.034	—	0.034	—	0.75	0.25	—	—	Zhang & Franz (1987)
A3	1118-19	24.705	0.791	0.926	0.037	—	0.037	—	0.71	0.30	—	—	Zhang & Franz (1987)
A3	1118-20	24.616	0.799	0.922	0.039	—	0.039	—	0.71	0.29	—	—	Zhang & Franz (1987)
A3	1134-1	22.342	0.878	0.924	0.038	—	0.038	—	0.78	0.22	—	—	Zhang & Franz (1987)
A2	1134-2	19.825	0.993	0.920	0.040	—	0.040	—	0.88	0.12	—	—	Zhang & Franz (1987)
A2	1134-3	19.444	1.011	0.922	0.039	—	0.039	—	0.89	0.11	—	—	Zhang & Franz (1987)
A2	1134-4	20.638	0.950	0.924	0.038	—	0.038	—	0.84	0.16	—	—	Zhang & Franz (1987)
A2	1134-5	20.876	0.938	0.926	0.037	—	0.037	—	0.83	0.17	—	—	Zhang & Franz (1987)
A4	1134-6	24.084	0.856	0.880	0.060	—	0.060	—	0.71	0.29	—	—	Zhang & Franz (1987)
A4	1134-7	24.705	0.843	0.870	0.065	—	0.065	—	0.69	0.31	—	—	Zhang & Franz (1987)
A3	1134-8	27.628	0.716	0.916	0.042	—	0.042	—	0.63	0.37	—	—	Zhang & Franz (1987)
A3	1134-9	27.614	0.709	0.926	0.037	—	0.037	—	0.63	0.37	—	—	Zhang & Franz (1987)
A3	1134-10	25.832	0.759	0.924	0.038	—	0.038	—	0.67	0.33	—	—	Zhang & Franz (1987)
A3	1134-11	24.046	0.819	0.920	0.040	—	0.040	—	0.72	0.28	—	—	Zhang & Franz (1987)
A3	1134-12	23.527	0.825	0.934	0.033	—	0.033	—	0.74	0.26	—	—	Zhang & Franz (1987)
A3	1134-13	23.753	0.816	0.934	0.033	—	0.033	—	0.74	0.26	—	—	Zhang & Franz (1987)
A3	1134-14	23.245	0.833	0.936	0.032	—	0.032	—	0.75	0.25	—	—	Zhang & Franz (1987)
A3	1134-15	23.419	0.828	0.934	0.033	—	0.033	—	0.75	0.25	—	—	Zhang & Franz (1987)
C	1134-16	47.035	0.936	—	—	—	—	1.000	1.00	—	—	—	Duschkew et al. (1990)
C	1134-17	46.162	0.953	—	—	—	—	1.000	1.00	—	—	—	Duschkew et al. (1990)
C	1134-18	46.889	0.939	—	—	—	—	1.000	1.00	—	—	—	Duschkew et al. (1990)

Table 23 continued

Type	Fluid Nr.	Depth [m]	T_e [°C]	T_m (Ice) [°C]	T_m (Hydrate) [°C]	T_h (CO ₂) [°C]	P_h (CO ₂) [MPa]		T_h [°C]	P_h [MPa]	Salinity [mass%]		Na/(Na+Ca)	Salinity calculation
											NaCl	CaCl ₂		
C	1134-19	L	—	-60.0	—	6.4	4.1	LV→L	—	—	—	—	—	—
C	1134-20	L	—	-59.7	—	-3.8	3.1	LV→L	—	—	—	—	—	—
A4	1134-21	LV	~-21	-13.9	—	—	—	—	336.0	13.3	LV→L	17.7	—	1 Bodnar (1993)
A2	1134-22	LV	~-21	-4.0	—	—	—	—	233.7	2.6	LV→L	6.4	—	1 Bodnar (1993)
A4	1134-23	LV	~-21	-15.2	—	—	—	—	355.4	16.8	LV→L	18.8	—	1 Bodnar (1993)
A3	1134-24	LV	~-21	-5.1	—	—	—	—	354.9	16.7	LV→L	8.0	—	1 Bodnar (1993)
A3	1134-25	LV	~-21	-5.0	—	—	—	—	321.9	11.1	LV→L	7.9	—	1 Bodnar (1993)
A3	1134-26	LV	~-21	-6.2	—	—	—	—	312.4	9.7	LV→L	9.5	—	1 Bodnar (1993)
A3	1134-27	LV	~-21	-5.9	—	—	—	—	283.9	6.4	LV→L	9.1	—	1 Bodnar (1993)
A3	1134-28	LV	~-21	-5.9	—	—	—	—	328.0	12.0	LV→L	9.1	—	1 Bodnar (1993)
A3	1134-29	LV	~-21	-6.1	—	—	—	—	288.5	6.9	LV→L	9.3	—	1 Bodnar (1993)
A3	1134-30	LV	~-21	-5.8	—	—	—	—	319.7	10.8	LV→L	8.9	—	1 Bodnar (1993)
A3	1134-31	LV	~-21	-5.5	—	—	—	—	281.2	6.1	LV→L	8.5	—	1 Bodnar (1993)
A3	1134-32	LV	~-21	-5.2	—	—	—	—	282.5	6.2	LV→L	8.1	—	1 Bodnar (1993)
A3	1134-33	LV	~-21	-4.6	—	—	—	—	301.2	8.3	LV→L	7.3	—	1 Bodnar (1993)
A2	1134-34	LV	~-21	-4.3	—	—	—	—	189.4	1.0	LV→L	6.9	—	1 Bodnar (1993)
A2	1134-35	LV	~-21	-4.7	—	—	—	—	200.2	1.3	LV→L	7.4	—	1 Bodnar (1993)
C	1134-36	L	—	-59.0	—	-16.6	2.2	LV→L	—	—	—	—	—	—
A2	1137-1	LV	~-21	-5.4	—	—	—	—	247.8	3.4	LV→L	8.4	—	1 Bodnar (1993)
A2	1137-2	LV	~-21	-8.5	—	—	—	—	224.1	2.1	LV→L	12.3	—	1 Bodnar (1993)
A2	1137-3	LV	~-21	-8.7	—	—	—	—	204.3	1.4	LV→L	12.5	—	1 Bodnar (1993)
B1	1137-4	LV	~-51	-21.8	—	—	—	—	274.4	5.5	LV→L	4.4	17.5	0.20 Oakes et al. (1990)
A3	1137-5	LV	~-21	-4.1	—	—	—	—	351.0	16.0	LV→L	6.6	—	1 Bodnar (1993)
A3	1137-6	LV	~-21	-5.0	—	—	—	—	386.0	23.5	LV→L	7.9	—	1 Bodnar (1993)
A3	1137-7	LV	~-21	-4.0	—	—	—	—	340.0	14.0	LV→L	6.4	—	1 Bodnar (1993)
A2	1137-8	LV	~-21	-8.9	—	—	—	—	199.4	1.2	LV→L	12.7	—	1 Bodnar (1993)
A2	1137-9	LV	~-21	-5.9	—	—	—	—	146.1	0.5	LV→L	9.1	—	1 Bodnar (1993)
A2	1137-10	LV	~-21	-8.9	—	—	—	—	220.4	2.0	LV→L	12.7	—	1 Bodnar (1993)
A2	1137-11	LV	~-21	-8.3	—	—	—	—	183.6	0.9	LV→L	12.0	—	1 Bodnar (1993)
B1	1137-12	LV	~-51	-21.1	—	—	—	—	270.8	5.2	LV→L	4.3	17.2	0.20 Oakes et al. (1990)
B1	1137-13	LV	~-51	-21.8	—	—	—	—	278.9	5.9	LV→L	4.4	17.5	0.20 Oakes et al. (1990)
B1	1137-14	LV	~-51	-22.1	—	—	—	—	221.0	2.0	LV→L	4.4	17.6	0.20 Oakes et al. (1990)
B1	1137-15	LV	~-51	-21.2	—	—	—	—	198.3	1.2	LV→L	4.3	17.2	0.20 Oakes et al. (1990)
B1	1137-16	LV	~-51	-23.8	—	—	—	—	251.7	3.7	LV→L	4.6	18.2	0.20 Oakes et al. (1990)
B2	1137-17	LV	~-51	-37.2	—	—	—	—	174.5	0.7	LV→L	5.5	22.2	0.20 Oakes et al. (1990)
B2	1137-18	LV	~-51	-39.6	—	—	—	—	158.6	0.5	LV→L	6.7	21.3	0.24 Oakes et al. (1990)

