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STRATIGRAPHIC AND METAMORPHIC CONSTRAINTS
ON THE TECTONIC EVOLUTION OF THE VALHALLA COMPLEX.

SOUTHERN BRITISH COLUMBIA

by

PETER M. SCHAUBS, B.Sc. (Hons.)

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of
Master of Science

Department of Earth Sciences

Carleton University

Ottawa, Ontario

1995

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ON THE TECTONIC EVOLUTION OF THE VALHALLA COMPLEX,
SOUTHERN BRITISH COLUMBIA"

submitted by Peter M. Schaub, B.Sc. (Hons.)
in partial fulfilment of the requirements for
the degree of Master of Science

Thesis Supervisor

Chair, Department of Earth Sciences

Carleton University

December 1995

Frontispiece

View of Lucifer Peak, looking north across the Gwillim Lakes.

Abstract

The Valhalla complex is an exhumed metamorphic core complex situated within the southern Omineca belt of the Canadian Cordillera. Sheets of upper amphibolite-facies paragneiss occur at three structural levels, one of which (1c) lies in the hanging wall of the Gwillim Creek shear zones, while two windows are exposed in the footwall (1a and 1b). The Valhalla assemblage is a heterogeneous package of metasedimentary rocks which lies in the uppermost paragneiss sheet and includes semipelitic and psammitic schist, marble, calc-silicate gneiss, quartzite, quartzite-cobble metaconglomerate, pelitic schist, amphibolite gneiss and ultramafic boudins. Lithologic similarity of the Valhalla assemblage with rocks in the Goat Ranges, in the Kootenay Arc, permits a tentative correlation with the Badshot Formation, Lardeau Group and Milford Group. The Valhalla assemblage comprises the upside down limb of an isoclinally folded F_1 recumbent nappe which was subsequently thinned by up to 80% as result of east directed compressional tectonics and movement on the Gwillim Creek shear zones. Based on similar hanging-wall stratigraphies, the Gwillim Creek shear zones may be correlated with the West Bernard fault, in the Kootenay Arc. It is also possible that the Gwillim Creek shear zones are correlative with a structure that is imaged by seismic reflections and forms the roof of a duplex, east of the Valhalla complex, which is floored by the basal décollement of the Rocky Mountain fold and thrust belt.

Petrographic observations reveal that the peak of metamorphism was synchronous with the dominant S_2 foliation and that different structural sheets share a common metamorphic history. S_2 fabric development at high structural levels is synchronous with fabrics associated with the Gwillim Creek shear zones, at structurally low levels. The

Gwillim Creek shear zones were active at the peak of metamorphism (~75 Ma) and resurface in the southern region of the Valhalla complex near Vallican. Petrographic observations and thermobarometric results indicate that peak thermal conditions were approximately 775 °C and 6.5 - 7 kbars in the structurally highest domain. Structurally low levels are characterized by a large variation in thermobarometric data and some anomalously high values, when compared to data from the structurally highest paragneiss sheet (1c). The high values recorded by samples in these sheared areas may be the result of disequilibrium caused by the introduction of fluids or the juxtaposition, by shearing, of minerals that were not in chemical equilibrium.

A period of decompression, which occurred during the Late Cretaceous, is recorded by plagioclase moats and different closure temperatures of the GASP and GRAIL geobarometers. This may be a response to exhumation due to movement along the underlying Monashee décollement. Rare evidence of retrograde metamorphism indicates that paragneisses of the Valhalla complex were exhumed quickly, following the peak of metamorphism.

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Original Contribution

This project was based on field work carried out by the author in the last week of August, 1993 and from mid-June to the end of August, 1994. Original contributions include the detailed mapping of a package of paragneisses in the Valhalla complex, which were subdivided, named and correlated to outlying sequences in the southern Omineca belt. Metamorphic petrology was carried out on semipelitic to pelitic schists, amphibolite gneisses, carbonate rocks and ultramafic schists. Quantitative mineral analyses were obtained for pelitic schists and amphibolite gneisses which were used in thermobarometric calculations. The combination of detailed stratigraphic data, metamorphic and deformational relationships observed in thin-section, and thermobarometric data has resulted in an interpretation of the pre-Eocene tectonic evolution of the Valhalla complex and has also placed constraints on the timing and displacement direction of the Gwillim Creek shear zones.

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CHAPTER 1: INTRODUCTION AND OBJECTIVES

The Valhalla complex is a 30 by 90 km structural culmination which lies in the southern portion of the Omineca belt and is contained within the larger Shuswap metamorphic complex (Fig. 1.1). In the Valhalla complex, arched sheets of paragneiss, granitic rocks and intervening thrust faults (Figs. 1.2, 1.3) were exhumed on the Eocene Slocan Lake fault (SLF) -Valkyr shear zone (VSZ) extensional fault system (Carr *et al.* 1987). The Gwillim Creek shear zones (GCSZ) in the Valhalla complex are two ~ 50 m thick horizons of significant ductile strain which occur in the deepest exposed structural levels of the complex. The duplication of geology and the apparent easterly-directed shear sense has led to the interpretation that the shear zones are east verging thrust faults (Parrish *et al.* 1985; Parrish *et al.* 1988).

The Valhalla complex provides a case study for the evolution of tectonic models of the region. In the 1960's, Reesor (1965, 1970) viewed granitic rocks in the complex as Precambrian basement gneisses and believed that the complex had developed as a mantled gneiss dome. Parrish (1984) recognized the Slocan Lake Fault on the east side of the complex as a major extensional structure, and later Carr (1986), Carr and others (1987) and Parrish and others (1988) revealed that the present configuration of the Valhalla complex is a result of Eocene exhumation and that granitic rocks in the Valhalla complex are no older than Cretaceous. Parrish and others (1988) described the Gwillim Creek shear zones, in the deepest structural levels of the complex, and interpreted them to be Cretaceous or younger easterly directed thrust faults that were possibly linked to the Foreland belt. It has been

demonstrated that kinematic links exist between thrust faults in the Omineca belt and those in the Foreland fold and thrust belt (Price 1981; Brown and Read 1983; Brown *et al.* 1986; Price 1986; Brown and Journeay 1987; Parrish *et al.* 1988; Brown *et al.* 1991; Brown *et al.* 1993; Parrish 1995; Carr 1995). Parrish (1995) summarizes U-Pb geochronology studies, and presents data from the southern Omineca belt which indicate that the age of deformation and peak of metamorphism decreases going down structural section. In this model, west verging in-sequence thrusting during the Mesozoic progressively thickened the crust and placed hot thrust sheets onto cool footwalls. Peak thermal ages of ~ 75 Ma have been estimated by Heaman and Parrish (1991) for the Valhalla complex and it has been inferred that the Valhalla complex lies at mid-crustal levels above the Monashee complex, which records thermal peaks at ~ 55 Ma (Parrish 1995).

New insights have been gained from geological research programs in the southern Omineca belt including the southern Cordillera Lithoprobe seismic program (Cook *et al.* 1987; Cook *et al.* 1988; Cook *et al.* 1992). Advances in the understanding of the regional geology in the southern Omineca belt as a result of geochronological studies (Archibald *et al.* 1983; Archibald *et al.* 1984; Carr *et al.* 1987; Parrish *et al.* 1988; Carr 1992; Scammell 1993), mapping, and structural studies of faults (Höy 1977; 1980, Klepacki 1985; Carr *et al.* 1987; Corbett and Simony 1984; Simony *et al.* 1992; Bardoux 1993; Johnson 1994), together with seismic reflection data, have set the stage for new regional reconstructions.

The focus of this study is directed toward the pre-Eocene deformation history of the northern part of the complex, and the stratigraphy and metamorphic history of paragneiss sheets that occur at three different structural levels. The aim is to build on the extensive

geochronological, petrological and structural studies of the Valhalla complex and combine this information with new stratigraphic correlations and thermobarometric data to constrain the timing, magnitude and direction of displacement on the GCSZ, in order to develop a new model for the tectonic evolution of the Valhalla complex. This will constrain future palinspastic reconstructions linking the Omineca and Foreland belts.

In order to consider correlation of the GCSZ to faults in the Foreland fold and thrust belt, the hanging wall - footwall relationships and lithologies must be known. Based on detailed hanging wall stratigraphy and Lithoprobe seismic reflection data, the primary objectives of this study are: 1) to describe the heterogeneous package of paragneisses within the Valhalla complex and to compare them with the regional stratigraphy; 2) to attempt to correlate the Gwillim Creek shear zones with faults to the east in the Kootenay Arc and Purcell Anticlinorium.

The presence of pelitic schists within the paragneiss sheets, which occur at three different structural levels in the Valhalla complex, facilitates a comparison of metamorphic conditions at the three structural levels. The wide range in bulk compositions represented by pelitic schists, mafic gneisses, marbles, calc-silicate gneisses and ultramafic schists and variation within lithologies allows the application of a variety of geothermometers and barometers in order to try to establish pressure-temperature conditions. Careful observations of the relationship between metamorphic minerals, reaction textures and deformation will allow the linkage of quantitative data to the geologic history. Further objectives of this study are, therefore: 1) to characterize the metamorphism of paragneisses at different structural levels and in different domains; 2) to establish pressure-temperature paths, or parts thereof,

for the paragneisses of the Valhalla complex; 3) to determine if there is any variation in thermal histories across the Gwillim Creek shear zones by examining the differences in pressure or temperature conditions between the upper and lower sheets of paragneiss; and 4) to combine resultant data with published thermo- and geochronological studies.

Figure 1.1 a) Tectonic Assemblage map of the southern Omineca Belt, simplified from Wheeler and McFeely (1991) and modified after Carr (1991) and Johnson (1994). Important tectonic elements include the Adams Lake-Clearwater-Vavenby area (ACV), the Goat Ranges (GR), the Greenwood-Grandforks area (GGF), the Malton complex (MA), the Monashee complex (MO), the Nemo Lakes belt (NL), the Pinnacles area (P), the Riondel Nappe (RN), the Scrip Nappe (SN), Thor-Odin dome (TO) and the Valhalla Complex (VC). Important plutons include the Fry Creek batholith (FC), the White Creek batholith (WC) and the Whatshan batholith (W). Thrust faults include the Hall Lake fault (HLF), the Monashee décollement (MD), the Moyie fault (MF), the St. Mary fault (SMF) and the West Bernard fault (WBF). Normal faults include the Columbia River fault (CRF), the Okanagan Valley fault (OF), the North Thompson fault (NTF), the Slocan Lake fault (SLF), and the Valkyr shear zone (VSZ).

Figure 1.1 b) Terrane map of the southern Omineca Belt, simplified after Wheeler and others (1991).

Figure 1.1 c) Morphogeological belts of the Canadian Cordillera.

Figure 1a. Tectonic assemblage map of the southern Omineca Belt.

Figure 1b. Terrane map of the southern Omineca Belt.
Modified after Wheeler and others (1991).

Upper Plate

- Middle Eocene Coryell syenite, granite
- Eocene College Creek granite
- Late Cretaceous granitic rocks
- Middle Jurassic granitic rocks
- Middle Paleozoic - Early Mesozoic rocks of allochthonous Quesnallia terrane
- Paragneiss - age uncertain

Valhalla complex (Lower Plate)

- Early Eocene Ladybird granite
- Paleocene Airy Quartz Monzonite
- Late Cretaceous Mulvey granodiorite
- Late Cretaceous Kinnaird Gneiss
- Middle Devonian Trail Gneiss
- Valhalla Assemblage
- Castlegar Gneiss

Thrust fault

Slocan Lake fault

Steep normal fault

Valkyr shear zone

Geologic contact

GCSZ Gwillim Creek shear zones

CRF Columbia River Fault

Figure 1.2. Geology of the Valhalla complex. Modified after Carr et al. 1987 and P. Simony (unpublished data).

Figure 1.3. Generalized cross-section of the Valhalla Complex. Adapted from Parrish et al. (1988).

CHAPTER 2: GEOLOGIC SETTING AND STRATIGRAPHY OF THE VALHALLA ASSEMBLAGE

2.1 Introduction

The Canadian Cordillera may be described in terms of five morphogeological belts (Monger *et al.* 1982): 1) the Rocky Mountain foreland thrust and fold belt; 2) the Omineca belt; 3) the Intermontane belt; 4) the Coast plutonic belt; and 5) the Insular belt (Fig. 1.1a). The Omineca belt is the metamorphic and plutonic hinterland of the Foreland thrust and fold belt and was formed in conjunction with the docking of the Intermontane Superterrane to the North American craton during the Mesozoic to Early Cenozoic crustal shortening and thickening (Monger *et al.* 1982).

The Valhalla complex lies in the southern Omineca belt within the Shuswap metamorphic complex. Geological entities to the east of the Valhalla complex include the Nelson batholith, Kootenay Arc and Purcell Anticlinorium. The middle Jurassic Nelson batholith is bordered on the east and south by the Kootenay Arc (Fig. 1.1b) which is an east-facing arcuate feature comprising sedimentary and volcanic rocks of the Kootenay terrane and marginal basin rocks of the Slide Mountain terrane (Archibald *et al.* 1983; Archibald *et al.* 1984; Roback *et al.* 1994). The east side of the Kootenay Arc forms the west flank of the Purcell anticlinorium, a north-plunging asymmetrical fold cored by the (Belt) Purcell Group (Gabrielse comp. 1991). On the west side the Valhalla complex, adjacent geology includes Jurassic and Cretaceous plutons, the Thor-Odin - Pinnacles area, and allochthonous metasedimentary and metavolcanic rocks of the Quesnellia terrane, some of which are in the

upper plate of extensional faults systems (see Parrish *et al.* 1988).

This chapter presents the regional stratigraphy of the southern Omineca belt in order to provide a framework to compare the stratigraphy and deformation style of paragneisses of the Valhalla complex. Emphasis is placed on the stratigraphy and structural style of the Goat Ranges, Riondel Nappe and the Scrip Nappe (Fig. 1.1). A description of the stratigraphy of paragneisses in the Valhalla complex is followed by correlations to appropriate areas.

2.2 Regional stratigraphy of the southern Omineca belt

In the southern Omineca belt the Mesoproterozoic Purcell Supergroup (Fig. 1.1c) is the oldest package of sedimentary rocks and rests upon the North American basement. It comprises a sequence of shallow-marine and non-marine rocks that overlie a sequence of fine-grained, basinal clastic rocks in the west, and platformal clastic and carbonate rocks in the east (Aitken and McMechan 1991). The Neoproterozoic Windermere Supergroup lies unconformably on the (Belt) Purcell Supergroup and was deposited between 780 and 570 Ma (Gabrielse and Campbell 1991). The presence of rapid facies changes and a large variety of sedimentary rocks has led to the interpretation that the Windermere Supergroup formed adjacent to, and on the rifted western margin of ancestral North America (Stewart 1972; Ross 1991). During the Neoproterozoic and Cambrian, quartzites of the Hamill Group and carbonates of the Badshot Formation were deposited unconformably on the Windermere Supergroup (Reesor 1973; Read and Wheeler 1976; Fritz *et al.* 1991). These shallow-water platformal rocks make up the upper part of the North American miogeocline (Fig. 2.1).

The Kootenay terrane was deposited to the west of what has been generally agreed upon to be miogeoclinal rocks, and separates the shallow-water platformal rocks of the miogeocline from accreted rocks of the Intermontane Superterrane (Archibald *et al.* 1983; Klepacki 1985). The Kootenay terrane consists mostly of coarse clastic and volcanic rocks of the Lardeau Group and part of the Eagle Bay assemblage, which have been interpreted to lie conformably on the Badshot Formation and are depositionally linked to the miogeocline (Price 1981; Colpron and Price 1995). Due to its similarity to grits in the Windermere Supergroup, Wheeler (1966) suggested that the Lardeau Group is part of an allochthonous slice of Windermere strata. Later, Wheeler and others (1991) proposed that the Kootenay terrane was suspect and therefore it should be designated a pericratonic terrane. Smith and Gehrels (1992a) suggested that the Lardeau Group was tectonically inverted and thrust over the Badshot Formation, based on correlations with the lithologically similar Covada Group in the southern Kootenay arc. Finally, Colpron and Price (1995) propose that the change from shallow-water sedimentary rocks of the miogeocline to coarse clastic and mafic volcanic rocks of the Lardeau Group represents episodic periods of extensional rifting which occurred during the early Paleozoic.

The Kootenay terrane also includes the Davis and Keen Creek assemblages of the Carboniferous Milford Group (Fig. 2.1), which lie unconformably on, but are depositionally linked to the Lardeau Group (Klepacki 1985; Roback *et al.* 1994). The Slide Mountain terrane is a marginal basin that, together with the overlying accreted Quesnellia terrane, was obducted onto the Kootenay terrane and miogeocline (Monger 1977; Monger *et al.* 1982; Klepacki 1985). In the southern Omineca belt, the Slide Mountain terrane consists of the

McHardy assemblage of the Milford Group and overlying Permian volcanic rocks of the Kaslo Group (Klepacki 1985). The Keen Creek and Davis assemblages of the Milford Group are included in the Kootenay terrane and are in fault contact with the McHardy assemblage (Klepacki 1985). The presence of the Milford Group in both the Kootenay and Slide Mountain terranes depositionally links the two (Fig. 2.1) and limits the distance of the Slide Mountain terrane from ancestral North America (Klepacki 1985; Roback *et al.* 1994). Kaslo Group volcanics were extruded within an ocean ridge, which was proximal to the margin of North America, and probably also represents the eastern margin of a Permian marginal basin (Roback *et al.* 1994).

Permian sedimentary and volcanic rocks of the Mount Roberts Formation and Triassic sedimentary rocks of the Slocan Group lie unconformably on the Kaslo Group, belong to the Quesnellia terrane and represent a thick section of deep-water sediment which were deposited in a marginal basin.

2.3 Geology of the Valhalla complex

2.3.1 General geology

In the Valhalla complex, arched sheets of upper amphibolite-facies paragneiss, granitic rocks and intervening thrust faults (Gwillim Creek shear zones) were exhumed due to extensional faulting (Carr *et al.* 1987; Parrish *et al.* 1988). The Gwillim creek shear zones (GCSZ) have been interpreted to be part of a thrust fault system that links the Omineca belt and the Foreland belt (Cook *et al.* 1988, 1992; Parrish *et al.* 1988). The Valhalla complex

was exhumed from mid-crustal depths by approximately 15 km of extensional displacement on the Slocan Lake (SLF) -Valkyr (VSZ) fault system during Early Eocene time (Figs. 1.2, 1.3; Carr *et al.* 1987). The lower plate high-grade rocks of the Valhalla complex were juxtaposed against upper plate greenschist to amphibolite-facies metasedimentary rocks of the Quesnellia terrane and granitic rocks of the Nelson batholith (Fig. 1.2). The 159-175 Ma Nelson batholith (Parrish and Wheeler 1983) in the hanging wall of the SLF cooled below $\sim 500^{\circ}\text{C}$ during the Jurassic and late Cretaceous and was generally below 300°C when the Valhalla complex was at its metamorphic peak (Carr *et al.* 1987).

Three sheets of paragneiss (Figs. 1.2, 1.3) in the Valhalla complex are separated by sheets of granitoid rocks. The lowest paragneiss sheet (1a) is exposed in a window at the deepest structural level of the complex in the footwall of the GCSZ. The middle sheet (1b) is under- and overlain by the ~ 110 Ma Mulvey granodiorite gneiss. The lower contact is intrusive and the upper contact is the upper strand of the GCSZ. The uppermost sheet (1c) is sandwiched between the Mulvey granodiorite gneiss below and the 63 Ma Airy quartz monzonite and the 59-56 Ma Ladybird granite above (Carr *et al.* 1987). The uppermost sheet has been polydeformed by at least three periods of folding (Parrish *et al.* 1985; Carr *et al.* 1987). The southern part of the complex (Fig. 1.2) consists of heterogeneous quartzofeldspathic Castlegar paragneiss, Late Cretaceous leucocratic hornblende $\pm$ biotite Kinnaird orthogneiss, and the Devonian Trail amphibolitic gneiss (Simony 1979; Halwas and Simony 1986; Simony and Armstrong 1990).

The GCSZ constitute sheared contacts between the two windows of paragneiss and the overlying Mulvey granodiorite gneiss, with an apparent easterly sense of displacement

(Parrish *et al.* 1988). The GCSZ are imaged in subsurface seismic reflection data and may be correlative with east verging structures that are imaged to the east within the Kootenay Arc and Purcell Anticlinorium, and to the west below the Pinnacles area and Vernon Arch (Cook *et al.* 1988, 1992; Varsek and Cook 1994; Cook and Van der Velden 1995; Carr 1995). The age of movement on the GCSZ is bracketed between 51 and 100 Ma Parrish (1995). Igneous rocks cross-cutting the GCSZ give U-Pb zircon ages of 50-51 Ma (Parrish *et al.* 1988) and 52 Ma (Parrish 1995), and the 100 Ma Mulvey granodiorite is sheared by the GCSZ (Carr *et al.* 1987). Based on thermal history studies, Parrish and others (1988) and Heaman and Parrish (1991) suggested that the GCSZ were active at the thermal peak of metamorphism, at approximately 70-80 Ma.

The complex is roofed by the arched ductile Valkyr shear zone (VSZ) and is bounded on the eastern margin by the ductile - brittle Slocan Lake fault (SLF), both of which deform 59-55 Ma Ladybird granite and pegmatite. The VSZ has a maximum thickness of 2-3 km and is exposed around the northern, southern and eastern periphery of the complex. It was active at amphibolite-facies metamorphism, between 59 and 54 Ma (Carr *et al.* 1987). The SLF is an easterly dipping normal fault that truncates the VSZ and was active between 54 and approximately 45 Ma (Carr *et al.* 1987). The fault was active through the ductile-brittle transition and final motion occurred at greenschist-facies metamorphism as indicated by syn-kinematic albite, chlorite and muscovite within the 100-800 m thick fault zone (Carr *et al.* 1987). Muscovite with a Rb-Sr age of 54.5 ± 1.5 Ma, grew at temperatures below the closure temperature of Sr in feldspar and dates the greenschist facies movement on the SLF (Parrish *et al.* 1988). The SLF and VSZ are genetically related; movement along the SLF outlasted

the VSZ during the Early to Middle Eocene (Carr *et al.* 1987).

The Slocan Lake fault and Valkyr shear zone juxtapose the high-grade rocks of the Valhalla complex against low-grade rocks in the upper plate. The upper plate (Fig. 1.2) consists of Pennsylvanian low-grade metasedimentary rocks of the Mount Roberts Formation and Triassic volcanic rocks of the Rossland Group, both belonging to the accreted Quesnellia terrane, Middle Jurassic Nelson Batholith and equivalent plutonic rocks to the west, and late Cretaceous two mica granites (~ 100 Ma) and intrusives of the 79 Ma Watshan Batholith. To the north, middle-high grade metasedimentary rocks of the Nemo Lakes belt are thought to be in part equivalent to the Paleozoic Lardeau Group as well as the Triassic Slocan Group (Parrish 1981).

Rocks within the Valhalla complex were exhumed rapidly along the SLF and VSZ, preserving sillimanite - potassium feldspar grade conditions and yielding Eocene K/Ar cooling ages (Carr *et al.* 1987). Retrograde metamorphism is rare and indicates that rocks of the Valhalla complex were exhumed rapidly. Cooling rates of the Valhalla complex are estimated to be between 15-20 °C / Ma (Heaman and Parrish 1991), however Spear and Parrish (in prep.) suggest even faster, periodic cooling rates up to 1000 °C / Ma over a 0.1 Ma period.

Paragneisses of the Valhalla complex are characterized by their heterogeneity and abundant migmatites, leucosome and cross-cutting granitic rocks. Granitic pegmatites and leucogranites belonging to the Ladybird suite occur throughout the complex (Carr *et al.* 1987; Parrish *et al.* 1988). The absolute age of the paragneisses in the Valhalla complex is only broadly constrained. Detrital zircon ages of ~1400, 1700 and 2700 Ma were obtained

from two sample localities in the upper paragneiss sheet (1c) and place a maximum age of 1400 Ma on the deposition of at least part of the protoliths of the paragneisses (Parrish 1991; Ross and Parrish 1991). A minimum age of deposition of the paragneisses is constrained by the intrusive Mulvey granodiorite, which has a maximum age of ~110 Ma (Carr *et al.* 1987; Parrish *et al.* 1988; Parrish 1992). A summary of geochronological data from the Valhalla complex is presented in Table 2.1.

2.3.2 Structure

The Valhalla complex is a fault bounded culmination which has generally outward dipping foliations which define its domal nature. Within the large scale culmination, there are two northern and southern subculminations which Reesor (1965) termed the Valhalla and Passmore domes, respectively (Fig. 1.2, cross-section A; see also the structural geology map and cross-section in Reesor 1965). A third subculmination occurs in the southern portion of the complex near Castlegar and Trail (Simony 1979). The major domal shape of the complex has been interpreted to be a result of tectonic denudation due to exhumation along Eocene normal faults (Carr *et al.* 1987; Parrish *et al.* 1988), however the reason for the secondary subculminations is uncertain.

Three domains are delineated within the Valhalla paragneisses on the basis of structural level and the presence or absence of transposed fabrics (Fig. 2.2 cross-section A,B,C). Domain 1 constitutes sheet 1c at high structural levels and is divided into northern (1a) and southern (1b) subdomains. Domain 2 is also contained within sheet 1c but is at a deeper structural level and contains a transposition fabric that is interpreted to be related to

the GCSZ. Domain 3 occurs in sheet 1a in Gwillim Creek and contains a transposition fabric related to the GCSZ which forms the upper boundary of this domain. Domain 1 offers the best exposure and continuous stratigraphy, whereas rocks are not well exposed in domains 2 and 3. Nomenclature of structural sheets (1a-1c) is retained because of previous use.

Fabrics related to D_1 are virtually absent in the field and only recognized in thin-section as quartz inclusions trails in garnet. At the highest structural level of paragneisses within sheet 1c on the west side of the complex (domain 1a), S_2 is the predominant foliation and is parallel to the west flank of the complex and the contacts of geologic units. S_2 transposes bedding which is defined by variations in the relative amounts of calcite and quartz in marble (Plate 1a) and compositional layering in all other rock types. In pelitic and semipelitic schists, S_2 is defined by platy minerals such as biotite and discrete layers of sillimanite. In calc-silicate gneisses and amphibolite gneisses, it is defined by the segregation of amphiboles and quartzo-feldspathic minerals and is parallel to compositional layering. S_2 contains the dominant lineation, L_2 , a mineral lineation. Lineations are defined by sillimanite needles, quartz ribbons and rare aligned biotite aggregates in semipelitic and pelitic schists and most commonly by amphibole in calc-silicate and amphibolite gneisses. The S_2 fabric is folded by abundant W to NW plunging F_3 folds. On the east side of the complex, sheet 1c is significantly thinner and folds are absent due to transposition and attenuation resulting from motion on the SLF and possibly the GCSZ. Also on the east side, mineral lineations are oriented down the dip of the SLF (east plunging) and are inferred to have been rotated to this position during faulting. The same fabric development is observed in the southern portion of the paragneisses near Airy Creek and Slocan Ridge and constitutes

domain 1b.

The GCSZ project toward the southerly areas (cross-section A) at the structural level of domain 2 and are consistent with interpretations of seismic data that suggest that the GCSZ resurface in the Passmore-Vallican area (Cook *et al.* 1988). In domain 2 in the Slocan River Valley, the fabric is more intense with respect to domain 1b and preexisting fabrics are transposed. Although this transposition fabric is generally parallel to S_1 in higher structural levels, it is uncertain if it is a result of the same structural event, and is therefore designated S_T . Folds are rare, but where present, are rootless or have sheared limbs. Sheath folds have fold axes parallel with the lineation. Leucogranites and pegmatites that are clearly discordant in domain 1b become transposed in domain 2 where they are not obviously cross-cutting. Sillimanite forms a strong stretching lineation with fractures oriented perpendicular to S_T .

At deep structural levels beneath the GCSZ (sheets 1a, domain 3), a transposition fabric predominates (S_T) that is interpreted to have developed during motion on the GCSZ. As in domain 2, folds are rare and where present occur as sheath folds. The GCSZ are 50 m thick horizons of ductile strain and grain size reduction which reduced the normally coarse K-feldspar megacrystic Mulvey granodiorite to a biotite schist. In thin-section, quartz forms discrete bands. The GCSZ are parallel to S_T , however it is uncertain if this transposition fabric and S_2 in domain 1 resulted from the same deformation event.

Local areas on Perry Ridge contain a strong fabric with no apparent strain gradient into adjacent areas. It is possible that the mylonitic fabric defines a shear zone that is contiguous with the GCSZ, but it is also possible that it delineates another shear zone of unknown magnitude or displacement. Fold axes on Perry Ridge are shallowly plunging and

trend in a general W to NW direction. Axial surfaces are also subhorizontal and dip to the west.

Folding in Domain 1

Evidence for D_1 structures in the Valhalla complex include rare F_1 isoclinal folds and inverted stratigraphy inferred from regional correlations presented later in this chapter. The stratigraphic and structural relationships in the area between Lucifer Col and Black Prince (Fig. 2.3) are uncertain but suggest the presence of a first phase fold hinge that is obscured by large volumes of granitic rocks. Parrish and others (1985) reported a large first phase isoclinal fold in the Gwillim Lakes area but evidence to support this was not observed by this author. The timing of first phase folding is not well constrained in the Valhalla complex. The ~110 Ma Mulvey granodiorite contains the dominant S_2 fabric. This fabric is interpreted to be synchronous with the peak of metamorphism at ~75 Ma (Heaman and Parrish 1991, see discussion of timing of metamorphism and deformation in chapter 3). Therefore, the absolute minimum age for F_1 folding is ~75 Ma. There is no reported evidence to suggest that the Mulvey cross-cuts F_1 folds and the maximum age is constrained by the age of strata that is deformed (see section 2.5 on regional correlations). Carr (1991) presented a model which divides the crust into three crustal zones. Parrish (1995) builds on this model and divides the crust into five levels where he proposes that the age of deformation and metamorphism decreases with deeper structural levels. The upper zone lies in the hanging walls of Eocene normal faults and has deformation and cooling ages which are primarily Jurassic. At deep crustal levels in the Monashee complex, ages of metamorphism and

deformation are essentially Paleocene-Eocene (Parrish 1995). In these models, the Valhalla complex should have Cretaceous deformation ages, but age constraints from previous geochronological studies and this study do not constrain the maximum age to Cretaceous. Jurassic D_1 deformation (F_1 folding) in the Valhalla complex cannot be ruled out.

F_2 folds in domain 1 are overturned, tight asymmetric folds which are refolded by F_3 folds (Plate 1c). F_2 folds are difficult to distinguish from F_3 folds, due to their coaxiality, and D_2 and D_3 may represent one protracted folding event. S_2 axial planar cleavages are rare. F_2 folds leucosome, biotite and sillimanite, and therefore postdates the peak of metamorphism.

Third phase folds are the dominant fold generation in domain 1 (Plate 1b). They are open to close folds that vary from centimetre- to metre-scale structures ((Plate 1a and Plate 2a, b, respectively). Fold hinges have a variable orientation, but generally plunge moderately to shallowly W to NW (Fig. 2.4). F_3 axial surfaces are W to SW dipping and F_3 folds are E to NE verging. F_3 folds peak metamorphic minerals of sillimanite, biotite and concentrated layers of garnet.

Evidence for a fourth phase of deformation is in the occurrence of rare broad, tens of metre-scale open folds with steep axial planes (Fig. 2.4). F_4 folds are best exposed in the Hela Peak area where a large Z-fold (looking NW) occurs near the contact with the Ladybird granite (Fig. 2.3). Crenulations in semipelitic to pelitic schists may also be related to D_4 deformation.

Faults are rare within the Valhalla complex. One north-south striking, nearly vertical, minor normal fault occurs near Urd Peak, and offsets the Demers marble by approximately

10 m. Steep, north-south oriented joints also occur near the Demers Lakes. These brittle features may be related to similarly oriented ultramafic dykes in this area.

Fabrics in thin-section

In thin-section, S_2 is defined by the preferred alignment of biotite and sillimanite and discrete layers of quartz, K-feldspar and plagioclase. The peak mineral assemblage of garnet, biotite, sillimanite, K-feldspar, rutile and ilmenite is contained within this foliation and also occur in the pressure shadows of garnet. Garnets contain an internal schistosity defined by quartz which is oblique to the dominant external S_2 fabric. Sillimanite inclusions occur near garnet rims and are often parallel to the external foliation (S_2). Quartz inclusion trails are interpreted to represent S_1 which was overgrown by garnets, implying that garnet growth began following D_1 . The main fabric (S_2) began to develop at high temperatures and pressures during garnet growth, which is indicated by the occurrence of sillimanite inclusions within garnet that can be traced into the external S_2 . S_2 is interpreted to have developed during the thermal peak because the peak minerals (sillimanite, potassium feldspar, biotite) occur with pressure shadows associated with garnet. Deformation outlasted garnet growth because these same minerals wrap around the garnet porphyroblasts. F_3 folds deform the S_2 main fabric and all peak metamorphic minerals, and therefore postdate the peak of metamorphism. Rare muscovite grains oriented sub-parallel to S_2 are crenulated by F_3 and indicate that third phase folding occurred after the rocks had cooled substantially. A complete discussion of the relationships between metamorphism and deformation is presented in chapter 3.

2.4 The Valhalla assemblage

2.4.1 Introduction

The paragneisses within the Valhalla complex comprise a heterogeneous package of metasedimentary rocks. They were originally mapped as the Hybrid Gneiss (Unit 1) by Reesor (1965 p. 15), who described the unit as "intimately interlayered rocks consisting of a metasedimentary fraction with leucogranite-gneiss and pegmatitic interlayers". Reesor (1965) also mapped out the major carbonate marker units within the Hybrid Gneiss, however no detailed mapping of stratigraphy or correlation was attempted. Parrish and others (1985) described a quartz-pebble conglomerate in the Gwillim Lakes area and suggested that it may be correlative with the Carboniferous Milford Group. Mapping for this project was carried out throughout the complex, including the lower window in Gwillim Creek; however, attention was concentrated in the area of best exposure, the west-central flank of the complex between Mount Rinda and the Demers Lakes (Fig. 2.3). This area lies in the uppermost paragneiss sheet (1c) and in the hanging wall of the GCSZ. A laterally continuous stratigraphy was identified and is referred to as the Valhalla assemblage.

Distinctive marble, calc-silicate - quartzite-cobble metaconglomerate and ultramafic units were used as stratigraphic markers. A mappable sequence of lithologies including semipelitic to pelitic schist and gneiss, psammitic gneiss, quartzite, marble, calc-silicate gneiss, quartz-pebble to cobble metaconglomerate, amphibolite gneiss, and ultramafic boudins occur in the Valhalla assemblage. The Valhalla assemblage is characteristically lacking appreciable amounts of amphibolite and orthogneiss. The predominant siliciclastic

rocks are semipelitic schists and gneisses and psammitic gneisses, with lesser amounts of pelitic schist. All rock types are characterized by the presence of ubiquitous leucogranites and pegmatites (Plate 2c, d), which consist of multiple generations of concordant to discordant stocks and dykes ranging from strongly deformed to totally undeformed. In many cases, these granitic rocks make up 75% of any particular outcrop. The stratigraphy of metasedimentary rocks within the Valhalla complex is preserved despite the large volume of these young granitic rocks (Plate 3a). Map units are not always continuous, but can be followed along strike, where screens or schlieren of paragneisses are normally present within the leucogranites.

2.4.2 Lithology

A variety of rock types occur within the Valhalla assemblage. The distinguishing characteristics and mineralogy of each are described in Table 2.2 in order to avoid repetition in the subsequent section characterizing the Valhalla assemblage.

Paleocene - Eocene leucogranites and pegmatites

A considerable amount of the stratigraphy in the Valhalla complex is intruded by both concordant and discordant granites, which comprise leucocratic biotite-bearing pegmatite, coarse-grained granite and weakly foliated to undeformed, locally garnetiferous, medium-grained leucogranite (Plate 3a). The garnetiferous granite occurs as small stocks and sheets that often form mountain peaks and are up to tens of metres thick. Biotite clots and knots are common, often replacing garnet porphyroblasts. In many cases, the granitic

rocks do not constitute mappable bodies, but occur as metre-scale thick layers that often make up 50 to 75% of outcrops and ridges (Plate 3a). Pegmatites and coarse-grained granites are thought to be Ladybird granite equivalents that have been dated at 59-56 Ma (Carr *et al* 1987) and are the product of crustal melting (Carr 1992).

In the southern, structurally higher areas south of Perry Ridge (Fig. 1.2), granitoid rocks occur as sub-concordant to clearly discordant dykes up to 3 m thick which make up to 75% of unit 11. The peak-forming homogeneous bodies of garnet-bearing granite stocks that abound in the area between Mount Rinda and Hela Peak are absent in the southern area. In contrast, pegmatites and leucogranites within the paragneisses of the Gwillim Creek windows have been transposed and do not obviously cross-cut the main S_T fabric.

Up to five granitoid phases may be present in one outcrop, as was mapped at station 130 (Map 1), at the head of Bannock Burn. They are described in order from oldest to youngest:

- 1) Thin layers (< 1 cm wide) of plagioclase-quartz leucosome are oriented parallel to the predominant (S_2) foliation in pelitic, semipelitic and migmatitic schists (Plate 3b).

- 2) Boudins up to 1 m thick of fine- to medium-grained, well-foliated granite contain biotite - potassium feldspar - plagioclase $\pm$ hornblende $\pm$ garnet. The hornblende content varies from 5-15%. The amount of fabric is also variable in these granitic rocks and ranges from weakly to well foliated.

- 3) Medium-grained granite that contains 3-5% biotite clots and no hornblende. These 10-20 cm wide bands show pinch and swell textures and are commonly weakly foliated (Plate 1b).

4) Undeformed to weakly-deformed, discordant, medium-grained granite and pegmatite are up to 1m thick.

5) Sugary textured undeformed aplite dykes which cross-cut pegmatites of (4) are rare and are up to 30 cm thick.

This description is representative of the area between Mount Rinda and Hela Peak. Aplite dykes may be a younger phase of the undeformed granite and pegmatite (#4) and are not always present.

Ultramafic and mafic intrusive dykes

Metre-wide, near vertically dipping mafic pyroxene-plagioclase $\pm$ olivine dykes are the youngest rocks in the Valhalla complex. They are traceable for 1 to 2 km and have little offset along strike. These dykes intrude both the upper and lower plates, as well as the Coryell syenite and are younger than 51.5 Ma (Bevier 1987). These dykes were described by Reesor (1965 p. 40) as basaltic dykes.

South of Woden Peak, a fine-grained, very hard and clinkery weathering, olivine-bearing ultramafic dyke was observed. On the weathered surface it is pitted due to the weathering of some unknown mineral which gives it a vesicular appearance. In the areas north of the Hird Lakes and surrounding the western Demers Lakes, numerous 0.5-1.5 m wide, near vertical, north-south trending ultramafic to mafic dykes are spaced 200-500 m apart. Mafic mineral content varies from 60-90%. Some dykes contain 20% 1-2 mm laths of plagioclase, while others contain 20-30% serpentinized (?) phenocrysts of olivine. Still other dykes appear to contain little plagioclase or relict olivine phenocrysts, and instead

contain diopside. Zoned phenocrysts of plagioclase are observed in thin-section and no metamorphic textures are observed. The presence of rare chilled margins suggests that these dykes intruded the Valhalla complex after it had cooled.

2.4.3 Stratigraphy of metasedimentary units

Map units are ordered from structurally lowest to highest and the terms "underlying" and "overlying" are used in a structural context; however, this does not imply stratigraphic ordering (Fig. 2.5). It is possible that the entire Valhalla assemblage is inverted, and that unit 1 is the youngest stratigraphic unit. This will be discussed in the section entitled "Regional correlation of the Valhalla assemblage". There is a strong transposition foliation within the Valhalla assemblage and therefore unit thicknesses reported here are not the original thicknesses of unmetamorphosed and unstrained protoliths. An estimate of the present thickness of the metasedimentary package is between 1.5-2 km. The reader is referred to Figure 2.2 and Map 1 for the locations of the following units and Figure 2.4 for the order of units.

Unit 1. Quartzo-feldspathic gneiss

Unit 1 is a light-grey weathering quartzo-feldspathic gneiss which is commonly tightly folded (Plate 1b). Psammite and semipelitic schist occur as rare 10 cm layers and make up less than 5% of the unit. At the crest of the ridge joining Mount Bor and Black Prince, a 10 m thick hornblende-plagioclase amphibolite gneiss is present and is most likely contained within unit 1. Unit 1 is the structurally lowest unit mapped in the uppermost

paragneiss sheet, carried in the hanging wall of the GCSZ and is underlain by the Mulvey gneiss. It has a minimum thickness of 50 m. At the basal contact over an interval of approximately 10 m, there is a significant increase in the volume of leucogranite and pegmatite approaching the Mulvey granodiorite. There is no apparent strain gradient at the contact and it is interpreted to be an intrusive contact. The contact between units 1 and 2 is not often observed. In the area between Mount Bor and Lucifer Col, unit 1 occurs amongst the leucogranite and pegmatites which make up approximately 75% of the ~1 km square flat glaciated area. The stratigraphic and structural relationships in the area between Lucifer Col and Black Prince (Fig. 2.3) are unclear, but it is possible that a first phase fold hinge lies here and is concealed by the large volumes of granitic rocks.

Unit 2. Hird Lakes marker

The Hird Lakes unit is a 10-20 m thick marker that varies along strike between a dark-green weathering, calc-silicate gneiss (2a-cs) and quartzite-pebble to cobble metaconglomerate (2a-cg), with either a calc-silicate or psammitic matrix. Marble (2b) occurs at the same structural level and is included within this map unit.

2a-cs. calc-silicate gneiss

The calc-silicate gneiss (2a-cs) varies from area to area, commonly contains discrete, biotite-rich layers, and has a thickness on the order of 10 m. In the Gwillim basin, the unit is a diopside-bearing calc-silicate (Table 2.2) with discrete biotite layers. Near Black Prince (Fig. 2.3), fine- to medium-grained marble is interlayered with calc-silicate gneiss on a scale

of 1-3 m, and makes up 50% of the unit. Marble and calc-silicate gneiss layers are cross-cut by ~2-10 cm wide actinolite veins that are a late feature. At the Gwillim Lakes and the head of Gwillim Creek, the unit is predominantly calc-silicate gneiss and occurs as xenoliths within coarse grained granite and pegmatite (Plate 2d). Near the head of Gwillim Creek, there is a distinctive metre-wide layer of foliated magnetite-calcite-diopside calc-silicate within the marble and calc-silicate gneiss.