Type	Fluid Nr.	Bulk properties		Mole Fraction (total fluid inclusion)					Volume Fraction [at 20 °C]				EOS
		V_m [cm ³ /mol]	ρ [g/cm ³]	X_{H_2O}	X_{Na+}	X_{Ca2+}	X_{Cl-}	X_{CO_2}	φ_{liq}	φ_{vap}	φ_{aq}	φ_{CO_2}	bulk properties
C	1134-19	49.636	0.887	—	—	—	—	1.000	1.00	—	—	—	Duschk et al. (1990)
C	1134-20	46.352	0.949	—	—	—	—	1.000	1.00	—	—	—	Duschk et al. (1990)
A4	1134-21	23.662	0.868	0.882	0.059	—	0.059	—	0.72	0.28	—	—	Zhang & Franz (1987)
A2	1134-22	21.406	0.881	0.960	0.020	—	0.020	—	0.83	0.17	—	—	Zhang & Franz (1987)
A4	1134-23	24.213	0.855	0.876	0.062	—	0.062	—	0.70	0.30	—	—	Zhang & Franz (1987)
A3	1134-24	27.089	0.704	0.950	0.025	—	0.025	—	0.65	0.35	—	—	Zhang & Franz (1987)
A3	1134-25	24.877	0.766	0.950	0.025	—	0.025	—	0.71	0.29	—	—	Zhang & Franz (1987)
A3	1134-26	23.965	0.804	0.940	0.030	—	0.030	—	0.73	0.27	—	—	Zhang & Franz (1987)
A3	1134-27	22.824	0.842	0.942	0.029	—	0.029	—	0.77	0.23	—	—	Zhang & Franz (1987)
A3	1134-28	24.868	0.883	0.942	0.029	—	0.029	—	0.71	0.29	—	—	Zhang & Franz (1987)
A3	1134-29	22.963	0.838	0.940	0.030	—	0.030	—	0.76	0.24	—	—	Zhang & Franz (1987)
A3	1134-30	24.453	0.785	0.942	0.029	—	0.029	—	0.72	0.28	—	—	Zhang & Franz (1987)
A3	1134-31	22.795	0.840	0.946	0.027	—	0.027	—	0.77	0.23	—	—	Zhang & Franz (1987)
A3	1134-32	22.906	0.833	0.948	0.026	—	0.026	—	0.77	0.23	—	—	Zhang & Franz (1987)
A3	1134-33	23.902	0.794	0.954	0.023	—	0.023	—	0.74	0.26	—	—	Zhang & Franz (1987)
A2	1134-34	20.311	0.931	0.956	0.022	—	0.022	—	0.87	0.13	—	—	Zhang & Franz (1987)
A2	1134-35	20.528	0.925	0.952	0.024	—	0.024	—	0.86	0.14	—	—	Zhang & Franz (1987)
C	1134-36	43.332	1.016	—	—	—	—	1.000	1.00	—	—	—	Duschk et al. (1990)
A2	1137-1	21.683	0.882	0.946	0.027	—	0.027	—	0.81	0.19	—	—	Zhang & Franz (1987)
A2	1137-2	20.971	0.939	0.920	0.040	—	0.040	—	0.83	0.17	—	—	Zhang & Franz (1987)
A2	1137-3	20.597	0.958	0.920	0.040	—	0.040	—	0.84	0.16	—	—	Zhang & Franz (1987)
B1	1137-4	21.525	1.004	0.884	0.013	0.030	0.073	—	0.79	0.21	—	—	Zhang & Franz (1987)
A3	1137-5	27.480	0.687	0.958	0.021	—	0.021	—	0.64	0.36	—	—	Zhang & Franz (1987)
A3	1137-6	30.176	0.631	0.950	0.025	—	0.025	—	0.58	0.42	—	—	Zhang & Franz (1987)
A3	1137-7	26.637	0.708	0.960	0.020	—	0.020	—	0.66	0.34	—	—	Zhang & Franz (1987)
A2	1137-8	20.514	0.963	0.918	0.042	—	0.042	—	0.85	0.15	—	—	Zhang & Franz (1987)
A2	1137-9	19.628	0.979	0.942	0.029	—	0.029	—	0.89	0.11	—	—	Zhang & Franz (1987)
A2	1137-10	20.897	0.945	0.918	0.041	—	0.041	—	0.83	0.17	—	—	Zhang & Franz (1987)
A2	1137-11	20.242	0.971	0.922	0.039	—	0.039	—	0.86	0.14	—	—	Zhang & Franz (1987)
B1	1137-12	21.468	1.003	0.886	0.012	0.030	0.072	—	0.79	0.21	—	—	Zhang & Franz (1987)
B1	1137-13	21.622	0.999	0.884	0.013	0.030	0.073	—	0.78	0.22	—	—	Zhang & Franz (1987)
B1	1137-14	20.534	1.053	0.883	0.012	0.031	0.074	—	0.82	0.18	—	—	Zhang & Franz (1987)
B1	1137-15	20.193	1.067	0.886	0.012	0.030	0.072	—	0.84	0.16	—	—	Zhang & Franz (1987)
B1	1137-16	21.037	1.036	0.878	0.013	0.032	0.077	—	0.80	0.20	—	—	Zhang & Franz (1987)
B2	1137-17	19.950	1.140	0.851	0.016	0.039	0.094	—	0.83	0.17	—	—	Zhang & Franz (1987)
B2	1137-18	19.758	1.148	0.849	0.019	0.037	0.093	—	0.84	0.16	—	—	Zhang & Franz (1987)