In the Hird Lakes area, the calc-silicate gneiss is less massive than in the Gwillim basin. The content of phlogopite is higher giving the rock a more schistose texture. Coarse-grained, white weathering scapolite occurs as masses up to 10 cm thick.

2a-cg. quartzite-pebble metaconglomerate

A distinctive quartzite-pebble to cobble metaconglomerate, with calc-silicate or semipelitic matrix (2a-cg), first described by Parrish and others (1985), occurs in the vicinity of the most eastern Gwillim Lake, south of Hird Lakes and near Rocky Lakes. The metaconglomerate is generally calc-silicate matrix supported with elliptical rounded and occasionally blocky clasts of relatively clean quartzite and vein quartz which range in size from 1x2 to 5x10 cm (Plate 3b). The metaconglomerate is under- and overlain by 5-10 m thick dark-green weathering calc-silicate schist or gneiss. Metaconglomerate layers are approximately 30 cm to 2 m thick in the Gwillim Lakes area and up to 20 m in the Rocky Lakes area, perhaps due to thickening in a fold hinge. In the Rocky Lakes area, a 20 m thick, clast suppo

argillaceous quartzite (Plate 4a). Clasts are rounded and up to 10 cm in diameter. This change in matrix composition may be the result of variations in protolith.

2b. marble.

A 10 m thick marble outcrops on the ridge separating the headwaters of Bannock Burn and Drinnon Lake (Fig. 2.3) and is typical of marbles in the Valhalla complex (Table 2.2). Based on structural projections, it may correlate along strike with the Hird Lakes conglomerate. The presence of marbles interlayered with the calc-silicate (2a-cs) near the Gwillim Lakes suggests that variations in protolith are possible along strike. For this marble to correlate to unit 2a, a change in protolith and depositional environment is required.

Unit 3. Drinnon quartzite

3a. quartzite

A 150-200 m thick clean, homogeneous, rusty to pinkish, buff-grey weathering quartzite with minor biotite-rich millimetre- to centimetre-scale layers outcrops south of Mount Gregorio and north of Drinnon Lake (Fig. 2.3). Contact relationships are unclear due to poor exposure, but no compositional gradation is observed near the top or base of the unit.

3b. psammitic gneiss - migmatitic gneiss - semipelitic schist

This package of rocks is approximately 150-200 m thick and consists of rusty weathering semipelitic schist, psammitic gneiss, migmatitic gneiss and quartzite interlayered

on a scale of metres with minor of pelitic schist and amphibolite gneiss. These siliciclastic rocks are predominantly quartzo-feldspathic in composition with widely varying amounts of biotite (5-50%). In the more biotite-rich pelitic layers, sillimanite and garnet are common. On the ridge to the south of the Black Prince, crenulated sillimanite-rich semipelitic to pelitic schists are interlayered with migmatitic gneiss on a scale of tens of centimetres to metres. Migmatitic gneiss contains 50% quartzo-feldspathic leucosome and 50% millimetre to centimetre thick biotite layers. On the west side of the Gwillim Lakes, above the Hird Lakes metaconglomerate (2a-cg), unit 3b is predominantly migmatitic schist with up to metre-thick discordant and concordant leucogranites and pegmatites (Plate 4b).

3c. quartzo-feldspathic gneiss - pelitic schist

In the vicinity of the Rocky Lakes and south of the Hird Lakes, a 100 m thick package of quartzo-feldspathic gneiss and pelitic schist is characteristic of most of the unit. Rare, 5 m thick layers of garnet-sillimanite schist are also present. The quartzo-feldspathic gneiss is interlayered, on the millimetre to centimetre scale, with quartzo-feldspathic leucosome.

3c-cq. calcareous quartzite

A 75-100 m thick calcareous quartzite (3c-cq) is present locally in the Hird Lakes area where it overlies the quartzo-feldspathic gneiss and pelitic schist of unit 3c. This subunit consists of calcareous or pitted quartzite interlayered, on the metre scale, with lesser amounts of calc-silicate gneiss and semipelitic schist. West of Urd Peak, a pitted, white to

buff weathering calcareous quartzite is interlayered, on the centimetre scale, with diopside-bearing calc-silicate gneiss. Layering is straight, with little variation in thickness (Plate 4c). Minor coarse-grained marble occurs as less than 1 m thick layers and make up less than 5% of the unit.

This unit (3c-cq) is not present to the north of Urd Peak. Near the Demers Lake, semipelitic schists and crenulated garnet-sillimanite schists occur at the same structural level. Along strike from south to north, there is a dramatic facies change from clean quartzite (3a) to semipelitic and pelitic schist (3b) and then to pitted quartzite (3c-cq). The variation within unit 3 may represent facies changes or structural complications such as faulting. However, the continuity of the underlying Demers marble (4b, described below), which has no apparent offset, disputes both of these ideas. Another hypothesis is that this unit (3c) is actually an enigmatic thickened portion of the Demers marble (4b). There are no structural reasons to attribute thickening to folding.

Unit 4. Demers marble

4a. marble - calc-silicate

A coarse-grained, commonly siliceous marble unit, at most 10 metres thick occurs discontinuously 3 km along strike on the ridge south of Drinnon Lake, west of Wicca Lake and west of the Gwillim Lakes (Fig. 2.3). It is not as prominent as other marble marker units. Minor calc-silicate is associated with the marble and occurs as metre-sized boudins and discontinuous layers. Contact relationships are uncertain due to the presence of

leucogranite and scarce outcrop.

4b. marble - calc-silicate - siliceous marble

North of the Hird Lakes, a 5-10 m thick marble is characterized by 30 cm-1 m interlayers of marble, calc-silicate, calcareous quartzite and psammitic gneiss. Lesser amounts of calc-silicate and siliceous marble are interlayered with the marble, on a centimetre scale. Contacts of unit 4b with units 3c-cq and 5b are conformable and no mineralogical or grain-size change is observed towards them. North of the Hird Lakes, the marble is closely associated with calcareous quartzite (3c-cq). It is possible that units 4b and 3c-cq belong to the same package, although calcareous quartzite is not observed along strike in either direction. Further west along strike, thin marble (4b) is clearly distinguishable from surrounding siliciclastic rocks (3c and 5c) and is characteristically thin. Unit 4b is observed discontinuously along 5 km, from Urd Peak to the ridge north of the western Demers Lake. Blocks of marble lie at the base of a steep cliff near the Rocky Lakes where Reesor (1965) mapped a carbonate layer. This is interpreted to be continuous with unit 4b. Based on structural projections and the under- and overlying lithology, this marble unit (4b) is correlated with thin marbles west of the Gwillim Lakes and at the head of Bannock Burn (4a).

4c. marble - siliceous marble

A 20 m thick marble marker was observed west of Hela Peak in the northern part of the complex, and contains layers of diopside calc-silicate and locally 1-2 cm wide quartz rich

layers (Plate 2b). It is tentatively correlated with the marble observed north of Demers Lakes (4b), as well as unit 4a, south of Drinnon Lake. This correlation is based on structural projections, relative thickness and the fact that it is more siliceous than other marbles.

Unit 5. Hoder Creek composite unit

5a. semipelitic schist - quartzite - marble - calc-silicate - amphibolite

A 75-100 m thick heterogeneous package of rocks consists of 1-4 metre thick layers of psammitic to semipelitic schist, argillaceous quartzite, marble, calc-silicate gneiss, and amphibolite gneiss which are exposed along a steep slope in the headwaters of Hoder Creek, near the parking lot accessing Valhalla Park (Fig. 2.3). Marble layers are 30 cm to 2 m wide and are spaced 20-30 m apart. Three metre wide diopside-rich (20%, more diopside than normal) calc-silicate gneiss (Plate 4d), overlies 30 m of argillaceous quartzite, garnet-sillimanite pelitic to semipelitic schist and amphibolite gneiss. Boudins of medium-grained, 100% diopside are common within marble and psammitic gneiss layers. Amphibolite gneiss occurs as 0.5 to 2 m thick layers, as well as metre-scale boudins. A quartzite - calc-silicate metaconglomerate with a biotite-quartz-feldspar matrix, also occurs within the section south of the Hoder Creek parking lot. Clasts are smaller than those near the Gwillim Lakes (unit 2a-cg) and approximately 50% of the clasts are light-green weathering calc-silicate gneiss, while the remainder are made up of quartzite and white vein quartz. The relative position of the metaconglomerate within this unit does not aid in the interpretation of stratigraphic younging. There does not appear to be any apparent rhythm to the ordering of siliciclastic

and carbonate units, nor is there any indication of gradation in primary grain size from top to bottom.

To the south-east, the area near the headwaters of Bannock Burn is characterized by an increase in the amount quartzite and carbonate rocks and a decrease in the amount of amphibolite gneiss. Pitted calc-silicate and clean quartzite are interlayered on the centimetre scale in this area. Locally this area contains 10-30 cm thick discontinuous psammitic gneiss layers.

5b. Semipelitic schist

A greater than 100 m thick, rusty to dark-brown weathering homogeneous, crumbly weathering semipelitic to pelitic schist forms the ridge west of Urd Peak and is characterized by many crags and pillar-like blocks. The actual thickness of this unit is unknown, since its upper contact projects above a ridge. The semipelitic schist is friable with many fractures. It is an aluminum-poor unit, lacking garnet and sillimanite and is homogeneous throughout.

5c. semipelitic schist - psammitic gneiss

A light-brown to grey weathering, homogeneous, 100-200 m thick unit of semipelitic and psammitic gneiss to argillaceous quartzite is observed in the northern area west of Hela Peak, above the Demers marble (4c). True pelitic schist is rare, and garnet is completely absent. Semipelitic schist, locally contains distinctive knots of sillimanite, 1-2 cm in size, which were not observed anywhere else in the Valhalla complex. The lack of amphibolite gneiss and pelitic schist, as well as the association with a carbonate unit (4c), makes the

correlation of units 5c and 5b feasible.

Unit 6. Bannock Burn marble

A 5-10 m thick, homogeneous marble marker was observed in the Bannock Burn valley on the northern flank of Rinda Ridge. It commonly has a black, weathering colour. Contact relationships are sharp, as there appears to be no gradation in mineralogy or grain-size near the top or base of the marble. Calc-silicate interlayers and boudins are rare.

Unit 7. Semipelitic schist

Unit 7 is a 30 to 40 m thick, rusty to black weathering sequence consisting of semipelitic schist with minor amounts of pelitic schist and psammitic gneiss interlayered on a scale of tens of centimetres to metres. It is observed immediately below unit 8 on the north flank of Rinda Ridge, at the base of steep cliffs. It is generally an aluminum-poor section although garnet and sillimanite occur locally. Where present, garnet occurs as ≤ 3 mm porphyroblasts and sillimanite occurs as fibrous mats and glassy needles. In more pelitic areas, this schist is characterized by a distinctive yellow, weathered surface.

Unit 8. Rinda Ridge composite unit

8a. semipelitic schist - marble - calc-silicate gneiss - quartzite - amphibolite gneiss

A heterogeneous sequence may be described from structurally lowest to highest as:

- 1) 1-2 m thick marble layers with intervening semipelitic to pelitic schist and psammite; 2)

discontinuous pods of ultramafic (marker unit 8a-u), with associated minor coarse-grained metagabbroic anorthosite; 3) amphibolite, interlayered amphibolite and calc-silicate and marble; 4) psammite, marble, calc-silicate gneiss and calcareous schist (Plate 5a) and quartzite (Plate 4c); and 5) semipelitic to pelitic schist, psammite (Plate 3b) and argillaceous quartzite. A 2-5 m thick amphibolite (Plate 2b) layer on Rinda Ridge, grades downward into centimetre-scale interlayered amphibolite and calc-silicate gneiss (Plate 5c) and is unique to this area. Relatively continuous amphibolite gneiss layers of this thickness are uncharacteristic in the uppermost paragneiss sheet (sheet 1c, Fig. 1.2), between Mount Rinda and Hela Peak.

8a-u - ultramafic schists

A number of 4-6 m wide metamorphosed olivine-diopside-tremolite ultramafic pods (Plate 6a) which form a discontinuous, yet concordant stratigraphic marker (Plate 6b) were observed on Rinda Ridge. Hornblende-plagioclase-quartz $\pm$ garnet amphibolite gneiss and coarse-grained gabbroic anorthosite were observed in association with ultramafic rocks along strike. The fresh surface is a pistachio-green colour due to the presence of tremolite, diopside and olivine. Along the same ridge, but to the northwest, an ultramafic boudin was observed above the Rinda marble (unit 9) and consists of nearly 100% tremolite (station 146, Map 1). At roughly the same stratigraphic level to the west, a dark-green to black weathering rock containing phenocrysts of olivine along with phlogopite and probable chromite occurs, but no visible tremolite or diopside is present (station 136, Map 1). This is possibly a young dyke similar to those occurring near the Hird Lakes, as it does not

contain the distinctive tremolite composition. In the same vicinity (station 156, Map 1), boulders of ultramafic that are probably outcrop (or near outcrop), contain much phlogopite, minor serpentine and possibly pyroxene and brucite. Whether the ultramafics above the Rinda marble are reliable stratigraphic markers or are the same as those seen on Rinda Ridge is unclear. Those near Mount Rinda appear to be a reliable stratigraphic marker due their relatively continuous nature.

8b. marble - calc-silicate gneiss - semipelitic schist

A 100 m thick carbonate-rich package of rocks consists of centimetre to metre-scale interlayered coarse-grained marble, calc-silicate gneiss and semipelitic schist to psammitic gneiss. Marble makes up the smallest component of the unit as 3 to 4, < 1 m thick layers spaced at 30-40 m intervals. The rest of the section consists of 1 cm to < 1 m thick layers of green-grey weathering calc-silicate gneiss and psammite (Plate 6c). There is an increase in the ratio of semipelitic layers to carbonate layers downwards and an apparent gradational contact with unit 7. The occurrence and thinly interlayered nature of the marble, calc-silicate and psammite is distinctive. Though both units 8a and 8b occur at the same structural level and both contain metre wide marble layers, there seems to be a lateral, southward increase in the amount of amphibolite and ultramafic rocks within unit 8a.

Unit 9. Rinda marble

This 20-40 m thick, homogeneous, coarse-grained granoblastic marble is the most distinctive and easily mappable layer within the Valhalla assemblage (Plate 7a). The

thickness of 30 m is relatively constant near Bannock Burn and along Rinda Ridge but the unit thins to 20 m towards Woden Peak (Fig. 2.3). Layering, where present, is defined by thin graphitic layers. Diopside-rich calc-silicate gneiss boudins and discontinuous interlayers are 30 cm to 1 m thick, making up less than 5% of the unit. Although not always observable, the lower contact with unit 8b appears conformable. No apparent compositional gradation is present on either the upper or lower contact, and contacts appear conformable and sharp.

Sporadically occurring plagioclase-rich chunks and dismembered layers are 1-10 cm wide and commonly outline F_2 and/or F_3 folds, where no other layering is visible. These are probably dismembered pegmatites that were emplaced prior to F_2 or F_3 folding.

Unit 10

Unit 10a. Quartzite - psammitic gneiss

A >10 m thick, rusty weathering, coarse-grained, homogeneous quartzite is observed above the Rinda marble and outcrops discontinuously along strike for 3 km along Rinda Ridge at the headwaters of Bannock Burn. It often has a massive appearance and the rusty weathering is likely to have been due to minor amounts of hematite. In other areas, a flaggy, rusty brown weathering, argillaceous quartzite to psammitic gneiss overlies the marble. The grain size and variation from quartzite to psammitic gneiss is not systematic but is in sharp contact with the Rinda marble.

Unit 10b. Psammitic gneiss - argillaceous quartzite

A >50 m thick package of psammitic gneiss, argillaceous quartzite and garnet sillimanite schist (Plate 2c) with minor calc-silicate and clean quartzite occurs above the Rinda marble. Layers are 5-10 m thick and are interlayered on this scale. Locally, above the Rinda marble, a white weathering quartzite with 1-2 cm wide calcareous layers containing diopside and calcite was observed. Minor amphibolite gneiss occurs as boudins and discontinuous layers of metre thickness.

A fine- to medium-grained garnetiferous hornblende-bearing granodiorite gneiss with a moderately strong S_2 fabric occurs above the Rinda marble (unit 9). Hornblende makes up 20-25% and biotite is rare. Due to strong S_2 gneissic fabric, which is absent from other granitic rocks, this granodiorite gneiss appears to be the oldest granitoid in the Valhalla complex.

Unit 11. Undivided rocks: semipelitic to pelitic schist - migmatitic gneiss - amphibolite gneiss

A heterogeneous group of rocks, of uncertain thickness, consist of pelitic schist, semipelitic schist and gneiss, migmatite and amphibolite gneiss. It occurs in the southern area of paragneisses on the west side of domain 1b in the Passmore Dome (Fig. 1.2). The gneisses weather a light-grey to rusty colour, schists commonly weather yellow and amphibolites are black to dark-grey weathering (Plate 7b). Locally, pelitic schists are quite sillimanite-rich and may contain up to 30% sillimanite. Coarse- to medium-grained hornblende-bearing, felsic granitic gneiss occurs locally and is more common than in the other structurally underlying units. Amphibolite gneiss occurs as metre-scale discontinuous

layers and boudins that constitute 25-75% of a typical outcrop. This unit has a significantly higher proportion of amphibolite gneiss than any others in the Valhalla assemblage. Pelites almost always contain sillimanite and garnet, 30-50% biotite and are migmatitic. In many cases, a distinct segregation between biotite restite and plagioclase-quartz leucosome is visible. Elsewhere in the Valhalla assemblage, melt pods and discontinuous leucosome layers are common, but garnet-biotite restite of this nature is not. Restite occurs in layers up to 50 cm thick and may comprise as much as 90% biotite and 20% 2-20 mm diameter garnet. Garnets are commonly altered to retrograde biotite and/or chlorite in both restite and paleosome. Leucosome is coarse-grained and consists of plagioclase, quartz $\pm$ potassium feldspar $\pm$ garnet. Rock types other than semipelitic to pelitic schist and amphibolite are rare in this unit but are observed on the east side of the complex along Highway 6 (Fig.1.2). Clean, buff weathering quartzite, calc-silicate gneiss and marble occur in minor amounts as less than 3 m thick layers. Boudins of dark-green to black weathering ultramafic up to 1 m in diameter occur north of Slocan. The lithologic associations are not apparently systematic and no distinguishing characteristics or stratigraphic relationships are apparent.

Slocan Ridge

On Slocan Ridge (Fig. 1.2), there is an abundance of leucosome within pelitic schist and garnet-hornblende-plagioclase amphibolite, making up to 50% of the unit. Near the base of the ridge along Highway 6, sillimanite-rich schists and garnet-hornblende amphibolite gneisses predominate. At ~ 975 m elevation, there is a decrease in the amount of amphibolite and argillaceous quartzites and garnet-bearing semipelitic to pelitic schists are

common.

Perry Ridge

Perry Ridge (Fig. 1.2) consists of psammite, semipelitic to pelitic schist, quartzite, marble, calc-silicate gneiss and amphibolite gneiss much the same as units 7-9 in the Bannock Burn valley and along Rinda Ridge. On the north side of the ridge, units are difficult to follow due to scarce and discontinuous outcrop along logging roads. On the south side of the ridge, two marble layers are present, and the lower one has a thickness of at least 20 m. This marble layer is probably correlative to a marble layer mapped on the north side of the ridge. The only other marble of this thickness is the Rinda marble, however they are not correlative because there is no similarity with surrounding rock types and they occur at different structural levels. The presence of two relatively thick marbles in close proximity to each other might suggest that these are two limbs of an overturned isoclinal fold but there was no evidence for this, nor was isoclinal folding of this scale observed anywhere else in the Valhalla assemblage. The relationship between the rocks on Perry Ridge and the rest of the sequence in the Valhalla complex remains uncertain.

Gwillim Creek windows

The paragneisses in the Gwillim Creek windows consist primarily of argillaceous quartzite, quartzo-feldspathic gneiss, semipelitic and pelitic schist and minor amphibolite gneiss and are similar to rocks of unit 11 (Plate 7b c). Rare 2-3 cm garnet and 2x5 mm sillimanite porphyroblasts occur in pelitic schist, but generally the rocks have meager

amounts of aluminosilicate minerals. Carbonate units were not observed, although Reesor (1965 p. 22) noted them. The only other distinguishing characteristic is the presence of more argillaceous quartzite relative to semipelitic and pelitic schist. The lack of any good marker units makes a correlation between the Gwillim Creek windows (paragneiss sheet 1a and 1b, Figs. 1.2, 1.3) and the structurally higher main sheet 1c of paragneisses difficult. Rocks in the Gwillim Creek windows may not correlate to any other units of the Valhalla assemblage due to a large displacement on the Gwillim Creek shear zones.

2.5 Regional correlations of the Valhalla assemblage

On the basis of mappable sequences of partially transposed stratigraphy containing some distinctive marker horizons, a regional correlation of the Valhalla assemblage is proposed. This is done bearing in mind that: 1) the rocks are at upper-amphibolite facies and often migmatitic; 2) the original thickness of units is uncertain due to possible transposition and other structural complications, such as cryptic thrusts; 3) there are no primary sedimentary structures or fossils preserved; and 4) that Paleocene - Eocene leucogranites and pegmatites may constitute up to 75% of any one outcrop. Despite these significant complications, the persistence of markers and distinctive packages along strike indicate that a relict stratigraphy has been preserved. Distinctive units include the Rinda marble (unit 9), Hird Lakes calc-silicate gneiss - metaconglomerate (unit 2a-cs, 2a-cg) and the ultramafic boudins (unit 8a-u) of the Rinda Ridge composite unit.

The age of the Valhalla assemblage is older than the 100 ± 5 Ma igneous crystallization age of Mulvey granodiorite gneiss (Carr *et al.* 1987). Ross and Parrish (1991)

suggested that the quartzite-cobble metaconglomerate (2a-cg) is Late Proterozoic to Middle Paleozoic. Detrital zircons from a quartzite layer from the vicinity of the metaconglomerate yielded ages between ~1400-2759 Ma (Ross and Parrish 1991). These dates only reveal the age of the source area and place a maximum age of ~1400 Ma on the sediment deposition.

The Valhalla assemblage is a heterogeneous sequence of rocks that contains conglomerates, calc-silicate gneisses and marbles interlayered with 50-100 m thick units of aluminum poor semipelitic to pelitic schists at its structurally lowest level (units 1-3). Proceeding up in structural direction, the sequence becomes more carbonate rich with metre thick marbles and calc-silicates gneisses, interlayered with quartzites and slightly more aluminum-rich pelitic rocks (units 4-8). There is also an increase in amphibolite gneisses and ultramafic rocks which are absent from the structurally lower sections. This is overlain by a thick marble and quartzite layers, respectively (units 9-10). At the structurally highest level, a thick unit of pelitic schist and amphibolite gneiss predominates (unit 11).

A primary environment for the Valhalla assemblage may be described as a shallow-water, nearshore environment that was changing often and influenced by terrestrial sediments and minor volcanism as evidenced by the interlayering of quartzites, carbonates, pelitic rocks and amphibolite gneisses. The Valhalla assemblage is unlike the thick, homogeneous, deep-water, marginal-basin type sediments of the Slocan Group, nor is it indicative of an island-arc setting like the Kaslo Group. The lack of thick quartzites and conglomerates also makes it unlike terrestrial sedimentary rocks of some parts of the Purcell Supergroup.

The correlation of the Valhalla assemblage proposed in this study is based on a comparison of descriptions of Neoproterozoic to Paleozoic rocks exposed in the Goat Ranges

(Klepacki 1985), Thor-Odin - Pinnacles area (Carr 1991), the Riondel area (Höy 1977, 1980), the Kootenay Arc (Fyles and Eastwood 1962; Fyles 1964; Read 1973; Reesor 1973), the Greenwood - Grandforks area (Little 1983; Fyles 1990), the Adams Lake - Clearwater - Vavenby area (Schiarizza and Preto 1987) and the area of the Scrip Nappe (Raeside and Simony 1983; Scammell 1991, 1993). Based on literature describing the Paleozoic strata in the Omineca belt, the most reasonable interpretation is that the Valhalla assemblage is correlative with part of the Neoproterozoic and Eocambrian to Carboniferous stratigraphy of North America and the Kootenay terrane (Table 2.3). In this interpretation, the Valhalla assemblage is inverted, for which the implications are presented in chapter 4.

2.5.1 Goat Ranges

The Goat Ranges located to the northeast of the Valhalla complex (Fig. 1.1) consist of Paleozoic to Triassic low-grade metasedimentary and metavolcanic rocks of the Hamill to Slocan Group and are described by Klepacki (1983), Klepacki and others (1985), Klepacki and Wheeler (1985) and Klepacki (1985).

Based on thickness, potential correlatives of the Rinda marble (unit 9) are either the Badshot Formation or the Basal Limestone member of the Davis assemblage of the Milford Group. The former is favoured because the sequence of interlayered marbles, calc-silicate gneisses and pelitic schists (unit 8), marble (unit 9), and quartzite (unit 10) is best correlated with the Index Formation, Badshot Formation and Hamill Group, respectively. This implies an inverted sequence. If the Valhalla assemblage is not inverted and the Rinda marble is correlative to the Badshot Formation it would require units 8 and below be in part correlative

to the Hamill Group. The small amount of quartzite in unit 8 is not consistent with this.

The Rinda marble is not correlative with the Basal Limestone member of the Davis assemblage because it would require that either 1) the sequence is upright, in which case units 10-11 would in part be correlative to the Milford Group, or 2) the sequence is inverted, in which case units 8-1 would be in part correlative to the Milford Group. Both cases are unlikely correlations because units 10-11 lack the carbonates and conglomerates of the Milford Group, and unit 8 contains ultramafic rocks which have not been documented in the Milford Group.

Conglomerates are often distinctive and less abundant than most other rock types in the Omineca belt. Possible correlatives of the Hird Lakes metaconglomerate (unit 2a-cg) are contained within the Keen Creek assemblage of the Milford Group, the Cooper Conglomerate of the McHardy assemblage, within the Milford Group, and the Marten Conglomerate (Klepacki 1985). The most viable correlative of the Hird Lakes metaconglomerate occurs in the area of Wilson Creek in the Goat Ranges and is described by Klepacki (1985). This conglomerate is contained within the Siliceous Wacke Member of the Keen Creek assemblage (Klepacki 1985) within the Milford Group, and has an age of Upper Mississippian - Lower Pennsylvanian. Klepacki (1985) describes plagioclase-actinolite granulite and quartz-cobble conglomerate channel deposits that lie at the base of the overlying Banded Limestone Member, which is a 10-30 m buff weathering hard calc-silicate (quartz-zoisite-tremolite) and silicified limestone. Conglomerate clasts are comprised of granular quartz cobbles and foliated quartzite. Klepacki (1985, p. 87) described the contact between a "rusty mica schist and marble units that is gradational with

1-20 m of intervening intermediate composition: quartz-feldspar-dolomite-biotite-actinolite schist or grey quartz-plagioclase-biotite-granulite (calc-schist)'. Both the clast and matrix compositions of the conglomerate in the Wilson Creek area appear to be compatible with the Hird Lakes metaconglomerate; however, there is no marble in contact with the Hird Lakes metaconglomerate equivalent to the Banded Limestone Member. The Hird Lakes calc-silicate (2a-cs) may be equivalent to the associated calc-schist described by Klepacki (1985).

The Cooper Conglomerate consists of metadiorite, mafic volcanic and quartz monzonite clasts within a matrix of fine-grained quartz-biotite-plagioclase-sphene, or a rusty weathering quartz-cobble conglomerate with clasts of sugary quartzite (Klepacki 1985). Since the Hird Lakes metaconglomerate contains only quartzite clasts, this is not a likely correlation. Parrish and others (1985) suggest that the Cooper conglomerate and the Hird Lakes metaconglomerate are correlative due to the absence of appreciable quartzites associated with the Hird Lakes metaconglomerate. However, the matrix of Cooper Conglomerate is not the same as the calc-silicate matrix of the Hird Lakes metaconglomerate and a correlation is not tenable.

The Permian Marten Conglomerate lies unconformably on the Kaslo Group and is overlain unconformably by the Slocan Group (Klepacki 1985). It is composed of greenstone, diorite and serpentinite clasts, in a rusty weathering, green, calcareous phyllite matrix. Beds of limestone are also present. The limestone layers and the matrix composition of the Marten conglomerate could represent the protolith of the matrix of the Hird Lakes metaconglomerate. However, none of the clast types mentioned by Klepacki (1985) are observed in the Hird Lakes metaconglomerate.

2.5.2 Thor-Odin - Pinnacles area

The Thor-Odin - Pinnacles area (Fig. 1.1) consists of a heterogeneous package of metasedimentary and mafic rocks (Carr 1991) similar to those of the Valhalla assemblage. Carr (1991) has divided the area into two stratigraphic groups: the Gold Range assemblage (Hamili Group to Slocan Group correlatives) and the Fawn Lake assemblage (Horsethief Creek Group correlatives). Based on stratigraphic ordering and lithologic similarity, unit 10, the Rinda marble (unit 9), the Rinda Ridge composite unit (unit 8a, 8a-u) and the Hird Lakes metaconglomerate are correlated with the Mount Symonds quartzite-bearing unit, the Empress marble, the Lower Mount Fosthall composite unit and the Vidler calc-silicate gneiss of the Gold Range assemblage, respectively. The distinctive sequence of psammites, calc-silicates and marbles (Lower Mount Fosthall Composite unit), marble (Empress marble), and quartzites (Mount Symonds quartzite-bearing unit) has been correlated to the Index Formation of the Lardeau Group, Badshot Formation and Hamill Group, respectively, by Carr (1991). Both unit 8 of the Valhalla assemblage and the Lower Mount Fosthall Composite unit contain interlayered psammites, calc-silicate gneisses, marbles and ultramafic rocks, which is a suitable correlation.

Ultramafic pods in the Thor-Odin - Pinnacles area, occur at two different stratigraphic levels. Unit 7a (the lower Mount Fosthall composite unit) contains phlogopite-orthopyroxene-clinopyroxene-tremolite-olivine-calcite bearing ultramafic gneiss as layers, blocks and pods. Carr (1991) has suggested that these are high-grade equivalents of talc schists which occur in the Lardeau Group (Sears 1979; Zwanzig 1973) and has correlated the

Mount Fosthall Composite Unit with the Index Formation of the Lardeau Group, based in part on this correlation. This is a possible correlative to unit 8a-u of the Valhalla assemblage, based on similar composition and nature of the pods, as well as the association with marbles, calc-silicates gneisses, amphibolites gneisses, pelitic schists and quartzites.

The Vidler calc-silicate gneiss of the Gold Range assemblage consists of calcareous quartzite, marble and minor psammitic cobble metaconglomerate, which Carr (1991) has correlated with the siliceous argillite member of McHardy assemblage of the Milford Group, as described by Klepacki (1985).

The Fawn Lake assemblage consists of migmatitic semipelitic and psammitic paragneiss and amphibolite gneiss. Unit 11 of the Valhalla assemblage is comparable to this assemblage as well as the semipelite-amphibolite (SPA) of the Horsethief Creek Group, due to its lack of carbonate and mature siliciclastic rocks.

2.5.3 Riondel area

The Riondel area is located in the Kootenay Arc to the east of the Valhalla complex (Fig. 1.1). Höy (1977, 1980) has correlated units H, B and L of the Riondel Nappe to the Hamill Group, Badshot Formation and Lardeau Group, respectively. Höy's (1977) description of unit L2 as "diopside-rich calc-silicate layers, thin rusty-weathering calcite marble layers, and less commonly hornblende-biotite gneiss and micaceous quartzite" is similar to unit 8b of the Valhalla assemblage. Höy (1977) also describes a marble layer (L3iii) that is possibly correlative to the Bannock Burn marble (unit 6). A correlation of unit 8 to unit L2 and the Bannock Burn marble to unit L3iii is consistent with an inverted

Valhalla assemblage.

2.5.4 Nemo Lakes belt

The Nemo Lakes belt, located immediately north of the Valhalla complex (Fig. 1.1), consists of sillimanite-grade metasedimentary rocks, including semipelitic and calcareous schists, marbles, amphibolites and ultramafic rocks. This belt of rocks is correlative to parts of the Lardeau and Slokan group, on the basis of lithologic similarity and Rb-Sr whole rock ages (Parrish 1981). Ultramafic rocks in the Nemo Lakes belt are described by Parrish (1981) as pod-like, lenticular bodies up to 800 m in length, composed of anthophyllite, forsterite, enstatite, talc, chlorite, clino amphibole and serpentine. These ultramafics are enclosed by hornblende-plagioclase amphibolite and are interpreted as alpine-peridotites (Parrish 1981). They are bounded on both contacts by predominantly pelitic schists with intervening layers of calc-schist and marble. A correlation between the Nemo Lakes belt and the Valhalla assemblage is not reasonable because surrounding lithologies are dissimilar. The former has characteristically large volumes of pelitic schist, while the Valhalla assemblage has a heterogeneous nature.

2.5.5 Eagle Bay assemblage

The Eagle Bay assemblage in the Adams Lake-Clearwater-Vavenby area contains a succession of rocks ranging from possibly Windermere Supergroup to Milford Group (Schiarizza and Preto 1987). The area lies on the western edge of the Omineca belt (Fig. 1.1) and comprises low grade metavolcanic and metasedimentary rocks including the distinctive

up to ~1000 m thick Tshinakin limestone (EBGt) which is correlative with the Badshot Formation.

There are four different conglomerate bearing units within the Eagle Bay assemblage, two of which resemble the conglomerates in the Valhalla assemblage. Unit EBGcg is a polymictic conglomerate which occurs at the base of unit EBG, and consists of a fine-grained light- to medium-green calcareous, chlorite-sericite-quartz schist matrix with quartzite, limestone, dolostone, chlorite schist and vein quartz clasts (Schiarizza and Preto 1987). Unit EBSc is a quartz-pebble to boulder conglomerate with predominantly quartzite clasts and often has a calcareous matrix. Unit EBS has been correlated to the Lardeau Group. Schiarizza and Preto (1987) mention that it often underlies volcanics of unit EBM and this is not the case in the Valhalla complex.

None of the units in the Eagle Bay assemblage of the Adams Lake-Clearwater-Vavenby area have a striking similarity to marker units in the Valhalla assemblage except the EBSc conglomerate, which is insufficient to make a viable correlation. In the Eagle Bay assemblage, mafic volcanic rocks under- and overlie the Tshinakin limestone (Schiarizza and Preto 1987). This relationship is absent in the Valhalla assemblage, and therefore a confident correlation between the Eagle Bay assemblage in the Adam Lake-Clearwater-Vavenby area and the Valhalla assemblage is not possible.

2.5.6 Scrip Nappe

The Scrip Nappe, located north of the Monashee complex (Fig. 1.1) consists of inverted Horsethief Creek Group strata which have been metamorphosed to amphibolite-

facies (Raeside and Simony 1983; Scammell 1990, 1993). The Horsethief Creek Group has been divided into 5 members: the lower clastic, lower carbonate, semipelite-amphibolite, middle marble and upper clastic member (Wheeler 1963; Reesor 1973; Brown *et al.* 1978; Poulton and Simony 1980; Raeside and Simony 1983; Pell and Simony 1987). Overall, proportions of lithologies are similar between the Valhalla assemblage and rocks in the Scrip and Seymour ranges. There are numerous marble layers and the amount of amphibolites and metavolcanics is relatively low (Scammell 1990, 1993). Scammell (1990) describes quartz-cobble to boulder conglomerate in the southern Scrip and northern Seymour ranges; however, quartzite-pebble metaconglomerates with calc-silicate matrix like the Hird Lakes metaconglomerate are absent in the Scrip Range (Scammell pers. comm. 1995).

Ultramafic rocks of similar composition and nature also occur in the Scrip Nappe. They are present throughout the section, whereas in the Valhalla assemblage, ultramafics appear to be concentrated within two stratigraphic units (8 and 10). Although both the Valhalla assemblage and the Scrip Nappe have similar rock types, the ordering of units is not compatible, and therefore there is no compelling reason to correlate the Valhalla assemblage with rocks of the Scrip Nappe.

2.5.7 Greenwood-Grand Forks area

The Greenwood-Grand Forks area located to the southwest of the Valhalla complex (Fig. 1.1) is underlain by greenschist-facies Late Paleozoic and Mesozoic volcanic and sedimentary rocks that are possibly correlative to the Carboniferous Milford Group (Preto 1970; Little 1983; Fyles 1990). The Knob Hill and Attwood groups contain limestone with

Permian aged fauna and are overlain by the Triassic Brooklyn conglomerate (Fyles 1990). Paleozoic rocks consist of chert, greenstone, diorite and serpentinite of the Knob Hill Group and grey argillite, limestone and minor volcanic rocks of the Attwood Group (Fyles 1990). The only rocks that are similar to those in the Valhalla complex are serpentinites within the Knob Hill Group, which are interpreted to have Carboniferous or Permian ages and to be tectonically emplaced along structures at various times during the Mesozoic and Tertiary (Fyles 1990). The Greenwood-Grand Forks area does not contain the same volume of marble or limestone or any marker units that have comparable thicknesses to the Rinda marble. The amount of chert and volcanics and the angularity and type of clasts within the Knob Hill Group conglomerates is dissimilar to the Hird Lakes metaconglomerate. The distinct differences between the rocktypes and primary environments of the Greenwood - Grand Forks area and the Valhalla assemblage does not allow a correlation.

2.5.8 Mount Roberts Formation in the Trail area

In the Trail area to the south of the Valhalla complex, sedimentary rocks thought to be part of the Mount Roberts formation contains siltstone, slate, greywacke and conglomerate (Simony 1979). Pebble conglomerate contains clasts of quartzite, chert, siltstone and volcanic rock. These rocks are thought to be of Pennsylvanian age (Little 1978). The wide range in clast types of conglomerate and the lack of carbonate layers does not enable a correlation between the Mount Roberts Formation near Trail and the Valhalla assemblage to be made.

2.6 Summary

Detailed mapping of stratigraphy in the Valhalla complex has recognized a heterogeneous package of metasedimentary rocks named the Valhalla assemblage (Figs. 2.3, 2.5). The Valhalla assemblage contains conglomerates, calc-silicate gneisses and marbles interlayered with 50-100 m thick units of aluminum poor semipelitic to pelitic schists at its structurally lowest level (units 1-3). Proceeding up in structural direction, the sequence becomes more carbonate rich with metre thick marbles and calc-silicates gneisses, interlayered with quartzites and slightly more aluminum-rich pelitic rocks (units 4-8). There is also an increase in amphibolite gneisses and ultramafic rocks which are absent from the structurally lower sections. This is overlain by a thick marble and quartzite layers, respectively (units 9-10). At the structurally highest level, a thick unit of pelitic schist and amphibolite gneiss predominates (unit 11).

Based on lithologic similarity and relative ordering of the distinct Rinda marble (unit 9), Hird Lakes metaconglomerate (unit 2a) and ultramafic pods (8a-u), a correlation of the Valhalla assemblage to units ranging from Horsethief Creek Group to the Keen Creek assemblage of the Milford Group can be made (Table 2.3). Key elements of this correlation are the unique quartzite clast - calcareous matrix of the Hird Lakes metaconglomerate, concentration of the ultramafic rocks within a particular structural horizon, the lack of significant quartzites below the Rinda marble and the relative abundance of carbonates (high) and amphibolites (low) below the Rinda marble. These correlations indicate that the Valhalla assemblage is inverted of which the tectonic implications are discussed in chapter 4..

Age (Ma)	Event
52	Aplite dykes cross-cut Gwillim Creek shear zones
54-45	Movement along the Slocan Lake fault
58-47	K/Ar dates from hornblende, muscovite and biotite record temperature decrease from 500 - 280 °C
59-54	Movement on the Valkyr shear zone
59-55	Ladybird granite suite intrudes during extensional faulting
60	Growth of metamorphic zircon in amphibolite Titanite cools below 600 °C closure temperature
63	Intrusion of Airy quartz monzonite, minimum age for S ₂ development
<65	Cooling and uplift (U-Pb thermochronology) caused by uplift and erosion
~65	Melting and growth of igneous zircons (formed after thermal peak by decompression melting)
70-65	Pegmatites containing igneous zircon intruded metasedimentary rocks
80-75	Thermal peak; closure of zircon and monazite; GCSZ and S ₂ proposed to be active at this time
100-<92	Oldest age possible for Gwillim Creek shear zones (Mulvey gneiss is thoroughly sheared)
110	Crystallization of Mulvey granodiorite and Kinnaird gneiss, maximum age for S ₂
>110--290	Age of first phase folding implied from stratigraphic correlations (post Mississippian) and age of Mulvey granodiorite
>110-1400	Absolute ages constraints for deposition of sedimentary protoliths followed by or synchronous with minor igneous events (mafic dykes, volcanic?, granitic intrusion)
~1400, 1700,2700	Crystallization of igneous rocks later eroded and provided zircon and monazites that were deposited in sedimentary rocks of Valhalla assemblage.

Table 2 1. Compilation of geo- and thermochronology and structural and stratigraphic constraints for tectonic events in the Valhalla complex from Carr and others (1987), Parrish and others (1988), Parrish (1990), Heaman and Parrish (1991), Ross and Parrish (1991), Parrish (1995) and this study.