Table 23 continued

Type	Fluid Nr.	Depth [m]	T_e [°C]	T_m (Ice) [°C]	T_m (Hydrate) [°C]	T_h (CO ₂) [°C]	P_h (CO ₂) [MPa]		T_h [°C]	P_h [MPa]		Salinity [mass%]		Na/(Na+Ca)	Salinity calculation
												NaCl	CaCl ₂		
B2	1137-19	LV	~-51	-42.1	—	—	—	—	111.4	0.5	LV→L	5.7	23.0	0.20	Oakes et al. (1990)
B2	1137-20	LV	~-51	-42.4	—	—	—	—	169.4	0.7	LV→L	5.2	23.8	0.18	Oakes et al. (1990)
C	1137-21	L	—	-56.9	—	2.8	0.9	LV→L	—	—	—	—	—	—	—
C	1137-22	L	—	-57.9	—	10.5	0.9	LV→L	—	—	—	—	—	—	—
C	1137-23	L	—	-59.3	—	-17.3	2.1	LV→L	—	—	—	—	—	—	—
A1	1138-1	LV	~-21	-0.7	—	—	—	—	250.4	3.6	LV→L	1.2	—	1	Bodnar (1993)
A1	1138-2	LV	~-21	-0.8	—	—	—	—	213.2	1.7	LV→L	1.4	—	1	Bodnar (1993)
A1	1138-3	LV	~-21	-0.8	—	—	—	—	370.0	19.8	LV→L	1.4	—	1	Bodnar (1993)
A1	1138-4	LV	~-21	-1.2	—	—	—	—	360.5	17.8	LV→L	2.1	—	1	Bodnar (1993)
A2	1138-5	LV	~-21	-4.3	—	—	—	—	220.3	2.0	LV→L	6.9	—	1	Bodnar (1993)
A2	1138-6	LV	~-21	-4.3	—	—	—	—	180.1	0.8	LV→L	6.9	—	1	Bodnar (1993)
A2	1138-7	LV	~-21	-4.4	—	—	—	—	191.4	1.0	LV→L	7.0	—	1	Bodnar (1993)
A2	1138-8	LV	~-21	-4.4	—	—	—	—	220.1	2.0	LV→L	7.0	—	1	Bodnar (1993)
A2	1138-9	LV	~-21	-4.4	—	—	—	—	118.9	0.5	LV→L	7.0	—	1	Bodnar (1993)
A2	1138-10	LV	~-21	-4.4	—	—	—	—	188.4	1.0	LV→L	7.0	—	1	Bodnar (1993)
A2	1138-11	LV	~-21	-4.5	—	—	—	—	184.8	0.9	LV→L	7.2	—	1	Bodnar (1993)
A2	1138-12	LV	~-21	-4.8	—	—	—	—	227.5	2.3	LV→L	7.6	—	1	Bodnar (1993)
A2	1138-13	LV	~-21	-4.9	—	—	—	—	180.8	0.8	LV→L	7.7	—	1	Bodnar (1993)
A2	1138-14	LV	~-21	-5.1	—	—	—	—	209.6	1.6	LV→L	8.0	—	1	Bodnar (1993)
A2	1138-15	LV	~-21	-5.2	—	—	—	—	218.1	1.9	LV→L	8.1	—	1	Bodnar (1993)
A2	1138-16	LV	~-21	-5.4	—	—	—	—	214.6	1.7	LV→L	8.4	—	1	Bodnar (1993)
A2	1138-17	LV	~-21	-5.4	—	—	—	—	208.6	1.5	LV→L	8.4	—	1	Bodnar (1993)
A2	1138-18	LV	~-21	-5.4	—	—	—	—	207.4	1.5	LV→L	8.4	—	1	Bodnar (1993)
A2	1138-19	LV	~-21	-5.4	—	—	—	—	199.5	1.2	LV→L	8.4	—	1	Bodnar (1993)
A2	1138-20	LV	~-21	-5.4	—	—	—	—	248.3	3.5	LV→L	8.4	—	1	Bodnar (1993)
A2	1138-21	LV	~-21	-5.5	—	—	—	—	210.2	1.6	LV→L	8.5	—	1	Bodnar (1993)
A2	1138-22	LV	~-21	-5.5	—	—	—	—	199.5	1.2	LV→L	8.5	—	1	Bodnar (1993)
A2	1138-23	LV	~-21	-5.5	—	—	—	—	190.0	1.0	LV→L	8.5	—	1	Bodnar (1993)
A2	1138-24	LV	~-21	-5.6	—	—	—	—	208.6	1.5	LV→L	8.7	—	1	Bodnar (1993)
A2	1138-25	LV	~-21	-5.7	—	—	—	—	208.8	1.5	LV→L	8.8	—	1	Bodnar (1993)
A2	1138-26	LV	~-21	-5.7	—	—	—	—	210.5	1.6	LV→L	8.8	—	1	Bodnar (1993)
A2	1138-27	LV	~-21	-5.7	—	—	—	—	220.2	2.0	LV→L	8.8	—	1	Bodnar (1993)
A2	1138-28	LV	~-21	-5.7	—	—	—	—	202.4	1.3	LV→L	8.8	—	1	Bodnar (1993)
A2	1138-29	LV	~-21	-5.7	—	—	—	—	214.6	1.7	LV→L	8.8	—	1	Bodnar (1993)
A2	1138-30	LV	~-21	-5.7	—	—	—	—	206.5	1.5	LV→L	8.8	—	1	Bodnar (1993)
A2	1138-31	LV	~-21	-6.0	—	—	—	—	214.2	1.7	LV→L	9.2	—	1	Bodnar (1993)

Type	Fluid Nr.	Bulk properties		Mole Fraction (total fluid inclusion)					Volume Fraction [at 20 °C]				EOS
		V_m [cm ³ /mol]	ρ [g/cm ³]	X_{H_2O}	X_{Na+}	X_{Ca2+}	X_{Cl-}	X_{CO_2}	φ_{liq}	φ_{vap}	φ_{aq}	φ_{CO_2}	bulk properties
B2	1137-19	19.371	1.185	0.845	0.016	0.041	0.098	—	0.86	0.14	—	—	Zhang & Franz (1987)
B2	1137-20	19.941	1.157	0.843	0.014	0.043	0.100	—	0.83	0.17	—	—	Zhang & Franz (1987)
C	1137-21	48.352	0.910	—	—	—	—	1.000	1.00	—	—	—	Duschek et al. (1990)
C	1137-22	51.330	0.857	—	—	—	—	1.000	1.00	—	—	—	Duschek et al. (1990)
C	1137-23	43.190	1.019	—	—	—	—	1.000	1.00	—	—	—	Duschek et al. (1990)
A1	1138-1	22.642	0.802	0.992	0.004	—	0.004	—	0.79	0.21	—	—	Zhang & Franz (1987)
A1	1138-2	21.140	0.860	0.992	0.004	—	0.004	—	0.85	0.15	—	—	Zhang & Franz (1987)
A1	1138-3	34.271	0.531	0.992	0.004	—	0.004	—	0.52	0.48	—	—	Zhang & Franz (1987)
A1	1138-4	31.888	0.573	0.988	0.006	—	0.006	—	0.56	0.44	—	—	Zhang & Franz (1987)
A2	1138-5	21.013	0.900	0.956	0.022	—	0.022	—	0.84	0.16	—	—	Zhang & Franz (1987)
A2	1138-6	20.131	0.940	0.956	0.022	—	0.022	—	0.88	0.12	—	—	Zhang & Franz (1987)
A2	1138-7	20.350	0.930	0.956	0.022	—	0.022	—	0.87	0.13	—	—	Zhang & Franz (1987)
A2	1138-8	21.002	0.902	0.956	0.022	—	0.022	—	0.84	0.16	—	—	Zhang & Franz (1987)
A2	1138-9	19.224	0.895	0.956	0.022	—	0.022	—	0.92	0.08	—	—	Zhang & Franz (1987)
A2	1138-10	20.290	0.933	0.956	0.022	—	0.022	—	0.87	0.13	—	—	Zhang & Franz (1987)
A2	1138-11	20.220	0.937	0.954	0.023	—	0.023	—	0.87	0.13	—	—	Zhang & Franz (1987)
A2	1138-12	21.168	0.898	0.952	0.024	—	0.024	—	0.83	0.17	—	—	Zhang & Franz (1987)
A2	1138-13	20.147	0.945	0.950	0.025	—	0.025	—	0.87	0.13	—	—	Zhang & Franz (1987)
A2	1138-14	20.722	0.920	0.950	0.025	—	0.025	—	0.85	0.15	—	—	Zhang & Franz (1987)
A2	1138-15	20.913	0.913	0.948	0.026	—	0.026	—	0.84	0.16	—	—	Zhang & Franz (1987)
A2	1138-16	20.825	0.919	0.946	0.027	—	0.027	—	0.84	0.16	—	—	Zhang & Franz (1987)
A2	1138-17	20.692	0.924	0.946	0.027	—	0.027	—	0.85	0.15	—	—	Zhang & Franz (1987)
A2	1138-18	20.667	0.926	0.946	0.027	—	0.027	—	0.85	0.15	—	—	Zhang & Franz (1987)
A2	1138-19	20.502	0.933	0.946	0.027	—	0.027	—	0.86	0.14	—	—	Zhang & Franz (1987)
A2	1138-20	21.698	0.882	0.946	0.027	—	0.027	—	0.81	0.19	—	—	Zhang & Franz (1987)
A2	1138-21	20.725	0.924	0.946	0.027	—	0.027	—	0.85	0.15	—	—	Zhang & Franz (1987)
A2	1138-22	20.501	0.934	0.946	0.027	—	0.027	—	0.86	0.14	—	—	Zhang & Franz (1987)
A2	1138-23	20.318	0.942	0.946	0.027	—	0.027	—	0.86	0.14	—	—	Zhang & Franz (1987)
A2	1138-24	20.688	0.926	0.944	0.028	—	0.028	—	0.85	0.15	—	—	Zhang & Franz (1987)
A2	1138-25	20.690	0.927	0.944	0.028	—	0.028	—	0.85	0.15	—	—	Zhang & Franz (1987)
A2	1138-26	20.727	0.926	0.944	0.028	—	0.028	—	0.85	0.15	—	—	Zhang & Franz (1987)
A2	1138-27	20.943	0.916	0.944	0.028	—	0.028	—	0.84	0.16	—	—	Zhang & Franz (1987)
A2	1138-28	20.558	0.933	0.944	0.028	—	0.028	—	0.85	0.15	—	—	Zhang & Franz (1987)
A2	1138-29	20.816	0.922	0.944	0.028	—	0.028	—	0.84	0.16	—	—	Zhang & Franz (1987)
A2	1138-30	20.642	0.929	0.944	0.028	—	0.028	—	0.85	0.15	—	—	Zhang & Franz (1987)
A2	1138-31	20.800	0.925	0.942	0.029	—	0.029	—	0.84	0.16	—	—	Zhang & Franz (1987)

Table 23 continued

Type	Fluid Nr.	Depth [m]	T_e	T_m (Ice)	T_m (Hydrate)	T_h (CO2)	P_h (CO ₂)	T_h	P_h	Salinity [mass%]		Na/(Na+Ca)	Salinity calculation	
			[°C]	[°C]	[°C]	[°C]	[MPa]	[°C]	[MPa]	NaCl	CaCl ₂			
A2	1138-32	LV	~-21	-6.6	—	—	—	198.5	1.2	LV→L	10.0	—	1	Bodnar (1993)
A2	1138-33	LV	~-21	-7.6	—	—	—	118.4	0.5	LV→L	11.2	—	1	Bodnar (1993)
A2	1138-34	LV	~-21	-7.7	—	—	—	150.0	0.5	LV→L	11.3	—	1	Bodnar (1993)
A2	1138-35	LV	~-21	-7.8	—	—	—	200.4	1.3	LV→L	11.5	—	1	Bodnar (1993)
A2	1138-36	LV	~-21	-7.8	—	—	—	184.7	0.9	LV→L	11.5	—	1	Bodnar (1993)
A2	1138-37	LV	~-21	-7.8	—	—	—	184.7	0.9	LV→L	11.5	—	1	Bodnar (1993)
A2	1138-38	LV	~-21	-7.8	—	—	—	150.0	0.5	LV→L	11.5	—	1	Bodnar (1993)
A2	1138-39	LV	~-21	-7.9	—	—	—	152.4	0.5	LV→L	11.6	—	1	Bodnar (1993)
A2	1138-40	LV	~-21	-7.9	—	—	—	173.9	0.7	LV→L	11.6	—	1	Bodnar (1993)
A3	1138-41	LV	~-21	-10.0	—	—	—	332.5	12.7	LV→L	13.9	—	1	Bodnar (1993)
A3	1138-42	LV	~-21	-10.0	—	—	—	370.0	19.8	LV→L	13.9	—	1	Bodnar (1993)
C	1138-43	L	—	-56.8	—	-11.0	2.6	LV→L	—	—	—	—	—	—
C	1138-44	L	—	-57.2	—	10.7	4.6	LV→L	—	—	—	—	—	—
D	1138-45	LL	—	-57.3	9.1	18.5	5.5	LV→L	330.0	—	LL→L	4.3	—	Duan et al. (1992)
C	1138-46	L	—	-57.6	—	10.7	4.6	LV→L	—	—	—	—	—	—
C	1138-47	L	—	-57.8	—	9.4	4.4	LV→L	—	—	—	—	—	—
C	1138-48	L	—	-57.9	—	10.6	4.6	LV→L	—	—	—	—	—	—
C	1138-49	L	—	-59.5	—	7.6	4.2	LV→L	—	—	—	—	—	—
C	1138-50	L	—	-59.5	—	-20.6	1.9	LV→L	—	—	—	—	—	—
C	1138-51	L	—	-60.1	—	-10.0	2.6	LV→L	—	—	—	—	—	—
D	1143-1	LL	—	-62.3	8.7	16.5	5.3	LV→L	dec	—	5.0	—	—	Duan et al. (1992)
D	1143-2	LL	—	-61.9	8.2	8.7	4.4	LV→L	dec	—	5.9	—	—	Duan et al. (1992)
D	1143-3	LL	—	-62.5	8.6	9.6	4.5	LV→L	dec	—	5.2	—	—	Duan et al. (1992)
D	1143-4	LLV	—	-61.5	7.6	22.6	6.1	LV→L	dec	—	6.9	—	—	Duan et al. (1992)
D	1143-5	LL	—	-59.9	9.3	9.6	4.5	LV→L	dec	—	3.9	—	—	Duan et al. (1992)
D	1143-6	LL	—	-60.0	7.7	19.9	5.7	LV→L	dec	—	6.8	—	—	Duan et al. (1992)
D	1143-7	LLV	—	-61.7	7.1	24.2	6.3	LV→L	dec	—	7.8	—	—	Duan et al. (1992)
D	1143-8	LL	—	-62.1	7.0	10.1	4.5	LV→L	dec	—	8.0	—	—	Duan et al. (1992)
D	1143-9	LL	—	-62.5	7.5	16.2	5.2	LV→L	dec	—	7.1	—	—	Duan et al. (1992)
D	1143-10	LL	—	-61.9	8.2	11.4	4.7	LV→L	dec	—	5.9	—	—	Duan et al. (1992)
D	1143-11	LL	—	-57.9	8.2	9.7	4.5	LV→L	dec	—	5.9	—	—	Duan et al. (1992)
D	1143-12	LL	—	-58.0	7.9	19.2	5.6	LV→L	dec	—	6.4	—	—	Duan et al. (1992)
D	1143-13	LL	—	-60.0	7.6	12.7	4.8	LV→L	dec	—	6.9	—	—	Duan et al. (1992)
D	1143-14	LL	—	-61.2	7.4	11.7	4.7	LV→L	dec	—	7.3	—	—	Duan et al. (1992)
D	1143-15	LL	—	-62.0	7.3	9.1	4.4	LV→L	dec	—	7.5	—	—	Duan et al. (1992)
A3	1143-16	LV	~-21	-5.4	—	—	—	321.0	10.9	LV→L	8.4	—	1	Bodnar (1993)