Marble	coarse grained, granoblastic brown to beige weathering with white fresh surface calcite $\pm$ dolomite $\pm$ diopside $\pm$ graphite diopside commonly occurs as crystals 3 mm in diameter and comprises 10% of the rock dolomite often forms positive weathering 2-3 mm sized crystals giving rock a knobby appearance layering is not well defined although graphitic layers may represent transposed bedding plagioclase forms chunks and discontinuous layers up to 4 cm wide that are interpreted to be a result of tectonism
Calc-silicate gneiss	commonly beige to light green weathering with white and green fresh surface quartz, plagioclase, diopside $\pm$ tremolite $\pm$ calcite $\pm$ phlogopite S ₂ gneissosity defined by 2mm to 3 cm thick straight bands of diopside and quartz-feldspathic layers dark green weathering, actinolite(tremolite) rich calc-silicate gneiss with discrete mm wide phlogopite-rich layers also present
Siliceous marble	granoblastic and coarse grained brown to beige weathered surface calcite, quartz $\pm$ dolomite $\pm$ diopside distinct gneissic layering 1-4 cm wide defined by calcite- and quartz- rich layers quartz layers make up to 25% of rock characterized by lack of diopside
Calcareous quartzite	buff to beige weathering with white fresh surface pitted or pock-marked appearance occurs from weathering of calcite out of quartz matrix predominantly granoblastic quartz with lesser amounts of calcite conspicuous lack of plagioclase and diopside

Table 2.2 Description of major rock types in the Valhalla assemblage.

Pelitic schist	<p>rusty brown to black weathering, migmatitic, leucosome is commonly garnetiferous leucosome or melt pods make up to 20% of rock and are 5 mm to 4 cm wide true pelites rare in Valhalla</p> <p>layers with greater than 30-40% biotite rare</p> <p>garnet-K-feldspar-sillimanite-biotite</p> <p>biotite defines main S_2 schistosity and is commonly intergrown with sillimanite which forms in fibrous matts, disseminated glassy needles and rarely as knots (Faserkiesel)</p> <p>garnet occurs as 2 mm to 2 cm porphyroblasts which are pre-syntectonic with respect to main foliation, sillimanite is almost always lineated</p>
Semipelitic schist	<p>brown to dark grey and black weathering</p> <p>garnet-sillimanite-K-feldspar-biotite</p> <p>commonly a biotite (20-30%)-quartzo-feldspathic schist</p> <p>S_2 schistosity to gneissosity defined by discrete mm wide biotite layers alternating with quartzo-feldspathic layers also on mm scale</p> <p>plagioclase rich leucosome present and makes up < 5% of rock</p>
Psammitic gneiss and argillaceous quartzite	<p>light grey to rusty brown weathering</p> <p>massive to granoblastic texture</p> <p>biotite, quartz, plagioclase $\pm$ graphite</p> <p>garnet and sillimanite are absent</p> <p>biotite and graphite makes up < 10% of rock and defines a weak S_2 foliation</p>
Quartzite	<p>light grey to light rusty red weathering, glassy to light grey fresh surface</p> <p>quartz makes up 95% of rock while biotite and/or graphite makes up to 5% and defines weak foliation and possibly bedding; hematite causes red staining</p> <p>generally massive to granoblastic appearance but rock breaks parallel to what could be considered transposed bedding plane</p>

Table 2.2 (cont'd). Description of major rock types in the Valhalla assemblage.

Amphibolite gneiss and schist	<p>black weathering, black fresh surface</p> <p>grain size and mineralogy varies</p> <p>coarse grained garnet -quartz -hornblende-plagioclase gneiss contains up to 20% 3mm sized garnet porphyroblasts</p> <p>medium grained biotite-hornblende-plagioclase schists are less common and contain up to 20% biotite</p> <p>biotite and hornblende define S_2 foliation and are commonly aligned in a lineation</p> <p>gneissic layering is rare and is defined by the 1-2 cm alternation of hornblende and plagioclase bands</p>
Ultramafic schist	<p>bright green to greenish grey and black weathering, bright green to light green fresh surface</p> <p>occur as up to 5 m wide pods</p> <p>tremolite, diopside, $\pm$ olivine $\pm$ phlogopite</p> <p>weak fabric (S_2) is defined by phlogopite</p> <p>tremolite gives bright green colour and occurs as interlocking and often radiating crystals</p>

Table 2.2 (cont'd). Description of major rock types in the Valhalla assemblage.

Valhalla Complex (this study)	Goat Ranges Klepacki (1985)	Thor-Odin - Pinnacles Area Carr (1991)	Age
Unit 2a Hird Lakes calc-silicate gneiss - quartzite-pebble metaconglomerate	Milford Group Keen Creek Assemblage (quartzite conglomerates in Siliceous Wacke Member) or McHardy Assemblage?	Vidler calc-silicate with minor conglomerate?	U. Miss. - L. Penn.
Units 3,5-7 semipelitic to pelitic schist, quartzite, marble, calc-silicate gneiss, amphibolite gneiss	Milford Group Keen Creek Assemblage Siliceous Wacke and Upper Limestone Members?	No correlative unit	U. Miss. - L. Penn.
Unit 4 Demers marble	Banded Limestone Member	No correlative unit	U. Miss.
Unit 8a Rinda ridge composite unit: marble, calc-silicate gneiss, quartzite, ultramafic rocks	Lardeau Group Index Formation (calc-silicate gneiss, mica schist and gneiss)	Lower Mount Fosthall composite unit: calc-silicate, psammite, ultramafic rocks	L. Paleozoic
Unit 9 Rinda marble	Badshot Formation (limestone and marble)	Empress marble	L. Cambrian
Unit 10 quartzites	Hamill Group (quartzites)	Mount Symonds quartzite bearing unit	Eocambrian
Unit 11 pelitic schist, amphibolite gneiss with minor quartzite and marble	No correlative units exposed	Fawn Lake assemblage (correlated to Semipelitic-amphibolite member of the Horsethief Creek Group)	Neoproterozoic

Table 2.3. Regional correlation of the Valhalla Assemblage.

Figure 2.1. Schematic diagram of relationships between stratigraphy and terranes in the northern Kootenay arc. Modified from Klepacki (1985) and Roback et al. (1994).

Figure 2.2. Map showing limit of domains in paragneisses of the Valhalla complex.

- Early Eocene Ladybird granite
 - Paleocene Airy quartz monzonite
 - Late Cretaceous Mulvey granodiorite
 - middle Jurassic granitic rocks
 - Valhalla Assemblage intruded by K-feldspar megacrystic granite
 - Valhalla Assemblage comprising >75% leucogranite
 - Valhalla Assemblage
-
- 10a Quartzite, psammite
 - 10b Semipelitic schist, psammite, argillaceous quartzite
 - 9 Rinda marble
 - 8a Rinda Ridge composite unit: marble, calc-silicate gneiss, psammite, semipelitic to pelitic schist, quartzite, amphibolite gneiss, ultramafic rocks (8a-u)
 - 8b Marble, calc-silicate gneiss, semipelitic schist, psammite
 - 7 Semipelitic to pelitic schist, psammite
 - 6 Bannock Burn marble
 - 5a Hocer Creek composite unit: psammite, pelitic schist, argillaceous quartzite, marble, calc-silicate gneiss, amphibolite gneiss
 - 5b Semipelitic to pelitic schist, psammite
 - 5c Semipelitic schist, psammite
 - 4a Marble, calc-silicate gneiss
 - 4b Demers marble
 - 4c Marble, siliceous marble
 - 3a Quartzite
 - 3b Semipelitic to pelitic schist, migmatite, argillaceous quartzite
 - 3c Quartzofeldspathic gneiss, pelitic schist, calcareous quartzite (3c-cq)
 - 2a Hird Lakes calc-silicate (2a-cs) - quartzite cobble metaconglomerate (2a-cg)
 - 2b Marble
 - 1 Quartzofeldspathic gneiss

Figure 2.3. Geology of the Valhalla assemblage.

Figure 2.3

Figure 2.4. a) Fold axes b) poles to axial surfaces.

Figure 2.5. Stratigraphy of the Valhalla Assemblage.

Figure 2.6. Folded obduction surface model for Riondel Nappe, based on Brown and Lane (1988). Diagram modified from Varsek and Cook (1991).

Figure 2.7

Figure 2.7. Lithoprobe seismic reflection cross-section through portions of the southern Omineca belt and Rocky Mountain foreland fold and thrust belt copied after Varsek and Cook (1994). Thrust faults include the Gwillim Creek shear zones (GCSZ), the Hall Lake fault (HLF) the Moyie fault (MF), the Monashee décollement (MD), the Redding Creek fault (RCF), the Redwall fault (RWF), the St. Mary's fault (SMF) and the West Bernard fault (WBF). Normal faults include the Ainsworth fault (AF), the Lussier River fault (LRF), the Slocan Lake fault (SLF) and the Valkyr shear zone (VSZ). Other features are the K-reflectors (K), which have been correlated to the GCSZ by Varsek and Cook (1994), the Rocky Mountain basal detachment (RMBD), the Rocky Mountain trench (RMT) and the Riondel Nappe (RN).

Plate 1

Plate 1

Plate 1a. Strongly folded Demers marble (4c) near Hela Peak. Resistant, brown weathering layers are siliceous, while recessive layers are marble

Plate 1b. Tightly folded quartzo-feldspathic gneiss of unit 1 near Mount Bor. Pegmatite is concordant with gneissic layering and is also folded.

Plate 1c. Interference pattern of F_3 refolding F_2 in quartzo-feldspathic gneiss of unit 3c located near the Rocky Lakes.

Plate 2

Plate 2

Plate 2a. Outcrop-scale east-verging overturned fold in Hird Lakes quartzite-cobble metaconglomerate.

Plate 2b. Metre-scale east-verging, z-fold in amphibolite layer on Rinda Ridge.

Plate 2c. Typical nature of coarse-grained leucogranite intruding pelitic schist (10b). Note that layering is not totally disrupted, which allows units to be followed along strike.

Plate 2d. Metre-sized xenoliths of calc-silicate gneiss (unit 2a-cs) within a stock of coarse grained leucogranite, located near the edge of the eastern Gwillim Lake.

2

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

PRECISIONSM RESOLUTION TARGETS

Plate 3

Plate 3

Plate 3a. Typical nature of semipelitic and pelitic (brown) separated by metre thick pegmatites and leucogranites of the Ladybird suite.

Plate 3b. Centimetre-scale layering in north-east verging, Z-folded psammitic gneiss and leucosome of Rinda Ridge composite unit (8a), near Mount Rinda.

Plate 3c. Quartzite-pebble metaconglomerate (2a-cg) with calc-silicate matrix, near Hird Lakes.

3b

3c

3a

Plate 4

Plate 4

Plate 4a. Quartzite-cobble metaconglomerate (2a-cg) in contact with a psammitic layers, near Rocky Lakes.

Plate 4b. Metre scale layering in migmatitic gneiss of unit 3b. Dark -coloured layers are composed of sillimanite biotite schist, while leucocratic layers are concordant coarse-medium grained leucogranite.

Plate 4c. Millimetre-centimetre straight, gneissic layering of calcareous quartzite (3c-cq), west of Urd Peak.

Plate 4d. Tightly folded calc-silicate gneiss of Hoder Creek composite unit (5a), on ridge separating drainages of Drinnon Lake and Bannock Burn.

Plate 5

Plate 5

Plate 5a. Centimetre-scale interlayered marble and calcareous schist of Rinda Ridge composite unit (8a).

Plate 5b. Beige-buff weathering, clean quartzite layer within Rinda Ridge composite unit (8a), with overlying concordant pegmatite.

Plate 5c. Interlayered and refolded calc-silicate and amphibolite gneiss of Rinda Ridge composite unit (8a), near Mount Rinda.

5b

5c

5d

Plate 6

Plate 6

Plate 6a. Typical greenish-brown weathering nature of ultramafic pods (8a-u), near Mount Rinda. In lower left, amphibolite gneiss associated with ultramafics is visible.

Plate 6b. Rubbly, metre-scale outcrop of metamorphosed ultramafic rock (8a-u), near Mount Rinda.

Plate 6c. Decimeter scale interlayered marble, calc-silicate gneiss and semipelitic schist of unit 8b, on north flank of Rinda Ridge.

6a

6b

6c

Plate 7

Plate 7

Plate 7a. Buff weathering, coarse-grained Rinda marble (9). Although interference pattern is unclear it is most likely F3 refolding F2.

Plate 7b. Typical nature of pelitic schist, amphibolite boudins and pegmatite within undivided units of the Valhalla Assemblage along Highway 6 and along logging roads in the southern portion of Valhalla complex.

Plate 7c. Western (upper) Gwillim Creek shear zone. Lower, brown weathering unit is Valhalla Assemblage (paragneisses), while upper, grey weathering unit is Mulvey granodiorite.

CHAPTER 3: METAMORPHISM OF PARAGNEISSES IN THE VALHALLA COMPLEX

3.1 Introduction

Stratigraphic correlations place few constraints on the magnitude of displacement or vergence of the GCSZ, and do not give any indication of whether the shear zones are thrust or extensional faults. The aim of this chapter is to characterize and compare the metamorphic history of paragneisses in the hanging wall and footwall of the GCSZ. Textural evidence is used to determine the relative timing of metamorphism with respect to deformation, and thermobarometry is used to deduce differences in pressure-temperature conditions of paragneisses across the GCSZ and at different structural levels within the Valhalla complex. Integration of the textural study with thermobarometry is used to infer parts of the pressure-temperature paths from the different structural levels in the Valhalla complex.

The wide range of bulk compositions in the Valhalla complex facilitates independent determinations of pressure-temperature conditions. Mineral assemblages and textures in marbles, calc-silicate gneisses and ultramafic schists were not studied in detail; however, they do provide general constraints using a petrogenetic grid and are consistent with conditions determined using thermobarometry. Thermobarometry was carried out on pelitic schists, amphibolite gneisses and one sample of marble. Textural observations and chemical data in pelitic schists were used to relate the timing of metamorphic reactions to deformation. Zoning patterns and chemical data obtained from microprobe and SEM analyses were used

to help decipher the reaction history of pelitic schists. These textures and chemical data were used as a guide to suggest which minerals were in chemical equilibrium and which portions of the pressure-temperature path were represented by the compositions that were used in thermobarometric calculations.

3.2 Analytical methods

Sixty samples of pelitic to semipelitic schist, twelve samples of amphibolite gneiss, nineteen samples of marble and calc-silicate gneiss, and five samples of ultramafic schist were examined using the petrographic microscope to determine metamorphic assemblages and textures. Minerals from thirteen samples of pelitic schist and five samples of amphibolite gneiss were analysed using the electron microprobe at Carleton University. Two samples (PCA-93-84, PCA-200-85) of pelitic schist collected by Sharon Carr were analysed by Marc St. Onge at the Geological Survey of Canada and the data have been incorporated into this study. The Cambridge Microscan 5 electron microprobe was coupled to an ORTEL Si energy dispersive x-ray detector, which was operated at 20 kV accelerating potential, with a 3.0 nanoampere beam current measured on a Faraday cup. The counting time of all elements was 120 seconds live time and raw X-ray spectra were calculated into oxide weight percent using the EDDI computer program (Pringle 1989). The calculation of Fe^{+3} in ilmenite was carried out using the EDDI program, which uses a stoichiometric method modelled after Droop (1987).

In pelitic schists and amphibolite gneisses, at least two garnet-bearing domains were analysed within each thin-section. Quantitative mineral analyses from the microprobe and

X-ray maps from the SEM were used to detect compositional zoning and its relationship to texture. Reconnaissance analyses taken on two samples of marble and one sample of calc-silicate included scapolite, plagioclase, diopside, hornblende and forsterite.

Quantitative data for garnet, biotite, plagioclase and ilmenite were obtained for pelitic schists. In each thin-section, up to five different spatially related biotites were analysed: 1) grains in contact with garnet rims; 2) proximal biotite grains ~0.1-0.5 mm away from the garnet rim and separated by non-ferro-magnesium minerals; 3) grains in garnet pressure shadows; 4) biotite inclusions in garnet; and 5) biotite grains enclosed by wormlike quartz in garnet (armoured biotite grains). Biotite grains that are in the matrix but near garnet rims and are not in direct contact with garnet are herein referred to as proximal biotite grains. Plagioclase inclusions in garnet, plagioclase grains in contact with garnet, and plagioclase grains in the matrix as close as possible to garnet without actually touching it were also analysed. As ilmenite was not observed in contact with garnet, ilmenite grains as near as possible to the garnet were analysed. In amphibolite gneisses, hornblende, biotite, and plagioclase were analysed to observe differences between grains in contact with garnet and those within 1-2 mm of the garnet. Hornblende inclusions in garnet were analysed where present.

Thermobarometric data were obtained from minerals in contact with garnet and also those minerals that were in the matrix but within the same thin-section domain. In pelitic schists, inferred post peak temperatures and pressures (T₁, P₁) were obtained from garnet rims adjacent to non-ferromagnesium minerals, and from biotite and plagioclase grains less than 1 mm away from garnet. The compositions of these proximal matrix biotite grains were

used to avoid the effects of the latest Fe-Mg exchange between garnet and biotite. In samples that did not contain plagioclase in contact with garnet, compositions from matrix plagioclase grains as close as possible to the garnet rim were used in calculations. Temperatures and pressures representative of a lower pressure-temperature part of the pressure - temperature path (T2, P2) were obtained from garnet rims in direct contact with biotite and plagioclase grains in contact with the garnet rims. Since no pattern in composition was observed between plagioclase grains in contact with garnet and those in the matrix, P1 and P2 pressures are virtually the same. P2 pressures that intersect T1 are an artifact formed as a result of moving down the same GASP isopleth calculated for P1.

Garnet compositions used in thermobarometric calculations were obtained from the average of 1-4 data points from a similar textural location, and were within 1-2 mole % of each other. Biotite and plagioclase compositions were obtained by averaging at least two data points from each mineral. In some instances, one analysis of biotite was used due to small grain size. The same procedures were applied to garnet, hornblende, plagioclase and biotite in amphibolite gneisses.

Pressures and temperatures were generated using the computer program TWEEQU (Berman 1991) which calculates temperatures and pressures from equilibria calculated using the thermodynamic database of Berman (1988, 1990) and Mader and Berman (1992) and is internally consistent because it uses the same thermodynamic data for all phases and the same solution models for the appropriate mineral in each equilibrium. Empirical calibrations of geothermometers and geobarometers often only give reasonable data when a particular solution model is applied. This program allows the user to calculate as many equilibria as

possible, both stable and metastable, however, not all of these are independent. The degree to which more than 2 independent equilibria intersect at a single pressure-temperature point is used as a test for the relative equilibration state of all minerals, assuming that the mineral systems closed at the same time. This method assumes that mineral analyses, activity solution models and thermodynamic data are all reliable. In this study, only the most robust thermometers and barometers were applied; those with extensive and well constrained thermodynamic data and with relative insensitivity to errors in input data. For this reason equilibria involving pargasite, Fe-pargasite and Fe-tschermakite were excluded in amphibolite gneisses because thermodynamic data are less certain for these end-members than they are for other amphibole end-members. All reactions presented in this study are listed with the high temperature or pressure side on the right hand side.

Thermometry of pelitic schists was based on the garnet - biotite exchange equilibrium (e.g. Ferry and Spear 1978);

Barometry was based on the GASP (e.g. Ghent 1976) net-transfer equilibrium;

and the GRAIL (Bohlen *et al.* 1983) equilibrium;

In pelitic schists, some assemblages allowed the application of both the GASP and GRAIL barometers. This allowed for a test of the relative equilibrium of the assemblage garnet-biotite-plagioclase-sillimanite-quartz-ilmenite-rutile. The various equilibria used in

thermobarometric calculations operate by different microprocesses and therefore it might be expected that different equilibria would "close" or "freeze in" at different temperatures. Readjustment of the GASP equilibrium involves breaking of tetrahedral Al-Si bonds in plagioclase and a change in garnet-plagioclase proportions. The GRAIL equilibrium involves Fe-Mg exchange and therefore a lower closure temperature may be expected for GRAIL than for the GASP equilibrium. If Fe-Mg exchange outlasts the operation of net-transfer reactions these two barometers might be expected to record two points along a pressure-temperature path. Alternatively, intersections of the garnet-biotite thermometer and GASP and GRAIL barometers at a single pressure-temperature point, would suggest that all phases last equilibrated at the same pressure-temperature conditions.

Thermobarometry of amphibolite gneisses was carried out using TWEEQU to compute the positions of the garnet - hornblende - plagioclase - quartz barometer of Kohn and Spear (1990);

(4) tremolite + anorthite = tschermakite + grossular + pyrope + quartz,

the garnet - hornblende thermometer (e.g. Graham and Powell 1984);

(5) almandine + tremolite = Fe-tremolite + pyrope,

and the garnet-biotite thermometer (reaction 1). To gain a better understanding of the prograde history of amphibolite gneisses, reaction (5) was applied to samples with hornblende inclusions in garnet. Plagioclase inclusions are absent in garnet and therefore reaction (4) could not be applied. The solution models of Berman (1990), McMullin and others (1991), Fuhrman and Lindsley (1988), and Mader and Berman (1992) were used for garnet, biotite, plagioclase and hornblende, respectively. Fixed activities for ilmenite were

calculated assuming ideal mixing.

Thermobarometry was carried out on one sample of marble, for which the equilibrium:

(6) anorthite + calcite = meionite (Ca-scapolite)

was used to constrain peak temperatures. This equilibrium was also generated with TWEEQU using the solution model of Oterdoom and Gunter (1983) for scapolite.

3.3 Petrology of paragneisses

3.3.1 Pelitic schist

Pelitic schists in the Valhalla complex contain the assemblage quartz - biotite - plagioclase $\pm$ garnet $\pm$ sillimanite $\pm$ potassium feldspar (see Appendix B for modal abundances), which places them in the upper-amphibolite metamorphic facies above the breakdown of muscovite. Accessory minerals include ilmenite, rutile, pyrite, zircon, apatite and monazite. Mineral assemblages for individual samples are presented in Appendix B. Kyanite was observed in one sample by Carr (pers. comm. 1994), but has not been found in any other samples. Peak conditions are constrained by the presence of sillimanite, potassium feldspar and abundant melt, and by the absence of prograde muscovite and kyanite (Fig. 3.1). Metamorphic conditions are further constrained by the absence of orthopyroxene, which is indicative of granulite facies metamorphism (Harley 1988, Fig. 3.1). Retrograde metamorphism is generally restricted to late faults and fractures. However, it is rarely penetrative and is represented by randomly oriented chlorite that replaced biotite in garnet

pressure shadows and fractures, and by non-aligned radiating muscovite and sericite that occurs in plagioclase (Appendix B).

Pelitic schists are described in terms of the three domains presented in chapter 2. The first area (domain 1a) is the structurally highest, and occurs on the west side of the complex between Mount Rinda and Hela Peak in the hanging wall of the GCSZ (Fig. 3.2). Domain 1b occurs in the southern area of the paragneisses at higher structural level than domain 2 and has the same structural characteristics as domain 1a (see section 2.2, cross-section A). Domain 2 occurs in the southern portion of the paragneisses in the area of Vallican, below domain 1b. Domain 3 occurs in the lower Gwillim Creek window (sheet 1a, Fig. 3.2, section 2.2). Textural, chemical and thermobarometric data, as well as textures which relate metamorphic reactions to deformation for each of the three domains are presented in the following sections. Within each domain, the textures and chemical data will be presented for individual mineral species in relation to each other.

Domain 1 - Valhalla assemblage (sheet 1c, west side)

Textures, mineral compositions and reaction histories

Pelitic schists of the Valhalla assemblage, between Mount Rinda and Hela Peak (Fig. 2.3) may be divided into two bulk compositions based on the relative proportions of sillimanite and plagioclase. The first rock type is a strongly foliated pelitic schist, which has a foliation defined by biotite and discrete layers of sillimanite, and quartz and feldspar. Garnet porphyroblasts are common. The second rock type is also a pelitic schist, based on

biotite content, but has a moderately to weakly developed foliation. Biotite does not wrap around garnet porphyroblasts, but abuts them, and is commonly randomly oriented. Sillimanite is rare or absent, and plagioclase is abundant. These sillimanite poor schists have ragged, angular garnet porphyroblasts with uneven rims and many fractures (Plate 8a).

Garnet

Garnet occurs as subhedral to anhedral porphyroblasts and poikiloblasts, ranging from 0.5 mm to 2 cm in size (Plate 8a, 8b). Small and closely spaced quartz grains appear to represent true inclusions that have been incorporated into the garnet crystal during its growth. Commonly, inclusions are concentrated in the core of the garnet and show no preferred orientation (Plate 8c). There is no compositional difference between areas of the garnet core with high and low numbers of inclusions. The inclusion-free rim texture may be either the result of: 1) a second phase of garnet growth, or 2) a slower rate or a fluid enhanced phase of garnet growth allowing included phases to be consumed or excluded from the crystal, rather than frozen in. Thus garnet growth may have been achieved by reaction:

or

If reaction (7) were operative, then the high concentration of quartz inclusions in the core of certain garnets may indicate an excess of quartz that could not be consumed by the garnet forming reaction. Reaction (8) would explain the scarcity of plagioclase in some samples, although this is more likely to be a function of bulk composition. Garnets also contain many

fractures which are commonly oriented at nearly 45° to the foliation, and are interpreted to be caused by stress applied to the coherent garnet grains.

Garnet often has many large quartz embayments (Plate 8b) which are interpreted to represent the final consumption of garnet following the peak of metamorphism. Quartz occurring as embayments, wormlike inclusions and halos around garnet (Plate 8a) may be the result of the garnet consuming reaction (7) proceeding in the opposite direction as described in the previous paragraph. Sillimanite and biotite are not commonly in close proximity to these quartz embayments and therefore reaction (7) may not be responsible for the production of quartz; however if it is, then biotite and sillimanite may increase in size rather than nucleating new grains.

Inclusions in garnet include quartz, biotite, plagioclase, sillimanite, apatite, ilmenite and rarely rutile (Plate 8d). Inclusions may make up to 40% of the garnet. Where inclusion trails of quartz are aligned they are at a high angle to the external foliation (Plate 9a). Quartz inclusion trails are usually straight and cannot be traced to the external foliation, suggesting that the garnet overgrew a preexisting foliation (S_1).

S_2 contains the peak metamorphic mineral assemblage. The initiation of garnet growth occurred prior to S_2 and the onset of coarse grained minerals. Sillimanite inclusions often occur within the garnet rim and are generally parallel to the external foliation (Plate 9b). This texture suggests that garnet growth continued during prograde metamorphism at sillimanite grade and the onset of S_2 foliation development. Peak minerals aligned within S_2 wrap around garnet porphyroblasts and indicate that deformation outlasted metamorphism. Peak metamorphic minerals (biotite, sillimanite and K-feldspar) occur in the pressure

shadows, indicating that the peak of metamorphism was synchronous with S_2 .

Garnet zoning

Microprobe analyses show the typical diffusion zoning patterns (type 3) described by Tracy (1982). Relatively flat profiles of Fe, Mg, Ca, and Mn are observed in the cores of all garnets (Fig. 3.3). Garnet rims in contact with biotite have Fe/Fe+Mg ratios that are 5-8 mole percent higher relative to the core (Fig. 3.3). Garnet rims in contact with either quartz, plagioclase or potassium feldspar have lower Fe/Fe+Mg ratios than those rims in contact with biotite, but also show a ~5 mole % increase relative to the core. Increases in Fe and decreases in Mg, in the same sample, at rims in contact with biotite are attributed to Fe-Mg exchange via reaction (1). The other common ferro-magnesium mineral in pelitic schists of the Valhalla complex is ilmenite, but it is rarely observed in contact with garnet and it is therefore unlikely that exchange between ilmenite and garnet is responsible for increased Fe levels in garnet rims. If exchange reactions were the only reactions taking place, increased Fe levels would only be present where biotite is in contact with the garnet rim, and this is not the case. The fact that garnet rims have higher Fe/Fe+Mg relative to the core, regardless of whether the garnet is in contact with biotite or not, suggests that both net-transfer and exchange reactions were taking place. Garnet may have been consumed via reaction (7) or (8), producing both a garnet rim and new biotite grains with an increased Fe content. Fe/Fe+Mg ratios are also elevated where garnets contain biotite inclusions (Fig. 3.3). This is interpreted to be a result of the Fe-Mg exchange between garnet and biotite (reaction 1) during the cooling portion of the pressure temperature path.

Ca content remains relatively constant from garnet core to rim (Fig. 3.3), including most of the samples where the garnet rim is in direct contact with plagioclase. Mn zoning is slight in most cases. Some samples exhibit sharp increases of 1-2 mole % spessartite towards the rim which may be attributed to retrograde conditions during cooling (e.g. Yardley 1977).

The flat zoning profiles of garnet cores in Valhalla complex are interpreted to be a result of diffusion. At temperatures above 675 °C, diffusion rates in garnet are fast enough that garnet is able to equilibrate to ambient P-T-X conditions, thus homogenizing garnet compositions from rim to core and erasing all previous growth zoning (Yardley 1977).

Sillimanite

Sillimanite is present in most pelitic schists of the Valhalla complex making up to 2% of the rock. The large amount of sillimanite, the presence of potassium feldspar and the lack of muscovite in the peak metamorphic assemblage indicates that these rocks lie on the high temperature side of the second sillimanite isograd:

Sillimanite is aligned in the main transposition fabric and occurs in the pressure shadows of garnet. Sillimanite rarely occurs as radiating non-aligned masses suggesting that some sillimanite growth either outlasted deformation in some areas or grew in areas of low strain (Plate 9c).

Plagioclase

Plagioclase makes up 5-20% of most samples. Porphyroclasts occur within discrete layers of partially recrystallized quartz. Deformation twins are common. Plagioclase was observed, in some cases, forming narrow moats around garnet (Plate 9d). The moats are discontinuous and are likely to have been to be the result of garnet consuming reactions that occurred during decompression (reaction 2). In one case, plagioclase replaces garnet and the relict shape of the garnet contains sillimanite and biotite aligned in S_2 (Plate 10a). This appears to be an example of the advanced stage of reaction (8). Most plagioclase moats around garnet are interpreted to be a result of reaction (2) because plagioclase moats are solid and intergrowths of plagioclase, sillimanite and biotite are absent. These symplectites might be expected if reaction (8) were responsible for the formation of plagioclase moats around garnet.

Matrix plagioclase grains range in composition from albite to labradorite between samples (An 19 to An 48, Appendix C), however grains within a sample do not vary more than ~ 5-10 mole %. Grains in contact with garnet have a slightly narrower range in composition, from An 22 to An 49, and no systematic difference in An content is related to textural location. Plagioclase inclusions in garnet have an An content that ranges from 26 to 30, and are elevated in Ca relative to plagioclase that occurs in the matrix and adjacent to garnet in the same sample (An 23 - 25, Appendix C). Although An contents may vary within a plagioclase grain, coherent or concentric compositional zoning is absent.

Quartz

Quartz makes up to 30% of pelitic schists and most often occurs as aggregates of

grains and ribbons. In quartz ribbons recovery is not advanced. Grain size is quite variable and many subgrains are present. Grain boundaries are generally seriate and 120° grain boundaries are rare, suggesting that strain rates and temperature conditions were such that minerals did not recover and reorganize strain features such as subgrains. Quartz is more abundant in sillimanite poor rocks.

Myrmekite is observed as vermicular symplectites of quartz and plagioclase (Plate 10b) and is attributed to the breakdown of potassium feldspar:

(Evans and Guidotti 1966).

Retrograde muscovite is often associated with myrmekite.

Biotite

Biotite makes up to 40% of pelitic schists. It defines the foliation in most samples and is often found intergrown with sillimanite, suggesting simultaneous growth via reaction (7) or (8). It occurs as disseminated grains in samples where its modal abundance is lower (15-20%). Biotite is commonly concentrated in the pressure shadows of garnet (Plates 8c, 10c). Contacts with garnet are usually sharp, but biotite also occurs as embayments in garnet and, in this case, is interpreted to have formed during garnet consumption. The normally sharp grain boundaries are consistent with relative equilibrium between the garnet and biotite grains.

Biotite exhibits compositional variations that are related to the five different spatial associations with respect to garnet, as described previously (Appendix C). Biotite inclusions,

within quartz inclusions in garnet, and matrix grains of biotite have the highest Ti content (up to 10 mole %). Armoured inclusions are normally found in "inclusions" of quartz that have been interpreted to be a product of consumption. These quartz "inclusions" embay garnet from outside the plane of section. Unarmoured biotite inclusions and grains in contact with, and in the pressure shadows of garnet have the lowest Fe/Fe+Mg ratios (~0.45), while matrix grains have the highest Fe/Fe+Mg ratios (~0.5). The high Fe levels of biotite grains in direct contact with garnet and unarmoured biotite inclusions is interpreted to be a result of Fe-Mg exchange occurring during cooling along a retrograde pressure-temperature path.

Ilmenite and rutile

Ilmenite occurs in most samples and rutile is less common, but the two are never found together in samples within domain 1a in the hanging wall of the GCSZ. In rare instances, ilmenite occurs as inclusions in garnet. The absence of rutile might indicate low pressure or increased Fe bulk compositions. Ilmenite occurs in the pressure shadows of garnet indicating its presence at the peak of metamorphism (Plate 10c).

In samples PS-332-94, from domain 1b, rutile overgrows ilmenite. There are two net-transfer reactions that may be responsible for this; either the GRAIL reaction (3) or;

(11) ilmenite + anorthite + quartz = grossular + almandine + rutile.

In sample PS-332-94, ilmenite in contact with rutile contains higher Mg levels than those grains elsewhere in the sample. Mn and Mg make up minor amounts substituting for Fe²⁺ (Appendix C). The absence of rutile may be attributed to an Fe-rich bulk composition.

Retrograde minerals

Prograde muscovite is not observed in any samples and is evidence that these rocks overstepped the second-sillimanite isograd (reaction 10). The reaction

(12) muscovite + quartz + Na-plagioclase = sillimanite + Na-orthoclase + Na-poor plagioclase + melt (Thompson 1982)

might also explain the production of melt as well as the consumption of muscovite and plagioclase. However, pelitic schists in the Valhalla complex do not contain Na-poor plagioclase. For this reason, it is more likely that reaction (10) resulted in the consumption of muscovite and plagioclase, and the production of potassium feldspar and sillimanite.

Retrograde minerals are post- S_2 and are not aligned in this foliation. Retrograde muscovite occurs as radiating starburst shaped clusters and also as sericitic alteration in plagioclase. In samples where F_4 crenulations are observed, muscovite appears to be subparallel with the S_2 fabric that is folded. This suggests that the muscovite grew after D_2 , but prior to D_3 or D_4 . Sillimanite has rare thin rinds of muscovite, which is probably a retrograde product of reaction (9). Muscovite is commonly found in contact with or within the same thin-section domain as potassium feldspar which is consistent with reaction (9).

Retrograde chlorite replaces biotite and is sometimes associated with rutile. It occurs along fractures within garnet and shows a distinct anomalous blue colour under crossed nichols.

The presence of only local retrograde minerals indicates that these rocks cooled quickly and did not have a sufficient water content to form new hydrous minerals. Retrograde metamorphism is rare however, and its general absence is consistent with rapid

exhumation and cooling rates in the Valhalla complex.

Timing relationships between metamorphism and deformation

The textural and chemical relationships described above provide evidence for a relative chronology of metamorphic and deformation events (Fig. 3.4). The earliest fabric recognized in thin-section occurs as inclusion trails of quartz in garnet which represent S_1 (Fig. 3.4a). These inclusion trails are aligned at an angle to the external foliation and cannot be traced from the garnet to the matrix. Garnets are interpreted to have grown over this older foliation, indicating that garnets started to grow after D_1 (Fig. 3.4b). Peak metamorphic minerals including sillimanite, biotite and K-feldspar are aligned in the main S_2 fabric and occur in the pressure shadows of garnet. Sillimanite inclusions in garnet are generally parallel to the external foliation and occur within garnet rims (Fig. 3.4c). This texture demonstrates that sillimanite began to grow during the formation of S_2 foliation and that garnet was growing before and during the early stages of sillimanite growth and S_2 formation. Since peak metamorphic minerals are aligned parallel to S_2 and wrap around garnet, it is interpreted that S_2 deformation outlasted garnet growth (Fig. 3.4d). Garnets are commonly elongate and lozenge shaped, and oriented at oblique angles to S_2 . Preferential garnet consumption and resorption on faces parallel to the elongation direction of garnet occur in areas of high stress and occurred during S_2 deformation to account for these shapes (Fig. 3.4d).

Garnets are homogeneous except for ~5-10 mole % Fe/Fe+Mg zoning at their rims. This rim is concentric and consistent regardless of adjacent phases (Fig. 3.4e). This suggests

that net-transfer reactions involving the consumption of garnet and production of biotite, were occurring while temperature decreased and are responsible for the increased Fe levels in garnet rims relative to the garnet core rather than Fe-Mg exchange via reaction (1). The lack of symplectitic intergrowths of plagioclase, sillimanite and biotite suggests that the GASP reaction (2) is a more likely means of forming plagioclase moats. Increased Fe levels of garnet rims where garnet is not in contact with ferro-magnesium minerals cannot be attributed to the GASP equilibrium. Quartz embayments around garnet are attributed to the consumption of garnet, but a specific reaction for the formation of this texture is lacking. Since D₂ deformation outlasted the thermal peak of metamorphism, and quartz related to garnet consumption cross-cuts textures attributed to this deformation, it is possible that decompression caused melting. Quartz embayments truncate concentric Fe/Fe+Mg zoning patterns, which suggests that two successive reactions are responsible for zoning followed by garnet consumption (Fig. 3.4e). The first resorbed the garnet, causing concentric zoning (reaction 7), while the second involved consumption and final breakdown of the garnet. The presence of solid (not symplectitic) plagioclase moats suggests that reaction (2) was responsible for the production of these moats, as a result of decompression.

Textures indicative of cooling and retrograde metamorphism, following deformation and decompression, include randomly oriented muscovite that formed as a result of the breakdown of potassium-feldspar, and chlorite that replaced biotite and grew along garnet fractures. Third- and fourth-phase folding events occurred after metamorphism since all minerals are folded including retrograde muscovite (Plate 10d).

Textures and chemical data in samples from domain 1b are nearly identical to

samples from domain 1a, but may be differentiated by the presence of rutile in some samples from domain 1b. Peak minerals are folded by F_2 , garnets are elongate, commonly skeletal, and quartz embayments cross-cut zoning patterns.

Domain 2 - Passmore-Vallican

Textures and mineral compositions

Domain 2 occurs structurally below domain 1b in the Slocan River Valley near Vallican and Passmore. Five samples were studied and analyses were obtained from three of these samples (Fig. 3.2). At this low structural level, samples contain a more intense fabric than samples in domain 1, which is reflected by the segregation of leucosome layers into thin semi-continuous bands, a strong sillimanite lineation and elongate garnet porphyroblasts around which the transposition fabric is wrapped. Along with these textures observed in hand specimen, samples from domain 2 may be differentiated from domain 1 by the presence of significant plagioclase moats around garnet and by calcium zoning in garnet (Plates 9d, 11).

Garnet zoning

Garnets are subhedral, commonly elongate porphyroblasts to poikiloblasts, containing fractures oriented 45° to the extension direction. Garnet in sample PS-28a-93 (Fig. 3.2) has higher grossular content ($X_{Ca} = 0.078 - 0.102$) than all other samples within the Valhalla complex and is more complexly zoned than other samples. Garnets in sample

PS-28a-93 exhibit are Ca zoning; from rim to core, grossular content decreases ~5 mole % into a trough and then increases 5 mole % to level off in the core, and finally increases ~ 1 mole % towards the other rim (Fig. 3.5). Garnet also exhibits increased Fe/Fe+Mg levels of 10 mole % from core to rims where in contact with plagioclase. Rare symplectites of biotite and quartz are observed in contact with garnet rims in sample PS-28b-93, which would suggest that garnet was being consumed as a result of net-transfer reaction (7), while sillimanite, quartz and biotite were produced. This reaction (7) may also have produced increased Fe levels in garnet rims not in contact with biotite, but widespread textural evidence is lacking. Solid moats of plagioclase that are not symplectitic may be attributed to the breakdown of garnet via the GASP reaction (2).

In sample PS-28b-93, Mn is enriched and Ca is depleted near a 0.5 mm wide biotite inclusion (Fig 3.3a). This may be due to the introduction of fluids along the fracture in this particular sample, since biotite is not a Ca rich phase. In other samples, Mn and Ca are not affected by biotite inclusions (Fig. 3.3c).

Plagioclase

Plagioclase makes up to 15% of samples in this southern region and often forms discontinuous moats around garnet rims. The An content of plagioclase moats varies from 37 to 51, within one sample. Portions of the moats that occur in the pressure shadows of the garnet have higher An (51) than portions that are at garnet rims parallel with the elongation direction (An 38). There is no spatial relationship between An content within the moat and distance away from the garnet. Matrix plagioclase in the same sample is An 50 - An 52.

Sample PS-28a-93 also contains quartz inclusions that have a thin rim of plagioclase with an An content of 48, which is similar to both matrix plagioclase grains and plagioclase moats in the same sample. This texture also suggests that garnet and quartz were breaking down to form plagioclase via reaction (2). The variability of plagioclase compositions in moats around garnet suggests that growth occurred at different times, in different areas around the garnet.

Sillimanite, quartz and biotite

Sillimanite is abundant in samples from the southern domain making up to 30% of the rock and occurring as intergrown mats with biotite. Quartz ribbons are partially annealed and seriate grain boundaries and subgrains are common. Quartz rarely occurs as teardrop shaped grains in quartz-biotite symplectites. Biotite makes up to 30% of the rock and is concentrated in garnet pressure shadows.

Titanium phases

Rutile and ilmenite are found together in two samples and in contact with each other in one sample. Textures suggesting the timing of formation of ilmenite or rutile relative to one another are absent. Both phases are elongate and aligned parallel to S_2 , and often occur in the pressure shadows of garnet which might indicate their presence at the peak of metamorphism.

Retrograde metamorphism

Retrograde metamorphism is represented by randomly oriented muscovite grains that are in close contact with K-feldspar and sillimanite, suggesting the reverse of reaction (9). Chlorite is also present and grew at the expense of biotite. Rutile is commonly associated with chlorite replacing biotite. Chlorite is more common in samples at this structural level (domain 2) and suggests that this area cooled less quickly than domain 1 or that more fluids were present than in other domains, which would have allowed retrograde metamorphism to take place. The introduction of fluids along shear zones may also be responsible for the abundance of retrograde minerals.