Table 23 continued

Type	Fluid Nr.	Bulk properties		Mole Fraction (total fluid inclusion)					Volume Fraction [at 20 °C]				EOS
		V_m [cm ³ /mol]	ρ [g/cm ³]	X_{H_2O}	X_{Na^+}	$X_{Ca^{2+}}$	X_{Cl^-}	X_{CO_2}	φ_{liq}	φ_{vap}	φ_{aq}	φ_{CO_2}	bulk properties
A2	1138-32	20.478	0.945	0.936	0.032	–	0.032	–	0.85	0.15	–	–	Zhang & Franz (1987)
A2	1138-33	19.336	1.010	0.928	0.036	–	0.036	–	0.90	0.10	–	–	Zhang & Franz (1987)
A2	1138-34	19.735	0.991	0.926	0.037	–	0.037	–	0.88	0.12	–	–	Zhang & Franz (1987)
A2	1138-35	20.519	0.954	0.926	0.037	–	0.037	–	0.85	0.15	–	–	Zhang & Franz (1987)
A2	1138-36	20.250	0.966	0.926	0.037	–	0.037	–	0.86	0.14	–	–	Zhang & Franz (1987)
A2	1138-37	20.250	0.966	0.926	0.037	–	0.037	–	0.86	0.14	–	–	Zhang & Franz (1987)
A2	1138-38	19.738	0.991	0.926	0.037	–	0.037	–	0.88	0.12	–	–	Zhang & Franz (1987)
A2	1138-39	19.773	0.990	0.926	0.037	–	0.037	–	0.88	0.12	–	–	Zhang & Franz (1987)
A2	1138-40	20.082	0.975	0.926	0.037	–	0.037	–	0.87	0.13	–	–	Zhang & Franz (1987)
A3	1138-41	23.984	0.831	0.910	0.045	–	0.045	–	0.72	0.28	–	–	Zhang & Franz (1987)
A3	1138-42	25.749	0.774	0.910	0.045	–	0.045	–	0.67	0.33	–	–	Zhang & Franz (1987)
C	1138-43	44.544	0.988	–	–	–	–	1.000	1.00	–	–	–	Duschkew et al. (1990)
C	1138-44	51.421	0.856	–	–	–	–	1.000	1.00	–	–	–	Duschkew et al. (1990)
D	1138-45	23.747	0.928	0.818	0.011	–	0.011	0.160	–	–	0.68	0.32	Duan et al. (1996)
C	1138-46	51.421	0.856	–	–	–	–	1.000	1.00	–	–	–	Duschkew et al. (1990)
C	1138-47	50.847	0.866	–	–	–	–	1.000	1.00	–	–	–	Duschkew et al. (1990)
C	1138-48	51.375	0.857	–	–	–	–	1.000	1.00	–	–	–	Duschkew et al. (1990)
C	1138-49	50.103	0.878	–	–	–	–	1.000	1.00	–	–	–	Duschkew et al. (1990)
C	1138-50	42.547	1.034	–	–	–	–	1.000	1.00	–	–	–	Duschkew et al. (1990)
C	1138-51	44.777	0.983	–	–	–	–	1.000	1.00	–	–	–	Duschkew et al. (1990)
D	1143-1	22.727	0.942	0.835	0.014	–	0.014	0.137	–	–	0.73	0.27	Duan et al. (1996)
D	1143-2	29.469	0.920	0.620	0.012	–	0.012	0.356	–	–	0.42	0.58	Duan et al. (1996)
D	1143-3	25.036	0.940	0.755	0.013	–	0.013	0.219	–	–	0.60	0.40	Duan et al. (1996)
D	1143-4	23.134	0.918	0.828	0.019	–	0.019	0.134	–	–	0.72	0.28	Duan et al. (1996)
D	1143-5	29.826	0.918	0.620	0.008	–	0.008	0.364	–	–	0.41	0.59	Duan et al. (1996)
D	1143-6	32.775	0.851	0.587	0.013	–	0.013	0.387	–	–	0.36	0.64	Duan et al. (1996)
D	1143-7	21.372	0.936	0.866	0.023	–	0.023	0.088	–	–	0.82	0.18	Duan et al. (1996)
D	1143-8	24.243	0.939	0.766	0.021	–	0.021	0.192	–	–	0.64	0.36	Duan et al. (1996)
D	1143-9	21.206	0.954	0.864	0.020	–	0.020	0.096	–	–	0.82	0.18	Duan et al. (1996)
D	1143-10	19.575	0.979	0.911	0.018	–	0.018	0.053	–	–	0.93	0.07	Duan et al. (1996)
D	1143-11	32.478	0.905	0.537	0.010	–	0.010	0.443	–	–	0.33	0.67	Duan et al. (1996)
D	1143-12	29.873	0.872	0.656	0.014	–	0.014	0.316	–	–	0.44	0.56	Duan et al. (1996)
D	1143-13	24.134	0.915	0.780	0.018	–	0.018	0.184	–	–	0.65	0.35	Duan et al. (1996)
D	1143-14	24.099	0.937	0.777	0.019	–	0.019	0.185	–	–	0.65	0.35	Duan et al. (1996)
D	1143-15	23.256	0.948	0.795	0.020	–	0.020	0.165	–	–	0.69	0.31	Duan et al. (1996)
A3	1143-16	24.667	0.775	0.946	0.027	–	0.027	–	0.71	0.29	–	–	Zhang & Franz (1987)

Table 23 continued

Type	Fluid Nr.	Depth [m]		T_e	T_m (Ice)	T_m (Hydrate)	T_h (CO2)	P_h (CO ₂)	T_h	P_h	Salinity [mass%]		Na/(Na+Ca)	Salinity calculation	
				[°C]	[°C]	[°C]	[°C]	[MPa]	[°C]	[MPa]	NaCl	CaCl ₂			
A3	1143-17		LV	~-21	-6.0	—	—	—	294.3	7.5	LV→L	9.2	—	1	Bodnar (1993)
A3	1143-18		LV	~-21	-5.8	—	—	—	289.8	7.0	LV→L	8.9	—	1	Bodnar (1993)
A3	1143-19		LV	~-21	-6.3	—	—	—	330.0	12.3	LV→L	9.6	—	1	Bodnar (1993)
A3	1143-20		LV	~-21	-5.9	—	—	—	290.1	7.0	LV→L	9.1	—	1	Bodnar (1993)
C	1143-21		L	—	-59.7	—	-13.4	2.4	LV→L	—	—	—	—	—	—
C	1143-22		L	—	-58.1	—	-10.7	2.6	LV→L	—	—	—	—	—	—
C	1143-23		L	—	-60.2	—	3.4	3.8	LV→L	—	—	—	—	—	—
C	1143-24		L	—	-59.6	—	1.7	3.6	LV→L	—	—	—	—	—	—
C	1143-25		L	—	-61.0	—	6.6	4.1	LV→L	—	—	—	—	—	—

Table 23 continued

Type	Fluid Nr.	Bulk properties		Mole Fraction (total fluid inclusion)					Volume Fraction [at 20 °C]				EOS
		V_m [cm ³ /mol]	ρ [g/cm ³]	X_{H_2O}	X_{Na+}	X_{Ca2+}	X_{Cl-}	X_{CO_2}	ϕ_{liq}	ϕ_{vap}	ϕ_{aq}	ϕ_{CO_2}	bulk properties
A3	1143-17	23.215	0.829	0.942	0.029	—	0.029	—	0.76	0.24	—	—	Zhang & Franz (1987)
A3	1143-18	23.075	0.832	0.942	0.029	—	0.029	—	0.76	0.24	—	—	Zhang & Franz (1987)
A3	1143-19	24.830	0.777	0.938	0.031	—	0.031	—	0.71	0.29	—	—	Zhang & Franz (1987)
A3	1143-20	23.066	0.833	0.942	0.029	—	0.029	—	0.76	0.24	—	—	Zhang & Franz (1987)
C	1143-21	44.007	1.000	—	—	—	—	1.000	1.00	—	—	—	Duschk et al. (1990)
C	1143-22	44.613	0.986	—	—	—	—	1.000	1.00	—	—	—	Duschk et al. (1990)
C	1143-23	48.555	0.906	—	—	—	—	1.000	1.00	—	—	—	Duschk et al. (1990)
C	1143-24	47.990	0.917	—	—	—	—	1.000	1.00	—	—	—	Duschk et al. (1990)
C	1143-25	49.713	0.885	—	—	—	—	1.000	1.00	—	—	—	Duschk et al. (1990)

Table 24, XRD analyses

Sample	05-ok-85	05-ok-91	05-ok-90	05-ok-88	05-ok-96	05-ok-97	05-ok-95	05-ok-93	05-ok-98	05-ok-99	05-ok-100	05-ok-101
Bt [mass%]	9.66	48.77	7.77	32.68	9.82	2.87	16.64	22.06	12.88	14.53	14.76	18.34
Qtz [mass%]	1.65	3.79	46.09	13.27	37.02	31.87	32.94	33.66	46.55	43.68	45.82	14.80
Al [mass%]	13.65	4.89	8.65	0.00	8.31	10.35	5.25	0.00	1.97	4.02	2.19	0.00
Chl [mass%]	13.64	4.95	4.67	0.00	12.74	11.58	8.44	0.00	1.88	2.28	1.41	1.33
Ms [mass%]	5.60	5.37	4.54	23.12	6.27	6.81	4.00	5.65	2.95	5.07	4.04	3.91
An25 [mass%]	40.58	30.06	21.03	13.65	10.10	6.84	0.00	35.22	19.35	25.46	24.75	57.98
Tr [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Po [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ccp [mass%]	0.00	0.00	0.00	0.00	0.00	1.63	0.00	0.00	0.00	0.00	0.00	0.00
Cal [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
An100 [mass%]	0.82	2.17	1.23	17.28	10.08	12.53	8.31	3.41	7.95	2.94	4.61	3.63
Dol [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lz [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or [mass%]	14.39	0.00	6.01	0.00	5.67	15.51	3.41	0.00	2.34	2.01	2.43	0.00
Tur [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mc [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
An50 [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	21.01	0.00	0.00	0.00	0.00	0.00
Hbl [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.14	0.00	0.00	0.00
Pen [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tlc [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mag [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fay [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Montmorillonite [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg Cal [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Summe [mass%]	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 24 continued

Sample	05-ok-38	05-ok-40	05-ok-42	05-ok-11	05-ok-13	05-ok-18	05-ok-19	05-ok-20	05-ok-23	05-ok-26	05-ok-30	05-ok-43
Bt [mass%]	15.63	14.53	18.66	4.23	18.81	1.15	0.00	0.00	0.00	0.00	14.09	4.63
Qtz [mass%]	33.94	44.92	37.70	8.54	35.14	1.72	0.00	0.00	18.18	0.00	1.67	36.46
Al [mass%]	0.00	0.00	0.00	1.21	3.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chl [mass%]	2.76	2.20	1.26	5.09	1.45	4.83	14.27	45.06	0.00	8.85	0.00	0.06
Ms [mass%]	3.87	3.00	3.87	3.27	0.88	3.34	0.00	0.00	0.00	0.00	0.00	6.27
An25 [mass%]	40.90	26.49	32.52	3.89	32.35	0.00	0.00	0.00	0.00	0.00	0.00	26.61
Tr [mass%]	0.00	0.00	0.00	62.22	0.00	55.09	38.20	0.00	12.61	0.00	51.60	0.00
Di [mass%]	0.00	0.00	0.00	2.56	0.00	3.41	1.32	0.00	65.21	0.00	0.00	0.00
Po [mass%]	0.00	0.00	0.00	6.04	1.45	6.62	0.00	0.00	1.04	0.00	0.00	5.93
Ccp [mass%]	0.00	0.43	0.00	0.18	0.00	0.00	0.00	0.00	0.88	0.00	1.15	0.86
Cal [mass%]	0.00	0.00	0.00	2.79	0.00	0.00	33.87	10.60	0.00	35.09	0.00	0.00
An100 [mass%]	2.91	8.44	1.70	0.00	6.63	0.00	0.00	0.00	0.00	0.00	0.00	6.69
Dol [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	52.46	3.42	0.00
Lz [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	43.02	0.00	3.60	13.97	0.00
Or [mass%]	0.00	0.00	4.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.49
Tur [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mc [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
An50 [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hbl [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pen [mass%]	0.00	0.00	0.00	0.00	0.00	2.53	0.00	0.00	0.00	0.00	0.00	0.00
Tlc [mass%]	0.00	0.00	0.00	0.00	0.00	21.33	0.00	0.00	0.00	0.00	0.00	0.00
Mag [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	6.88	1.32	0.00	0.00	2.02	0.00
Fay [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	5.47	0.00	0.00	0.00	0.00	0.00
Montmorillonite [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.09	0.00	0.00	0.00
Mg Cal [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.08	0.00
Summe [mass%]	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 24 continued

Sample	05-oku-45	05-oku-49	05-oku-55	05-oku-62	05-oku-66	05-oku-68	05-oku-73	05-oku-77	05-oku-79	05-oku-84	05-oku-82
Bt [mass%]	7.79	22.26	16.00	13.23	31.52	28.06	17.11	0.00	6.00	29.80	0.00
Qtz [mass%]	39.79	37.51	43.62	19.71	9.11	21.62	47.92	26.24	22.94	3.94	35.77
Al [mass%]	6.63	0.00	0.00	0.00	0.00	0.00	0.00	31.90	3.18	0.00	40.64
Chl [mass%]	0.37	1.01	1.33	0.11	0.16	0.00	0.00	0.00	0.00	0.00	0.00
Ms [mass%]	1.01	1.06	1.08	4.23	3.69	4.60	3.27	1.30	4.27	4.77	1.37
An25 [mass%]	17.99	28.29	30.50	19.13	51.69	42.40	29.88	10.73	25.02	57.69	20.11
Tr [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Po [mass%]	4.04	0.00	0.00	10.51	0.00	0.00	0.00	0.00	4.97	0.00	0.00
Ccp [mass%]	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cal [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
An100 [mass%]	1.80	4.16	2.88	6.00	3.83	3.33	1.83	1.16	2.33	3.80	2.11
Dol [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lz [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or [mass%]	5.42	5.71	4.58	26.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tur [mass%]	15.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mc [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.68	31.28	0.00	0.00
An50 [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hbl [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pen [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tlc [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mag [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fay [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Montmorillonite [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg Cal [mass%]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Summe [mass%]	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 25, main and trace element composition of selected samples along the drill core

Biotitgneis							biotite mica shist		
mass %	05-oku-90 689.8 m	05-oku-96 752.05 m	05-oku-97 758.5 m	05-oku-95 794.8 m	05-oku-100 1087.95 m	05-Oku-84 2340.3 m	mass %	05-oku-85 537.4 m	05-oku-91 584.55 m
SiO ₂	70.42	68.27	66.03	67.53	70.26	51.10	SiO ₂	49.44	42.22
Fe ₂ O ₃ (T)	5.06	5.86	4.66	6.13	5.34	9.47	Fe ₂ O ₃ (T)	8.64	14.65
TiO ₂	0.53	0.70	0.59	0.70	0.65	0.96	TiO ₂	1.17	1.16
Al ₂ O ₃	11.81	12.26	11.74	13.97	12.33	21.10	Al ₂ O ₃	21.82	21.02
MnO	0.06	0.08	0.06	0.07	0.07	0.12	MnO	0.10	0.14
MgO	2.25	2.49	2.01	2.81	2.07	4.09	MgO	3.83	6.42
CaO	2.26	2.19	4.74	2.46	3.25	3.62	CaO	3.48	1.83
Na ₂ O	2.79	2.11	2.36	2.77	2.20	4.52	Na ₂ O	4.25	2.23
K ₂ O	1.60	2.59	2.98	2.69	2.01	3.98	K ₂ O	3.13	5.97
P ₂ O ₅	0.12	0.14	0.06	0.14	0.15	0.07	P ₂ O ₅	0.13	0.05
SO ₃	0.11	0.10	0.55	0.15	0.31	0.04	SO ₃	0.10	0.13
LOI	1.74	2.13	4.42	0.72	1.21	0.52	LOI	4.03	2.52
Total	98.75	98.93	100.19	100.13	99.84	99.58	Total	100.12	98.34
ppm							ppm		
V	75.40	91.8	81.1	101.6	81.9	184.2	V	196.8	306.8
Cr	72.10	102.1	87.9	93	87.1	132.2	Cr	182.3	259
Co	71.90	71.6	34.2	67.7	79.9	43.4	Co	47.7	57.4
Ni	44.70	46.2	38.7	50.4	40.7	74.7	Ni	71.3	137.1
Cu	0.00	0	43.5	25.3	75.4	39.3	Cu	0	120.3
Zn	76.00	75.1	30.1	92.9	63	150.9	Zn	96.9	196.3
Ga	15.90	16.3	14.7	18.6	15.6	27	Ga	25.7	31
Ge	0.00	0	0	0	0	0	Ge	0	0
As	0.00	0	0	0	0	0	As	0	0
Se	0.00	0	0	0	1.5	0	Se	0	0
Rb	61.80	99.2	98.7	102.5	78	181	Rb	129.4	257.7
Sr	199.70	131.3	132.7	160.1	165.1	282.7	Sr	293.4	174
Y	0.00	21.1	20	0	20.1	30.1	Y	38.1	30.1
Zr	95.40	192.6	158.9	146.8	172.1	295.6	Zr	305.5	161.5
Nb	0.00	0	0	10	0	13.8	Nb	14.2	14.3
Mo	0.00	0	0	0	0	0	Mo	0	0
Ag	0.00	0	0	0	3.2	0	Ag	0	0
Sn	0.00	0	0	0	2.6	2.6	Sn	2.8	3
Sb	0.00	0	0	0	0	0	Sb	0	0
Ba	441.10	351.4	620.8	481	410.2	751.8	Ba	786.1	1054
La	24.10	34	29.4	28.6	30.6	50.7	La	57.2	53.3
Ce	0.00	65.9	58.2	57.6	62.1	107.9	Ce	112.3	106.6
Hf	0	0	0	6.4	6.2	7.8	Hf	9.4	5.3
W	637.3	620.4	248.3	534.7	628.9	122.4	W	153	65.4
Pb	18	0	0	12.1	10.5	22.3	Pb	19.5	18.6