Timing of metamorphism with respect to deformation

Timing relationships between metamorphism and deformation are slightly different than those observed in domain 1. S_T contains the peak metamorphic minerals of garnet, sillimanite, biotite, K-feldspar, rutile and ilmenite. This fabric wraps around garnet porphyroblasts and the peak metamorphic minerals occur in garnet pressure shadows. Evidence that garnet overgrew a preexisting fabric is rare in domain 2, but some samples do contain aligned quartz inclusions that are oriented obliquely to the external transposition fabric. Sillimanite inclusions in garnet occur near the rim and are commonly parallel to the external transposition foliation (S_T). The presence of these two inclusion varieties indicates that garnet overgrew an existing S_1 fabric, represented by quartz inclusions, and continued to grow during S_T , represented by sillimanite inclusion. Plagioclase moats around garnet are common in this domain and were formed during resorption and consumption of garnet following the thermal peak of metamorphism. Deformation outlasted plagioclase formation

and the thermal peak of metamorphism because plagioclase is concentrated in garnet pressure shadows and appears to have been consumed along garnet rims parallel to the extension direction. Quartz embayments and textures inferred to be a result of garnet breakdown are less common in domain 2 than in domain 1, and may reflect differences in the ability of reactions to occur, perhaps controlled by kinetics. It may also reflect slight bulk compositional differences or different pressure-temperature conditions in domain 2. Randomly oriented retrograde muscovite is common in domain 2 and suggests that this area remained at a temperature sufficient to grow muscovite, whereas samples from domain 1 cooled more rapidly or had an increased amount of fluids relative to domain 1.

Gwillim Creek windows (sheet 1a -Domain 3 and sheet 1b)

Textures and mineral compositions

Four samples of pelitic schist were studied from sheets 1a and b, the Gwillim Creek windows. These samples are characterized by the strong alignment of minerals within the transposition fabric and by extensive consumption of garnet and replacement of biotite by chlorite.

Garnet

Garnet in the Gwillim Creek windows is commonly elongate, up to 2 cm long with quartz occupying embayments. Higher Mg levels in garnet cores and biotite grains from domain 3 (5-10 mole % higher, $\sim 0.28 X_{Mg}$, Appendix C), than samples from domains 1 or

2, reflect a more Mg-rich bulk composition. Garnet cores are homogeneous and rims are elevated in Fe (~ 5 mole %) and lower in Mg (~5 mole %) relative to the core. Ca content in garnet is fairly consistent (~ 5 mole %) throughout the core but decreases to less than 5 mole % at the rim. Ca levels also decrease near quartz (melt?) inclusions within the garnet, by < 5 mole % suggesting that modification of garnet rim composition and formation of quartz at the expense of garnet resulted from the same net-transfer reaction, or that two reactions were occurring simultaneously.

Plagioclase, sillimanite, biotite and quartz

Plagioclase makes up 5-15 % of samples from the Gwillim Creek window and has a consistent An composition (32-36). A discontinuous plagioclase moat in sample PCA-200-85, occurs around only one garnet (in the pressure shadow) and has a variable An content of 38 to 45.

Sillimanite occurs as porphyroblasts up to 2 cm long. Sillimanite inclusions in garnet are strongly aligned and parallel to the external foliation (Plate 9b).

Biotite grains located with particular spatial relationships to garnet show a systematic variation in composition. Biotite inclusions in garnet and biotite grains in contact with garnet rims have the highest Fe levels ($X_{Fe} \sim 0.7$). Ti levels in biotite are highest in matrix grains and armoured biotite inclusions. Matrix grains, however, have a variable Ti content ($X_{Ti} = 0.05 - 0.10$, Appendix D), which may not be explained by relative distance away from the garnet.

Ilmenite and rutile

Ilmenite and rutile were observed in direct contact in sample PCA-200-85, in a similar relationship as that observed in sample PCA-93-84 from domain 2. Both rutile and ilmenite are elongate and aligned in the transposition fabric. In sample PCA-200-85, rutile is cored by ilmenite. This suggests an increase in pressure, since rutile is on the high pressure side of reaction (3). This texture may be a relict texture preserving part of the prograde path. In sample PS-348-94, also from domain 3, there is abundant rutile, but ilmenite is absent. Garnet cores in sample PS-348-94 have Fe levels up to 4 mole % lower than garnet in PCA-200-85 and therefore the absence of ilmenite may be a function of bulk composition.

Retrograde metamorphism

Retrograde metamorphism is common in samples from the Gwillim Creek window and quite extensive in some samples. Muscovite halos surround sillimanite porphyroblasts in samples from sheet 1b (Plate 11a), and chlorite replaced biotite and occurs along garnet fractures in samples from both sheets 1a and 1b. The abundance of retrograde minerals in domain 3 is interpreted to be a result of fluid introduction along the GCSZ which allowed retrograde reactions to take place at these deep structural levels.

Timing of metamorphism with respect to deformation

Aligned quartz inclusions in garnet are absent and therefore evidence for D_1 is not observed in domain 3, in contrast to domains 1 and 2. The main fabric in this domain (S_1)

wraps around garnet porphyroblasts and contains the peak metamorphic mineral assemblages of sillimanite, K-feldspar and biotite, which also occur in garnet pressure shadows. Sillimanite inclusions in garnet occur near the garnet rim and are continuous with sillimanite grains in pressure shadows, suggesting that garnet growth began prior to the development of S_1 and continued during this deformation period. Rare plagioclase moats around garnet suggest that these rocks underwent a period of decompression following the thermal peak. Consumption of garnet is more extensive than in domains 1 and 2, as exhibited by near skeletal garnets and the abundance of quartz embayments. Retrograde metamorphism occurs as the replacement of biotite by chlorite and is more prevalent in domain 3, relative to domains 1 and 2. The main fabric in samples from the Gwillim Creek windows is a transposition fabric (S_T) associated with the GCSZ. It is uncertain if S_2 in domain 1 and the GCSZ are synchronous. S_T transposes all folds, contains the peak metamorphic mineral assemblage and outlasts metamorphism. S_T in domain 3 could be a result of the same D_2 deformation period which occurred in domain 1, or it could be a result of shearing along the GCSZ which realigned metamorphic minerals.

3.3.2 Amphibolite gneiss

Textures and mineral compositions

Amphibolite gneisses have a variable range in mineral assemblage, grain size and texture, reflecting different bulk compositions and different possible protoliths. All samples of amphibolite gneiss were collected from sheet 1c in domains 1 and 2. They contain the

assemblage hornblende - plagioclase - quartz $\pm$ garnet $\pm$ biotite $\pm$ ilmenite $\pm$ titanite $\pm$ rutile $\pm$ clinopyroxene. Clinopyroxene was observed in only one fine-grained sample which is devoid of garnet. Some samples contain euhedral hornblende and lack biotite, while others contain ragged hornblende and biotite. The presence of hornblende, plagioclase and garnet is indicative of amphibolite-facies metamorphism. The presence of pyroxene (diopside) in one sample also containing hornblende and plagioclase, suggests that these rocks may have reached lower granulite-facies metamorphism. The presence of pyroxene may also be a function of a more Ca rich bulk composition, allowing clinopyroxene to form. The textural and mineralogical variation in amphibolite gneisses is reflected in the wide range of analysed mineral compositions.

Garnet

Garnets are rounded, often skeletal, and embayed by quartz and are up to 6 mm in diameter (Plate 11b). Poikiloblastic garnets contain up to 50% inclusions of quartz, hornblende and ilmenite. Inclusions are often concentrated in garnets cores as they are in pelitic schists (Plate 11c). Plagioclase commonly forms coronas around garnets and may be a result of the reaction (Plate 12a):

(13) tschermakitic-hornblende + garnet + quartz = tremolitic-hornblende + plagioclase.

The formation of plagioclase moats around garnet in mafic gneisses may be similar to the formation of plagioclase as a result of garnet breakdown in pelitic schists.

Garnets have ~ 10 mole % lower almandine component and ~10-15 mole % higher grossular component than garnets in pelitic schists. The mole % of almandine, pyrope,

grossular and spessartite do not vary more than ~ 5 mole % within garnet (Fig. 3.6). Some samples exhibit slight decreases in X_{Ca} towards the rim and then a sharp increase at the rim (Fig. 3.6). The general decrease in Ca towards the rim may be attributed to plagioclase moat growth around the garnet porphyroblasts, where plagioclase grew at the expense of garnet. The final increase of Ca at garnet rims may be attributed to late fluid infiltration or possibly an increase in pressure. Fe also increases gradually from core to rim and drops sharply at the rim.

Plagioclase and quartz

Plagioclase and quartz make up 20 - 35% of the rock and are usually subequal in modal abundance. Systematic differences in composition between matrix grains and grains in contact with garnet are not observed. Plagioclase occurring as moats around garnet have An contents ranging from 35 - 60 and have no spatial pattern. This wide range probably represents the continuing growth of plagioclase around garnet rims during decompression or continued heating following the peak of pressure. There are no sympathetic changes of the grossular content in garnet with respect to An content in plagioclase moats.

Hornblende

Most mafic gneisses in the Valhalla complex contain up to 65% hornblende. In plane polarized light hornblende varies from light brown, to olive green and dark green. Grains are equigranular and have sharp grain boundaries with adjacent grains of plagioclase, quartz, biotite and garnet. Hornblende is usually evenly distributed within a sample but rarely forms

discrete bands, alternating with quartz and feldspar. Fe/Fe+Mg ratios in both matrix grains and those in contact with garnet range from ~ 0.45 - 0.58, in all samples. Inclusions in sample PS-26-93 have a lower Fe level (~ 41 mole %) than matrix hornblende grains (~ 45 mole %) in the same sample (Appendix D).

Biotite

Biotite makes up to 30% of mafic gneisses. In some samples, biotite and hornblende are equal in proportion and both are aligned in the foliation plane. The large modal amounts of biotite in some mafic gneisses may be attributed to a sedimentary origin. In other samples, biotite is a younger phase that overgrows hornblende and along fractures in garnet. Biotite was analysed in three samples, and although intersample variance is large (Appendix D), grains within a sample are relatively homogeneous and do not vary more than 0.036 Fe/Fe+Mg per sample.

Rutile, ilmenite and titanite

Titanium bearing phases include ilmenite, titanite and rutile. Ilmenite constitutes up to 5% of the mafic gneisses as equigranular, disseminated grains and as vermicular inclusions in garnet. Rare vermicular intergrowths of ilmenite (possibly magnetite) and an unknown mineral (possibly orthopyroxene) may be similar to symplectites described by Barker (1990, p. 56) and Mackenzie and others (1982, p. 53), but their significance is unknown. Titanite and rutile are less common. In sample PS-27b-93, an inclusion of carbonate in garnet contains an inclusion of rutile, but its significance is also unknown.

Plagioclase forms rare coronas around ilmenite inclusions in garnet, as well as embayments in garnet.

Retrograde metamorphism

Retrograde minerals are sparse in amphibolite gneisses of the Valhalla complex. Chlorite commonly replaces biotite, and plagioclase commonly contains retrograde muscovite (sericite) along fractures.

Timing of metamorphism with respect to deformation

The peak metamorphic mineral assemblage in amphibolite gneisses includes garnet, hornblende, biotite, and plagioclase and is aligned in S_1 . Biotite, hornblende and plagioclase have sharp grain boundaries when in contact with garnet and are found in the pressure shadows of garnet, indicating that the peak of metamorphism was synchronous with deformation (D_1). Inclusions in garnet are not aligned and therefore the timing of events before S_1 is not recorded in amphibolite gneisses. Garnet is often skeletal and contains the same sort of quartz embayments that some garnets in pelitic schists do. These embayments are interpreted to have formed during deformation, but following or during the thermal peak of metamorphism.

3.3.3 Marbles and calc-silicate gneisses

Mineral assemblages in carbonate rocks of the Valhalla complex are in general agreement with metamorphic conditions recorded by pelitic schists and amphibolite gneisses.

Due to the absence of suitable mineral assemblages and the fact that carbonate rocks do not generally exhibit strong fabrics, marbles and calc-silicate gneisses in the Valhalla complex are not exceptionally suitable for thermobarometry or deciphering the relationships between metamorphism and deformation. Marbles in the Valhalla assemblage contain the assemblage calcite $\pm$ phlogopite $\pm$ diopside $\pm$ forsterite $\pm$ titanite $\pm$ scapolite $\pm$ tremolite $\pm$ graphite $\pm$ apatite. Rutile and amphibole (hornblende?) occur in one sample, while chlorite and plagioclase occur as retrograde minerals. Calc-silicate gneisses contain the assemblage quartz - diopside - titanite $\pm$ scapolite $\pm$ phlogopite $\pm$ plagioclase $\pm$ potassium feldspar $\pm$ tremolite $\pm$ spinel. Green amphibole occurs as a retrograde mineral replacing diopside. Granoblastic textures predominate, although diopside often forms blocky irregular shaped masses, as opposed to disseminated grains. Titanite is present in almost all samples as rounded grains, making up to 5% of the rock.

Reesor (1965, p. 50) suggested that the presence of scapolite- and forsterite-bearing assemblages in the Valhalla complex indicates lower granulite facies. Typical granulite assemblages contain wollastonite, scapolite and grossular (Harley 1988), however wollastonite and grossular are absent in the Valhalla complex.

Scapolite breaks down via the fluid independent reaction:

(6) anorthite + calcite = meionite (Ca-scapolite) (Goldsmith and Newton 1977).

In one sample, rims of plagioclase and symplectites of plagioclase and calcite occur around scapolite porphyroblasts (Plate 14b). In other samples, the breakdown of scapolite is more advanced and plagioclase and calcite replace half of the original scapolite grain. This is interpreted to be a retrograde effect of reaction (6) and implies significant cooling, either

isobaric or polybaric, since the reaction curve has a very steep pressure-temperature slope. Scapolite porphyroblasts in marbles and calc-silicates are virtually the same in composition with equivalent anorthite contents ($\text{EqAn} = [(\text{Al}-3) \times 100] / 3$) contents of 64 - 74. Sulphur is absent and chlorine ranges from $X_{\text{Cl}} = 0.12 - 0.20$. Fixed activities were calculated using the solution of model of Oterdoom and Gunter (1983) which is based on the experimental data of Goldsmith and Newton (1977). Using this activity model in conjunction with TWEEQU, temperatures of approximately 800 °C were calculated. Symplectites of plagioclase and quartz (myrmekite) are also present in marbles and calc-silicates.

Diopside is ubiquitous in calc-silicate gneisses comprising up to 40% of the mode, but it is less abundant in marbles. Retrograde amphibole (tremolite) commonly replaces diopside in a haphazard fashion. Diopside is more iron-rich in calc-silicate gneisses ($\text{Fe}/\text{Fe}+\text{Mg} = 0.393 - 0.526$) than in marbles ($\text{Fe}/\text{Fe}+\text{Mg} = 0.014$). Forsterite occurs as up to 2 mm sized porphyroblasts. The presence of forsterite has been attributed to the dedolomitization of marbles in prograde metamorphism (Spear 1993, p. 455) and is consistent with the absence of dolomite in marble samples. Mg levels in forsterite are approximately $X_{\text{Fo}} = 96$. Non-pleochroic amphibole occurs in marbles and has high magnesium levels ($\text{Fe}/\text{Fe}+\text{Mg} = 0.030$).

3.3.4 Ultramafic schist

Ultramafic schists are restricted to unit 8 of the Valhalla assemblage which occurs in the structurally highest sheet (1c, domain 1) and one outcrop on the east side of the complex near Slocan and the SLF (Map 1). Ultramafic schists in the Valhalla complex

contain the assemblage tremolite - olivine - orthopyroxene $\pm$ clinopyroxene $\pm$ phlogopite $\pm$ serpentine $\pm$ chromite. Olivine is highly fractured and altered to serpentine (Plate 12c). Diopside is overgrown by tremolite. Tremolite is the main component in some samples, making up 90% of the rock. Grains are randomly oriented, coarse-grained and radiating. Phlogopite overgrows all minerals except serpentine (Plate 12c).

The first appearance of tremolite and the disappearance of diopside may have been achieved by the reaction:

however, as Spear (1993, p. 472) notes, the assemblage diopside - forsterite reappears at higher temperatures. Enstatite occurs as broken up grains separated by phlogopite which has grown along fractures. Enstatite appears at approximately 675 °C (~ 7 kbars), via the reaction:

and is stable to higher temperatures. Orthopyroxene is also partially replaced by tremolite (Plate 12d) which might suggest that the reaction:

has taken place (Fig. 3.7). The absence of anthophyllite does not constrain peak temperatures even though it has a relatively low stability field (600-800 °C, Spear 1993, p. 470). The lack of anthophyllite does not constrain pressure-temperature conditions well because reaction (15) consumes anthophyllite at ~650-700 °C at 7 kbars (Fig. 3.7) in quartz free mineral assemblages.

Metamorphic mineral assemblages in ultramafic schists are more temperature

dependent than pressure dependent because most reactions curves are quite steep in the system $\text{MgO} - \text{CaO} - \text{SiO}_2 - \text{H}_2\text{O} \pm \text{CO}_2$. Metamorphic conditions in ultramafic schists are not well constrained because the minerals present have a wide stability and there are few reactions indicating the breakdown of these minerals. Mineral assemblages in ultramafic schists indicate general agreement with mineral assemblages and thermobarometry of pelitic schists and amphibolite gneisses and are consistent with amphibolite facies metamorphism.

3.3.5 Summary

From the petrographic and chemical observations discussed in the previous sections, it may be concluded that peak metamorphic mineral assemblages from four different bulk compositions and three different domains are consistent with upper amphibolite facies metamorphism. Peak metamorphic minerals (sillimanite, K-feldspar, biotite) in pelitic schists are aligned in S_2 , in domain 1, and S_T in domains 2 and 3, and also occur in the pressure shadows of garnet, indicating that metamorphism was synchronous with deformation in all three domains. In detail, some reaction textures are observed in domains 2 and 3 that allow a distinction from domain 1. Plagioclase moats around garnet and Ca zoning in garnet is more pronounced in domain 2, while elongate garnets, extensive quartz embayments in garnet, and retrograde chlorite are typical of domain 3. Domain 3 also has a more Mg rich pelitic bulk composition than domains 1 or 2, which is reflected in up to 15 mole % higher Mg levels in both garnet and biotite in domain 3.

3.4 Thermobarometry, petrology and comparison of structural levels

Petrographic observations suggest that metamorphism was synchronous with deformation in all three domains. Petrography also indicates that peak metamorphic conditions are similar at different structural levels with a peak metamorphic mineral assemblage of biotite, garnet, sillimanite, K-feldspar, ilmenite and rutile in pelitic schists. Thermobarometry was employed to quantify the metamorphic conditions of domains 1, 2, and 3, at different structural levels. Mineral textures and chemical data are interpreted to link compositions and pressure-temperature conditions of mineral pairs to portions of the pressure-temperature path.

3.4.1 Pelitic schist

Only portions of the pressure-temperature path are preserved in pelitic schists of the Valhalla complex. Estimates of the peak metamorphic conditions can be made from petrographic observations, but thermobarometric data are not representative of the peak because garnet and biotite compositions are thought to have been modified by the effects of diffusion and retrograde reactions. Plagioclase and biotite in the matrix are interpreted to have been modified during or following the thermal peak, by garnet-consuming reactions (7) or (8) and are not in equilibrium with garnet cores. Net-transfer reactions are thought to have been active in some samples during cooling and exhumation due to the presence of continuous and concentric Fe/Fe+Mg zoning in garnets, bearing no relationship to other ferro-magnesium minerals. Biotite grains formed as a result of these reactions have higher Fe/Fe+Mg ratios than biotite present at the peak of metamorphism, and therefore produce anomalously high temperatures when combined with data from garnet cores (~850-1000 °C).

Since biotite grains have a wide range in composition, it was assumed that only grains proximal to garnet rims, with lower Fe levels than biotite grains in contact represent near peak compositions and have not been affected by later Fe-Mg exchange. Proximal biotite grains record conditions near but following the thermal peak of metamorphism (T1). Garnet rims in contact with biotite yield the lowest temperatures (T2) due to Fe-Mg exchange, as a result of cooling.

Plagioclase shows little variation between grains in the matrix and those in contact with garnet, and therefore pressure calculations are problematic. If plagioclase grains in the matrix had lower An contents than plagioclase moats around garnet it might be suggested that matrix grains are representative of peak pressures and plagioclase moats represent part of the decompression path. The same might be said if matrix plagioclase grains were zoned and had lower An content in the core than at the rim. These relationships do not exist in samples from the Valhalla complex because no zoning patterns or systematic relationships between An content and textural variety of plagioclase were observed. For this reason, plagioclase grains in contact with garnet (as moats or otherwise) are believed to be in chemical equilibrium with garnet and produce pressures interpreted to be near- to post-peak conditions. Where plagioclase is in contact with garnet, it usually occurs as moats, suggesting that it formed as a result of a decompression reaction such as (2). If the plagioclase moats and the proximal biotite grains were both formed as a result of garnet consumption, then all three minerals should be in relative chemical equilibrium and produce genuine data. This will produce quantitative data for near-peak temperatures and part of the decompression path of pelitic schists in the Valhalla complex.

When applying the GRAIL barometer, chemical equilibrium was assumed between garnet rims and proximal matrix biotite, and ilmenite. Since the GRAIL equilibrium is Fe dependent, any increase in Fe in garnet rims due to Fe-Mg exchange between garnet and biotite will give an erroneously higher pressure, where it intersects with the garnet-biotite thermometer.

Domain 1: 1a - The Valhalla assemblage (sheet 1c, west side) and 1b - Slocan Ridge, Airy Creek

Thermobarometry was carried out on 6 samples from domain 1a and 2 samples from domain 1b. The intersection between the garnet-biotite thermometer and GASP barometer was employed in all samples and the GRAIL barometer was used in one sample from domain 1b. In domain 1a, on the west side of the Valhalla complex average post peak temperatures (T_1) and pressures (P_1) range from 736 ± 10 to 777 ± 50 °C and 5.8 ± 0.3 to 7.1 ± 1 kbars, respectively (Table 3.2, Figs. 3.8-3.9). The magnitude of the error represents the standard deviation among the number of calculations carried out in one sample (See Table 3.2). In domain 1b, garnet-biotite temperatures (T_1) and GASP pressures (P_1) range from 790 ± 26 to 764 ± 21 °C and 6.5 ± 0.7 to 7.5 ± 0.3 kbars respectively. The GRAIL barometer intersects the garnet-biotite thermometer at nearly the same pressure (7.3 ± 0.3 kbars) as the GASP barometer, implying equilibration of all minerals at the same pressure and temperature (Fig. 3.8, 3.9, Table 3.2). These results are consistent with the metamorphic mineral assemblage and with petrographic observations suggestive of textural equilibrium. Later and lower post-peak temperatures on the cooling path (T_2 , Table 3.2) of 600 ± 16 to 721 ± 13 °C

are recorded by biotite grains in contact with garnet rims. Since no systematic difference in composition was observed between plagioclase grains in direct contact with garnet or matrix plagioclase grains, reliable pressures cannot be associated with these temperatures (T2). Pressures produced are merely a function of moving down the same GASP isopleth used for the calculation of P1 to where it intersects the lower temperature (T2) (Fig. 3.8). In sample PS-277-94, discontinuous plagioclase rims have a variable An content, yield pressures from 4.7 to 8.3 kbars, and have likely recorded a period of decompression.

Biotite inclusions and garnet cores yield temperatures of 600 - 730 °C (Table 3.2) which are lower than estimates for the thermal peak. These inclusions appear to have been affected by retrograde Fe-Mg exchange and therefore do not record peak temperature or any part of the prograde pressure-temperature path.

Armoured biotite inclusions are biotite inclusions enclosed in quartz inclusions contained within garnet. Spear and Parrish (in prep.) pair armoured biotite inclusion compositions with garnet core compositions and interpret the temperature to represent apparent thermal peak. Armoured biotite inclusions from this study yield temperatures of approximately ~850 °C (Table 3.2). These data are interpreted to represent peak thermal conditions.

The simultaneous increase in Fe levels of both garnet and biotite may be attributed to reaction (7) proceeding with decreasing temperature. Normal Fe-Mg exchange via reaction (1) would result in increased Fe in garnet and decreased Fe in biotite as temperatures decreased. The simultaneous progress of reactions (1) and (7) causes Fe to increase in both garnet and biotite. The assemblage biotite-garnet-sillimanite-K-feldspar-quartz-H₂O is

divariant in the KFMASH system, forming a T-X (Fe) loop at constant pressure in which the Fe in both garnet and biotite increase as temperature decreases and garnet is consumed while biotite is produced. In sample PS-4-94 plagioclase is abundant (~20%), sillimanite is rare and biotite is commonly randomly oriented. This might suggest that biotite formed via reaction (8) after the peak of metamorphism and possibly after deformation had ceased (or at least decreased). From chemical analyses, it is not apparent that sample PS-4-93 has a different bulk composition than samples with abundant sillimanite and little plagioclase.

Plagioclase inclusions were analysed in two samples and their compositions record pressures of 4.6 to 5.8 kbars (at fixed temperature - 800 °C, Table 3.2) when paired with compositions from garnet cores. Pressure calculations using garnet core compositions and plagioclase inclusions were done assuming that sillimanite was present. These pressures are lower than pressures calculated from garnet rims and matrix plagioclase grains in the same sample even at temperatures of ~ 800 °C (Table 3.2). These plagioclase inclusions may have been enclosed by the garnet prior to the thermal peak, before the garnet was compositionally homogenized. The relatively low diffusion rate of Ca would have minimized cation exchange between garnet and plagioclase, and it is unlikely that garnet cores and plagioclase inclusions re-equilibrated after garnet homogenisation.

Thermobarometric data from all samples in domains 1a and 1b are consistent with each other and with petrographic observations, peak metamorphic mineral assemblages and mineral reactions. These data indicate temperatures and pressures of ~750 °C and ~6.5 kbars. It is uncertain if biotite inclusion compositions in garnet reflect conditions representative of the prograde pressure-temperature path when paired with the compositions of garnet cores.

The low temperatures recorded by biotite inclusions and garnet cores ($\sim 650^\circ\text{C}$) suggest that biotite inclusions underwent Fe-Mg exchange during cooling. Plagioclase inclusions were interpreted to have been frozen in the garnet during the prograde path and had no apparent mechanism to reequilibrate with the garnet core which was compositionally homogenised during the thermal peak of metamorphism.

Domain 2 - Vallican area

Samples near Vallican (domain 2) are structurally deeper and record near-peak temperatures (T1) and pressures (P1) from 819 ± 48 to $935 \pm 27^\circ\text{C}$ and 9.8 ± 1.5 to 11.5 ± 0.5 kbars, respectively. Pressures and temperatures fall partly into stability fields indicated by mineral assemblages and textures, however they also overlap the kyanite and orthopyroxene stability fields. Kyanite has been reported in one sample from this domain by Carr (pers. comm. 1994). GRAIL data intersect the garnet-biotite thermometer at substantially lower pressures (7.1 ± 0.2 to 7.6 ± 0.3 kbars, Fig. 3.9, Table 3.2) than the GASP barometer. This difference will be addressed in the discussion section (3.4.3). Biotite rims in contact with garnet rims record lower temperatures (T2) than T1 but they are higher than those of domains 1a and 1b at higher structural levels.

Domain 3 - sheet 1a (lower Gwillim Creek window)

Thermobarometry was carried out on two samples from the GCW (sheet 1a) and record garnet-biotite temperatures (T1) and GASP pressures (P1) of 849 ± 50 to $901 \pm 60^\circ\text{C}$ and 8.5 ± 1 to 9.2 ± 1.4 kbars, respectively (Table 3.2, Fig. 3.9). The GRAIL barometer

intersects the garnet-biotite thermometer at lower pressures (6.3 ± 0.1 kbars) than the GASP barometer does (Table 3.2, Fig. 3.9). Biotite grains in contact with garnet rims (T2) record temperatures of 690 ± 58 and 796 ± 1 °C (Table 3.2).

3.4.2 Amphibolite gneiss

Thermobarometric data from hornblende inclusions in garnet, garnet-biotite pairs and garnet-hornblende pairs in amphibolite gneisses record a large portion of the pressure temperature path. Temperatures and pressures recorded by amphibolite gneisses are in general agreement with those calculated from garnet rims and proximal biotite grains in pelitic schists (Table 3.3). Garnet in amphibolite gneisses exhibits only subtle zoning patterns, and therefore pressures and temperatures do not vary much between pairs of 1) garnet rims in contact with ferro-magnesium minerals (biotite and hornblende), 2) garnet rims in contact with quartz or plagioclase and proximal biotite or hornblende or, 3) the average of all data from the garnet and garnet paired with grains of hornblende and biotite in direct contact with garnet or within the matrix. Three samples were studied from domain 1a, one sample from domain 1b, and one sample from domain 2 (Figs. 3.11, 3.12, Table 3.3). Garnet-hornblende-plagioclase equilibria (reactions 4 and 5) in domain 1a record temperatures and pressures that range from 691 ± 12 to 780 ± 11 °C and 6.9 ± 0.5 to 8.0 ± 0.3 kbars, respectively. Samples from domain 1b record temperatures and pressures from 755 ± 22 to 789 ± 32 °C and 8.5 ± 0.6 to 10.3 ± 1.7 kbars.

PS-52-94 from domain 1b has a wider range in temperature (750 - 848 °C) and pressure (8.4 - 13.4 kbars) than all other samples, reflecting the variable composition of

plagioclase moats surrounding garnet (Appendix D). Inclusions of hornblende in garnet give slightly lower temperatures (642 - 682 °C) compared to grains of hornblende in either the matrix or in direct contact with garnet (Table 3.3). Since plagioclase inclusions in garnet were absent in samples with hornblende inclusions, no pressure data were obtained. If hornblende inclusions are paired with matrix plagioclase, assuming that plagioclase compositions did not change, then pressures are in the range of 6.5 kbars, and are consistent with a clockwise pressure-temperature path.

The intersection of garnet-biotite pairs, using reactions (1) and (4), record higher temperatures than garnet-hornblende temperatures (Figs. 3.11, 3.12). These data range from 842 ± 7 to 856 ± 23 °C in domain 1a and 827 ± 27 °C in domain 2, and are higher than garnet biotite temperatures (T1) recorded by pelites at the same structural level.

3.4.3 Summary

Thermobarometric data from the three domains are summarized in Figures 3.9, 3.10 and 3.12 and Tables 3.2 and 3.3. The main conclusions that may be drawn from textural and thermobarometric data are: (i) samples from the structurally highest domains (1a and 1b) record the lowest and most consistent inter- and intra-sample pressures and temperatures; (ii) GRAIL data are consistent with GASP data in domain 1; (iii) domain 2 contains significant plagioclase moats and Ca zoning in garnet; (iv) samples in domain 3 have a Mg bulk composition higher in Mg than samples from domains 1 or 2 and contain abundant retrograde chlorite and extensive quartz embayments in garnet; (v) domains 2 and 3 have a wide range in temperature and pressure within and between samples, some of which overlap data from

domain 1; (vi) GRAIL data are consistently lower than GASP data in domains 2 and 3; and (vii) the similarity of textures and thermobarometric data between domain 2 (Vallican area) and domain 3 (lower Gwillim Creek window - sheet 1a) is consistent with the structural projections (Cross-section A) and the interpretation that the Gwillim Creek shear zones resurface in the Passmore-Vallican area (Cook *et al.* 1988).

3.4.4 Discussion

In domains 2 and 3 pressures generated using the intersection between the GRAIL barometer and the garnet-biotite thermometer are generally lower than those of GASP (Figs. 3.8, 3.9). GRAIL pressures are fairly constant when calculated using garnet rims and biotite grains in direct contact with garnet, garnet rims and proximal biotite grains, and garnet cores and matrix biotite grains. GRAIL data are ~ 3 kbars lower than GASP data in both domain 2 and domain 3. Variation in An content of plagioclase occurs within plagioclase moats surrounding garnet in all three domains, but does not result in a significantly wide range (~9-12 kbars) in pressures using the GASP equilibrium within the same sample except for one sample (PS-28a-93, Fig. 3.9). The difference in data from these two barometers may be a result of either different closure temperatures, or disequilibrium.

The consistently 3 kbar lower values recorded by the GRAIL equilibrium suggests that, on the scale of the sample, minerals involved in the GASP and GRAIL equilibria did not equilibrate at the same pressure and temperature, but that on a local scale, minerals involved in the individual equilibria were in equilibrium. The interpretation that GRAIL pressures represent a later point on the pressure-temperature path at which mineral rims were

in equilibrium is consistent with the GRAIL equilibrium involving Fe-Mg exchange, which is easier to activate than the breaking of Ca-Si-Al bonds required for the GASP reaction to proceed. Since the GRAIL barometer and the garnet-biotite thermometer both involve Fe-Mg exchange, it is assumed that they represent the same point on the pressure-temperature path. No temperature may be confidently associated with the GASP pressure data in domains 2 and 3. GASP pressures are likely to have had a higher temperature associated with them. The observation of kyanite in one sample by Carr (pers. comm. 1994) and the fact that some GASP pressure data plot in the kyanite stability field suggest that these data are representative of near peak pressures.

The wide variation in temperature data from domains 2 and 3 (~775 - 980 °C) may be the result of increased Fe levels due to the downward progression of reaction (7). This reaction may not have proceeded in domain 1 because of rapid cooling and quenching at higher structural levels, whereas domains 2 and 3 may have remained at high temperatures longer allowing reaction (7) to proceed.

Alternatively, the wide range in plagioclase moat compositions (An 38-52) and calculated pressures, and the fact that GRAIL and GASP data do not intersect may be attributed to disequilibrium. Disequilibrium may be the a result of two processes: 1) fluids which were introduced along shear zones, and 2) shearing itself. Strain fabrics are quite strong in some samples and the effects of mechanical transport or enhanced diffusion are unknown. Biotite grains that may have never been in chemical equilibrium with garnet may now be in relatively close proximity, due to deformation.

Temperatures calculated using the garnet-biotite thermometer in amphibolite gneisses

yield temperatures up to 150 °C higher than those calculated using the garnet-hornblende thermometers, at the same pressure (Table 3.3). The large variation between garnet-biotite data in amphibolite gneisses and pelitic schists may be a function of more Mg rich bulk compositions (amphibolites) recording higher temperatures. Mg rich bulk compositions generally record higher temperatures. This is exemplified by reaction (1) where higher temperatures are recorded by pyrope-rich - annite-rich pairs. Garnet rims in direct contact with biotite grains produce high temperatures (~850 °C) and show little evidence of Fe-Mg exchange during cooling. Temperatures recorded by garnet-biotite pairs in amphibolite gneisses are in agreement with temperatures recorded by armoured biotite inclusions and garnet cores in pelitic schists which suggests that peak temperatures were approximately 850 °C.

The variation (up to 150 °C) between garnet-hornblende and garnet-biotite temperatures within amphibolites may be a result of the two equilibria recording different portions of the pressure-temperature path. Garnet-biotite pairs record an earlier portion of the pressure-temperature path close to the thermal peak, while garnet-hornblende pairs record part of the cooling path. These data are consistent with petrographic observations and the peak metamorphic mineral assemblage in pelitic schists and amphibolite gneisses (Fig. 3.12). Alternatively, garnet-hornblende temperatures may be less reliable due to variable oxidation states of hornblende relative to the thermodynamic calibration and therefore produce lower temperatures than the garnet-biotite equilibrium.

The fact that GRAIL pressures are consistently lower than GASP data in the structurally low domains (2 and 3) suggest a period of decompression following the peak of

metamorphism. GRAIL data at higher structural levels (domain 1) do not record this period of exhumation because they were exhumed early and the mineral system cooled quickly. Samples at deeper structural levels (domains 2 and 3) remained hot for a longer period.

3.6 Conclusions

Textural observations and thermobarometric data are summarized in Figures 3.4, and 3.8-3.12, respectively. Subtle textural differences observed in thin-section characterize the three domains of paragneisses at three different structural levels in the Valhalla complex. The thermal peak of metamorphism was synchronous with the main D_2 fabric forming deformation period in all three structural levels and all geographic areas. Peak minerals include biotite, sillimanite, K-feldspar, rutile and ilmenite, all of which are aligned in the main fabric (S_2 and S_T) and occur in the pressure shadows of garnet porphyroblasts. This fabric represents D_2 in sheet 1c, shearing on the GCSZ in the lower reaches of the Slocan River Valley and in the lower Gwillim Creek window. Textural and thermobarometric data indicate that shearing in the Vallican area and the Gwillim creek windows was synchronous with D_2 in sheet 1c. GRAIL pressures are consistently 3 kbars lower than GASP pressures within samples from domains 2 and 3 and are interpreted to record lower post-peak portions of a decompression path as a result of different closure temperatures of the two equilibria. Samples in the Vallican area also contain plagioclase moats which record a wide range of pressures (~7-11 kbars) attributed to continued plagioclase growth during this period of decompression. GRAIL and GASP data are nearly identical at higher structural levels (Figs. 3.8, 3.9) and may not have recorded this period of decompression because rapid exhumation

"froze" both equilibria. In domains 2 and 3 the GASP reaction was "frozen", while minerals involved in the GRAIL reaction continued to reequilibrate along the decompression path (Figs. 3.8, 3.9). Consumption of garnet and retrograde metamorphism which occurred during cooling was more pronounced in the Gwillim Creek windows, due possibly to the introduction of fluids which facilitated melting reactions.

Amphibolite gneisses also record a portion of the cooling and decompression pressure-temperature path. Garnet-biotite equilibria record near thermal peak conditions and garnet-hornblende pairs record post-peak temperatures along the cooling path (Fig. 3.12). Garnet-biotite temperatures recorded by amphibolite gneisses are consistent with garnet-armoured biotite inclusion temperatures recorded by pelitic schists and are representative of peak thermal conditions ($\sim 850^{\circ}\text{C}$). Marbles record temperatures of at least 800°C , as indicated by the breakdown of scapolite to plagioclase and calcite.

Textures relating metamorphism and deformation and thermobarometry do not clearly record a clockwise pressure-temperature path for the Valhalla complex. In domains 2 and 3 pressures recorded by the GRAIL equilibrium are $\sim 3\text{ kbars}$ lower than data recorded by the GASP equilibrium. Garnet-biotite temperature data are interpreted to be in equilibrium with the GRAIL pressure data and therefore temperatures associated with the GASP pressure data are likely to have been higher. The compositions of hornblende inclusions in garnets of amphibolite gneisses suggest that they were enclosed along the prograde portion of a clockwise pressure-temperature path. Pressures calculated from plagioclase inclusions in garnet of pelitic schists record low pressures (6.5 kbars), which possibly suggest that rocks underwent a counter-clockwise pressure temperature path.

Reliable pressure-temperature data could not be obtained from these inclusions because mineral assemblages did not allow it. The presence of ilmenite coring rutile in pelitic schist might also suggest a counterclockwise pressure-temperature path and more work must be done to determine the prograde pressure-temperature trajectory of the Valhalla complex. A clockwise pressure-temperature path would imply that the overall tectonic setting for the Valhalla complex was compressional (England and Thompson 1984).

Domain 1 Sheet 1c (west side)	Domain 2 Sheet 1c (south end including Vallican area)	Domain 3 Sheet 1a (Gwillim Creek windows)
<p>1. S_0, deposition of sedimentary rocks, minor intrusion of granitoid rocks, and either volcanism or intrusion of mafic dykes</p> <p>presence of ultramafic rocks may indicate a tectonic boundary but no direct evidence for this exists</p> <p>2. S_1 fabric recognized as inclusion trails in garnet</p> <p>3. F_1, rare isoclinal folds, correlations indicate Valhalla assemblage is the upside down limb of a recumbent isoclinal fold.</p> <p>4. Garnet begins to prior to S_2 and overgrows S_1.</p> <p>5. Formation of S_2, garnet growth continues during onset of sillimanite grade metamorphism and S_2.</p>	<p>1. S_0 deposition of sedimentary rocks</p> <p>2. S_1 observed as rare quartz inclusion trails in garnet.</p> <p>3. F_1? none observed</p> <p>4. Garnet starts to grow prior to S_2</p> <p>5. Formation of S_T: sillimanite begins to grow and is included in garnet</p>	<p>1. S_0 deposition of sedimentary rocks</p> <p>2. No evidence of S_1 or F_1.</p> <p>3. F_1?, none observed Were the folds transposed or did this event occur at this level?</p> <p>4. Garnet starts to grow prior to S_T</p> <p>5. S_T forms: sillimanite begins to grow and is included in garnet</p>

Table 3.1. Relative chronology of deformation and metamorphic events.

6. S_2 is moderate to strong and occurs at thermal peak with sillimanite, biotite, K-feldspar and melt in pressure shadows of garnet	6. S_T is strong and occurs at thermal peak with sillimanite, biotite, K-feldspar, and melt in pressure shadows of garnet. S_T transposes all existing fabrics and folds	6. S_T is strong and occurs at thermal peak with sillimanite, biotite, K-feldspar, and melt in pressure shadows of garnet. Shearing along the Gwillim Creek shear zones synchronous with S_2 in domain 1
7. Deformation outlasts garnet growth since sillimanite and biotite wraps around garnet and metamorphic . minerals are folded about F_2 ?	7. Deformation outlasts garnet growth since sillimanite and biotite wraps around garnet and occur in garnet pressure shadows.	7. Deformation outlasts garnet growth since sillimanite and biotite wraps around garnet and occur in garnet pressure shadows.
8. In situ melting, some reequilibration and resorption of garnet during deformation, evidence that rocks did not remain at high T for a long period of time from variable grain size and seriate boundaries in quartz ribbons, to north (Hela Peak, Hird Lake) sillimanite is randomly oriented within knots that aligned in foliation plane.	8. In situ melting? some reequilibration and resorption of garnet, evidence that rocks did not remain at high T for a long period of time from variable grain size and seriate boundaries in quartz ribbons. Decompression plagioclase moats.	8. In situ melting? Garnets are strongly embayed by quartz Preferential consumption and resorption of garnet occurs parallel to extension direction during shearing because.
9. F_2+F_3 coaxial (one long protracted event?)-folds all peak metamorphic minerals, sillimanite aligned parallel to fold axes (synchronous?), few axial planar minerals.	9. F_2+F_3 coaxial (one long protracted event?)-folds S_T and all peak mineral, sillimanite aligned parallel to fold axes (synchronous?), very few axial planar minerals Folds are transposed at deeper levels.	9. F_2+F_3 folds not observed transposed or didn't form.

Table 3.1 (cont'd.) Relative chronology of deformation and metamorphic events.

10. Valkyr shear zone imposes fabric in northern and western part of domain	10. Slocan Lake Fault zone transposes all folds and lineations, and truncates domal shape of complex
11. Cooling Muscovite grows at expense of K-feldspar and sillimanite Chlorite replaces biotite and grows along garnet fractures.	11. Cooling Muscovite grows at expense of K-feldspar and sillimanite Chlorite replaces biotite and grows along garnet fractures.
12. F ₄ crenulations and broad warps Muscovite is subparallel to S ₂ fabric being crenulated	10. Cooling Muscovite grows at expense of K-feldspar and sillimanite Chlorite replaces biotite and grows along garnet fractures

Table 3.1 (cont'd.) Relative chronology of deformation and metamorphic events.

Table 3.2

Table 3.2. Thermobarometric data from pelitic schists.

T1 - Post peak temperatures and pressures calculated from garnet-proximal biotite pairs (T1) separated by plagioclase, quartz or potassium feldspar; and plagioclase in contact with the garnet rim (P1), where possible.

T2 - Temperatures calculated from garnet rims in direct contact with biotite reflecting near closure temperatures for reaction 1. Pressures are not reliable since they were calculated with the same plagioclase compositions used in T1 and are merely a function of moving down the GASP isopleth to where it intersects the garnet - biotite thermometer at T2.

GASP - anorthite = sillimanite + grossular + quartz

GRAIL - almandine + rutile = ilmenite + sillimanite + quartz

The numbers in the first column are for cataloguing composition combinations. The second, third, and fourth columns refer to the garnet, biotite and plagioclase compositions used to calculate the temperatures and pressures. These data may be found in Appendix C. GASP data are found in the fifth and sixth columns, while GRAIL data are found in the seventh and eighth columns. Average temperatures and pressures and standard deviations are located at the bottom of the columns.

Domain 1a - sheet 1c, west side

PS-4-93				GASP				PS-9-93				GASP							
T1	gt	bt	pl	T	P			T1	gt	bt	pl	T	P						
40	d	g	a	737	6.1	-	-	10	c	c	b	721	5.4	-	-				
41	d	g	b	738	6.3	-	-	11	c	c	a	724	5.9	-	-				
42	h	i	d	846	8.0	-	-	13	f	d	b	743	5.5	-	-				
43	h	i	c	844	7.7	-	-	14	e	e	b	740	5.8	-	-				
44	j	h	a	803	7.2	-	-	15	e	e	a	745	5.9	-	-				
45	j	h	d	808	8.1	-	-	16	f	d	a	742	6.2	-	-				
46	c	g	a	720	5.5	-	-					736	5.8						
47	c	g	b	721	5.7	-	-					10	0.3						
				777	6.8			T2											
				50	1.0			1	a	a	b	583	3.0	-	-				
T2								2	a	a	a	585	3.3	-	-				
24	a	e	a	673	4.2	-	-	3	b	b	b	616	3.5	-	-				
25	a	e	b	634	4.4	-	-	4	b	b	a	617	3.8	-	-				
26	b	d	b	772	6.6	-	-					600	3.4						
27	b	d	a	770	6.4	-	-					16	0.3						
28	f	b	c	565	3.4	-	-												
29	f	b	d	566	3.5	-	-												
30	l	c	d	678	5.4	-	-												
31	l	c	c	677	5.2	-	-												
32	k	j	c	702	5.9	-	-												
33	k	j	d	703	6.1	-	-												
				670	5.1														
				69	1.1														
PS-136c-94								PS-169-94								GASP			
T2	gt	bt	pl	T	P			T1	gt	bt	pl	T	P						
23	b	c	a	675	4.5	-	-	41	i	l	d	834	7.4	-	-				
24	b	c	b	682	5.7	-	-	42	i	j	d	781	6.6	-	-				
25	a	b	a	744	6.6	-	-	43	h	k	d	723	5.4	-	-				
26	a	b	b	736	5.3	-	-	45	a	m	f	769	6.6	-	-				
27	e	e	a	658	4.0	-	-	46	a	n	f	780	6.7	-	-				
28	e	e	b	665	5.2	-	-					777	6.5						
				662	4.6							35	0.7						
				4	0.6			T2											
								30	g	f	d	663	4.8	-	-				
								32	f	g	d	607	3.6	-	-				
								35	d	a	f	689	5.0	-	-				
								37	c	b	f	667	4.6	-	-				
								39	j	o	f	747	5.2	-	-				
												675	4.6						
												45	0.6						

Table 3.2. Thermobarometric data for pelitic schists.

PS-277-94				GASP				PS-344-94				GASP			
T1	gt	bt	pl	T	P			T1	gt	bt	pl	T	P		
1	a	b	a	714	4.7	-	-	36	k	i	d	736	6.0	-	-
4	a	d	a	719	4.8	-	-	37	h	j	d	786	6.7	-	-
6	f	f	c	745	7.9	-	-	38	c	k	e	804	6.4	-	-
7	f	g	c	768	8.3	-	-					775	6.4		
23	i	b	d	749	6.8	-	-					29	0.3		
24	i	d	d	754	6.9	-	-	T2							
25	h	g	e	724	5.4	-	-	43	a	d	e	706	4.7	-	-
				748	7.1			44	b	c	e	724	5.1	-	-
				14	1.0			47	e	f	e	707	5.2	-	-
T2								48	f	g	e	729	5.1	-	-
9	b	c	a	688	5.3	-	-	51	g	e	e	738	5.6	-	-
12	c	a	a	644	5.7	-	-					721	5.1		
14	e	e	c	691	5.4	-	-					13	0.3		
				674	5.5	-	-								
				21	0.2										

Domain 1b - sheet 1c. Slocan Ridge, Airy Creek

PS-61-94				GASP				PS-332-94				GASP		GRAIL			
T1	gt	bt	pl	T	P			T1	gt	bt	pl	T	P	T	P		
35	c	j	a	800	6.5	-	-	40	g	k	a	780	7.6	780	7.6		
36	d	j	a	747	5.5	-	-	42	a	j	a	734	7.1	733	6.9		
37	d	k	a	753	5.6	-	-	44	d	i	c	778	7.7	776	7.3		
38	c	k	a	807	6.7	-	-					764	7.5	763	7.3		
39	h	g	b	798	6.5	-	-					21	0.3	21	0.3		
40	j	h	b	814	7.4	-	-	T2									
41	j	i	b	808	7.3	-	-	28	c	f	b	650	4.7	662	7.0		
				790	6.5			30	k	e	b	731	6.4	736	7.3		
				26	0.7			33	i	d	d	691	6.0	697	7.1		
T2								34	f	a	a	712	5.9	721	7.4		
21	b	a	a	690	4.3	-	-					696	5.8	704	7.2		
24	a	b	a	652	4.0	-	-					30	0.6	28	0.2		
26	f	d	b	742	5.6	-	-										
27	g	e	b	708	5.3	-	-										
				698	4.8												
				32	0.7												

Table 3.2. Thermobarometric data for pelitic schists.

Domain 2 - Sheet 1c, Vallican

PS-28a-93				GASP				PS-28b-93				GASP				GRAIL			
T1	gt	bt	pl	T	P			T1	gt	bt	pl	T	P	T	P	T	P		
1	c	a	a	858	11.0	-	-	36	c	g	b	959	12.2	959	7.9				
15	b	a	d	775	8.4	-	-	37	d	g	b	920	11.2	899	7.6				
16	g	f	c5	868	11.7	-	-	38	i	h	a	913	11.1	891	7.3				
17	g	f	c1	862	10.6	-	-	39	i	h	b	913	11.2	-	-				
18	g	b	h	917	10.6	-	-	40	c	g	a	983	12.0	-	-				
19	h	b	h	894	10.1	-	-	41	d	g	a	919	11.0	-	-				
20	i	b	g	873	8.5	-	-					935	11.4	916	7.6				
21	j	b	f	804	7.1	-	-					27	0.5	30	0.3				
				856	9.8														
				43	1.5			T2											
								26	b	c	a	885	10.1	867	7.0				
T2								27	b	c	b	885	10.2	-	-				
4	e	d	c	913	11.9	-	-	28	a	b	b	853	7.5	853	7.5				
5	f	e	c	814	10.4	-	-	29	a	b	a	852	7.4	-	-				
				854	11.2							869	8.8	860	7.3				
				50	1.0							16	1.4	7	0.2				

PCA-93-84				GASP		GRAIL	
T1	gt	bt	pl	T	P	T	P
32	e	g	c	841	11.1	819	7.4
33	f	g	d	728	9.6	714	7.1
34	a	e	b	870	11.4	844	7.0
35	b	f	b	856	11.6	830	6.9
37	g	g	b	832	10.2	815	7.3
38	j	h	e	786	9.2	775	7.1
				819	10.5	800	7.1
				48	0.9	44	0.2

T2							
18	h	a	a	878	21.9	800	7.4
21	c	d	b	744	9.4	731	7.0

Domain 3 - sheet 1a, lower Gwillim Creek window

PCA-200-85				GASP		GRAIL		PS-348a-94				GASP			
T1	gt	bt	pl	T	P	T	P	T1	gt	bt	pl	T	P		
27	a	a	a	844	8.3	833	6.4	36	c	q	a	875	8.7	-	-
30	a	a	b	844	8.3	-	-	37	d	p	a	901	9.9	-	-
28	f	e	d	970	10.5	946	6.4	38	h	n	c	851	8.4	-	-
29	f	e	c	972	10.8	-	-	39	i	o	c	768	7.1	-	-
35	f	c	d	947	10.1	924	6.2					849	8.5		
36	f	c	c	949	10.5	-	-					50	1.0		
37	a	a	e	836	6.9	-	-								
38	a	a	f	842	8.0	-	-								
				901	9.2	901	6.3	T2							
				60	1.4	49	0.1	30	a	h	a	750	6.4	-	-
								31	b	i	a	745	7.0	-	-
								32	f	k	c	621	4.4	-	-
T2								33	g	m	c	643	5.5	-	-
33	d	d	c	796	7.8	785	5.9					690	5.8		
34	d	d	d	795	7.6	-	-					58	1.0		

Table 3.2. Thermobarometric data for pelitic schists.

unarmoured biotite inclusions
in garnet at fixed P (8Kbars)Armoured biotite inclusions
in garnet at fixed P (8Kbars)

Domain 1a

Domain 1b

PS-136c-94 GT BT
11 d a 665 8.0

PS-61-94 GT BT
14 i f 810 8.0

PS-169-94
21 e e 600 8.0
22 e d 610 8.0
23 c c 635 8.0

PS-332-94
19 h c 830 8.0
21 b g 810 8.0

PS-344-94
23 d b 680 8.0
24 d a 700 8.0

Domain 3

Domain 1b

PS-348-94
1 1.24 f 865 8.0
2 1.25 g 885 8.0

PS-61-94
13 i g 730 8.0

PS-332-94
20 j b 765 8.0

Domain 2

PS-28b-93
16 f a 905 8.0
17 g e 818 8.0

Domain 3

PS-348-94
3 1.2,3 a 670 8.0
4 1.4,5 c 720 8.0
5 1.6,7 d 680 8.0
6 1.8,9 e 670 8.0

Unarmoured plagioclase inclusions in garnet at fixed T (750, 800 °C)

Domain 1a

PS-169-94 GT PL
4 3.11 4.1 750 4.9 800 5.5
5 3.11 4.2 750 4.6 800 5.7
6 3.9 4.3 750 4.9 800

PS-344-94
4 3.3 1.4 750 5.8 800 6.6
5 3.3 1.5 750 5.7 800 6.4
6 2.5 1.6 750 4.7 800 5.3-6.6
4.6-5.8

Table 3.2. Thermobarometric data for pelitic schists.

Table 3.3

Table 3.3. Thermobarometric data for amphibolite gneisses.

GT-HN, TR-TS is the intersection between the garnet - tremolite thermometer (reaction 5) and the garnet-hornblende-plagioclase barometer (reaction 4). GT-BT, TR-TS is the intersection between the garnet-biotite thermometer (reaction 1) and the garnet-hornblende-plagioclase barometer (reaction 4). Columns are arranged in the same manner as Table 3.2. Mineral compositions used for calculations are listed in Appendix D.

Domain 1a - sheet 1c, west side

PS-26-93		GT-HN				GT-BT		
		GT	HN	PL	BT	TR-TS	TR-TS	
1	RIM-T	C	A	A	-	688	7.3	-
2		D	B	A	-	702	7.4	-
6	ALL-T	B	E	E	C	692	6.6	901
7		F	A	A	-	693	7.4	-
8		F	B	A	-	701	7.4	-
9		F	E	A	-	734	7.8	-
10	ALL-M	B	J	C	E	679	7.1	854
11		B	J	C	D	679	7.1	836
12		F	F	B	A	706	7.3	850
13		F	F	B	B	706	7.3	841
						698	7.3	856
						15	0.3	23
								0.2
PS-115-94								
1		B	F	B	A	761	7.0	847
2		A	C	E	D	783	8.2	829
3		A	C	F	E	784	8.3	844
4		A	C	G	B	794	8.4	840
5		B	D	A	C	792	8.2	850
6		B	D	C	-	783	8.2	-
7		B	D	D	-	793	8.3	-
8		B	E	D	-	786	8.2	-
9		B	E	C	-	785	8.0	-
10		B	E	A	-	786	8.2	-
11		B	F	A	-	767	7.9	-
12		B	F	C	-	766	7.8	-
13		B	F	D	-	766	7.9	-
						780	8.0	842
						11	0.3	7
								1.2
PS-248-94								
1		D	A	D	-	694	7.3	-
2		B	C	A	-	717	7.9	-
3		D	A	D	-	677	6.6	-
4		C	C	A	-	676	6.5	-
5		F	B	C	-	696	6.5	-
6		F	B	D	-	698	6.7	-
7		C	D	A	-	690	7.0	-
8		C	D	B	-	683	6.6	-
						691	6.9	-
						12	0.5	-

Table 3.3 Thermobarometric data for amphibolite gneisses.

Domain 1b

PS-52-94

1	B	B	A	-	776	8.7	-	-
2	B	B	B	-	807	13.4	-	-
3	D	C	B	-	788	13.1	-	-
4	D	C	A	-	759	8.6	-	-
5	G	F	H	-	843	10.6	-	-
6	G	F	I	-	848	11.4	-	-
7	F	G	I	-	785	10.0	-	-
8	F	G	H	-	781	9.3	-	-
9	A	E	A	-	753	8.8	-	-
10	A	E	B	-	782	12.2	-	-
13	B	B	J	-	778	9.1	-	-
14	D	C	J	-	761	8.9	-	-
15	A	E	J	-	750	8.4	-	-
16	G	F	E	-	847	11.2	-	-
17	F	G	G	-	782	9.4	-	-
					789	10.3		
					32	1.7		

PS-29A-93

1	A	-	-	B	-	-	-	-
2	C	-	-	A	-	-	-	-
3	D	B	A	-	744	8.0	-	-
4	E	C	A	-	740	8.1	-	-
5	F	A	B	-	788	9.5	-	-
6	B	B	A	-	721	7.6	-	-
7	G	C	A	A	767	8.8	815	9.6
8	G	B	A	B	767	8.8	839	10.0
					755	8.5	827	9.8
					22	0.6	12	0.2

Hornblende inclusions in garnet

26-3	A	H	-	-	647	9.7	-	-
-4	E	D	-	-	646	8.7	-	-
-5	E	C	-	-	682	9.6	-	-
52-12	C	D	-	-	712	8.6	-	-
248-11			-	-	667	7.8	-	-
-12			-	-	698	5.8	-	-

Table 3.3 Thermobarometric data for amphibolite gneisses.

Figure 3.1

Figure 3.1. Petrogenetic grid for pelitic schists showing important melt equilibria modified after Yardley (1989), Spear and Cheney (1989) and Spear (1993). Those equilibria labelled with numerals correspond to those used in the text.

A) albite + potassium feldspar + quartz + H₂O = melt (Luth *et al* 1964)

B) muscovite + potassium feldspar + quartz + H₂O = melt (Thompson 1982)

C) muscovite + plagioclase + quartz = potassium feldspar + aluminosilicate + liquid (LeBreton and Thompson 1987)

8) biotite + plagioclase + aluminosilicate + quartz = garnet + potassium feldspar + liquid (LeBreton and Thompson 1987)

10) muscovite + quartz = potassium feldspar + aluminosilicate + melt (Thompson 1982)

D) biotite + quartz + plagioclase = orthopyroxene + potassium feldspar + liquid (Clemens and Wall 1981)

E) biotite + sillimanite = garnet + cordierite + potassium feldspar (Spear and Cheney 1989)

Figure 3.2. Thermobarometry sample locality map.

Figure 3.3

Figure 3.3. Compositional zoning profiles of garnet from pelitic schists. Cores are flat due to homogenization of the garnet at high temperatures. Increases in Fe and decreases in Mg at rims are due to net-transfer reactions consuming garnet and producing biotite along with Fe-Mg exchange between garnet and biotite. Decrease in Ca and increase in Mn near the biotite inclusion in sample PS-28b-94 are likely due to the introduction of fluids along a fracture.

Figure 3.4

Figure 3.4. Schematic illustrations outlining chronology of metamorphic and deformation events as observed from petrographic and chemical data.

- a) S_1 formed and is defined by quartz inclusions..
- b) Garnet overgrew S_1 fabric.
- c) Garnet included sillimanite oriented in S_2 indicating that S_2 began to form during prograde metamorphism and garnet growth continued during part of S_2 formation.
- d1) Garnet growth stopped and preferential resorption of garnet occurred giving elongate shape to garnet while S_2 continued and wrapped around garnet porphyroblasts.
- d2) Garnet consumption created increased Fe/Fe+Mg levels about rim of garnet while plagioclase moats formed around garnet.
- e) Melt producing reactions formed vermicular quartz which cross-cuts Fe zoning. Plagioclase moats are diminished along garnet rims parallel to S_2 fabric due to continued deformation.

Figure 3.5

Figure 3.5. Zoning profiles of garnet in sample PS-28a-93 (domain 2), located near Vallican. This sample shows rare Ca zoning and is attributed to decompression reactions consuming garnet and precipitating plagioclase as moats around the garnet. $\text{Fe}/\text{Fe}+\text{Mg}$ increases toward the rim are also attributed to net-transfer reactions consuming garnet.

Figure 3.6

Figure. 3.6 Zoning profiles of garnet from amphibolite gneisses. Profiles are relatively homogeneous from core to rim and indicate that rims were affected little by retrograde effects during cooling.

Figure. 3.7 Petrogenetic grid for ultramafic schists calculated using TWEEQU computer program (Berman 1991). Ath - anthophyllite, Atg - antigorite, Di - diopside, En - enstatite, Fo - forsterite, Qtz - quartz, Tc - talc, Tr - tremolite, W - water.

Figure 3.8

Figure 3.8. Representative plots for T1, P1 data from pelitic schists, generated using the computer program TWEEQU. Multiple lines for individual equilibria indicate that more than one mineral pair was used.

Equilibria:

- 1) almandine + phlogopite = pyrope + annite
 - 2) anorthite = grossular + sillimanite + quartz (GASP)
 - 3) sillimanite + quartz + ilmenite = almandine + rutile (GRAIL)
- a) PS-9-93 - domain 1a, Rinda Ridge.
 - b) PS-332-94 - domain 1b, Slocan Ridge.
 - c) PCA-93-84 - domain 2, Vallican.
 - d) PCA-200-85 - domain 3, lower Gwillim Creek window (sheet 1a)

Plate 8

Plate 8a. Ragged garnet porphyroblast with a moat of quartz grains separating it from the surrounding matrix. Field of view (F.O.V) 4.8 mm. Sample PS-4-93, sheet 1c, domain 1a.

Plate 8b. Garnet porphyroblast in pelitic schist with quartz embayments interpreted to be a product of garnet breakdown during melting. F.O.V. 2.4 mm. Sample PS-19-93, sheet 1c, domain 1a.

Plate 8c. Garnet porphyroblast with inclusions concentrated in the core and an inclusion free rim. F.O.V. 4.8 mm. Sample PS-136c-94, sheet 1c, domain 1a.

Plate 8d. Plagioclase, quartz and biotite inclusions in garnet porphyroblast. F.O.V. 2.4 mm. Sample PS-332-94, sheet 1c, domain 1b.

q - quartz, p - plagioclase, i - ilmenite, s - sillimanite

Figure 3.9

Figure 3.9. Petrogenetic grids for pelitic schists and thermobarometric data results from the Valhalla complex. Data represents post but near-peak pressures and temperatures calculated from garnet rims, proximal biotite, and plagioclase in contact with the garnet rim, where possible. These data are representative of the temperature at which reaction (8) closed. Rhombohedra are generated from maximum and minimum pressures and temperatures from TWEQU plots as presented in figure 3.7. Shaded areas are the intersection range for GRAIL and the garnet-biotite thermometer, while unshaded areas are the intersection range for GASP and the garnet biotite thermometer.

Equilibria:

A) albite + potassium feldspar + quartz + H_2O = melt

B) muscovite + potassium feldspar + quartz + H_2O = melt

C) muscovite + plagioclase + quartz = potassium feldspar + aluminosilicate + liquid

8) biotite + plagioclase + aluminosilicate + quartz = garnet + potassium feldspar + liquid

10) muscovite + quartz = potassium feldspar + aluminosilicate + melt

D) biotite + quartz + plagioclase = orthopyroxene + potassium feldspar + liquid

a) Samples PS-4-93, PS-9-93, PS-169-94, PS-277-94 and PS-344-94 from the west side of sheet 1c (domain 1a) and samples PS-61-94 (Airy Creek) and PS-332-94 (Slocan Ridge, domains 1b). Data is in agreement with petrographic observations.

b) Samples PS-28a-93, PS-28b-93, and PCA-93-84 from the area of Vallican (domain 2) in the Slocan River Valley. These samples show a large variation in pressure and temperature and large difference between GASP and GRAIL data. Sample 28a has variable compositions of plagioclase rimming garnet which indicate different portions of a decompression period (large trapezoid).

c) Samples PCA-200-85 and PS-348-94 from the lower Gwillim Creek window (sheet 1a, domain 3). These samples record a large variation and higher temperatures than sheet 1c but have similar pressures.

a)

b)

c)

Figure 3.11

Figure 3.11. Representative plots of equilibria for amphibolite gneisses generated using the computer program TWEEQU.

1) tremolite + anorthite = tschermakite + grossular + pyrope + quartz

2) almandine + tremolite = Fe-tremolite + pyrope

3) almandine + phlogopite = pyrope + annite

a) PS-26-93 - domain 1a, Rinda Ridge

b) PS-52-94 - domain 1b, Airy Creek

c) PS-248-94 - domain 1a, Hird Lakes

d) PS-115-94 - domain 1a, Rinda Ridge

Figure 3.11. Compilation of thermobarometric data from amphibolite gneisses. Boxes represent maximum and minimum pressure and temperature presented in Table 3.3. Unshaded areas represent the intersection of the garnet-amphibole thermometer (reaction 5) and the garnet-plagioclase-amphibole barometer (reaction 4). The shaded area is the intersection area of the garnet-biotite thermometer (reaction 1) and reaction 4. The aluminosilicate equilibria are shown for reference. Anomalous high pressures recorded by PS-52-94 are a result of local disequilibrium between garnet and plagioclase moats.

Plate 8

Plate 8

Plate 8a. Ragged garnet porphyroblast with a moat of quartz grains separating it from the surrounding matrix. Field of view (F.O.V) 4.8 mm. Sample PS-4-93, sheet 1c, domain 1a.

Plate 8b. Garnet porphyroblast in pelitic schist with quartz embayments interpreted to be a product of garnet breakdown during melting. F.O.V. 2.4 mm. Sample PS-19-93, sheet 1c, domain 1a.

Plate 8c. Garnet porphyroblast with inclusions concentrated in the core and an inclusion free rim. F.O.V. 4.8 mm. Sample PS-136c-94, sheet 1c, domain 1a.

Plate 8d. Plagioclase, quartz and biotite inclusions in garnet porphyroblast. F.O.V. 2.4 mm. Sample PS-332-94, sheet 1c, domain 1b.

q - quartz, p - plagioclase, i - ilmenite, s - sillimanite

Plate 9

Plate 9

Plate 9a. Garnet porphyroblast with inclusions of quartz and sillimanite (S₁). Biotite and sillimanite foliation (S₂) wraps around garnet and occurs in pressure shadows. F.O.V. 4.8 mm. Sample PS-21-93. sheet 1c, domain 1a.

Plate 9b. Sillimanite inclusions in garnet porphyroblast are aligned parallel with the external foliation and continuous with aligned minerals in the pressure shadow. F.O.V. 2.4 mm. Sample PCA-200-8, sheet 1a, domain 3.

Plate 9c. These sillimanite mats in pelitic schist are oriented in the foliation plane but some crystals within the mat appear to be randomly oriented. F.O.V. 4.8 mm. Sample PS-277-94, sheet 1c, domain 1a.

Plate 9d. Garnet porphyroblast surrounded by discontinuous mat of fine-grained plagioclase. F.O.V. 4.8 mm. Sample PS-28a-93, sheet 1c, domain 2.

g - garnet, s - sillimanite, p - plagioclase, q - quartz

Plate 10

Plate 10

Plate 10a. Advanced stage of garnet consumption with plagioclase, sillimanite and biotite growing at expense of garnet in pelitic schist. F.O.V. 2.4 mm Sample PS-277-94, sheet 1c, domain 1a.

Plate 10b. Myrmekitic symplectite of quartz and plagioclase growing at the expense of potassium feldspar. F.O.V. 1.2 mm. Sample PS-64-94, sheet 1c, domain 1b.

Plate 10c. Garnet porphyroblast with pressure shadow of biotite and ilmenite. Note how the foliation contains sillimanite and biotite which wrap around garnet. F.O.V. 4.8 mm. Sample PS-58-94, sheet 1c, domain 1^a.

Plate 10d. F₃ crenulations in pelitic schist folding sillimanite and biotite. F.O.V. 4.8 mm. Sample PS-280-94, sheet 1c, domain 1a.

g - garnet, i - ilmenite, q - quartz, s - sillimanite, b - biotite, q - quartz

10b

10d

10a

10c

Plate 11

Plate 11

Plate 11a. Thin muscovite halo surrounds sillimanite porphyroblast in pelitic schist from sheet 1a. F.O.V. 2.4 mm. Sample PS-32-93, sheet 1b.

Plate 11b Garnet porphyroblast in amphibolite gneiss contains round hornblende and quartz inclusions. F.O.V. 4.8 mm. Sample PS-26-93, sheet 1c, domain 1a.

Plate 11c. Garnet porphyroblast surrounded by hornblende and biotite. Note that small inclusions of quartz are concentrated towards the core of the garnet. F.O.V. 4.8 mm. Sample PS-29a-93, sheet 1c, domain 2.

m - muscovite, s - sillimanite, h - hornblende, g - garnet, b - biotite, p - plagioclase

Plate 12

Plate 12

Plate 12a. Thin plagioclase rim around garnet porphyroblast in amphibolite gneiss. F.O.V. 4.8 mm.
Sample PS-52-94, sheet 1c, domain 1b.

Plate 12b. Symplectite of calcite and plagioclase (quartz?) rimming scapolite porphyroblast in marble.
F.O.V. 4.8 mm. Sample PS-223-94, sheet 1c, domain 1a.

Plate 12c. Olivine grain with serpentine filled fractures and surrounded by phlogopite. F.O.V. 4.8 mm.
Sample PS-7c-93, sheet 1c, domain 1a.

Plate 12d. Orthopyroxene grain partially replaced by tremolite. F.O.V. 4.8 mm. Sample PS-7d-93,
sheet 1c, domain 1a.

c - calcite, p - plagioclase, h - hornblende, ph - phlogopite, t - tremolite, o - olivine, opx - orthopyroxene,
sc - scapolite

CHAPTER 4: TECTONIC INTERPRETATION

4.1 Introduction

Previous work in the Valhalla complex has emphasized the geochronology of the granitic rocks and faults bounding the complex (Carr *et al.* 1987; Parrish *et al.* 1988; Carr 1995; Parrish 1995). This study brings forth new stratigraphic and thermobarometric data which elucidate the evolution of the Valhalla complex. Based on data presented in this study together with data from previous studies, the timing of compressional deformation and metamorphic events were used to place constraints on the tectonic evolution of the Valhalla complex and the Gwillim Creek shear zones (Tables 2.1, 3.1). Tectonic interpretations based on the conclusions made in chapters 2 and 3 are summarized in a geologic history of the Valhalla complex.

4.2 Summary of stratigraphic and metamorphic data

4.2.1 Stratigraphy

Paragneisses in the Valhalla complex occur at three structural levels separated by Cretaceous to Eocene granitic rocks and the Gwillim Creek shear zones. The uppermost paragneiss sheet (1c) is composed of a heterogeneous package of pelitic schists, marbles, calc-silicate gneisses, metaconglomerates, amphibolite gneisses and ultramafic schists, termed the Valhalla assemblage (Figs. 2.3, 2.4). At the base of the sheet (units 1-3), there is a sequence of conglomerates, calc-silicate gneisses, and marbles interlayered with 50-100

m thick units of aluminum-poor semipelitic to pelitic schist. Proceeding up in structural direction, the sequence becomes more carbonate-rich, with metre-thick marbles and calc-silicates gneisses interlayered with quartzites and slightly more aluminum-rich pelitic rocks (units 4-8). There is also an increase in amphibolite gneisses and ultramafic rocks, which are absent in the structurally lower sections. This sequence is overlain by thick marble and quartzite layers, units 9 and 10, respectively. In domains 1b and 2 in the southern area of the paragneisses, a thick unit of pelitic schist and amphibolite gneiss predominates (unit 11).

The Valhalla assemblage is correlated with rocks from the Neoproterozoic Horsethief Creek Group, Hamill Group, Badshot Formation, Lardeau Group and Milford Group (Table 2.3) and was thinned by up to 80%. Stratigraphic correlations indicate that the Valhalla assemblage has been inverted. These correlations have a bearing on three aspects of the tectonic evolution of the Valhalla complex: 1) the timing and mechanism for tectonic inversion of the Valhalla assemblage; 2) the significance and timing of thinning of the Valhalla assemblage; and 3) correlation of the GCSZ, possibly linking the Omineca belt to the Foreland belt.

4.2.2 Metamorphic Petrology

Textures relating the timing of metamorphism to deformation, coupled with thermobarometric data from various bulk compositions and mineral equilibria from three domains at successively deeper structural levels, place constraints on the timing and sense of displacement of the GCSZ. A period of near thermal peak decompression is inferred, firstly, from reactions responsible for plagioclase moats, and secondly, by the difference

between pressures determined from GRAIL and GASP equilibria, which are interpreted to represent a variation in closure temperature. The prograde pressure-temperature path of the Valhalla complex is not well constrained. If the Valhalla complex recorded a clockwise pressure-temperature path it would indicate that the complex was in a compressional tectonic setting (England and Thompson 1984, Harley 1988), which would be consistent with the interpretation of the GCSZ being compressional structures. The presence of rutile rimming ilmenite and the compositions of plagioclase inclusions in garnets of pelitic schists suggests that these rocks underwent a counter-clockwise P-T path, however, more data is required to confirm this.

Textural observations and thermobarometry indicate that the peak of metamorphism was synchronous with D_2 in sheet 1c, and movement on the GCSZ in the GCW and the Passmore dome. The peak of metamorphism has been interpreted to be 75 Ma (Heaman and Parrish 1991) and therefore the GCSZ were active at this time. The fact that thermobarometric data indicates that temperatures and pressures increase with structural level within the limits of normal thermal and pressure gradients implies that sheets 1c and 1a share the same thermal history. If metamorphism had totally predated the main deformation event (D_2) and movement on the GCSZ was east verging then one would expect to find hot rocks placed on cold rocks, and possibly an inverted thermal gradient. This is not the case.

4.2.3 Timing of deformation in the Valhalla complex

The youngest rocks of the Valhalla assemblage are correlated with the Carboniferous

Milford Group, therefore the deformation event that inverted them must be post Mississippian. The minimum age for first phase folding is constrained by the ~75 Ma peak of metamorphism and synchronous S_2 development. The idea that the first phase of folding occurred after the intrusion of the ~110 Ma Mulvey granodiorite cannot be dismissed because field relationships between the Mulvey granodiorite and F_1 folds were not observed. Although age constraints for F_1 folding are fairly broad (>75 - ~290 Ma), the timing of this deformation is inferred to be pre-Mulvey granodiorite because S_1 fabrics are not observed in the Mulvey granodiorite.

The Mulvey granodiorite is interpreted to be structurally duplicated by the GCSZ. The Mulvey granodiorite contains the dominant S_2 fabric present in the Valhalla assemblage and therefore at least part of the S_2 fabric development is younger than 110 Ma. The development of S_2 is interpreted to be synchronous with movement on the GCSZ which means that the GCSZ are also at least in part younger than 110 Ma. S_2 is interpreted to be synchronous with metamorphism which peaked at 75-80 Ma (see section 2.2) and therefore at least part of the S_2 development occurred before 75 Ma. It is possible that S_2 development and movement on the GCSZ began while the Mulvey granodiorite intruded. S_2 has a minimum age of >63 Ma because the Airy quartz monzonite does not contain this fabric. F_3 folds leucosome containing the S_2 fabric, sillimanite and biotite indicating that this folding event was syn- post metamorphic peak. These folding events are < 75 Ma because they are younger than the peak of metamorphism, which is inferred to be this age (Heaman and Parrish 1991).

4.3 Interpretations

4.3.1 Inverted stratigraphy

The Valhalla assemblage is interpreted to be the upside down limb of a large first phase recumbent fold similar to other recumbent nappes in the southern Omineca belt such as the Scrip Nappe (Raeside and Simony 1983), the Riondel Nappe (Höy 1977, 1980), and the Carnes Nappe (Brown and Lane 1988). The following section will evaluate the timing relationships of deformation in the Valhalla complex, based on stratigraphic correlations and published geochronological data, and compare this data with models for the timing of first phase folding in the Riondel and Scrip Nappes.

The timing, origin and tectonic setting of large scale recumbent nappes in the Kooienay Arc and eastern Omineca belt have been the subject of debate for some time. Inverted stratigraphy in the Omineca belt has been attributed to isoclinal F_1 folding of a surface related to the obduction of a marginal basin during the Early to Middle Jurassic (Brown *et al.* 1986). In this scenario, west verging F_1 folds resulted from the delamination of the North American crust from the mantle lithosphere about an east-dipping subduction zone (Brown *et al.* 1993). East-verging folds that overprint F_1 were formed as a result of east directed thrusting during the Middle Jurassic to Late Cretaceous (Brown *et al.* 1986; Price 1986; Brown and Journeay 1987; Brown *et al.* 1993).

Riondel Nappe

The Riondel Nappe, to the east of the Valhalla complex (Fig. 1.1), is a first phase

west verging fold which deforms Hamill to Lardeau group (and possibly Milford) strata. The nappe was refolded by east verging F_2 folds and coaxial F_3 folds (Höy 1977, 1980). Although first phase folding has been interpreted to be Paleozoic in some parts of the Kootenay Arc (Read and Wheeler 1976), it has been demonstrated that the lack of a cleavage in the Milford Group is a function of structural level (Struik 1981; Murphy 1987). Brown and Lane (1988) presented evidence that first phase folding in the Carnes nappe is Jurassic and is related to obduction of the Quesnellia terrane and subsequent backthrusting. Brown and others (1993) suggested that west verging folds in the southern Omineca belt are a result of folding of the obduction surface between the Quesnellia and Kootenay terranes due to delamination of the crust during east directed subduction of the mantle lithosphere.

In the Riondel Nappe, it is uncertain if the Carboniferous Milford Group was folded by first phase folding, however seismic reflection data suggest that it might have been (Varsek and Cook 1991). Cook and Varsek (1991) present two models for the formation of the Riondel Nappe. Model 1 is based on the model of Brown and Lane (1988). In the Riondel area, the Milford Group does not surface on the east limb of the Riondel Nappe. It is possible that the Milford Group is folded by first phase deformation and is truncated on the east limb of the Riondel Nappe by the West Bernard fault (Cook and Varsek 1991).

The second model of Cook and Varsek (1991) is based on the mapping of Read and Wheeler (1976) and Klepacki (1985), and suggests that west-directed folds were possibly related to the Paleozoic docking of the Kootenay terrane to the miogeocline. This raises another question concerning the boundary between the Kootenay terrane (Lardeau Group) and the North American miogeocline. Colpron and Price (1995) present evidence that the

Lardeau Group lies unconformably on and is depositionally linked to the miogeocline. This contradicts the "Lardeau shear zone" theory of Smith and Gehrels (1992b), which implies that the Kootenay terrane is allochthonous and was juxtaposed against the miogeocline by faulting. The inference that the Kootenay terrane and the miogeocline are depositionally linked would suggest that a Paleozoic deformation was not significant.

Scrip Nappe

The Scrip Nappe, located north of the Monashee complex (Fig. 1.1a), exhibits evidence for a Jurassic age for the first two phases of deformation in the southern Omineca belt. It contains a 50 km long inverted, southwest verging, F_1 limb of Horsethief Creek Group strata, which roots in the east and is refolded by later F_2 and F_3 coaxial deformation events (Raeside and Simony 1983). The first phase of folding was initiated with the onset of metamorphism in the Jurassic, followed by Middle to Late Jurassic F_2 and Early Cretaceous F_3 folds (Raeside and Simony 1983). The structure of the Scrip Nappe is consistent with the model of Brown and Lane (1988).

Eagle Bay assemblage

In the Adams Lake-Clearwater-Vavenby area, Schiarizza and Preto (1987) found that the dominant structural pattern is defined by Mesozoic deformation and they concluded that there is no clear evidence to suggest Paleozoic deformation in the Eagle Bay assemblage. This is consistent with observations in the Valhalla complex which suggest that Carboniferous aged Milford equivalents were involved in first phase folding and that

Paleozoic deformation was not responsible for isoclinal folding.

Timing of inversion in the Valhalla complex

Stratigraphic correlations indicate that the Valhalla assemblage is an inverted sequence of Horsethief Creek to Milford Group strata, and may have been inverted as a result of isoclinal folding, similar to other recumbent nappes such as the Riondel Nappe (Höy 1977, 1980) and Scrip Nappe (Raeside and Simony 1983). These nappes are inverted by primarily Jurassic deformation which has not been documented at the mid-crustal levels of the Valhalla complex. Although timing constraints place first phase folding between ~75 Ma (peak of metamorphism - S₂ development) and ~ 290 Ma (age of Milford Group correlatives) which are inverted, a pre-Mulvey granodiorite age of Early Cretaceous age is favoured for first phase folding in the Valhalla complex. This is consistent with the model of Parrish (1995) which suggests that deformation and metamorphism is younger at deeper structural levels in the southern Omineca belt. Although Jurassic first phase folding has not been documented at the mid-crustal structural level of the Valhalla complex, it cannot be ruled out because timing constraints are not narrow enough.

The inferred Early Cretaceous age of first phase folding in the Valhalla complex is consistent with the model of Brown and Lane (1988) and with seismic data from the Riondel area (Varsek and Cook 1991) which suggest that the present structural framework in the southern Omineca Belt was controlled by Jurassic or younger deformation.

4.3.2 Thinning of the Valhalla assemblage

The present thickness of the Valhalla assemblage is at most 1.5 km which implies that the sequence was thinned by up to 80%, if correlations presented in this study are correct. Together, the Hamill to Milford strata alone are upwards of 4 km thick in the Goat Ranges where they are less deformed than the Valhalla assemblage and metamorphosed to greenschist - lower amphibolite facies. S_2 fabrics are parallel to the contacts of units within the Valhalla assemblage and this fabric forming development is interpreted to be synchronous with movement on the GCSZ. Structural thinning during east directed compressional deformation and shearing associated with the GCSZ are likely to have been the cause of this thinning, since there are no kinematic or structural data to support extensional deformation prior to the Eocene.

Alternatively, thinning of the Valhalla assemblage may be synchronous with F_1 folding, where the bottom limb of the recumbent nappe was dragged out and thinned while the upper limb retained its original thickness.

4.3.3 Correlation of the Gwillim Creek shear zones

It has been proposed that the Gwillim Creek shear zones are major faults linking the Omineca belt to the Foreland fold and thrust belt (Parrish *et al.* 1987; Cook *et al.* 1988). This is based on correlative seismic reflection packages beneath the Kootenay Arc and Purcell Anticlinorium (Varsek and Cook 1994; Cook and Van der Velden 1995). The duplication of units in the Valhalla complex (Fig. 1.3, Cross section B), the easterly fold vergence in the Valhalla assemblage, as well as minor kinematic indicators suggesting top to the east displacement (Parrish *et al.* 1985) are evidence that the GCSZ are thrust faults.

No detailed structural study has been carried out on these shear zones. The correlation of the Valhalla assemblage to Paleozoic strata in the Kootenay Arc has implications for the correlation of the GCSZ to faults in this same area. A comparison of available structural, geochronological and seismic data from adjacent areas to the Valhalla complex in the Kootenay Arc and Purcell Anticlinorium and timing constraints on the GCSZ (this study) and published geochronological data has resulted in several possibilities for the correlation of the GCSZ and faults in the Kootenay Arc and Purcell Anticlinorium. The possible correlations are with either the West Bernard fault in the Riondel area (Fig. 1.1), the Moyie fault in the Purcell Anticlinorium or structures imaged by the subsurface K-reflectors below the Purcell Anticlinorium described by Varsek and Cook (1994).

The timing of displacement on the GCSZ is younger than the ~110 Ma deformed Mulvey granodiorite and older than 52 Ma cross-cutting aplite dykes (Parrish 1995). Parrish and others (1988) and Heaman and Parrish (1991) presented preliminary thermochronologic data which suggest that the thermal peak of metamorphism was at 75-80 Ma. Metamorphism is synchronous with fabrics associated with the GCSZ and therefore movement on the GCSZ is syn-metamorphic and occurred at approximately 75-80 Ma.