Table 25 continued

biotite mica shist										
	05-ok-88	05-ok-93	05-ok-98	05-ok-99	05-ok-101	05-ok-38	05-ok-40	05-Ok-42	05-Ok-18	05-Ok-49
mass %	711.5 m	887.3 m	939.65 m	1052.9 m	1218.2 m	1275.8 m	1292.3 m	1310.2 m	1331.5 m	1630.55 m
SiO ₂	50.79	63.46	70.00	70.45	57.98	65.74	68.89	67.84	40.35	67.57
Fe ₂ O ₃ (T)	10.90	7.32	5.60	5.00	6.14	5.65	5.54	5.82	7.87	6.31
TiO ₂	0.95	0.75	0.59	0.59	0.82	0.67	0.64	0.67	6.17	0.70
Al ₂ O ₃	19.55	14.73	11.64	12.53	18.65	14.95	13.00	13.63	9.75	13.76
MnO	0.10	0.07	0.09	0.06	0.06	0.08	0.08	0.06	0.11	0.08
MgO	4.88	3.04	2.27	2.23	3.18	2.40	2.32	2.42	11.20	2.61
CaO	1.90	2.45	3.80	2.18	3.78	3.23	3.17	2.45	18.46	2.75
Na ₂ O	1.81	2.92	1.64	2.68	4.81	3.42	2.37	2.96	0.07	2.56
K ₂ O	5.71	2.99	1.79	2.16	2.49	2.26	2.15	2.26	0.32	2.52
P ₂ O ₅	0.09	0.10	0.15	0.13	0.02	0.36	0.15	0.13	0.20	0.12
SO ₃	0.06	0.06	0.40	0.12	0.17	0.31	0.38	0.07	1.50	0.07
LOI	1.78	0.80	0.83	1.40	0.92	0.61	0.95	0.46	2.73	0.22
Total	98.52	98.69	98.80	99.52	99.03	99.66	99.64	98.78	98.73	99.28
ppm										
V	224.9	118.4	82.3	78	116.2	90	81.1	91.3	259	103.8
Cr	192.2	113.3	81.4	78.6	112.2	90.3	85.2	97.7	235.1	99.8
Co	66	57.2	83.2	85.3	56.4	53.2	76.9	54.5	62.7	51.8
Ni	95.8	54.4	53.1	43.9	40.3	44.5	45.4	46.4	529	50.9
Cu	70.1	45.3	38.6	15.8	66	28.1	48.7	10.6	93.8	137.3
Zn	156.7	104.4	96.9	63.4	86.8	72.8	75.8	77.6	193.3	80.1
Ga	29.3	21.5	14	16	21.1	18.1	15.8	16.5	18.5	15.6
Ge	0	0	0	0	0	0	0	0	0	0
As	0	0	0	0	0	0	0	0	0	0
Se	0	0	1.2	0	1.2	0	0	0	1.4	0
Rb	205	117.8	79.1	82.3	91.1	87.1	83.3	83	24.5	114.7
Sr	157.4	242.5	162.9	179.5	242.6	215.7	149.4	191.8	81.1	156.4
Y	27	25.8	0	0	21.8	24.2	20.2	21.2	34.2	21.8
Zr	148.2	187.7	135.3	141.4	192.2	146.5	150.3	162.9	67.6	168.9
Nb	12.9	12.1	0	0	10.8	10.2	0	0	19.4	0
Mo	0	0	0	0	0	0	0	0	0	0
Ag	0	0	0	0	0	0	0	0	0	0
Sn	3	2.6	0	0	2.3	2.4	0	2.1	10.9	2.5
Sb	0	0	0	0	0	0	0	0	0	0
Ba	1340	662.2	258.7	462.1	609.9	432.9	480.9	424	31	418.8
La	41.5	34.5	31.6	23.6	37.9	29.7	27.7	30.4	22.7	32.6
Ce	86.6	70.3	58.1	0	78.4	59.4	57.9	61.1	0	62.8
Hf	0	6.7	0	5.2	5.9	5.7	6	5.9	0	6
W	208.8	386.7	658.1	755.4	332.3	417.4	637.5	344.1	87.8	335.8
Pb	19.4	19.3	11.2	12.1	18.3	13.8	13.6	14.6	0	12.4

biotite mica shist					
	05-Oku-55 1784.95 m	05-Oku-62 1845.5 m	05-Oku-66 1885.2 m	05-Oku-73 1966.2 m	05-Oku-79 2247.6 m
mass %					
SiO ₂	70.72	54.95	52.03	68.26	59.73
Fe ₂ O ₃ (T)	5.39	11.36	10.08	6.64	10.71
TiO ₂	0.59	0.73	1.00	0.66	0.70
Al ₂ O ₃	12.37	13.81	19.65	12.98	13.07
MnO	0.05	0.04	0.12	0.07	0.04
MgO	2.26	3.67	4.29	2.79	2.37
CaO	2.21	3.14	2.78	1.78	3.27
Na ₂ O	2.90	1.57	4.01	2.27	2.15
K ₂ O	2.16	5.98	4.43	2.97	3.69
P ₂ O ₅	0.10	0.09	0.13	0.13	0.14
SO ₃	0.08	0.27	0.01	0.05	0.05
LOI	0.22	3.06	0.60	0.59	3.12
Total	99.06	98.68	99.11	99.20	99.03
ppm					
V	88.1	362.5	186.9	100.4	145.6
Cr	81.5	141.6	180.2	93.9	116.4
Co	50.4	89.6	52.8	55.6	94
Ni	34.6	225.1	91.5	53.5	185
Cu	82.2	188.1	0	68.2	269.5
Zn	67.6	212.9	193.8	86.2	99.7
Ga	14.6	21.2	27.6	16.5	20.8
Ge	0	0	0	0	0
As	0	0	0	0	0
Se	0	10.1	0	0	14.7
Rb	84.2	288.6	458.1	107.3	126.3
Sr	192.3	472.9	232.1	130.1	231
Y	0	22.7	29.3	20.8	22.1
Zr	145.9	147.2	151.1	164.6	135.3
Nb	0	0	13.4	0	0
Mo	0	0	0	0	0
Ag	0	2.8	0	0	2.2
Sn	0	4.1	7.4	2.3	2.8
Sb	0	0	0	0	0
Ba	471.1	722.5	811.4	608.3	719
La	34.1	32.5	39.3	28.8	30
Ce	60.6	74.5	86.8	63.7	66.6
Hf	0	6.8	7.6	6.2	0
W	361.4	409.7	124	405.2	475.7
Pb	15.8	23.2	19.7	15.3	14.7

Table 25 continued

Pegmatite			
	05-Oku-53 1658.3 m	05-Oku-59 1814.6 m	05-Oku-77 2007.3 m
mass %			
SiO ₂	74.34	73.16	73.51
Fe ₂ O ₃ (T)	0.36	0.36	0.43
TiO ₂	0.01	0.01	0.01
Al ₂ O ₃	14.83	14.82	14.90
MnO	0.07	0.02	0.03
MgO	0.02	0.02	0.02
CaO	0.47	0.72	0.70
Na ₂ O	5.42	4.97	4.68
K ₂ O	4.12	4.42	5.13
P ₂ O ₅	0.02	0.02	0.04
SO ₃	0.03	0.01	0.01
LOI	-0.03	-0.06	-0.17
Total	99.66	98.48	99.27
ppm			
V	0	0	0
Cr	0	0	0
Co	69.9	55.4	54.1
Ni	0	0	0
Cu	0	0	0
Zn	24.3	23.8	31
Ga	35.9	31.4	28
Ge	0	0	0
As	0	0	0
Se	1	1.2	1.1
Rb	321.8	248	260.2
Sr	13.4	10.5	0
Y	0	60.1	75
Zr	0	41.8	74.8
Nb	11	10.8	11.7
Mo	0	0	0
Ag	0	0	0
Sn	2.4	2.3	0
Sb	0	0	0
Ba	22.9	25.3	10.8
La	13.7	18.9	25.6
Ce	0	0	0
Hf	5.4	6.9	6.5
W	953.6	763.7	738.7
Pb	31.8	54.9	62.6