There are four thrust faults in the Kootenay Arc and the Purcell Anticlinorium that are possibly correlative to the GCSZ (Figs. 1.1a, 2.6). The West Bernard fault (WBF), in the Riondel area, carries Hamill to Milford Group strata in its hanging wall and is cross-cut by the Late Cretaceous (?) Fry Creek batholith (Reesor 1973; Archibald *et al.* 1984). Further to the west, the Hall Lake fault (HLF) is cut by the 111-129 Ma White Creek batholith (Wanless *et al.* 1968; Price 1981; Archibald *et al.* 1984), and the St. Mary fault (SMF) is

plugged by the 94 Ma Reade Lake stock (Höy and Van der Heyden 1988). The Moyie fault (MF) cuts across Devonian aged gneisses but its age is not further constrained, excluding later cross-cutting Tertiary normal faults. The HLF, SMF and MF all carry (Belt) Purcell Supergroup with minor Windermere Supergroup and Hamill Group strata in their hanging walls. The 129 Ma White Creek batholith cross-cuts the HLF and correlation with the GCSZ is inconsistent with a < 100 Ma movement on the GCSZ.

Both the WBF and the GCSZ carry inverted Paleozoic stratigraphy in their hanging walls. Timing of displacement is not well constrained for the WBF. The Fry Creek batholith truncates the WBF (Höy 1980) and K/Ar dates gathered by Reesor (1973) give ages of 76-86 Ma from biotite and 83-97 Ma from muscovite. Archibald and others (1984) found K/Ar ages to be 50-58 Ma, however these ages are related to cooling rather than emplacement. The present age data on the Fry Creek batholith constrain the age of displacement of the WBF to be between ~ 100 and 50 Ma. The age constraints on the GCSZ are between 110 and 52 Ma and therefore it is permissible to correlate the GCSZ and the WBF. Cook and Van der Velden (1995) discuss the possible correlation of the WBF with the GCSZ, but note that the WBF has been interpreted to be associated with the Jurassic accretion of the Kootenay Arc with the North American craton (Varsek and Cook 1991).

In the Midge Creek area, Leclair (1984) has correlated the Seeman Creek fault with the WBF. The Seeman Creek fault is cross cut by the 117 ± 1 Ma Baldy pluton (Leclair *et al.* 1993) which suggests a pre-Early Cretaceous age for the WBF. Although age data and similar hanging wall stratigraphy permit a correlation between the GCSZ and the WBF, more geochronological data must be collected from the Fry Creek batholith to constrain the age

of the WBF. If the correlation of the Seeman Creek fault to the WBF is correct (Leclair 1984) then the WBF is probably Early Cretaceous in age and therefore does not correlate to the GCSZ.

The GCSZ may also be correlative with the Moyie fault, which has a relatively unconstrained age. The MF cuts Devonian gneisses (Leech 1962; Benvenuto and Price 1979) and is cut by Tertiary normal faults. Since the strata in the hanging wall of the MF belongs to the Purcell Supergroup, it would require the GCSZ to cut down-section, eastward.

Varsek and Cook (1994) have correlated the GCSZ across the SLF with a series of sub-horizontal reflections, termed the "K-reflectors" (Fig. 2.7). "K - reflectors" form the roof thrust of a duplex, which is bounded on the bottom by the combined Rocky Mountain basal detachment (RMBD) - Monashee décollement (MD) reflections. These "K - reflectors" are also interpreted to truncate thrust faults in the Purcell Anticlinorium (HLF, SMF, MF) and merge with the RMBD-MD near the Rocky Mountain trench. The Monashee décollement was in motion in the Late Paleocene and had ceased by 58 Ma (Carr 1992; Scammell 1993). If the "K-reflectors" merge with the RMBD in the east (Varssek and Cook 1994), then it is likely that they do not project to the surface, and a correlation is not possible using similar hanging wall stratigraphy. It is also possible that the GCSZ occur as blind thrusts below the Purcell Anticlinorium.

In the Pinnacle Peaks area, to the west of the Valhalla complex a subsurface structure imaged by seismic reflection data lies in the hanging wall of the Arrow Park thrust (Carr 1991, 1995; Parrish 1992). The Arrow Park thrust is interpreted to be ~ 77 Ma based on the 79 ± 2 Ma age of the cross-cutting Watshan batholith. The Arrow Park thrust also lies in the

hanging wall of the > 58 Ma Monashee décollement. The seismic reflection in the hanging wall of the Arrow Park thrust has been interpreted to be correlative with the GCSZ, which is consistent with a break-forward sequence where the age of displacement on thrust faults decreases in age with depth (Carr 1995).

The GCSZ and the WBF, both carry inverted Paleozoic strata in their hanging walls, however a lack of solid age constraints on the WBF does not permit a correlation of the two faults. If they are correlative, either the GCSZ are older than the estimate of 70-80 Ma (Parrish *et al.* 1988) or the WBF is younger than the maximum age limits of ~100 Ma. A correlation of the GCSZ to the WBF might also indicate that the WBF is younger than the Jurassic age proposed by Varsek and Cook (1991). More geochronological work needs to be done to refine the age of the Fry Creek batholith and thereby more closely constrain the age of the WBF. Alternatively, the GCSZ may be part of the duplex that merges with the Rocky Mountain basal detachment beneath the Purcell Anticlinorium.

4.3.4 Decompression

The wide range in An content (~ 38-52) of plagioclase in moats around garnet and the difference between pressures calculated from GASP and GRAIL equilibria in domains 2 and 3 are interpreted to record a period of decompression which occurred after the metamorphic peak. Plagioclase moats formed as a result of decompression reactions and are thinner along garnet rims parallel to the S_T fabric than they are in garnet pressure shadows. This suggests that they were formed during or shortly after the thermal peak and before S_2 and S_T fabric development had ceased. The thermal peak of metamorphism has been

interpreted to be ~ 75 Ma (Heaman and Parrish 1991). Thermochronology also records a period of increased cooling rates at ~ 65 Ma (Heaman and Parrish 1991; Parrish 1995). Since decompression textures are truncated by the S_2 fabric and S_2 is interpreted to be syn- to post metamorphic, then decompression is constrained to <75 Ma and occurred before exhumation along the Paleocene-Eocene Slocan Lake-Valkyr normal fault system. Decompression may be the result of rapid exhumation of the Valhalla complex at ~75 Ma in response to thickening due to movement along the underlying Monashee décollement, as suggested by Parrish (1995). This is consistent with variable An in plagioclase moats and consistently lower GRAIL than GASP pressure data.

4.3.5 Variation in thermobarometric data within domains 2 and 3

The wide range of thermobarometric data from domains 2 and 3 (~775 - 980 °C, 7.1 - 12.2 kbars) compared with the consistent data of domain 1 does not easily discriminate between either a thrusting or extensional model for displacement on the GCSZ. Domain 1 and domains 2 and 3 are separated by ~ 1 km of structural thickness (Fig. 3.10, Cross-section B, C). Thermobarometric data from domains 2 and 3 overlap the data of domain 1 (~ 750 °C, 6.5 kbars) but some temperatures and pressures are up to 135 °C and 3 kbars higher than domain 1. If there were no structural breaks in the section, the difference between the temperatures (~ 850 °C) and pressures (~ 9 kbars) recorded by domains 2 and 3 and the ~ 750 °C and 6.5 kbar conditions of domain 1 indicate temperature and pressure gradients of ~ 100 °C km⁻¹ and ~ 2 kbars km⁻¹. Normal thermal and pressure gradients in continental crust are 25-30 °C km⁻¹ and 0.3 kbars km⁻¹, respectively. Since the development of the main

fabric is interpreted to be synchronous with metamorphism in the Valhalla complex, these normal gradients are expected. Some high temperatures and pressures may be the result of disequilibrium caused by the introduction of fluids.

Decompression textures and thermobarometry implying decompression may be explained by either thrust or normal faulting of the GCSZ. The pressure-temperature trajectory for pelitic schists and amphibolite gneisses is not well constrained for the Valhalla complex because data is lacking for the prograde portion of the pressure-temperature path. Plagioclase inclusion compositions in pelitic schist and the presence of ilmenite coring rutile suggest that rocks of the Valhalla complex underwent a counter-clockwise pressure-temperature path. However, GASP pressures from plagioclase-garnet data may not be reliable because it is unknown if sillimanite was present at the time of plagioclase inclusion. A clockwise pressure-temperature path is implied for the Valhalla complex from garnet rims and proximal biotite grains, and garnet rims and biotite grains in direct contact in pelitic schists (Fig. 3.9). This implies an overall compressional tectonic setting for the Valhalla complex which suggests that the GCSZ had a thrust displacement and that movement of these shear zones was synchronous with the thermal peak of metamorphism. Clockwise pressure-temperature paths have initially $dP/dT > 1$ and are interpreted to be the result of compressional deformation. Counter-clockwise pressure-temperature paths have initial $dP/dT < 1$ and are the result of extensional tectonism or plutonism (England and Thompson 1977, Harley 1988). This does not imply that extension within individual thrust sheets could not have taken place.

4.4 Conclusions

1. The Valhalla assemblage, the uppermost paragneiss sheet in the Valhalla complex, is correlated to Neoproterozoic to Paleozoic strata of the North American miogeocline and Kootenay terrane, including the Horsethief Creek Group, Hamill Group, Badshot Formation, Lardeau Group and Milford Group (Table 2.3).
2. Based on this correlation, the Valhalla assemblage is interpreted to be the upside limb of an F_1 isoclinally folded recumbent nappe, where F_1 folding is younger than the Mississippian aged Milford correlatives which it folds, and older than the ~ 75 Ma peak of metamorphism and S_2 development (Heaman and Parrish 1991; chapter 3). Based on the data presented by Parrish (1995) which suggests that the deformation at the mid-crustal level is Cretaceous, the age of inversion and F_1 folding in Valhalla complex is interpreted to be Cretaceous.
3. Textures observed in thin section indicate that deformation was synchronous with the peak of metamorphism at all structural levels. Metamorphism began prior to D_2 in the uppermost sheet (sheet 1c - domain 1a and 1b) and also prior to shearing in the Gwillim Creek windows (sheet 1a - domain 3) and in the area of Vallican (domain 2). Deformation also outlasted metamorphism at all structural levels. The metamorphic peak is inferred to be ~ 75 Ma (Heaman and Parrish 1991) and therefore the GCSZ were active at this time. Evidence of shearing, increased strain relative to higher structural levels, and similar thermobarometric data of domains 2 and 3 (sheet 1a - Gwillim Creek window) suggests that

the Gwillim Creek shear zones resurface in the Passmore Dome (Fig. 1.2. Cross-section A).

4. Stratigraphic correlations indicate that the Valhalla assemblage may have been thinned by up to 80% when compared to less deformed equivalents in the Goat Ranges to the northwest of the Valhalla complex (Fig. 1.1). Thinning is attributed to D_2 east directed compressional deformation and simultaneous shearing on the Gwillim Creek shear zones.

5. Although timing constraints are broad for the West Bernard fault, the Gwillim Creek shear zones are best correlated with this fault, because they both carry Paleozoic inverted strata in their hanging walls. Further geochronological constraints on the West Bernard fault may prove that it has an Early Cretaceous age of displacement. Other researchers have suggested that the Gwillim Creek shear zones are correlative with the "K-reflectors" that form the roof of the duplex that merges with the Rocky Mountain basal detachment beneath the Purcell Anticlinorium (Cook and Varsek 1994; Cook and Van der Velden 1995).

6. Thermobarometric data from domain 1 is consistent between different bulk compositions and different equilibria. Near peak conditions of $\sim 850^\circ\text{C}$ are recorded by garnet-biotite pairs in amphibolite gneisses and armoured biotite inclusions in garnets of pelitic schists. The breakdown of scapolite to plagioclase and calcite in marbles, indicates that peak temperature conditions were in excess of 800°C . Post to near-peak temperatures recorded by garnet-biotite pairs in pelites and garnet-hornblende pairs are estimated at $\sim 750^\circ\text{C}$ in the structurally high area of domain 1. Both GASP and GRAIL equilibria record

pressures of ~ 6.5 kbars in domain 1. Also in domain 1, ~ 600 °C temperatures representative of the cooling path are recorded by garnet and biotite pairs in direct contact with each other

7. Domains 2 and 3 are ~ 1 km structurally below domain 1 and record a wide range in garnet-biotite temperatures and associated GASP pressures ($\sim 775 - 980$ °C, $7.1 - 12.2$ kbars) some of which overlap data from domain 1. Averaged temperatures (~ 850 °C) and pressures (~ 9 kbars) recorded by samples from domains 2 and 3, taken with 750 °C and 6.5 kbar conditions of domain 1, indicate pressure and thermal gradients of ~ 100 °C km⁻¹ and ~ 2 kbars km⁻¹. Some anomalously high temperatures (~ 950 °C) recorded by sheared samples in domains 2 and 3 are likely to have been the result of the introduction of fluids and the juxtaposition, by shearing, of minerals which were not in equilibrium. High temperatures in domains 2 and 3 may also be a result of increased Fe levels due to the downward progression of reaction (7). GRAIL pressures recorded by samples from domains 2 and 3 are in equilibrium with garnet-biotite temperatures and consistent with pressures in domain 1. GASP are interpreted to represent near-peak pressure conditions.

8. Textures and thermobarometry indicate that a period of decompression followed the thermal peak of metamorphism as exhibited by 1) the consistent GRAIL pressures that are ~ 3 kbars lower than GASP pressures, and the variation of plagioclase moat compositions in pelitic schists; and 2) the variation in plagioclase composition of moats around garnet in amphibolite gneisses, which produces a wide range in pressures. GASP and GRAIL pressures record two points on the decompression path because of different closure

temperatures. Plagioclase moats attributed to the GASP reaction (2) which occurred during decompression are truncated by fabrics associated with S_2 and are therefore interpreted to be pre-Eocene. Evidence of retrograde metamorphism is scarce and so rocks in domains 2 and 3 are interpreted to have cooled rapidly after the thermal peak of metamorphism. Therefore, decompression occurred shortly after 75 Ma. This may be attributed to exhumation as a result of movement along the underlying Monashee décollement.

9. The prograde pressure-temperature path followed by rocks of the Valhalla complex is not well constrained. Pressures calculated from plagioclase inclusions in garnets of pelitic schists and rutile rimming ilmenite suggests that rocks underwent a counterclockwise pressure path. Reliable temperature data associated with pressures calculated from plagioclase inclusions is lacking and more work is required to constrain the prograde pressure-temperature path direction for the Valhalla complex.

4.4.1 Geologic history

The Valhalla complex is a domal shaped culmination in which arched sheets of upper amphibolite-facies paragneiss, granitic rocks, and intervening thrust faults were exhumed due to extensional faulting. Paragneisses in the highest structural level (sheet 1c, domain 1) consist of a heterogeneous package of metasedimentary rocks and metaplutonic rocks of the Valhalla assemblage. Based on stratigraphic correlations the sedimentary protoliths of Valhalla assemblage were likely to have been deposited during the Neoproterozoic to Mississippian with intervening periods of mafic plutonism and/or vulcanism. The presence

of metamorphosed ultramafic rocks in the Valhalla assemblage may represent obducted oceanic crust; however, the primary relationships with surrounding rocks are unclear.

First phase isoclinal folding resulted in the inversion of the Valhalla assemblage during the Early Cretaceous and is constrained by the age Mulvey granodiorite (~110 Ma) which is interpreted to postdate F_1 folding. Timing constraints for first phase folding are between 75 Ma (peak of metamorphism - S_2 development and ~290 Ma (inferred age of Milford correlatives). Other nappes in the southern Omineca belt have been inverted by primarily Jurassic deformation (Raeside and Simony 1983; Brown and Lane 1988). A Cretaceous age of inversion in the Valhalla complex is consistent with data presented by Parrish (1995), which suggests a Cretaceous age of deformation and metamorphism for mid-crustal levels of the Valhalla complex. Structural duplication of the Mulvey granodiorite and paragneisses along the GCSZ was synchronous with metamorphism and occurred during the middle of the Late Cretaceous (75-80 Ma). The GCSZ may be related to the WBF fault based on similar inverted Paleozoic hanging wall stratigraphy, however age constraints on the WBF must be refined. It has been proposed that the GCSZ are correlative to structures imaged by the "K-reflectors" beneath the Purcell Anticlinorium (Varsek and Cook 1994; Cook and Van der Velden 1995).

Textural observations indicate that metamorphism was simultaneous with deformation in all structural domains. Thermobarometric data in domains 2 and 3 record a wide range in temperatures (775 - 980 °C) and pressures (7.1 -12.2 kbars), some of which overlap data from domain 1 (~ 775 °C, 7 kbars). This indicates that the different structural levels share the same thermal history prior to and during movement along the GCSZ. D_3 in

the structurally highest sheet (1c - domain 1) was synchronous with movement on the GCSZ and outlasted metamorphism. F_3 and F_4 folds in the Valhalla assemblage fold all metamorphic minerals and are rare at deeper structural levels near the GCSZ. This suggests that either movement on the shear zones outlasted this deformation, or that all folds and deformation are related to shortening associated with the GCSZ as one protracted event.

Exhumation as a result of movement on the underlying Monashee décollement may have occurred at ~ 70-60 Ma as recorded by decompression textures (this study), thermobarometry (this study) and thermochronology (Heaman and Parrish 1991). The Airy quartz monzonite intruded at ~ 63 Ma and places a minimum age on S_2 development (Carr *et al.* 1987). This was followed by the intrusion of the Ladybird granite (59-55 Ma). Eocene extension and exhumation of the complex began with movement on the VSZ which occurred during and after the intrusion of the Ladybird granite. Movement on the Slocan Lake fault began at ~ 58 Ma at which time it merged with the Valkyr shear zone and continued to denude the complex until 45 Ma (Carr *et al.* 1987).

4.5 Suggested further work

Due to the limited outcrop in the Gwillim Creek windows and the lowest portion of the Slocan Valley, the data is sparse in these areas. Now that it has been established that transposition fabrics in the southern portion of the complex at low structural levels are not related to Eocene faulting, detailed structural studies documenting strain in the Passmore Dome (Fig. 1.2) should be pursued to determine if the GCSZ are present in this area. U-Pb geochronology of folded pegmatites and granitic dykes would constrain the age of folding.

Further detrital U-Pb geochronological studies of paragneisses might help to deduce the provenance of these rocks and comparison with other studies may further constrain correlations. Palinspastic cross-sections across the southern Omineca belt based on stratigraphic correlations made in this study, would indicate the magnitude of displacement on the GCSZ.

The idea that net-transfer reactions involving sillimanite increased Fe levels at garnet rims may be tested by analysing samples of pelitic schist lacking sillimanite. Further study of the metamorphic petrology, kinematics and structure in the Gwillim Creek windows may help to refine a model for the evolution of the Valhalla complex and the role of the GCSZ. Only two samples were studied from sheet 1a and both are in close proximity to the lower GCSZ. The wide range in temperatures may be due to the influx of fluids or juxtaposition of minerals in chemical disequilibrium causing local disequilibrium. Samples from areas further away from the GCSZ may yield better data. Amphibolite gneisses appear to be less affected by retrograde reactions and shearing, and therefore samples from the Gwillim Creek windows might place better constraints on the metamorphic conditions. No thermobarometric data was collected from sheet 1b, and although the pelitic schists are highly regressed and sheared, data from this area might also help to constrain conditions at the different structural levels of the complex. Peak temperatures are estimated to be 75-80 Ma in the Passmore-Vallican area (Parrish 1991, 1995). Thermochronologic studies and cooling data in domain (west side of sheet 1c) and the Gwillim Creek windows will demonstrate if the thermal peak occurred at the same time throughout the complex.

Figure 4.1 Pressure-temperature path followed by pelitic schist in Valhalla complex.

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Appendix A: Electron microprobe standards

Garnet

Fe, Si, Al - Ingamells garnet R1598
 Ca, Mg - Kakanui hornblende, United States National Museum 143965
 Cr - chromite, United States National Museum 117075
 Mn - synthetic tephroite (Mn_2SiO_4)

Biotite

Si, Al, Ti, Mg, Na - Kakanui hornblende, United States National Museum 143965
 K - synthetic phlogopite
 Fe - Ingamells garnet R1598
 Cr - chromite, United States National Museum 117075
 Mn - synthetic tephroite (Mn_2SiO_4)
 Cl - Tugtupite

Plagioclase

Si, Al, Ca, Na - natural, pure albite and synthetic anorthite
 K - microcline, United States National Museum 143966
 Fe - Kakanui hornblende, United States National Museum 143965

Hornblende

Si, Al, Ti, Fe, Mg, Ca, K, Na - Kakanui hornblende, United States National Museum 143965
 Cr - chromite, United States National Museum 117075
 Cl - Tugtupite

Ilmenite

Fe, Mn, Ti - ilmenite, United States National Museum 96189
 Mg, Cr - chromite, United States National Museum 117075

Pyroxene

Fe, Mg, Ca, Si, Al - Kakanui augite, United States National Museum 143965

Olivine

Fe, Mg, Si - San Carlos olivine, United States National Museum 111312
 Ni - NiO

Scapolite

Si, Al, Ca, Na - scapolite, United States National Museum R6600-1
 Cl - Tugtupite
 K - Kakanui hornblende, United States National Museum 143965

A number of other natural minerals were analysed as internal standards during each analytical session. These are listed in Jarosewich and others (1979):

e.g.

Garnet, United States National Museum 87375

Labradorite, United States National Museum 115900

Appendix B: Modal mineral abundances of pelitic schists

See map 1 in pocket for sample localities.

Bt - biotite
 Qtz - quartz
 Pl - plagioclase
 Sill - sillimanite
 Gt - garnet
 K-felds - potassium feldspar
 Rut - rutile
 Ilm - ilmenite
 Musc - muscovite
 Chl - chlorite

Sample	Bt	Qtz	Pl	Sill	Gt	Kfelds	Rut	Ilm	Musc	Chl	Textures	Domain	Probe
PCA-93-84	25	35	6	10	10	10	1	2		1	-pl. moat	2	*
PCA-109-84	40	25	5	15	10	5						1a	
PCA-200-85	30	20	15	15	10	5	1	1	1	2	-pl. moat -rut. cor ilm	3	*
PCA-204B-85	25	30	15	5	10	10	1	2	1	1		1a	
PS-4-93	30	20	30	5	10	5						1a	*
PS-9-93	30	25	15	15	10	5						1a	*
PS-10-93	30	30	10	20	5	5						1a	
PS-21A-93	30	35	25	2	8							1a	
PS-22-93	35	25	30	1	3	5			1			1a	
PS-24-93	20	50	20	5	5							1a	
PS-27B-93	30	25	10	15	15	3		2				2	
PS-27C-93	25	35	5	15	10	5		2		3		2	
PS-28A-93	35	20	5	15	15	5		3	2		pl. moat	2	*
PS-28B-93	35	15	5	20	15	5	1	2	2		pl. moat	2	*
PS-29B-93	35	35	10	5	8	5	1			1		2	
PS-29C-93	20	35	15	10		20						2	
PS-31-93	35	33	15		10				2	5			
PS-32-93	20	40	20	10		10							
PS-6A-94	35	45	10		5			2		3		1a	
PS-8B-94	30	35	20					5		10		1a	
PS-22-94	37	30	20		10			3				1a	
PS-32-94	35	40	20						5			1a	
PS-47-94	35	30	30		5							1b	
PS-48A-94	15	55	20	5	5							1b	

PS-50A-94	15	50	15	5	5	9			1		lb	
PS-56A-94	5	70	5	5	10	5					lb	
PS-57A-94	20	55	10	5	5		2	3			lb	
PS-58-94	25	50		10	10	5					lb	
PS-61-93	30	34	10	15	10					1	lb	*
PS-62B-94	25	35	10	10	10	10		1			lb	
PS-64-94	40	15	5	20	20						lb	
PS-76-94	35	30	10		15		2	3		5		
PS-77-94	15	40	35		10							
PS-86D-94	30	25	10	25	8			2				
PS-91-94	35	15	30		15			5				
PS-99-94	30	35	25		5					5		
PS-103-94	30	40	25	2	2				1		la	
PS-108-94	15	45	10	15	5	10			<1		la	
PS-110-94	20	55	20	5							la	
PS-111B-94	40	25	25		10						la	
PS-111C-94	35	30	20		15						la	
PS-134-94	40	25	25		9		1				la	
PS-136c-94	45	10	5	30	10						la	*
PS-143-94	30	40	20		5	5					la	
PS-144-94	30	20	5	25	10	9			1		la	
PS-169-94	30	30	15	10	10			5			la	*
PS-172-94	35	30	20	2	5	8					la	
PS-179-94	40	25		30					5		la	
PS-237-94	30	35	25	1	8					1	la	
PS-267B-94	30	30	15	20		4	1				la	
PS-277-94	35	30	10	15	5	5					pl. moat	*
PS-280-94	35	35	5	20	5						la	
PS-302-94	30	38	2	20		10					la	
PS-319-94	35	30	25		10						la	
PS-332-94	30	25	10	15	10	5		2	3		rut. cor. ilm	lb *
PS-344-94	30	25	15	15	15			<1			la	*
PS-348-94	25	32	5	15	10	10		3			3	*

Appendix C: Mineral analyses for pelitic schists

Appendix C

Abbreviations used in first row of garnet analyses are as follows

R1 - garnet rims in contact with biotite.

R2 - garnet rims in contact with non-ferromagnesian minerals

C - garnet cores

I - points in garnet core adjacent to biotite inclusions

Abbreviations in first row of biotite and plagioclase analyses are as follows:

incl. - occurs as inclusion in garnet

cont. - is in contact with garnet rim

Letters in second row of all analyses refer to point or average of points used in thermobarometric calculations which are referred to in Table 3.2.

Numbers in third row of all analyses refer to number of points used to obtain average value used in thermobarometric calculations.

Calculations to determine Fe^{+3} content in ilmenite were carried out because it commonly makes up a large part of this mineral. Fe^{+3} estimates are less reliable for garnet and do not make a substantial difference in thermobarometric calculations. Fe^{+3} calculations were not possible for biotite because of the variable H_2O content.

PS-4-93 garnet R1									
	a	b	c	d	e	1	2	3	4
Point	1.23	1.12	1.45,6	1.15,16	1.17-2	1.2-10	2.1	2.2	2.3
SiO2	37.12	37.93	38.53	37.71	37.07	38.51	37.77	37.79	38.16
Al2O3	21.53	21.05	21.67	21.08	21.09	21.58	20.84	21.03	21.84
TiO2	0.00	0.00	0.00	0.00	0.02	-	-	-	-
Cr2O3	0.00	0.00	0.00	0.00	0.02	-	-	-	-
FeO	32.34	34.55	33.46	33.45	33.15	33.04	33.46	32.47	32.48
MnO	1.02	1.86	1.08	1.47	2.08	0.92	0.87	0.56	0.79
MgO	5.50	3.48	4.75	4.10	4.20	5.16	4.74	5.09	5.93
CaO	2.16	2.00	2.01	1.95	2.16	2.02	1.97	2.01	1.97
Total	99.67	100.87	101.49	99.76	99.77	101.23	99.65	98.95	101.17
Si	5.910	6.034	6.024	6.029	5.950	6.024	6.031	6.041	5.958
Al	0.090	0.000	0.000	0.000	0.050	0.002	0.000	0.000	0.042
	6.000	6.034	6.024	6.029	6.000	6.025	6.031	6.041	6.000
Al	3.951	3.946	3.994	3.973	3.940	3.976	3.922	3.963	3.978
Ti	0.000	0.000	0.000	0.000	0.002	-	-	-	-
Cr	0.000	0.000	0.000	0.000	0.003	-	-	-	-
	3.951	3.946	3.994	3.973	3.944	3.976	3.922	3.963	3.978
Fe	4.306	4.596	4.375	4.473	4.450	4.322	4.469	4.341	4.241
Mn	0.137	0.251	0.144	0.199	0.283	0.123	0.118	0.076	0.104
Mg	1.306	0.826	1.106	0.978	1.004	1.202	1.129	1.214	1.380
Ca	0.369	0.341	0.336	0.335	0.371	0.338	0.337	0.344	0.329
	6.118	6.014	5.962	5.984	6.108	5.986	6.053	5.975	6.054
XCa	0.060	0.057	0.056	0.056	0.060	0.057	0.056	0.058	0.054
XMg	0.214	0.137	0.186	0.163	0.164	0.201	0.187	0.203	0.228
XFe	0.704	0.764	0.734	0.748	0.729	0.722	0.738	0.727	0.701
XMn	0.022	0.042	0.024	0.033	0.046	0.020	0.019	0.013	0.017
Fe/	0.767	0.848	0.798	0.821	0.816	0.782	0.798	0.781	0.754
Fe+Mg									

PS-28b-93 biotite

Point	inclusion							in contact							in contact																				
	a							b							c																				
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43		
SiO ₂	35.31	34.87	34.92	35.85	35.91	35.69	35.88	35.49	35.70	35.11	34.12	34.36	34.72	34.98	34.94	34.85	35.28	35.70	35.76	35.52	35.57	35.50	34.76	34.76	34.76	34.76	34.76	34.76	34.76	34.76	34.76	34.76	34.76		
Al ₂ O ₃	20.13	19.87	19.63	20.09	20.45	20.05	20.51	20.10	21.15	21.19	20.21	20.62	20.57	20.32	20.29	20.62	21.17	21.80	20.94	20.59	21.13	22.56	19.88	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.13		
TiO ₂	3.05	3.07	3.18	3.30	2.84	3.30	2.95	3.10	2.22	2.13	2.82	2.70	2.95	2.97	3.09	2.70	2.93	2.79	3.12	3.06	2.98	3.97	3.50	3.59	3.59	3.59	3.59	3.59	3.59	3.59	3.59	3.59	3.59		
Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
FeO	18.77	20.39	19.55	19.46	18.44	19.77	18.47	19.26	19.38	18.98	19.74	19.66	20.56	19.85	19.83	19.71	19.32	19.19	19.43	19.69	19.41	17.56	19.27	19.63	19.63	19.63	19.63	19.63	19.63	19.63	19.63	19.63	19.63	19.63	
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
MgO	9.75	9.02	8.97	9.17	10.03	9.07	10.01	9.43	8.99	9.05	8.19	8.20	7.56	8.28	8.19	8.35	8.14	8.39	8.24	8.21	8.25	6.97	8.23	8.19	8.19	8.19	8.19	8.19	8.19	8.19	8.19	8.19	8.19	8.19	
K ₂ O	9.41	9.11	9.06	9.42	9.25	9.47	9.27	9.28	9.67	9.38	9.23	9.13	9.65	9.12	9.36	9.36	9.44	9.54	9.54	9.30	9.46	6.85	9.30	9.31	9.31	9.31	9.31	9.31	9.31	9.31	9.31	9.31	9.31	9.31	
CaO	0.08	0.09	0.01	0.00	0.00	0.04	0.07	0.04	0.00	0.06	0.00	0.06	0.00	0.06	0.00	0.06	0.00	0.09	0.04	0.14	0.07	0.00	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	
Na ₂ O	0.08	0.00	0.35	0.01	0.13	0.00	0.21	0.11	0.28	0.46	0.40	0.54	0.08	0.26	0.56	0.37	0.16	0.00	0.01	0.23	0.10	0.00	0.38	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	
Cl	0.00	0.05	0.00	0.02	0.00	0.00	0.08	0.02	0.01	0.02	0.00	0.06	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.06	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
Total	96.58	96.47	95.67	97.32	97.05	97.39	97.45	96.85	97.40	96.38	94.71	95.33	96.09	95.84	96.26	96.00	96.45	97.51	97.08	96.74	96.95	93.41	95.42	96.20	96.20	96.20	96.20	96.20	96.20	96.20	96.20	96.20	96.20	96.20	
Total	96.58	96.46	95.67	97.32	97.05	97.39	97.43	96.84	97.40	96.38	94.71	95.32	96.09	95.84	96.26	96.00	96.45	97.51	97.08	96.74	96.95	93.41	95.41	96.20	96.20	96.20	96.20	96.20	96.20	96.20	96.20	96.20	96.20	96.20	
Si	5.278	5.258	5.292	5.324	5.315	5.308	5.297	5.296	5.300	5.265	5.242	5.238	5.270	5.292	5.275	5.269	5.284	5.275	5.319	5.313	5.298	5.338	5.286	5.272	5.272	5.272	5.272	5.272	5.272	5.272	5.272	5.272	5.272	5.272	
Al	2.722	2.742	2.708	2.676	2.685	2.692	2.703	2.704	2.700	2.735	2.758	2.762	2.730	2.708	2.725	2.731	2.716	2.725	2.681	2.687	2.702	2.662	2.714	2.728	2.728	2.728	2.728	2.728	2.728	2.728	2.728	2.728	2.728	2.728	
Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000		
Al	0.824	0.790	0.798	0.841	0.882	0.823	0.865	0.832	1.001	1.009	0.901	0.943	0.951	0.915	0.886	0.944	1.022	1.072	0.990	0.943	1.007	1.337	0.849	0.851	0.851	0.851	0.851	0.851	0.851	0.851	0.851	0.851	0.851	0.851	
Ti	0.343	0.349	0.362	0.369	0.316	0.369	0.328	0.348	0.248	0.240	0.326	0.309	0.336	0.337	0.351	0.307	0.331	0.310	0.349	0.344	0.334	0.449	0.400	0.407	0.407	0.407	0.407	0.407	0.407	0.407	0.407	0.407	0.407	0.407	
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Fe	2.346	2.572	2.478	2.416	2.283	2.458	2.280	2.405	2.407	2.380	2.536	2.507	2.610	2.511	2.504	2.494	2.420	2.372	2.417	2.463	2.418	2.208	2.451	2.476	2.476	2.476	2.476	2.476	2.476	2.476	2.476	2.476	2.476	2.476	2.476
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Mg	2.172	2.027	2.027	2.030	2.213	2.012	2.203	2.098	1.989	2.022	1.876	1.864	1.711	1.867	1.843	1.882	1.817	1.848	1.826	1.832	1.831	1.562	1.866	1.843	1.843	1.843	1.843	1.843	1.843	1.843	1.843	1.843	1.843	1.843	
Mg	5.685	5.738	5.685	5.655	5.694	5.662	5.676	5.682	5.645	5.651	5.639	5.623	5.608	5.630	5.584	5.626	5.590	5.602	5.582	5.582	5.589	5.556	5.566	5.577	5.577	5.577	5.577	5.577	5.577	5.577	5.577	5.577	5.577	5.577	
K	1.795	1.752	1.752	1.784	1.746	1.797	1.747	1.768	1.832	1.794	1.808	1.776	1.868	1.760	1.803	1.806	1.804	1.798	1.810	1.775	1.797	1.314	1.804	1.791	1.791	1.791	1.791	1.791	1.791	1.791	1.791	1.791	1.791	1.791	
Ca	0.013	0.014	0.002	0.000	0.000	0.006	0.011	0.007	0.000	0.009	0.000	0.009	0.000	0.010	0.000	0.004	0.002	0.015	0.007	0.023	0.012	0.000	0.007	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	
Na	0.023	0.000	0.103	0.002	0.037	0.000	0.060	0.032	0.080	0.133	0.119	0.160	0.022	0.077	0.165	0.108	0.045	0.000	0.004	0.067	0.029	0.000	0.113	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103
Na	1.831	1.766	1.857	1.786	1.783	1.803	1.818	1.806	1.912	1.936	1.927	1.945	1.890	1.847	1.968	1.918	1.851	1.813	1.821	1.865	1.838	1.314	1.924	1.900	1.900	1.900	1.900	1.900	1.900	1.900	1.900	1.900	1.900	1.900	
Cl	0.000	0.012	0.000	0.006	0.000	0.000	0.020	0.005	0.004	0.006	0.001	0.016	0.000	0.001	0.000	0.004	0.000	0.003	0.000	0.000	0.001	0.000	0.016	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	
XMg	0.382	0.353	0.358	0.359	0.389	0.355	0.388	0.369	0.352	0.358	0.333	0.331	0.305	0.332	0.330	0.334	0.325	0.330	0.327	0.328	0.328	0.281	0.335	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330
XFe	0.413	0.448	0.437	0.427	0.401	0.434	0.402	0.423	0.426	0.421	0.450	0.446	0.465	0.446	0.448	0.443	0.433	0.423	0.433	0.441	0.433	0.397	0.440	0.444	0.444	0.444	0.444	0.444	0.444	0.444	0.444	0.444	0.444	0.444	0.444
XTi	0.060	0.061	0.064	0.065	0.055	0.065	0.058	0.061	0.044	0.042	0.058	0.055	0.060	0.060	0.063	0.055	0.059	0.055	0.063	0.062	0.060	0.081	0.072	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073
XAl	0.145	0.138	0.141	0.149	0.155	0.145	0.152	0.146	0.177	0.179	0.160	0.168	0.170	0.163	0.159	0.168	0.183	0.191	0.177	0.169	0.180	0.241	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153
Fe/Mg	0.519	0.559	0.550	0.543	0.508	0.550	0.509	0.534	0.548	0.541	0.575	0.574	0.604	0.574	0.576	0.570	0.571	0.562	0.570	0.573	0.569	0.586	0.568	0.573	0.573	0.573	0.573	0.573	0.573	0.573	0.573	0.573	0.573	0.573	0.573
Fe+Mg																																			

PS-4-93 biotite

	cont				matrix				matrix				matrix				matrix			
	d				f				g				h				i			
	3	4	3	e	3	4	1-4	5	1	5	2	5	3	5	1	3	6	2	6	3
	3.1	4	3	7	9	4	1	4	5	1	3	5	1	3	6	1	3	6	1	3
Point	3.5	3.6	3.7	3.8	3.9	3.1	4	3	7	9	4	1	4	5	1	3	6	2	6	3
SiO2	36.11	35.18	35.66	35.01	35.04	34.80	35.24	34.39	35.00	35.09	35.14	35.06	35.18	35.12	34.69	34.73	35.21	34.88	35.43	35.18
Al2O3	19.57	19.29	20.85	19.81	19.79	19.77	20.15	18.45	18.41	18.98	18.84	18.82	18.84	18.82	19.36	19.12	19.69	19.39	18.99	19.11
TiO2	3.10	3.44	2.28	2.44	2.18	2.48	2.30	3.40	3.49	3.71	3.50	3.53	3.23	3.40	3.33	3.02	3.02	3.04	2.92	2.86
Cr2O3	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.04	0.00	0.00	0.01	0.13	0.09	0.13	0.12	0.10	0.14	0.12	0.11
FeO	16.61	17.26	17.46	18.59	18.30	18.58	18.12	19.22	19.11	19.18	19.17	19.17	19.44	19.28	19.24	19.32	19.68	19.58	19.93	19.71
MnO	0.00	0.00	0.00	0.02	0.04	0.01	0.02	0.00	0.01	0.05	0.02	0.02	0.14	0.12	0.12	0.12	0.14	0.13	0.14	0.16
MgO	10.07	9.35	8.18	8.96	9.61	9.21	8.92	8.85	9.24	9.14	9.00	9.06	9.23	8.95	9.34	9.17	9.07	9.17	9.37	9.20
K2O	8.98	9.06	8.85	9.32	9.15	9.29	9.11	9.21	9.35	9.51	9.32	9.35	0.03	0.02	0.00	0.02	0.01	0.00	0.00	0.06
CaO	0.09	0.19	0.19	0.16	0.30	0.18	0.22	0.19	0.11	0.22	0.17	0.17	0.53	0.49	0.38	0.46	0.20	0.28	0.24	0.30
Na2O	0.11	0.40	0.06	0.04	0.23	0.28	0.11	0.27	0.07	0.26	0.01	0.15	0.44	0.44	0.18	0.36	0.37	0.28	0.24	0.30
Cl	0.05	0.02	0.06	0.10	0.12	0.08	0.09	0.07	0.17	0.12	0.05	0.10	0.10	0.16	0.17	0.14	0.11	0.17	0.15	0.16
Total	94.69	94.19	93.59	94.45	94.76	94.66	94.27	94.06	95.87	96.87	95.08	95.47	97.25	96.72	96.88	96.94	95.82	95.62	97.26	96.23
Total	94.68	94.19	93.58	94.43	94.73	94.64	94.25	94.04	95.83	96.84	95.07	95.45	97.23	96.68	96.84	96.91	95.80	95.58	97.23	96.20
Si	5.429	5.361	5.436	5.356	5.339	5.318	5.377	5.323	5.337	5.350	5.340	5.338	5.257	5.273	5.272	5.267	5.274	5.294	5.274	5.281
Al	2.571	2.639	2.564	2.644	2.661	2.682	2.623	2.677	2.663	2.650	2.660	2.663	2.743	2.727	2.728	2.733	2.726	2.706	2.726	2.719
	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	0.897	0.825	1.183	0.929	0.894	0.879	1.001	0.690	0.728	0.703	0.728	0.712	0.756	0.773	0.758	0.762	0.744	0.729	0.750	0.741
Ti	0.351	0.395	0.261	0.281	0.250	0.285	0.264	0.396	0.397	0.419	0.401	0.403	0.364	0.381	0.383	0.376	0.353	0.346	0.340	0.346
Cr	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.001	0.005	0.000	0.000	0.002	0.016	0.011	0.015	0.014	0.012	0.017	0.014	0.014
Fe	2.089	2.199	2.227	2.379	2.332	2.375	2.313	2.488	2.418	2.404	2.446	2.439	2.432	2.426	2.412	2.423	2.502	2.496	2.497	2.498
Mn	0.000	0.000	0.000	0.003	0.005	0.001	0.003	0.000	0.002	0.007	0.003	0.003	0.018	0.015	0.015	0.016	0.018	0.017	0.018	0.018
Mg	2.258	2.123	1.858	2.043	2.182	2.098	2.028	2.042	2.085	2.042	2.047	2.054	2.058	2.007	2.088	2.051	2.055	2.083	2.091	2.076
	5.595	5.542	5.529	5.635	5.662	5.639	5.609	5.617	5.635	5.575	5.625	5.613	5.644	5.613	5.671	5.642	5.684	5.688	5.710	5.694
K	1.723	1.761	1.721	1.819	1.778	1.811	1.773	1.818	1.806	1.817	1.814	1.814	1.819	1.821	1.793	1.811	1.784	1.804	1.794	1.786
Ca	0.014	0.031	0.032	0.027	0.049	0.029	0.036	0.032	0.019	0.036	0.029	0.029	0.005	0.003	0.000	0.002	0.002	0.000	0.000	0.001
Na	0.033	0.119	0.016	0.013	0.067	0.084	0.054	0.080	0.020	0.074	0.004	0.045	0.128	0.129	0.054	0.104	0.110	0.084	0.070	0.088
	1.770	1.911	1.769	1.859	1.894	1.924	1.841	1.930	1.845	1.927	1.847	1.887	1.952	1.953	1.847	1.917	1.896	1.888	1.864	1.863
Cl	0.013	0.006	0.016	0.026	0.030	0.021	0.024	0.019	0.043	0.030	0.013	0.026	0.025	0.041	0.042	0.036	0.028	0.045	0.037	0.042
XMg	0.404	0.383	0.336	0.363	0.385	0.372	0.361	0.364	0.370	0.366	0.364	0.366	0.365	0.358	0.368	0.364	0.362	0.366	0.366	0.365
XFe	0.373	0.397	0.403	0.422	0.412	0.411	0.412	0.443	0.429	0.431	0.435	0.435	0.431	0.432	0.425	0.429	0.440	0.439	0.437	0.439
XTi	0.063	0.071	0.047	0.050	0.044	0.050	0.047	0.071	0.070	0.075	0.071	0.072	0.064	0.068	0.068	0.067	0.062	0.061	0.060	0.061
XAl	0.160	0.149	0.214	0.165	0.158	0.156	0.179	0.123	0.129	0.126	0.129	0.127	0.134	0.138	0.134	0.135	0.131	0.128	0.131	0.130
Fe*	0.481	0.509	0.545	0.538	0.517	0.531	0.533	0.549	0.537	0.541	0.544	0.543	0.542	0.547	0.536	0.542	0.549	0.545	0.544	0.546
Fe+Mg																				