Quartzite	
	05-Oku-34
mass %	1443.2 m
SiO ₂	31.41
Fe ₂ O ₃ (T)	3.36
TiO ₂	0.09
Al ₂ O ₃	6.59
MnO	0.14
MgO	6.18
CaO	26.53
Na ₂ O	0.06
K ₂ O	1.90
P ₂ O ₅	0.10
SO ₃	1.16
LOI	21.68
Total	99.19

ppm	
V	108.2
Cr	198.7
Co	25.8
Ni	267.5
Cu	0
Zn	10.9
Ga	13.8
Ge	0
As	13.8
Se	1.3
Rb	123.1
Sr	118.1
Y	0
Zr	31.7
Nb	0
Mo	0
Ag	2.4
Sn	2.9
Sb	0
Ba	34.5
La	38.1
Ce	58.6
Hf	0
W	191
Pb	0

black shist	
	05-Oku-43
mass %	1505.55 m
SiO ₂	59.63
Fe ₂ O ₃ (T)	6.26
TiO ₂	0.62
Al ₂ O ₃	11.32
MnO	0.05
MgO	3.62
CaO	3.63
Na ₂ O	2.96
K ₂ O	2.01
P ₂ O ₅	0.12
SO ₃	0.39
LOI	8.38
Total	98.97

ppm	
V	352.8
Cr	108.2
Co	98.2
Ni	159.1
Cu	223.7
Zn	1215
Ga	15.9
Ge	0
As	0
Se	8.8
Rb	96.3
Sr	125.5
Y	26.4
Zr	131.1
Nb	0
Mo	31.2
Ag	0
Sn	0
Sb	0
Ba	295.8
La	36.1
Ce	62.9
Hf	0
W	671.8
Pb	0

Table 25 continued			
Serpentinite			
	05-Oku-20	05-Oku-26	05-Oku-30
mass %	1374.9 m	1395.2 m	1434 m
SiO ₂	36.45	6.78	40.38
Fe ₂ O ₃ (T)	5.53	3.01	6.23
TiO ₂	0.06	0.03	0.06
Al ₂ O ₃	0.02	0.16	0.02
MnO	0.07	0.19	0.10
MgO	37.36	16.43	30.15
CaO	4.57	33.74	9.83
Na ₂ O	0.03	0.03	0.04
K ₂ O	0.05	0.01	0.01
P ₂ O ₅	0.02	0.17	0.06
SO ₃	1.96	1.69	4.61
LOI	13.58	36.84	7.97
Total	99.70	99.08	99.47
ppm			
V	29	0	0
Cr	1366	934.6	1093
Co	61.6	0	71.7
Ni	1747	738.7	1756
Cu	0	11.2	12.1
Zn	36.2	27.3	43.4
Ga	0	0	0
Ge	0	0	0
As	13.4	0	0
Se	0	0	0
Rb	0	0	0
Sr	0	52.5	13.7
Y	0	0	0
Zr	0	0	0
Nb	0	0	0
Mo	0	0	0
Ag	0	0	0
Sn	0	0	2.5
Sb	0	0	0
Ba	10.3	13.7	10.3
La	13.6	14.6	13
Ce	0	0	0
Hf	0	0	0
W	0	21.8	25.9
Pb	0	0	0

Skarn rock				
	05-Oku-19 1360.15 m	05-Oku-23 1381.6 m	05-Oku-41 1487.45 m	05-Oku-33 1442.5 m
mass %				
SiO ₂	27.00	55.24	77.83	70.71
Fe ₂ O ₃ (T)	6.28	3.84	3.62	4.83
TiO ₂	0.12	0.04	0.04	0.04
Al ₂ O ₃	2.20	2.41	0.02	0.02
MnO	0.09	0.10	0.04	0.05
MgO	17.93	13.97	6.67	7.18
CaO	23.13	20.46	9.83	8.14
Na ₂ O	0.07	0.11	0.04	0.04
K ₂ O	0.01	0.01	0.01	0.02
P ₂ O ₅	0.10	0.12	0.04	0.08
SO ₃	1.61	1.40	0.71	3.96
LOI	17.28	0.52	0.05	3.48
Total	95.81	98.23	98.89	98.55
ppm				
V	50.5	24.4	27.7	0
Cr	12280	1467	1420	180.6
Co	233.9	83.2	135.7	121.3
Ni	5462	1570	1841	1113
Cu	376.3	45.6	42.6	61.4
Zn	66.8	99.8	71.7	123.5
Ga	0	5.5	0	0
Ge	0	0	0	0
As	49.9	0	0	40.3
Se	3.2	2.3	2.1	3.3
Rb	0	0	0	0
Sr	49.4	18.9	11.1	12.1
Y	27.8	0	0	0
Zr	123.2	0	0	0
Nb	0	0	0	0
Mo	0	0	0	0
Ag	0	0	2.2	0
Sn	2.3	2.4	0	0
Sb	0	0	0	0
Ba	11.7	11.3	10.3	10.4
La	16.9	14.2	14	12.9
Ce	0	0	0	0
Hf	0	0	0	0
W	46.4	324.8	1031	799.8
Pb	0	0	0	0

Table 25 continued
Turmalinite

	05-Oku-45 1561.9 m
mass %	
SiO ₂	67.65
Fe ₂ O ₃ (T)	7.63
TiO ₂	0.72
Al ₂ O ₃	13.62
MnO	0.03
MgO	3.07
CaO	1.68
Na ₂ O	2.90
K ₂ O	0.93
P ₂ O ₅	0.14
SO ₃	0.10
LOI	0.36
Total	98.85
ppm	
V	117.2
Cr	97.6
Co	100.2
Ni	56.5
Cu	209.3
Zn	47.3
Ga	20.6
Ge	0
As	0
Se	8.7
Rb	31.2
Sr	126.1
Y	20
Zr	199.7
Nb	0
Mo	0
Ag	0
Sn	0
Sb	0
Ba	181.2
La	36.9
Ce	69.1
Hf	5.5
W	705.2
Pb	14.1

Table 26, Oxygen isotopes of quartz and biotite

Sample	$\delta^{18}\text{O}$ quartz [‰]	$\delta^{18}\text{O}$ biotite [‰]
05-OKU-91	12,6	6,9
05-OKU-91	12,0	6,7
05-OKU-88	12,8	7,6
05-OKU-88	12,5	7,5
05-OKU-93	12,5	7,9
05-OKU-93	12,8	7,6
05-OKU-22	12,1	6,5
05-OKU-22	12,6	7,5

Table 27, Hydrogen isotopes and water content of biotite samples

Sample	δD VSMOW [‰]	mass% water
05-OKV-91	-51	3,63
05-OKV-91	-51	3,52
05-OKV-88	-57	4,06
05-OKV-88	-56	3,89
05-OKV-93	-66	3,53
05-OKV-93	-65	3,47
05-OKV-22	-60	3,49
05-OKV-22	-60	3,26

Table 28, Hydrogen isotopes of fluid inclusions

Sample	δD VSMOW [‰]
05-OKU-10	-56,2
05-OKU-91	-58,9
05-OKU-88	-74
05-OKU-93	-64,1
05-OKU-94	-35,2
05-OKU-98	-46,3
05-OKU-99	-39,1
05-OKU-100	-69,3
05-OKU-101	-48,7
05-OKU-38	-36,7
05-OKU-39	-32,2
05-OKU-40	-56,5
05-OKU-42	-24,4
05-OKU-13	-18,5
05-OKU-22	-22,9
05-OKU-55	-22,2
05-OKU-70	-39,9
05-OKU-81	-29,6

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June 2007	Graduation of the study (Dipl. Ing.) with distinction
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October 2000 – June 2007	Course of study “Applied Geosciences” focus on economic geology and mineralogy at the University of Leoben
June 1999	High school graduation (Matura) at the “Aufbau- und Realgymnasium der Salesianer Don Boscos, Unterwaltersdorf (Austria)”

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