PS-4-93 biotite

PS-4-93 broilite	matrix												c nt cont											
	a												b c											
	d												3 4											
Point	11	12	13	14	15	16	17	18	19	11-9	21	22	23	24	25	26	27	28	21-3	24-7	31	32	33	34
SiO2	3591	3558	3584	3558	3604	3557	3495	3541	3512	3556	3554	3590	3595	3526	3517	3491	3516	3543	3580	3513	3445	3480	3515	3478
Al2O3	1919	1888	1916	1933	1930	1858	1880	1935	1915	1913	1959	1958	1972	1971	1987	2016	2041	1948	1963	2004	1993	1958	1965	1990
TiO2	310	301	299	297	290	282	281	275	279	290	153	148	128	182	148	148	149	143	143	157	235	252	253	251
Cr2O	000	000	000	000	000	000	004	009	001	002	000	000	000	000	000	000	000	000	000	000	000	000	000	
FeO	1927	1940	1955	1974	1951	1931	1914	1947	1902	1938	1762	1765	1706	1860	1806	1871	1853	1647	1744	1848	1853	1831	1886	1861
MnO	000	000	000	000	000	000	008	004	005	002	000	003	000	000	000	000	000	000	001	000	000	000	004	
MgO	958	930	939	936	956	956	950	902	916	938	1039	1070	1136	957	969	960	979	1184	1082	966	904	915	925	938
K2O	926	944	936	962	939	944	934	937	928	939	929	930	925	932	942	932	931	894	928	934	916	918	948	933
CaO	030	012	013	011	010	012	012	020	024	016	011	015	018	019	017	013	015	032	015	016	022	014	014	020
Na2O	037	055	018	014	021	026	021	044	045	031	039	060	038	027	020	014	040	040	046	025	043	033	016	020
Cl	005	010	002	008	007	004	009	016	006	007	015	013	012	012	016	011	015	008	013	014	007	012	004	009
Total	9703	9638	9662	9693	9708	9610	9508	9630	9533	9632	9461	9552	9530	9485	9422	9456	9539	9439	9514	9476	9418	9417	9526	9504
Total-	9702	9636	9662	9691	9706	9609	9506	9626	9532	9630	9458	9549	9527	9483	9418	9454	9536	9437	9511	9473	9416	9414	9525	9502
Si	5360	5367	5376	5337	5378	5370	5342	5350	5347	5359	5404	5407	5403	5374	5386	5339	5327	5365	5405	5357	5294	5341	5342	5296
Al	2640	2633	2624	2663	2622	2630	2658	2650	2653	2641	2596	2593	2597	2626	2614	2661	2673	2635	2595	2644	2705	2659	2658	2704
	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000
Al	0737	0724	0763	0755	0772	0747	0729	0794	0783	0756	0916	0883	0897	0915	0973	0972	0971	0841	0899	0958	0904	0883	0862	0868
Ti	0348	0341	0337	0336	0325	0320	0324	0312	0319	0329	0175	0167	0145	0209	0171	0170	0170	0162	0162	0180	0272	0291	0289	0287
Cr	0000	0000	0000	0000	0000	0000	0004	0011	0001	0002	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0004	0000	0000	
Fe	2405	2448	2453	2477	2435	2438	2447	2459	2422	2443	2241	2223	2144	2371	2313	2393	2348	2085	2203	2356	2382	2350	2398	2371
Mn	0000	0000	0000	0000	0000	0000	0011	0005	0007	0003	0000	0004	0000	0000	0000	0000	0000	0000	0001	0000	0000	0000	0005	
Mg	2131	2092	2099	2092	2125	2151	2165	2031	2078	2107	2356	2403	2546	2175	2213	2189	2210	2672	2435	2197	2072	2094	2095	2129
	5621	5605	5652	5660	5658	5656	5680	5612	5610	5639	5688	5680	5732	5670	5670	5724	5699	5760	5700	5691	5630	5622	5644	5660
K	1764	1817	1792	1841	1788	1818	1821	1806	1801	1805	1803	1787	1774	1812	1841	1818	1799	1727	1788	1818	1797	1798	1837	1813
Ca	0047	0019	0021	0018	0016	0020	0020	0032	0039	0026	0019	0024	0029	0031	0029	0021	0025	0051	0024	0027	0036	0023	0023	0033
Na	0106	0161	0051	0041	0062	0076	0061	0128	0133	0091	0116	0176	0112	0081	0058	0041	0117	0117	0135	0074	0129	0099	0047	0059
	1917	1997	1864	1900	1866	1914	1902	1966	1973	1922	1938	1987	1915	1924	1928	1880	1941	1895	1947	1918	1962	1920	1907	1905
Cl	0012	0025	0006	0020	0017	0011	0023	0041	0016	0019	0039	0034	0032	0032	0041	0029	0038	0022	0035	0035	0018	0031	0010	0024
XMg	0379	0373	0371	0370	0376	0380	0381	0362	0370	0374	0414	0423	0444	0384	0390	0382	0388	0464	0427	0386	0368	0372	0371	0276
XFe	0428	0437	0434	0438	0430	0431	0431	0438	0432	0433	0394	0391	0374	0418	0408	0418	0412	0362	0386	0414	0423	0418	0425	0419
XTi	0062	0061	0060	0059	0057	0057	0057	0056	0057	0058	0031	0029	0025	0037	0030	0030	0030	0028	0028	0032	0048	0052	0051	0051
XAl	0131	0129	0135	0133	0136	0132	0128	0141	0140	0134	0161	0155	0156	0161	0172	0170	0170	0146	0158	0168	0161	0157	0153	0153
Fe/Mg	0530	0539	0539	0542	0534	0531	0531	0548	0538	0537	0487	0481	0457	0522	0511	0522	0515	0438	0475	0518	0535	0529	0534	0527

PS-9-93 bottle

PS-9-93 bottle																			matrix
Point	in contact						in contact				matrix								
	a						b				c								
	B9-1.1	B9-1.2	B9-1.3	B9-1.4	B9-1.5	B9-1.6	B9-2.1	B9-2.2	B9-2.3	B9-2.4	B9-3.1	B9-3.2	B9-3.3	B9-3.4	B9-3.5	B9-3.6			
SiO2	37.87	34.88	35.22	35.31	35.43	35.19	35.15	35.28	35.00	34.64	35.20	35.03	35.66	35.65	35.57	35.91	35.73	35.70	
Al2O3	19.31	19.01	19.14	19.43	19.84	19.24	19.26	19.27	18.89	18.48	18.89	18.88	18.84	19.37	19.03	19.22	19.31	19.15	
TiO2	3.17	3.07	2.79	2.36	2.20	2.71	2.72	2.74	2.79	2.78	2.80	2.78	3.25	3.15	3.02	3.30	3.33	3.21	
Cr2O3	0.02	0.03	0.04	0.02	0.00	0.10	0.04	0.01	0.00	0.04	0.07	0.03	0.00	0.00	0.03	0.04	0.00	0.01	
FeO	18.85	18.54	18.82	18.42	18.23	18.78	18.61	18.56	18.48	18.12	18.19	18.34	18.84	19.03	18.61	18.93	18.97	18.87	
MnO	0.00	0.04	0.03	0.00	0.00	0.01	0.01	0.00	0.03	0.06	0.05	0.04	0.00	0.05	0.01	0.12	0.00	0.04	
MgO	9.43	9.79	9.51	10.21	10.21	9.85	9.83	10.21	9.99	9.78	10.11	10.02	9.53	9.81	9.65	9.61	9.40	9.60	
K2O	0.18	0.08	0.01	0.05	0.00	0.00	0.05	0.05	0.00	0.07	0.11	0.06	0.10	0.08	0.08	0.04	0.03	0.07	
CaO	9.29	9.38	9.52	9.41	9.23	9.48	9.39	9.55	9.38	9.37	9.38	9.42	9.38	9.56	9.58	9.46	9.47	9.49	
Na2O	0.00	0.05	0.17	0.02	0.22	0.22	0.11	0.14	0.16	0.27	0.33	0.23	0.00	0.00	0.00	0.00	0.04	0.01	
Cl	0.09	0.09	0.08	0.07	0.08	0.12	0.09	0.09	0.08	0.10	0.16	0.11	0.09	0.11	0.09	0.12	0.12	0.10	
Total	94.81	94.96	95.33	95.30	95.44	95.70	95.26	95.90	94.80	93.71	95.29	94.93	95.69	96.81	95.67	96.75	96.40	96.25	
Total-	94.79	94.94	95.31	95.28	95.42	95.67	95.24	95.88	94.78	93.69	95.25	94.90	95.67	96.79	95.65	96.72	96.37	96.23	
Si	5.333	5.322	5.357	5.351	5.347	5.334	5.341	5.327	5.345	5.360	5.352	5.346	5.390	5.333	5.377	5.369	5.363	5.366	
Al	2.667	2.678	2.643	2.649	2.653	2.666	2.659	2.673	2.655	2.640	2.648	2.654	2.610	2.667	2.623	2.631	2.637	2.634	
	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	
Al	0.743	0.740	0.789	0.821	0.876	0.772	0.790	0.757	0.746	0.730	0.737	0.743	0.746	0.749	0.768	0.756	0.778	0.759	
Ti	0.364	0.352	0.319	0.269	0.250	0.309	0.311	0.311	0.320	0.323	0.321	0.319	0.369	0.354	0.343	0.371	0.375	0.363	
Cr	0.003	0.004	0.005	0.003	0.000	0.012	0.005	0.001	0.000	0.004	0.009	0.004	0.000	0.000	0.004	0.005	0.000	0.002	
Fe	2.411	2.366	2.393	2.335	2.302	2.381	2.365	2.343	2.361	2.345	2.312	2.340	2.381	2.381	2.353	2.367	2.381	2.372	
Mn	0.000	0.005	0.004	0.000	0.000	0.001	0.002	0.000	0.004	0.008	0.006	0.005	0.000	0.006	0.001	0.015	0.000	0.005	
Mg	2.151	2.227	2.156	2.306	2.297	2.225	2.227	2.297	2.274	2.256	2.291	2.280	2.147	2.189	2.175	2.141	2.102	2.151	
	5.672	5.694	5.666	5.734	5.725	5.700	5.699	5.709	5.705	5.666	5.676	5.689	5.643	5.679	5.644	5.655	5.636	5.652	
K	0.029	0.013	0.002	0.007	0.001	0.000	0.009	0.008	0.000	0.012	0.018	0.010	0.017	0.013	0.013	0.006	0.005	0.011	
Ca	1.812	1.826	1.847	1.819	1.778	1.833	1.819	1.841	1.829	1.850	1.819	1.835	1.808	1.824	1.847	1.805	1.813	1.819	
Na	0.000	0.015	0.051	0.005	0.065	0.065	0.034	0.041	0.049	0.080	0.099	0.067	0.000	0.000	0.000	0.000	0.013	0.003	
	1.841	1.854	1.900	1.831	1.844	1.898	1.861	1.890	1.878	1.942	1.936	*.912	1.825	1.837	1.860	1.811	1.831	1.833	
Cl	0.023	0.022	0.021	0.017	0.020	0.030	0.022	0.023	0.022	0.027	0.042	0.025	0.023	0.027	0.022	0.031	0.030	0.027	
												ERR							
XMg	0.379	0.391	0.381	0.402	0.401	0.390	0.391	0.402	0.399	0.398	0.404	0.401	0.380	0.385	0.385	0.379	0.373	0.381	
XFe	0.425	0.416	0.422	0.407	0.402	0.418	0.415	0.410	0.414	0.414	0.407	0.411	0.422	0.419	0.417	0.419	0.422	0.420	
XTi	0.064	0.062	0.056	0.047	0.044	0.054	0.055	0.054	0.056	0.057	0.057	0.056	0.065	0.062	0.061	0.066	0.067	0.064	
XAl	0.131	0.130	0.139	0.143	0.153	0.135	0.139	0.133	0.131	0.129	0.130	0.131	0.132	0.132	0.136	0.134	0.138	0.134	
Fe/	0.528	0.515	0.526	0.503	0.501	0.517	0.515	0.505	0.509	0.510	0.502	0.507	0.526	0.521	0.520	0.525	0.531	0.524	
Fe+Mg																			

PS-9-93 plagioclase

	matrix a										matrix b									
	1.1	1.2	1.3	1.4	1.5	1.1-5	5	2.1	2.2	2.3	2.4	2.5	2.1-5	5	2.1	2.2	2.3	2.4	2.5	2.1-5
Points																				
SiO ₂	62.06	62.44	62.54	62.51	62.43	62.40	62.40	62.39	61.91	61.86	62.00	62.45	62.12	62.12	62.39	61.91	61.86	62.00	62.45	62.12
Al ₂ O ₃	23.02	23.33	23.18	23.24	23.09	23.17	23.17	23.30	23.20	23.46	23.43	23.19	23.32	23.32	23.30	23.20	23.46	23.43	23.19	23.32
K ₂ O	0.34	0.41	0.24	0.26	0.33	0.32	0.32	0.39	0.39	0.38	0.32	0.35	0.37	0.37	0.39	0.39	0.38	0.32	0.35	0.37
CaO	4.84	4.46	4.56	4.60	4.43	4.58	4.58	4.55	4.72	5.00	4.90	4.61	4.76	4.76	4.55	4.72	5.00	4.90	4.61	4.76
Na ₂ O	8.69	9.06	8.87	8.81	8.80	8.85	8.85	8.20	8.66	8.43	8.72	8.84	8.57	8.57	8.20	8.66	8.43	8.72	8.84	8.57
FeO	0.15	0.14	0.06	0.11	0.02	0.10	0.10	0.06	0.08	0.00	0.09	0.01	0.05	0.05	0.06	0.08	0.00	0.09	0.01	0.05
Total	99.10	99.84	99.45	99.53	99.10	99.40	99.40	98.89	98.96	99.13	99.46	99.45	99.18	99.18	98.89	98.96	99.13	99.46	99.45	99.18
Si	5.554	5.548	5.567	5.562	5.574	5.561	5.561	5.574	5.546	5.530	5.529	5.562	5.548	5.548	5.574	5.546	5.530	5.529	5.562	5.548
Al	2.428	2.443	2.432	2.437	2.431	2.434	2.434	2.454	2.450	2.472	2.463	2.434	2.455	2.455	2.454	2.450	2.472	2.463	2.434	2.455
	7.982	7.991	7.999	7.999	8.005	7.995	7.995	8.028	7.996	8.002	7.992	7.996	8.003	8.003	8.028	7.996	8.002	7.992	7.996	8.003
K	0.039	0.046	0.028	0.029	0.037	0.036	0.036	0.044	0.045	0.043	0.037	0.040	0.042	0.042	0.044	0.045	0.043	0.037	0.040	0.042
Ca	0.464	0.425	0.435	0.438	0.424	0.437	0.437	0.435	0.453	0.479	0.468	0.440	0.455	0.455	0.435	0.453	0.479	0.468	0.440	0.455
Na	1.508	1.562	1.531	1.520	1.524	1.529	1.529	1.421	1.504	1.461	1.507	1.527	1.484	1.484	1.421	1.504	1.461	1.507	1.527	1.484
	2.011	2.033	1.994	1.987	1.985	2.002	2.002	1.900	2.002	1.983	2.012	2.007	1.981	1.981	1.900	2.002	1.983	2.012	2.007	1.981
Fe	0.011	0.010	0.004	0.008	0.002	0.007	0.007	0.004	0.006	0.000	0.007	0.001	0.004	0.004	0.004	0.006	0.000	0.007	0.001	0.004
X An	0.231	0.209	0.218	0.220	0.214	0.218	0.218	0.229	0.226	0.242	0.233	0.219	0.230	0.230	0.229	0.226	0.242	0.233	0.219	0.230
X Ab	0.750	0.768	0.768	0.765	0.768	0.764	0.764	0.748	0.751	0.737	0.749	0.761	0.749	0.749	0.748	0.751	0.737	0.749	0.761	0.749
X Or	0.019	0.023	0.014	0.015	0.019	0.018	0.018	0.023	0.022	0.022	0.018	0.020	0.021	0.021	0.023	0.022	0.022	0.018	0.020	0.021

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	Point	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	1155	1953	2122	6-15.3	21	22	23
SiO2	3779	3779	3787	3784	3691	3788	3812	3733	3851	3774	3739	3783	3742	3699	3721	3752	3651	3779	3743	3734	3771	3762	3751	3751
Al2O3	2126	2128	2133	2085	2118	2151	2130	2153	2165	2165	2159	2176	2122	2151	2136	2153	2086	2144	2126	2139	2131	2126	2135	2119
TiO2	0.00	0.00	0.00	0.00	0.06	0.02	0.00	0.00	0.00	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.03	
Cr2O3	0.03	0.01	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	
FeO	3180	3200	3177	3201	3204	3225	3193	3289	3222	3211	3200	3147	3155	3128	3131	3219	3235	3177	3221	3068	3064	3018	3020	
MnO	1.03	1.46	1.71	2.29	1.90	1.39	1.17	1.72	1.83	1.88	1.29	1.66	1.25	0.90	0.73	2.27	2.02	1.60	1.94	0.78	1.05	1.09	1.18	
MgO	5.23	4.62	4.14	3.61	4.62	4.78	4.87	4.16	4.87	4.81	5.01	4.55	5.34	5.82	5.95	4.22	4.02	4.65	4.24	6.27	5.34	5.62	5.50	
CaO	3.03	3.13	3.28	3.20	3.10	3.21	3.19	3.07	3.04	2.48	3.05	2.91	2.81	2.53	2.39	2.19	3.17	3.21	2.86	2.83	3.64	3.77	4.19	
Total	100.23	100.37	100.09	98.87	100.81	101.29	100.39	101.88	101.39	103.30	100.94	99.23	99.49	99.16	99.43	98.26	100.77	99.93	99.97	99.61	99.55	99.55	99.81	
Si	5976	5995	6010	5978	5983	5979	5993	6020	5928	5932	5945	5988	5899	5931	5950	5944	5981	5959	5956	5961	5972	5946	5942	
Al	0.024	0.005	0.000	0.022	0.017	0.021	0.007	0.000	0.072	0.068	0.055	0.012	0.101	0.069	0.050	0.056	0.029	0.042	0.044	0.041	0.028	0.054	0.058	
	6.000	6.000	6.010	6.000	6.000	6.000	6.000	6.020	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.010	6.000	6.000	6.002	6.000	6.000	6.000	
Al	3938	3965	3993	3958	3925	3955	3959	3967	3935	3970	3976	3990	3942	3943	3975	3947	3972	3947	3978	3930	3949	3936	3899	
Ti	0.000	0.000	0.002	0.000	0.008	0.002	0.000	0.000	0.004	0.004	0.000	0.000	0.005	0.007	0.000	0.003	0.000	0.002	0.000	0.002	0.000	0.003	0.005	
Cr	0.004	0.001	0.000	0.000	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	-	-	-	
	3.942	3.966	3.995	3.958	3.937	3.958	3.959	3.967	3.939	3.974	3.976	3.990	3.947	3.950	3.975	3.950	3.972	3.950	3.978	3.933	3.949	3.939	3.904	
Fe	4206	4237	4219	4335	4232	4231	4219	4299	4232	4261	4205	4212	4208	4170	4152	4382	4282	4230	4297	4056	4067	4001	4001	
Mn	0.146	0.195	0.231	0.314	0.255	0.184	0.156	0.228	0.244	0.253	0.171	0.225	0.170	0.122	0.098	0.312	0.271	0.216	0.262	0.105	0.142	0.146	0.159	
Mg	1.232	1.090	0.979	0.871	1.087	1.118	1.148	0.968	1.139	1.136	1.175	1.086	1.270	1.382	1.407	1.025	0.948	1.103	1.008	1.478	1.263	1.328	1.299	
Ca	0.514	0.530	0.558	0.556	0.525	0.540	0.539	0.514	0.511	0.422	0.513	0.498	0.480	0.433	0.405	0.383	0.537	0.547	0.489	0.479	0.619	0.641	0.712	
	6.098	6.052	5.987	6.076	6.099	6.073	6.062	6.009	6.126	6.072	6.064	6.021	6.128	6.107	6.062	6.102	6.037	6.096	6.055	6.117	6.091	6.116	6.171	
XCu	0.084	0.088	0.093	0.092	0.086	0.089	0.089	0.086	0.083	0.069	0.085	0.083	0.078	0.071	0.067	0.063	0.089	0.090	0.081	0.078	0.102	0.105	0.115	
XMg	0.202	0.180	0.164	0.143	0.178	0.184	0.189	0.161	0.186	0.187	0.194	0.180	0.207	0.226	0.232	0.168	0.157	0.181	0.166	0.242	0.207	0.217	0.211	
XFe	0.690	0.700	0.705	0.713	0.694	0.697	0.696	0.715	0.691	0.702	0.693	0.700	0.687	0.683	0.685	0.718	0.709	0.694	0.710	0.663	0.668	0.654	0.648	
XMn	0.024	0.032	0.039	0.052	0.042	0.030	0.026	0.038	0.040	0.042	0.028	0.037	0.028	0.020	0.016	0.051	0.045	0.035	0.043	0.017	0.023	0.024	0.026	
Fe/Mg	0.773	0.795	0.812	0.833	0.796	0.791	0.786	0.816	0.788	0.790	0.782	0.795	0.768	0.751	0.747	0.810	0.819	0.793	0.810	0.733	0.763	0.751	0.755	

PS-28a-94 garnet																							
R2																							
g																							
1																							
	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.12	2.13	2.14	2.15	2.16	2.17	2.18	2.19	2.20	2.21	2.22	2.23	2.24	R1	R1
																						e	i
																						3	2
SiO2	37.32	37.18	37.36	37.34	36.25	37.66	37.25	37.71	37.52	37.64	37.30	37.50	37.02	37.12	37.55	37.34	37.60	37.36	38.41	37.45	37.68	21.22,23	21.62
Al2O3	21.12	21.34	21.06	21.10	20.60	21.39	21.03	21.61	21.52	21.63	21.70	21.54	21.40	21.24	21.43	21.39	21.44	20.94	21.79	21.04	20.95	37.83	37.35
TiO2	0.38	0.09	0.04	0.06	0.00	0.01	0.10	0.04	0.02	0.00	0.06	0.06	0.07	0.04	0.02	0.04	0.00	0.00	0.00	0.00	0.06	0.00	0.17
Cr2O3																						0.00	0.00
FeO	30.19	30.33	30.40	30.71	30.14	31.18	30.64	30.51	31.13	30.90	30.43	31.02	31.20	31.45	31.04	31.03	30.62	31.13	31.34	32.47	31.68	31.48	31.44
MnO	1.27	1.23	1.27	1.24	0.99	0.85	0.90	0.88	0.86	0.86	1.10	1.24	1.76	1.89	1.14	0.91	0.87	1.00	1.12	1.42	1.66	1.20	1.71
MgO	4.94	4.87	4.69	4.59	4.41	4.98	5.47	5.88	6.23	6.04	6.18	5.21	4.28	4.30	5.51	6.21	5.69	5.06	5.22	4.33	4.27	4.96	4.28
CaO	4.53	4.51	4.59	4.53	4.12	3.61	3.17	2.89	2.84	2.56	3.24	3.63	3.69	3.49	3.31	2.88	3.15	3.52	3.41	3.06	3.55	3.37	3.62
Total	99.75	99.55	99.41	99.57	96.51	99.68	98.56	99.52	100.12	99.63	100.01	100.20	99.42	99.53	100.00	99.80	99.37	99.01	101.59	99.78	99.85	100.21	99.64
Si	5.928	5.920	5.961	5.954	5.961	5.976	5.970	5.962	5.917	5.950	5.885	5.928	5.927	5.942	5.941	5.911	5.964	5.980	5.988	5.983	6.006	5.981	5.967
Al	0.072	0.080	0.039	0.046	0.039	0.024	0.030	0.038	0.083	0.050	0.115	0.072	0.073	0.058	0.059	0.089	0.036	0.020	0.012	0.017	0.000	0.019	0.037
	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.006	6.000	6.003
Al	3.882	3.925	3.922	3.920	3.954	3.977	3.941	3.988	3.917	3.980	3.920	3.942	3.966	3.950	3.936	3.902	3.972	3.931	3.992	3.945	3.937	3.962	3.952
Ti	0.046	0.011	0.004	0.007	0.000	0.001	0.012	0.005	0.002	0.000	0.007	0.007	0.009	0.005	0.002	0.005	0.000	0.000	0.000	0.000	0.007	0.000	0.008
Cr																			0.000	0.001	0.000	0.000	0.000
	3.928	3.936	3.926	3.927	3.954	3.978	3.953	3.993	3.919	3.980	3.927	3.949	3.975	3.955	3.938	3.907	3.972	3.931	3.992	3.946	3.944	3.962	3.960
Fe	4.011	4.039	4.056	4.096	4.145	4.139	4.106	4.035	4.105	4.085	4.015	4.101	4.177	4.211	4.107	4.108	4.063	4.167	4.087	4.340	4.224	4.165	4.201
Mn	0.170	0.167	0.171	0.168	0.138	0.114	0.122	0.117	0.114	0.115	0.147	0.166	0.239	0.257	0.153	0.122	0.117	0.136	0.148	0.193	0.224	0.161	0.232
Mg	1.170	1.155	1.115	1.091	1.081	1.178	1.307	1.386	1.464	1.423	1.453	1.227	1.021	1.026	1.301	1.465	1.345	1.207	1.213	1.031	1.014	1.169	1.018
Ca	0.770	0.770	0.784	0.774	0.726	0.615	0.544	0.489	0.479	0.433	0.547	0.615	0.633	0.599	0.561	0.489	0.535	0.603	0.570	0.524	0.606	0.571	0.620
	6.121	6.131	6.126	6.129	6.090	6.046	6.079	6.027	6.162	6.056	6.162	6.109	6.070	6.093	6.122	6.184	6.060	6.113	6.018	6.088	6.068	6.066	6.069
XCa	0.126	0.126	0.128	0.126	0.119	0.102	0.089	0.081	0.078	0.071	0.089	0.101	0.104	0.098	0.092	0.079	0.088	0.099	0.095	0.086	0.100	0.094	0.102
XMg	0.191	0.188	0.182	0.178	0.178	0.195	0.215	0.230	0.238	0.235	0.236	0.201	0.168	0.168	0.213	0.237	0.222	0.197	0.202	0.169	0.167	0.193	0.168
XFe	0.655	0.659	0.662	0.668	0.681	0.685	0.675	0.669	0.666	0.675	0.652	0.671	0.688	0.691	0.671	0.664	0.670	0.682	0.679	0.713	0.696	0.687	0.692
XMn	0.028	0.027	0.028	0.027	0.023	0.019	0.020	0.019	0.019	0.019	0.024	0.027	0.039	0.042	0.025	0.020	0.019	0.022	0.025	0.032	0.037	0.027	0.038
Fe/Mg	0.774	0.778	0.784	0.790	0.793	0.778	0.759	0.744	0.737	0.742	0.734	0.770	0.804	0.804	0.759	0.737	0.751	0.775	0.771	0.808	0.806	0.781	0.805

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	matrix						matrix				matrix				in contact													
	a			b			c		d		e		f		g				h				i					
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
Point	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
SiO2	34.47	35.60	35.29	35.01	35.55	35.29	35.20	35.18	35.34	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	
Al2O3	19.86	20.55	20.12	19.28	20.65	20.54	20.17	19.50	19.31	19.24	19.24	19.24	19.24	19.24	19.24	19.24	19.24	19.24	19.24	19.24	19.24	19.24	19.24	19.24	19.24	19.24	19.24	
TiO2	2.74	2.95	3.15	3.15	2.94	2.37	2.88	3.12	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	
Cr2O3	0.00	0.07	0.02	0.02	0.06	0.03	0.03	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	
FeO	18.55	18.49	18.93	19.32	18.45	18.80	18.76	19.67	19.22	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	
MnO	0.06	0.12	0.08	0.14	0.03	0.11	0.09	0.09	0.10	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	
MgO	7.99	8.60	8.45	8.68	8.88	8.69	8.55	8.43	8.35	7.78	7.78	7.78	7.78	7.78	7.78	7.78	7.78	7.78	7.78	7.78	7.78	7.78	7.78	7.78	7.78	7.78	7.78	
K2O	0.08	0.11	0.08	0.05	0.08	0.13	0.09	0.04	0.07	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	
CaO	9.34	9.73	9.65	9.57	9.63	9.69	9.60	9.59	9.40	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51	9.51	
Na2O	0.13	0.03	0.37	0.27	0.24	0.00	0.17	0.34	0.10	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	
Cl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Total	93.22	96.25	96.14	95.49	96.51	95.65	95.54	95.98	95.36	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	
Total	93.22	96.25	96.14	95.49	96.51	95.65	95.54	95.98	95.36	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	95.27	
Si	5.347	5.335	5.317	5.331	5.311	5.333	5.329	5.333	5.369	5.351	5.351	5.351	5.351	5.351	5.351	5.351	5.351	5.351	5.351	5.351	5.351	5.351	5.351	5.351	5.351	5.351	5.351	
Al	2.653	2.665	2.683	2.669	2.689	2.667	2.671	2.667	2.631	2.649	2.649	2.649	2.649	2.649	2.649	2.649	2.649	2.649	2.649	2.649	2.649	2.649	2.649	2.649	2.649	2.649	2.649	
Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	
Al	0.978	0.965	0.890	0.791	0.949	0.991	0.927	0.817	0.826	0.818	0.818	0.818	0.818	0.818	0.818	0.818	0.818	0.818	0.818	0.818	0.818	0.818	0.818	0.818	0.818	0.818	0.818	
Ti	0.320	0.333	0.357	0.360	0.330	0.270	0.328	0.355	0.394	0.397	0.397	0.397	0.397	0.397	0.397	0.397	0.397	0.397	0.397	0.397	0.397	0.397	0.397	0.397	0.397	0.397	0.397	
Cr	0.000	0.009	0.003	0.003	0.007	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	
Fe	2.407	2.317	2.385	2.461	2.305	2.376	2.375	2.494	2.442	2.538	2.538	2.538	2.538	2.538	2.538	2.538	2.538	2.538	2.538	2.538	2.538	2.538	2.538	2.538	2.538	2.538	2.538	
Mn	0.008	0.015	0.011	0.018	0.004	0.013	0.012	0.012	0.014	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	
Mg	1.848	1.922	1.898	1.969	1.978	1.957	1.929	1.905	1.890	1.774	1.774	1.774	1.774	1.774	1.774	1.774	1.774	1.774	1.774	1.774	1.774	1.774	1.774	1.774	1.774	1.774	1.774	
Mg	5.561	5.561	5.544	5.602	5.573	5.611	5.575	5.585	5.568	5.546	5.546	5.546	5.546	5.546	5.546	5.546	5.546	5.546	5.546	5.546	5.546	5.546	5.546	5.546	5.546	5.546	5.546	
K	0.013	0.018	0.013	0.007	0.012	0.021	0.014	0.007	0.012	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	
Ca	1.848	1.859	1.854	1.858	1.836	1.868	1.854	1.855	1.823	1.854	1.854	1.854	1.854	1.854	1.854	1.854	1.854	1.854	1.854	1.854	1.854	1.854	1.854	1.854	1.854	1.854	1.854	
Na	0.038	0.007	0.109	0.079	0.068	0.000	0.050	0.101	0.028	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	
Na	1.899	1.884	1.976	1.944	1.916	1.889	1.918	1.963	1.863	1.921	1.921	1.921	1.921	1.921	1.921	1.921	1.921	1.921	1.921	1.921	1.921	1.921	1.921	1.921	1.921	1.921	1.921	
Cl	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
XMg	0.332	0.346	0.342	0.351	0.355	0.349	0.346	0.341	0.339	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	
XFe	0.433	0.417	0.430	0.439	0.414	0.423	0.426	0.447	0.439	0.458	0.458	0.458	0.458	0.458	0.458	0.458	0.458	0.458	0.458	0.458	0.458	0.458	0.458	0.458	0.458	0.458	0.458	
XTi	0.058	0.060	0.064	0.064	0.059	0.048	0.059	0.064	0.071	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	
XAl	0.176	0.174	0.161	0.141	0.170	0.177	0.166	0.146	0.148	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	
Fe/	0.566	0.547	0.557	0.556	0.538	0.548	0.552	0.567	0.564	0.589	0.589	0.589	0.589	0.589	0.589	0.589	0.589	0.589	0.589	0.589	0.589	0.589	0.589	0.589	0.589	0.589	0.589	
Fe+Mg																												

PS-28a-93 biotite		in contact						matrix			matrix			matrix			matrix		
		e 3b						f			4			g			5		
		6						4			61			62			63		
		3.1						3.4			3.1-4			6.1			6.2		
		5.6						5.7			5.8			5.9			6.2		
		5.5						5.6			5.7			5.8			5.9		
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		5.5						5.5			5.6			5.7			5.8		
		5.5						5.5			5.6			5.7					

PS-28b-93 garnet										R2	
	I			h			3			I	3
Point	246	31	32	33	34	35	36	37	35-7		
SiO ₂	38.06	38.32	38.58	37.92	38.11	37.15	37.33	37.62	37.37		
Al ₂ O ₃	21.60	21.61	21.54	21.15	21.28	21.11	21.18				
TiO ₂	-	-	-	-	-	0.04	0.04	0.00	0.03		
Cr ₂ O ₃	-	-	-	-	-	0.07	0.05	0.00	0.04		
FeO	30.52	30.95	31.16	30.14	30.34	29.45	30.67	30.98	30.37		
MnO	0.62	0.80	0.64	0.63	0.75	1.23	1.45	1.54	1.41		
MgO	5.23	5.56	5.71	5.86	6.05	5.42	4.86	4.75	5.01		
CaO	3.42	2.99	2.81	2.92	3.06	3.29	3.51	3.36	3.39		
Total	99.45	100.06	100.65	99.08	99.85	97.80	99.19	99.36	98.78		
Si	6.016	6.027	6.023	6.001	5.994	5.979	5.961	6.001	5.980		
Al	0.000	0.000	0.000	0.000	0.006	0.021	0.039	0.000	0.020		
	6.016	6.027	6.023	6.001	6.000	6.000	6.000	6.001	6.000		
Al	4.025	3.974	4.002	4.031	3.986	3.991	3.967	3.969	3.976		
Ti	-	-	-	-	-	0.005	0.005	0.001	0.004		
Cr	-	-	-	-	-	0.009	0.006	0.000	0.005		
	4.025	3.974	4.002	4.031	3.986	4.005	3.978	3.970	3.984		
Fe	4.035	4.071	4.068	3.989	3.990	3.964	4.096	4.133	4.064		
Mn	0.083	0.107	0.085	0.084	0.100	0.167	0.197	0.208	0.191		
Mg	1.233	1.303	1.328	1.382	1.418	1.301	1.157	1.129	1.196		
Ca	0.580	0.504	0.470	0.495	0.515	0.568	0.601	0.574	0.581		
	5.930	5.985	5.951	5.950	6.023	6.000	6.051	6.044	6.032		
XCa	0.098	0.084	0.079	0.083	0.086	0.095	0.099	0.095	0.096		
XMg	0.208	0.218	0.223	0.232	0.235	0.217	0.191	0.187	0.198		
XFe	0.680	0.680	0.684	0.670	0.662	0.661	0.677	0.684	0.674		
XMn	0.014	0.018	0.014	0.014	0.017	0.028	0.033	0.034	0.032		
Fe'	0.766	0.758	0.754	0.743	0.738	0.753	0.780	0.785	0.773		
Fe+Mg											

PS-28b-93 biotite
in contact

	inclusion												matrix				matrix				matrix			
	e												f				g				h			
	7												4				4				3			
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
4.4 Point	41.4	52	51	53	54	55	56	57	51.7	61	62	63	64	61.4	71	72	73	74	71.4	81	82	84	81.4	
35.07 SiO ₂	35.07	35.62	34.22	36.10	36.09	36.15	35.52	36.20	35.70	35.12	34.91	34.33	34.58	34.74	34.86	35.48	34.94	35.41	35.17	35.42	35.25	34.78	35.15	
20.08 Al ₂ O ₃	20.66	19.52	18.82	19.71	20.08	19.77	20.03	20.04	19.71	19.65	19.22	19.41	19.36	19.41	19.57	20.78	19.58	20.41	20.09	19.88	19.86	19.61	19.78	
3.70 TiO ₂	3.69	4.01	4.06	4.33	4.28	4.17	3.74	4.09	4.10	4.55	4.51	4.25	4.27	4.40	4.04	3.58	4.15	3.74	3.88	4.28	4.57	4.77	4.54	
0.00 Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.11	0.03	0.08	0.07	0.04	0.09	0.07	
19.67 FeO	19.03	17.18	16.59	17.29	16.90	16.44	15.77	17.58	16.82	19.92	20.02	20.34	19.40	19.92	19.67	18.37	19.29	18.94	19.07	18.26	18.70	18.49	18.48	
0.00 MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.10	0.16	0.05	0.11	0.10	0.06	0.17	0.11	
7.98 MgO	7.84	9.78	9.50	9.69	10.13	10.63	10.64	9.58	9.99	7.95	7.66	7.48	7.79	7.72	8.61	7.67	8.31	7.96	8.14	8.51	8.37	7.98	8.29	
9.46 K ₂ O	8.73	9.29	9.02	9.52	9.46	9.26	9.01	9.52	9.30	9.32	9.24	9.25	9.21	9.26	0.05	0.09	0.01	0.00	0.04	0.00	0.02	0.03	0.02	
0.04 CaO	0.03	0.03	0.07	0.00	0.02	0.01	0.11	0.07	0.04	0.00	0.00	0.00	0.02	0.01	9.13	8.77	9.22	8.94	9.02	9.43	9.28	9.24	9.32	
0.44 Na ₂ O	0.29	0.17	0.30	0.12	0.05	0.19	0.19	0.40	0.20	0.02	0.07	0.19	0.67	0.24	0.68	0.28	0.53	0.44	0.48	0.27	0.51	0.56	0.45	
0.05 Cl	0.03	0.00	0.00	0.03	0.00	0.00	0.01	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.06	0.07	0.05	0.02	0.05	0.04	0.02	0.03	0.03	
96.49 Total	95.38	95.60	92.58	96.79	97.01	96.62	95.02	97.53	95.88	96.53	95.63	95.25	95.30	95.68	96.82	95.31	96.35	95.94	96.11	96.26	96.68	95.75	96.23	
96.48 Total	95.38	95.60	92.58	96.78	97.01	96.62	95.02	97.52	95.88	96.53	95.63	95.25	95.30	95.68	96.81	95.29	96.34	95.94	96.10	96.25	96.68	95.74	96.22	
5.283 Si	5.295	5.336	5.302	5.342	5.312	5.329	5.309	5.327	5.322	5.281	5.308	5.259	5.275	5.281	5.240	5.343	5.267	5.320	5.293	5.307	5.269	5.259	5.278	
2.717 Al	2.705	2.664	2.698	2.658	2.688	2.671	2.691	2.673	2.678	2.719	2.692	2.741	2.725	2.719	2.760	2.657	2.733	2.680	2.708	2.693	2.731	2.741	2.722	
8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	
0.848 Al	0.971	0.783	0.740	0.781	0.796	0.765	0.839	0.804	0.87	0.763	0.752	0.763	0.757	0.759	0.706	1.033	0.746	0.934	0.855	0.818	0.769	0.753	0.780	
0.419 Ti	0.419	0.452	0.473	0.482	0.474	0.463	0.420	0.453	0.460	0.515	0.515	0.490	0.490	0.503	0.457	0.405	0.471	0.422	0.439	0.483	0.514	0.543	0.513	
0.000 Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.014	0.013	0.004	0.009	0.008	0.005	0.011	0.008	
2.477 Fe	2.403	2.152	2.150	2.140	2.080	2.027	1.972	2.164	2.098	2.505	2.545	2.606	2.475	2.533	2.473	2.313	2.432	2.379	2.399	2.288	2.339	2.338	2.322	
0.000 Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.013	0.021	0.007	0.014	0.013	0.008	0.022	0.014	
1.792 Mg	1.766	2.185	2.194	2.138	2.223	2.336	2.371	2.101	2.221	1.783	1.736	1.708	1.772	1.750	1.930	1.723	1.867	1.782	1.826	1.900	1.866	1.799	1.855	
5.536	5.559	5.572	5.557	5.541	5.573	5.591	5.602	5.522	5.565	5.566	5.548	5.567	5.494	5.544	5.585	5.501	5.550	5.528	5.541	5.510	5.501	5.466	5.492	
1.818 K	1.682	1.776	1.784	1.797	1.777	1.741	1.719	1.787	1.769	1.787	1.792	1.807	1.792	1.795	0.008	0.014	0.001	0.000	0.006	0.000	0.004	0.006	0.003	
0.007 Ca	0.005	0.005	0.012	0.000	0.004	0.001	0.017	0.011	0.007	0.000	0.000	0.000	0.004	0.001	1.750	1.685	1.772	1.713	1.730	1.803	1.770	1.782	1.785	
0.129 Na	0.086	0.048	0.089	0.034	0.016	0.055	0.054	0.113	0.058	0.006	0.020	0.056	0.199	0.070	0.197	0.081	0.155	0.129	0.141	0.077	0.149	0.165	0.130	
1.954	1.773	1.829	1.885	1.831	1.797	1.797	1.790	1.911	1.834	1.793	1.812	1.863	1.995	1.866	1.955	1.780	1.928	1.842	1.876	1.880	1.923	1.953	1.919	
0.012 Cl	0.008	0.000	0.000	0.007	0.000	0.001	0.002	0.013	0.003	0.000	0.000	0.000	0.000	0.000	0.014	0.019	0.013	0.005	0.013	0.010	0.004	0.006	0.007	
0.324 XMg	0.318	0.392	0.395	0.386	0.399	0.418	0.423	0.380	0.399	0.320	0.313	0.307	0.323	0.316	0.346	0.313	0.336	0.322	0.329	0.345	0.339	0.329	0.338	
0.447 XFe	0.432	0.386	0.387	0.386	0.373	0.363	0.352	0.352	0.377	0.450	0.459	0.468	0.450	0.457	0.443	0.420	0.438	0.430	0.433	0.415	0.425	0.428	0.423	
0.076 XTi	0.075	0.081	0.085	0.087	0.085	0.083	0.075	0.082	0.083	0.093	0.093	0.088	0.089	0.091	0.082	0.074	0.085	0.076	0.079	0.088	0.093	0.099	0.093	
0.153 XAl	0.175	0.141	0.133	0.141	0.143	0.137	0.150	0.146	0.141	0.137	0.136	0.137	0.138	0.137	0.126	0.188	0.134	0.169	0.154	0.148	0.140	0.138	0.142	
0.580 Fe	0.576	0.496	0.495	0.500	0.483	0.465	0.454	0.507	0.486	0.584	0.594	0.604	0.583	0.591	0.562	0.573	0.566	0.572	0.568	0.546	0.556	0.565	0.556	

Fe+Mg

PS-28b-93 plagioclase

Points	1 1	1 2	1 3	matrix a 3	2 1	2 2	matrix b 2
SiO2	55.42	56.29	56.13	11.3	55.98	55.53	21-2 55.76
Al2O3	28.97	29.22	29.07	29.09	28.84	28.50	28.67
K2O	0.05	0.07	0.04	0.05	0.05	0.17	0.11
CaO	10.26	10.72	10.13	10.37	10.24	10.02	10.13
Na2O	5.37	5.29	5.47	5.38	5.60	5.37	5.49
FeO	0.08	0.17	0.15	0.13	0.03	0.05	0.04
Total	100.15	101.76	100.99	100.97	100.74	99.64	100.19
Si	4.972	4.975	4.990	4.979	4.992	5.004	4.998
Al	3.063	3.044	3.047	3.051	3.032	3.028	3.030
	8.035	8.019	8.037	8.030	8.024	8.032	8.028
K	0.005	0.008	0.004	0.006	0.006	0.020	0.013
Ca	0.987	1.015	0.965	0.989	0.978	0.968	0.973
Na	0.934	0.906	0.944	0.928	0.968	0.938	0.953
	1.926	1.929	1.913	1.923	1.952	1.926	1.939
Fe	0.006	0.012	0.011	0.010	0.003	0.004	0.004
X An	0.512	0.526	0.504	0.514	0.501	0.503	0.502
X Ab	0.485	0.470	0.493	0.483	0.496	0.491	0.490
X Or	0.003	0.004	0.002	0.003	0.003	0.003	0.003

Ps-28b-93 ilmenite

Points	1 1	1 2	1 3	1 1-3	2 1	2 2	2 3	2 1-3	3 1	3 2	3 3	3 1-3
TiO ₂	50.71	51.05	50.76	50.84	51.14	50.84	50.82	50.93	50.48	50.63	52.09	51.07
Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe ₂ O ₃	1.07	1.23	2.00	1.43	1.71	1.07	1.23	1.34	1.68	1.38	1.58	1.55
FeO	44.44	44.59	44.47	44.50	44.97	44.53	44.63	44.71	44.12	44.46	45.62	44.73
MnO	1.19	1.26	1.07	1.17	1.11	1.17	1.10	1.13	1.22	1.14	1.22	1.19
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	97.41	98.13	98.30	97.95	98.93	97.61	97.78	98.11	97.50	97.61	100.51	98.54
Ti	0.989	0.988	0.981	0.986	0.983	0.990	0.988	0.987	0.984	0.986	0.985	0.985
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe+3	0.021	0.024	0.039	0.028	0.033	0.021	0.024	0.026	0.033	0.027	0.030	0.030
	1.010	1.012	1.020	1.014	1.016	1.011	1.012	1.013	1.017	1.013	1.015	1.015
Fe+2	0.964	0.960	0.956	0.960	0.961	0.964	0.965	0.963	0.956	0.963	0.959	0.959
Mn	0.026	0.028	0.023	0.026	0.024	0.026	0.024	0.025	0.027	0.025	0.026	0.026
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.990	0.988	0.979	0.986	0.985	0.990	0.989	0.988	0.983	0.988	0.985	0.985
X Ti	0.979	0.976	0.962	0.972	0.968	0.979	0.976	0.974	0.968	0.973	0.970	0.970
X Fe+3	0.021	0.024	0.038	0.028	0.032	0.021	0.024	0.026	0.032	0.027	0.030	0.030
X Fe+2	0.974	0.972	0.977	0.974	0.976	0.974	0.976	0.975	0.973	0.975	0.974	0.974
X Mn	0.026	0.028	0.023	0.026	0.024	0.026	0.024	0.025	0.027	0.025	0.026	0.026
X Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
activity	0.953	0.949	0.939	0.947	0.944	0.954	0.953	0.950	0.941	0.949	0.945	0.945

PS-61-94 garnet

Point	1.1	1.2	1.3	1.4	1.5	1.6	1.8	1.7	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	R1 a	R1 b	R1 2
SiO2	37.85	38.28	38.43	38.46	38.46	38.17	38.46	38.31	38.07	38.15	38.23	38.32	36.95	36.90	37.12	37.28	37.14	37.85	38.28	
Al2O3	21.49	21.63	21.82	21.55	21.62	21.31	21.42	21.53	21.19	21.54	21.39	21.35	21.38	21.32	21.22	21.39	21.13	21.49	21.37	
TiO2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	
Cr2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.08	0.03	0.02	0.09	0.00	0.00	
FeO	34.07	33.88	33.18	33.22	33.04	32.95	32.91	33.36	33.07	34.05	34.32	34.01	33.10	33.70	33.02	33.36	33.31	34.07	34.17	
MnO	1.80	1.50	0.96	1.07	0.97	0.88	0.96	1.02	1.09	1.27	1.75	1.59	1.91	2.10	1.79	1.57	1.98	1.80	1.67	
MgO	4.58	5.28	5.80	6.01	5.88	5.99	6.06	5.72	5.59	5.31	4.49	4.79	5.10	4.58	5.28	5.65	4.82	4.58	4.64	
CaO	1.18	1.13	1.04	1.06	1.04	1.02	1.04	1.06	1.06	1.11	1.09	1.10	1.26	1.25	1.25	1.26	1.29	1.18	1.10	
Total	100.97	101.70	101.23	101.37	101.01	100.32	100.85	101.00	100.07	101.43	101.27	101.16	99.76	99.96	99.71	100.54	99.76	100.97	101.22	
Si	5.984	5.985	5.999	6.001	6.014	6.014	6.022	6.004	6.025	5.983	6.024	6.031	5.911	5.914	5.934	5.909	5.948	5.984	6.028	
Al	0.016	0.015	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.000	0.000	0.089	0.086	0.066	0.091	0.052	0.016	0.000	
	6.000	6.000	6.000	6.001	6.014	6.014	6.022	6.004	6.025	6.000	6.024	6.031	6.000	6.000	6.000	6.000	6.000	6.000	6.028	
Al	3.988	3.972	4.014	3.965	3.985	3.956	3.954	3.978	3.953	3.964	3.972	3.961	3.942	3.941	3.932	3.905	3.937	3.988	3.967	
Ti	-	-	-	-	-	-	-	-	-	-	-	-	0.000	0.003	0.000	0.002	0.000	0.000	0.000	
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.011	0.004	0.002	0.011	0.000	0.000	
	3.988	3.972	4.014	3.965	3.985	3.956	3.954	3.978	3.953	3.964	3.972	3.961	3.949	3.955	3.936	3.909	3.948	3.988	3.967	
Fe	4.504	4.430	4.331	4.335	4.320	4.341	4.309	4.374	4.377	4.465	4.522	4.476	4.428	4.516	4.415	4.422	4.462	4.504	4.499	
Mn	0.241	0.198	0.127	0.141	0.128	0.117	0.127	0.136	0.146	0.169	0.234	0.212	0.259	0.285	0.243	0.211	0.269	0.241	0.223	
Mg	1.081	1.231	1.349	1.398	1.371	1.406	1.415	1.336	1.318	1.241	1.055	1.123	1.217	1.094	1.259	1.335	1.151	1.081	1.089	
Ca	0.199	0.190	0.174	0.178	0.174	0.173	0.174	0.179	0.179	0.187	0.184	0.185	0.217	0.215	0.213	0.215	0.221	0.199	0.185	
	6.025	6.049	5.981	6.052	5.993	6.037	6.025	6.025	6.020	6.062	5.995	5.996	6.121	6.110	6.130	6.183	6.103	6.025	5.996	
XCa	0.033	0.031	0.029	0.029	0.029	0.029	0.029	0.030	0.030	0.031	0.031	0.031	0.034	0.032	0.034	0.034	0.034	0.033	0.031	
XMg	0.179	0.204	0.226	0.231	0.229	0.233	0.235	0.222	0.219	0.205	0.176	0.167	0.199	0.179	0.205	0.216	0.189	0.179	0.182	
XFe	0.748	0.732	0.724	0.716	0.721	0.719	0.715	0.726	0.727	0.737	0.754	0.746	0.723	0.739	0.720	0.715	0.731	0.748	0.750	
XMn	0.040	0.033	0.021	0.023	0.021	0.019	0.021	0.023	0.024	0.028	0.039	0.035	0.042	0.047	0.040	0.034	0.044	0.040	0.037	
Fe/Mg	0.806	0.783	0.763	0.756	0.759	0.755	0.753	0.766	0.769	0.783	0.811	0.799	0.784	0.805	0.778	0.768	0.795	0.806	0.805	

PS-61-94 garnet

	R2 c	R2 d	C e
Point	1.13,15	1.14,17	1.2-10
SiO ₂	37.04	37.02	38.31
Al ₂ O ₃	21.30	21.23	21.51
TiO ₂	0.00	0.02	-
Cr ₂ O ₃	0.05	0.09	0.00
FeO	33.06	33.51	33.30
MnO	1.85	2.04	1.08
MgO	5.19	4.70	5.74
CaO	1.26	1.27	1.06
Total	99.74	99.86	101.00
Si	5.923	5.931	6.005
Al	0.078	0.069	0.004
	6.000	6.000	6.009
Al	3.937	3.939	3.971
Ti	0.000	0.002	-
Cr	0.006	0.011	0.000
	3.943	3.952	3.971
Fe	4.422	4.489	4.365
Mn	0.251	0.277	0.143
Mg	1.238	1.123	1.341
Ca	0.215	0.216	0.179
	6.126	6.107	6.027
XCa	0.034	0.033	0.030
XMg	0.202	0.184	0.222
XFe	0.722	0.735	0.724
XMn	0.041	0.045	0.024
Fe	0.781	0.800	0.765
Fe+Mg			
	2.2	2.1	2.3
	2.4	2.5	2.6
	2.7	2.8	2.9
	2.10	2.11	2.12
	2.13	2.14	2.15
	2.16	2.17	2.18
	2.19	2.20	2.21
	2.22	2.23	2.24
	2.25	2.26	2.27
	2.28	2.29	2.30
	2.31	2.32	2.33
	2.34	2.35	2.36
	2.37	2.38	2.39
	2.40	2.41	2.42
	2.43	2.44	2.45
	2.46	2.47	2.48
	2.49	2.50	2.51
	2.52	2.53	2.54
	2.55	2.56	2.57
	2.58	2.59	2.60
	2.61	2.62	2.63
	2.64	2.65	2.66
	2.67	2.68	2.69
	2.70	2.71	2.72
	2.73	2.74	2.75
	2.76	2.77	2.78
	2.79	2.80	2.81
	2.82	2.83	2.84
	2.85	2.86	2.87
	2.88	2.89	2.90
	2.91	2.92	2.93
	2.94	2.95	2.96
	2.97	2.98	2.99
	3.00	3.01	3.02
	3.03	3.04	3.05
	3.06	3.07	3.08
	3.09	3.10	3.11
	3.12	3.13	3.14
	3.15	3.16	3.17
	3.18	3.19	3.20
	3.21	3.22	3.23
	3.24	3.25	3.26
	3.27	3.28	3.29
	3.30	3.31	3.32
	3.33	3.34	3.35
	3.36	3.37	3.38
	3.39	3.40	3.41
	3.42	3.43	3.44
	3.45	3.46	3.47
	3.48	3.49	3.50
	3.51	3.52	3.53
	3.54	3.55	3.56
	3.57	3.58	3.59
	3.60	3.61	3.62
	3.63	3.64	3.65
	3.66	3.67	3.68
	3.69	3.70	3.71
	3.72	3.73	3.74
	3.75	3.76	3.77
	3.78	3.79	3.80
	3.81	3.82	3.83
	3.84	3.85	3.86
	3.87	3.88	3.89
	3.90	3.91	3.92
	3.93	3.94	3.95
	3.96	3.97	3.98
	3.99	4.00	4.01
	4.02	4.03	4.04
	4.05	4.06	4.07
	4.08	4.09	4.10
	4.11	4.12	4.13
	4.14	4.15	4.16
	4.17	4.18	4.19
	4.20	4.21	4.22
	4.23	4.24	4.25
	4.26	4.27	4.28
	4.29	4.30	4.31
	4.32	4.33	4.34
	4.35	4.36	4.37
	4.38	4.39	4.40
	4.41	4.42	4.43
	4.44	4.45	4.46
	4.47	4.48	4.49
	4.50	4.51	4.52
	4.53	4.54	4.55
	4.56	4.57	4.58
	4.59	4.60	4.61
	4.62	4.63	4.64
	4.65	4.66	4.67
	4.68	4.69	4.70
	4.71	4.72	4.73
	4.74	4.75	4.76
	4.77	4.78	4.79
	4.80	4.81	4.82
	4.83	4.84	4.85
	4.86	4.87	4.88
	4.89	4.90	4.91
	4.92	4.93	4.94
	4.95	4.96	4.97
	4.98	4.99	5.00

PS-61-94 garnet

Point	2 18	2 20	2 22	2 24	2 23	2 25	2 26	2 27	2 28	2 29	2 30	R1 f	R1 g	R2 h	C i	R2 j	R2 k
SiO2	37 27	37 06	37 65	37 35	37 65	36 66	36 86	36 71	36 87	36 78	37 41	2 22 23	2 20	2 25 27	2 3 18	3 3	3 3
Al2O3	20 94	21 09	21 25	21 30	21 42	21 03	21 28	21 36	21 70	21 34	21 58	21 34	21 09	21 22	20 03	21 24	20 99
TiO2	-	-	-	-	-	0 01	0 05	0 00	0 00	0 00	0 07	0 00	0 00	0 02	-	0 00	0 00
Cr2O3	0 00	0 00	0 00	0 04	0 00	0 00	0 05	0 10	0 00	0 04	0 09	0 00	0 00	0 05	0 01	0 02	0 00
FeO	32 51	33 05	32 95	33 35	32 91	32 74	32 91	32 65	32 48	32 70	32 58	32 93	33 05	32 77	30 36	32 57	32 40
MnO	1 14	1 61	1 36	1 40	1 26	1 48	1 34	1 38	1 16	1 20	1 07	1 31	1 61	1 40	0 93	1 50	1 46
MgO	5 37	4 74	5 12	4 99	5 41	5 43	5 28	5 43	5 67	5 63	6 44	5 27	4 74	5 38	5 63	5 63	5 39
CaO	1 11	1 20	1 13	1 16	1 10	1 27	1 23	1 15	1 09	1 18	1 20	1 12	1 20	1 22	1 01	1 27	1 29
Total	98 34	98 75	99 46	99 59	99 75	98 62	99 00	98 78	98 97	98 87	100 44	99 61	98 75	99 30	93 41	99 30	98 60
Si	6 006	5 979	6 008	5 970	5 984	5 921	5 924	5 909	5 904	5 910	5 898	5 996	5 979	5 918	5 639	5 932	5 912
Al	0 300	0 021	0 000	0 030	0 016	0 079	0 076	0 091	0 096	0 090	0 102	0 008	0 021	0 082	0 012	0 068	0 071
	6 006	6 000	6 008	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 004	6 000	6 000	6 004	6 000	6 000
Al	3 978	3 989	3 995	3 983	3 996	3 924	3 956	3 962	4 000	3 952	3 908	3 996	3 989	3 947	3 744	3 939	3 936
Ti	-	-	-	-	-	0 001	0 006	0 000	0 000	0 000	0 008	0 000	0 000	0 002	-	0 000	0 000
Cr	0 000	0 000	0 000	0 005	0 000	0 000	0 006	0 013	0 000	0 005	0 011	0 000	0 000	0 006	0 001	0 002	0 004
	3 978	3 989	3 995	3 988	3 996	3 925	3 968	3 975	4 000	3 957	3 927	3 996	3 989	3 956	3 979	3 941	3 940
Fe	4 383	4 459	4 397	4 457	4 374	4 422	4 423	4 395	4 350	4 394	4 296	4 386	4 459	4 413	4 040	4 359	4 408
Mn	0 156	0 221	0 183	0 189	0 170	0 202	0 183	0 188	0 157	0 164	0 143	0 177	0 221	0 191	0 126	0 203	0 192
Mg	1 289	1 141	1 217	1 189	1 283	1 306	1 265	1 302	1 353	1 348	1 514	1 250	1 141	1 291	1 336	1 342	1 299
Ca	0 192	0 207	0 194	0 198	0 187	0 220	0 211	0 198	0 187	0 203	0 203	0 191	0 207	0 210	0 173	0 218	0 225
	6 020	6 028	5 991	6 033	6 014	6 150	6 082	6 083	6 047	6 109	6 156	6 003	6 028	6 105	6 029	6 122	6 124
XCa	0 032	0 034	0 032	0 033	0 031	0 036	0 032	0 029	0 031	0 032	0 028	0 032	0 034	0 032	0 029	0 035	0 036
XMg	0 214	0 189	0 203	0 197	0 213	0 212	0 208	0 214	0 224	0 221	0 246	0 208	0 189	0 211	0 222	0 219	0 212
XFe	0 728	0 740	0 734	0 739	0 727	0 719	0 727	0 723	0 719	0 719	0 698	0 731	0 740	0 723	0 670	0 712	0 718
XMn	0 026	0 037	0 031	0 031	0 028	0 033	0 030	0 031	0 026	0 027	0 023	0 029	0 037	0 031	0 021	0 033	0 031
Fe/ Fe+Mg	0 773	0 796	0 783	0 789	0 773	0 772	0 778	0 771	0 763	0 765	0 739	0 778	0 796	0 774	0 707	0 765	0 772

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Point	cont												matrix											
	a						b						c											
	1.1	1.2	1.3	1.4	1.5	1.6	1.1-3	1.4-6	2.1	2.2	2.3	2.4	2.5	2.1-2.4	3.1	3.2	3.3	3.4	3.5	3.6	3.7			
SiO2	35.57	35.17	35.06	35.40	35.11	35.28	35.27	35.26	34.80	34.62	34.20	34.24	33.88	34.55	36.10	35.27	35.51	35.63	35.48	34.88	36.22			
Al2O3	19.80	19.17	18.83	19.67	19.26	18.89	19.27	19.27	18.61	18.15	18.72	18.58	18.41	18.45	19.90	19.24	19.16	19.35	19.30	19.34	18.54			
TiO2	2.81	3.02	3.36	2.73	3.42	3.77	3.06	3.31	4.58	4.50	4.29	4.55	4.59	4.54	3.05	3.19	3.10	2.96	3.02	2.92	5.18			
Cr2O3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
FeO	17.14	17.77	18.18	16.80	17.59	17.68	17.70	17.36	18.03	17.90	17.07	17.68	17.27	17.87	18.17	17.93	17.87	18.23	18.09	18.16	17.95			
MnO	0.00	0.00	0.03	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
MgO	9.76	9.46	9.32	10.93	10.00	9.66	9.51	10.20	9.10	9.19	8.77	9.11	8.99	9.13	10.27	9.98	9.74	9.81	10.12	10.03	9.91			
K2O	9.24	9.34	9.43	9.48	9.57	9.49	9.34	9.51	9.23	9.27	9.08	9.37	9.01	9.29	9.68	9.05	9.33	9.47	9.50	9.40	9.45			
CaO	0.17	0.09	0.12	0.14	0.11	0.16	0.13	0.14	0.20	0.17	0.06	0.12	0.19	0.16	0.24	0.27	0.15	0.15	0.16	0.07	0.12			
Na2O	0.59	0.20	0.16	0.19	0.06	0.20	0.32	0.15	0.62	0.58	0.46	0.65	0.28	0.62	0.30	0.17	0.40	0.27	0.51	0.12	0.11			
Cl	0.16	0.20	0.11	0.15	0.16	0.16	0.16	0.16	0.21	0.17	0.19	0.15	0.21	0.18	0.21	0.15	0.14	0.20	0.13	0.15	0.14			
Total	95.24	94.42	94.60	95.49	95.28	95.25	94.75	95.35	95.38	94.56	92.88	94.45	92.83	94.80	97.92	95.25	95.40	96.07	96.31	95.07	97.62			
Total-	95.20	94.37	94.58	95.46	95.24	95.25	94.72	95.32	95.33	94.52	92.84	94.42	92.78	94.76	97.87	95.22	95.37	96.02	96.28	95.04	97.59			
Si	5.363	5.374	5.361	5.320	5.315	5.344	5.366	5.326	5.289	5.311	5.312	5.257	5.276	5.286	5.323	5.334	5.369	5.359	5.326	5.305	5.346			
Al	2.637	2.626	2.639	2.680	2.685	2.656	2.634	2.674	2.711	2.689	2.688	2.743	2.724	2.714	2.677	2.666	2.631	2.641	2.674	2.695	2.654			
Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000			
Al	0.882	0.827	0.755	0.803	0.752	0.717	0.821	0.757	0.623	0.592	0.740	0.619	0.656	0.611	0.783	0.764	0.782	0.790	0.740	0.771	0.572			
Ti	0.319	0.347	0.387	0.309	0.389	0.430	0.351	0.376	0.524	0.519	0.501	0.526	0.538	0.523	0.338	0.363	0.352	0.335	0.341	0.333	0.575			
Cr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
Fe	2.162	2.271	2.325	2.111	2.227	2.240	2.253	2.193	2.292	2.297	2.217	2.271	2.249	2.287	2.241	2.268	2.259	2.294	2.271	2.310	2.216			
Mn	0.000	0.000	0.004	0.000	0.000	0.000	0.001	0.000	0.000	0.002	0.005	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000			
Mg	2.195	2.154	2.123	2.448	2.258	2.180	2.157	2.295	2.062	2.100	2.031	2.086	2.087	2.083	2.257	2.250	2.196	2.200	2.265	2.273	2.179			
Mg	5.558	5.599	5.594	5.671	5.626	5.567	5.584	5.621	5.501	5.510	5.494	5.502	5.530	5.504	5.619	5.645	5.589	5.619	5.617	5.687	5.542			
K	1.777	1.820	1.839	1.817	1.849	1.834	1.812	1.833	1.790	1.813	1.799	1.836	1.790	1.813	1.821	1.746	1.800	1.817	1.820	1.824	1.779			
Ca	0.028	0.014	0.019	0.023	0.019	0.026	0.020	0.023	0.033	0.028	0.010	0.020	0.031	0.027	0.038	0.044	0.025	0.024	0.025	0.011	0.019			
Na	0.173	0.060	0.048	0.055	0.017	0.060	0.094	0.044	0.182	0.174	0.137	0.195	0.083	0.184	0.085	0.051	0.118	0.078	0.149	0.036	0.031			
Na	1.978	1.894	1.906	1.895	1.885	1.920	1.926	1.900	2.005	2.015	1.946	2.051	1.904	2.024	1.944	1.841	1.943	1.919	1.994	1.871	1.829			
Cl	0.041	0.053	0.028	0.038	0.040	0.040	0.041	0.039	0.054	0.044	0.051	0.040	0.055	0.046	0.053	0.039	0.036	0.051	0.032	0.038	0.036			
XMg	0.395	0.385	0.380	0.432	0.401	0.392	0.386	0.408	0.375	0.381	0.370	0.379	0.377	0.378	0.402	0.399	0.393	0.392	0.403	0.400	0.393			
XFe	0.389	0.406	0.416	0.372	0.396	0.402	0.403	0.390	0.417	0.417	0.404	0.413	0.407	0.415	0.399	0.402	0.404	0.408	0.404	0.406	0.400			
XTi	0.057	0.062	0.069	0.054	0.069	0.077	0.063	0.067	0.095	0.094	0.091	0.096	0.097	0.095	0.060	0.064	0.063	0.060	0.061	0.059	0.104			
XAl	0.159	0.148	0.135	0.142	0.134	0.129	0.147	0.135	0.113	0.107	0.135	0.113	0.119	0.111	0.139	0.135	0.140	0.141	0.132	0.136	0.103			
Fe+Mg	0.496	0.513	0.523	0.463	0.497	0.507	0.511	0.489	0.526	0.522	0.522	0.521	0.519	0.523	0.498	0.502	0.507	0.510	0.501	0.504	0.504			

PS-61-94 biotite

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PS-61-94 plagioclase									
Points	in contact								
	a								
	1 1	1 2	1 3	1 1-3	2 1	2 2	2 3	2 4	2 5 2 1-5
SiO ₂	60.72	61.69	61.48	61.30	61.29	62.65	61.51	60.99	61.71 61.63
Al ₂ O ₃	24.61	25.62	24.81	25.01	24.62	24.61	24.13	24.66	25.16 24.64
K ₂ O	0.08	0.13	0.11	0.11	0.24	0.26	0.20	0.08	0.16 0.19
CaO	5.65	6.07	5.70	5.81	5.52	5.52	5.70	5.74	5.79 5.65
Na ₂ O	7.92	7.67	7.94	7.84	7.98	8.06	8.13	7.87	8.07 8.02
FeO	0.03	0.07	0.20	0.10	0.00	0.00	0.00	0.01	0.09 0.02
Total	99.01	101.25	100.24	100.17	99.65	101.10	99.67	99.35	100.98 100.15
Si	5.435	5.401	5.439	5.425	5.451	5.486	5.474	5.439	5.422 5.454
Al	2.597	2.644	2.587	2.609	2.581	2.540	2.531	2.592	2.606 2.570
	8.032	8.045	8.026	8.034	8.032	8.026	8.005	8.031	8.028 8.024
K	0.010	0.015	0.013	0.013	0.027	0.029	0.023	0.009	0.018 0.021
Ca	0.542	0.569	0.540	0.550	0.526	0.518	0.544	0.549	0.545 0.536
Na	1.375	1.303	1.362	1.347	1.377	1.369	1.402	1.360	1.374 1.376
	1.927	1.887	1.915	1.910	1.930	1.916	1.969	1.918	1.937 1.934
Fe	0.002	0.005	0.015	0.007	0.000	0.000	0.000	0.001	0.007 0.002
X An	0.281	0.302	0.282	0.288	0.273	0.270	0.276	0.286	0.281 0.277
X Ab	0.714	0.691	0.711	0.705	0.713	0.715	0.712	0.709	0.709 0.712
X Or	0.005	0.008	0.007	0.007	0.014	0.015	0.012	0.005	0.009 0.011

PCA-93-84 garnet

Points	21	22	23	24	25	26	27	28	29	210	211	212	213	214	215	216	217	218	219	220	221
SiO ₂	36.91	37.71	37.79	38.19	37.72	37.71	38.27	38.18	37.89	38.00	38.04	37.89	38.24	37.94	37.92	38.28	37.70	38.00	37.96	37.81	37.68
Al ₂ O ₃	20.46	20.67	21.08	20.97	20.86	20.99	21.23	21.10	20.85	20.73	20.55	20.91	21.36	21.11	20.71	20.89	20.84	20.79	20.95	21.10	21.14
TiO ₂	0.08	0.05	0.13	0.03	0.03	0.07	0.10	0.06	0.14	0.20	0.00	0.00	0.13	0.03	0.05	0.04	0.03	0.08	0.09	0.16	0.12
Cr ₂ O ₃	0.10	0.03	0.00	0.06	0.09	0.08	0.14	0.08	0.04	0.07	0.02	0.05	0.06	0.03	0.04	0.12	0.06	0.08	0.04	0.07	0.09
FeO	34.74	33.70	33.42	32.80	32.68	32.20	32.95	32.43	31.81	32.32	32.53	32.47	32.08	32.31	32.51	32.66	32.81	32.81	32.28	32.91	32.98
MnO	0.69	0.49	0.31	0.34	0.27	0.33	0.45	0.53	0.50	0.50	0.42	0.36	0.45	0.43	0.32	0.37	0.44	0.43	0.40	0.48	0.46
MgO	4.41	5.29	5.65	6.01	5.99	6.43	6.21	6.63	6.02	6.43	6.41	6.14	6.28	6.22	6.36	6.23	6.08	5.83	5.96	6.20	5.93
CaO	1.86	1.64	1.74	1.68	1.65	1.60	1.66	1.63	1.74	1.66	1.67	1.67	1.75	1.55	1.65	1.71	1.69	1.70	1.72	1.79	1.65
Total	99.33	99.58	100.27	100.11	99.29	99.42	101.02	100.67	99.33	99.91	99.65	99.49	100.39	99.64	99.56	100.31	99.66	99.72	99.43	100.52	100.09
Si	5.965	6.021	5.979	6.027	6.006	5.984	5.988	5.986	6.030	6.006	6.032	6.014	5.999	6.006	6.015	6.026	5.990	6.028	6.024	5.956	5.964
Al	0.035	0.000	0.021	0.000	0.000	0.016	0.012	0.014	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.010	0.000	0.000	0.044	0.036
	6.000	6.021	6.000	6.027	6.006	6.000	6.000	6.000	6.030	6.006	6.032	6.014	6.000	6.006	6.015	6.026	6.000	6.028	6.024	6.000	6.000
Al	3.854	3.891	3.910	3.902	3.916	3.910	3.905	3.886	3.912	3.862	3.842	3.912	3.949	3.939	3.873	3.877	3.893	3.888	3.920	3.875	3.908
Ti	0.010	0.006	0.015	0.004	0.004	0.008	0.012	0.007	0.017	0.024	0.000	0.000	0.015	0.004	0.006	0.005	0.004	0.010	0.011	0.019	0.014
Cr	0.013	0.004	0.013	0.007	0.011	0.010	0.017	0.010	0.005	0.009	0.003	0.006	0.007	0.004	0.005	0.015	0.008	0.010	0.005	0.009	0.011
	3.886	3.900	3.938	3.913	3.931	3.929	3.934	3.903	3.934	3.895	3.844	3.919	3.972	3.947	3.884	3.897	3.904	3.908	3.935	3.903	3.934
Fe	4.696	4.500	4.422	4.329	4.352	4.273	4.312	4.252	4.234	4.272	4.314	4.310	4.209	4.277	4.313	4.300	4.360	4.353	4.264	4.336	4.366
Mn	0.094	0.066	0.042	0.045	0.036	0.044	0.060	0.070	0.067	0.067	0.056	0.048	0.060	0.058	0.043	0.049	0.059	0.058	0.054	0.064	0.062
Mg	1.062	1.259	1.332	1.414	1.421	1.521	1.448	1.549	1.428	1.514	1.515	1.452	1.468	1.467	1.504	1.462	1.440	1.378	1.410	1.455	1.399
Ca	0.322	0.281	0.295	0.284	0.281	0.272	0.278	0.274	0.297	0.281	0.284	0.284	0.294	0.263	0.280	0.288	0.288	0.289	0.292	0.302	0.280
	6.191	6.105	6.101	6.078	6.091	6.112	6.100	6.152	6.034	6.134	6.171	6.095	6.039	6.059	6.140	6.101	6.148	6.078	6.046	6.158	6.114
X Ca	0.052	0.046	0.048	0.047	0.046	0.045	0.046	0.045	0.049	0.046	0.046	0.047	0.049	0.043	0.046	0.047	0.047	0.048	0.048	0.049	0.046
X Mg	0.172	0.206	0.218	0.233	0.233	0.249	0.237	0.252	0.237	0.247	0.245	0.238	0.243	0.242	0.245	0.240	0.234	0.227	0.233	0.236	0.229
X Fe	0.758	0.737	0.725	0.712	0.714	0.699	0.707	0.691	0.702	0.696	0.699	0.707	0.697	0.705	0.702	0.705	0.709	0.716	0.709	0.704	0.714
X Mn	0.015	0.011	0.007	0.007	0.006	0.007	0.010	0.011	0.011	0.011	0.009	0.008	0.010	0.009	0.007	0.008	0.010	0.010	0.009	0.010	0.010
Fe	0.816	0.781	0.768	0.754	0.754	0.738	0.749	0.733	0.748	0.738	0.740	0.748	0.741	0.745	0.742	0.746	0.752	0.760	0.752	0.749	0.757
Fe•Mg																					

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PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

PRECISIONSM RESOLUTION TARGETS

PCA-93-84 biotite

PCA-93-84 biotite	in contact								matrix						matrix										
	a								b						c										
	8								6						7										
	11	12	13	14	15	16	17	18	11-8	21	22	23	24	25	26	21-6	121	122	123	124	125	126	127	121-7	131
SiO2	35.37	35.40	35.33	35.12	35.36	34.95	35.29	34.94	35.22	35.20	35.12	35.26	35.05	34.89	35.16	35.11	35.46	35.33	35.36	35.06	34.97	35.27	35.65	35.30	35.99
Al2O3	20.16	20.06	20.83	21.10	20.27	20.44	21.13	21.20	20.65	17.63	17.71	17.98	17.52	17.61	18.09	17.76	18.21	17.81	17.67	17.83	18.35	18.13	18.60	18.09	18.03
TiO2	1.22	1.24	1.02	0.85	0.84	0.71	0.61	0.73	0.90	4.11	4.41	4.42	4.37	4.64	4.62	4.43	4.29	4.37	4.16	4.68	4.84	4.78	4.76	4.55	3.58
Cr2O	0.05	0.06	0.08	0.08	0.10	0.04	0.14	0.04	0.07	0.08	0.08	0.06	0.02	0.05	0.03	0.05	0.11	0.11	0.00	0.08	0.08	0.17	0.12	0.10	0.09
FeO	19.73	19.24	19.76	19.62	20.24	20.01	19.19	19.69	19.69	20.05	19.88	19.65	19.59	19.90	19.28	19.73	19.38	19.67	20.04	19.08	18.94	18.83	18.63	19.22	19.53
MnO	0.00	0.03	0.05	0.01	0.02	0.09	0.00	0.05	0.03	0.00	0.00	0.08	0.00	0.02	0.02	0.02	0.06	0.05	0.00	0.07	0.00	0.00	0.06	0.03	0.03
MgO	9.61	9.91	9.76	9.94	9.94	9.87	9.77	10.32	9.89	9.24	8.94	9.31	9.02	9.14	8.85	9.08	9.29	9.58	9.39	9.24	8.68	8.82	8.98	9.14	10.05
CaO	3.06	0.05	0.08	0.05	0.07	0.06	0.16	0.07	0.08	0.13	0.05	0.07	0.05	0.06	0.07	0.07	0.11	0.05	0.11	0.06	0.10	0.06	0.09	0.08	0.10
K2O	9.86	9.65	9.87	9.75	9.73	9.54	9.79	9.58	9.72	9.58	9.48	9.56	9.48	9.40	9.40	9.48	9.58	9.40	9.52	9.51	9.44	9.52	9.68	9.52	9.38
Na2O	0.00	0.04	0.00	0.00	0.14	0.00	0.00	0.17	0.04	0.07	0.01	0.48	0.00	0.02	0.00	0.10	0.23	0.17	0.05	0.14	0.04	0.00	0.00	0.09	0.00
Cl																									
Total	96.06	95.68	96.78	96.52	96.71	95.71	96.08	96.79	96.29	96.09	95.68	96.87	95.10	95.73	95.52	95.83	96.72	96.54	96.30	95.75	95.44	95.58	96.57	96.13	96.78
Total	96.06	95.68	96.78	96.52	96.71	95.71	96.08	96.79	96.29	96.09	95.68	96.87	95.10	95.73	95.52	95.83	96.72	96.54	96.30	95.75	95.44	95.58	96.57	96.13	96.78
Si	5.349	5.358	5.301	5.276	5.324	5.309	5.316	5.238	5.309	5.351	5.353	5.311	5.370	5.319	5.346	5.342	5.334	5.329	5.357	5.325	5.316	5.350	5.343	5.337	5.394
Al	2.651	2.642	2.699	2.724	2.676	2.691	2.684	2.762	2.691	2.649	2.647	2.689	2.630	2.681	2.654	2.658	2.666	2.671	2.643	2.675	2.684	2.650	2.657	2.663	2.606
Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	0.944	0.938	0.986	1.014	0.922	0.969	1.068	0.985	0.978	0.511	0.535	0.504	0.534	0.483	0.588	0.526	0.563	0.497	0.513	0.518	0.605	0.593	0.630	0.560	0.580
Ti	0.139	0.141	0.115	0.096	0.095	0.081	0.069	0.082	0.102	0.470	0.505	0.501	0.503	0.532	0.528	0.507	0.485	0.496	0.474	0.535	0.553	0.545	0.537	0.518	0.404
Cr	0.006	0.007	0.009	0.010	0.012	0.005	0.017	0.005	0.009	0.010	0.010	0.007	0.002	0.006	0.004	0.006	0.013	0.013	0.000	0.010	0.010	0.020	0.014	0.011	0.011
Fe	2.496	2.436	2.480	2.465	2.549	2.542	2.417	2.469	2.482	2.549	2.534	2.475	2.510	2.537	2.452	2.510	2.438	2.482	2.539	2.424	2.408	2.389	2.335	2.431	2.448
Mn	0.000	0.004	0.006	0.001	0.003	0.012	0.000	0.006	0.004	0.000	0.000	0.010	0.000	0.003	0.003	0.003	0.008	0.006	0.000	0.009	0.000	0.000	0.008	0.004	0.004
Mg	2.166	2.236	2.183	2.226	2.230	2.234	2.193	2.306	2.222	2.094	2.031	2.090	2.059	2.076	2.005	2.059	2.083	2.154	2.120	2.092	1.967	1.994	2.006	2.059	2.245
Mg	5.751	5.761	5.779	5.812	5.810	5.843	5.764	5.852	5.757	5.633	5.615	5.588	5.609	5.637	5.580	5.610	5.589	5.647	5.646	5.587	5.543	5.542	5.530	5.583	5.691
Ca	0.010	0.008	0.013	0.008	0.011	0.010	0.026	0.011	0.012	0.021	0.008	0.011	0.008	0.010	0.011	0.012	0.018	0.008	0.018	0.010	0.016	0.010	0.014	0.013	0.016
K	1.903	1.864	1.889	1.869	1.869	1.849	1.881	1.832	1.869	1.858	1.843	1.837	1.853	1.828	1.823	1.840	1.838	1.809	1.840	1.843	1.831	1.842	1.851	1.836	1.794
Na	0.000	0.012	0.000	0.000	0.041	0.000	0.000	0.000	0.049	0.013	0.021	0.003	0.140	0.000	0.000	0.028	0.067	0.050	0.015	0.041	0.012	0.000	0.000	0.026	0.000
Na	1.912	1.883	1.902	1.877	1.921	1.859	1.907	1.893	1.894	1.900	1.854	1.989	1.861	1.844	1.835	1.880	1.923	1.867	1.973	1.894	1.859	1.852	1.865	1.876	1.810

Cl

Si	5.349	5.358	5.301	5.276	5.324	5.309	5.316	5.238	5.309	5.351	5.353	5.311	5.370	5.319	5.346	5.342	5.334	5.329	5.357	5.325	5.316	5.350	5.343	5.337	5.394
Al	2.651	2.642	2.699	2.724	2.676	2.691	2.684	2.762	2.691	2.649	2.647	2.689	2.630	2.681	2.654	2.658	2.666	2.671	2.643	2.675	2.684	2.650	2.657	2.663	2.606
Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	0.944	0.938	0.986	1.014	0.922	0.969	1.068	0.985	0.978	0.511	0.535	0.504	0.534	0.483	0.588	0.526	0.563	0.497	0.513	0.518	0.605	0.593	0.630	0.560	0.580
Ti	0.139	0.141	0.115	0.096	0.095	0.081	0.069	0.082	0.102	0.470	0.505	0.501	0.503	0.532	0.528	0.507	0.485	0.496	0.474	0.535	0.553	0.545	0.537	0.518	0.404
Cr	0.006	0.007	0.009	0.010	0.012	0.005	0.017	0.005	0.009	0.010	0.010	0.007	0.002	0.006	0.004	0.006	0.013	0.013	0.000	0.010	0.010	0.020	0.014	0.011	0.011
Fe	2.496	2.436	2.480	2.465	2.549	2.542	2.417	2.469	2.482	2.549	2.534	2.475	2.510	2.537	2.452	2.510	2.438	2.482	2.539	2.424	2.408	2.389	2.335	2.431	2.448
Mn	0.000	0.004	0.006	0.001	0.003	0.012	0.000	0.006	0.004	0.000	0.000	0.010	0.000	0.003	0.003	0.003	0.008	0.006	0.000	0.009	0.000	0.000	0.008	0.004	0.004
Mg	2.166	2.236	2.183	2.226	2.230	2.234	2.193	2.306	2.222	2.094	2.031	2.090	2.059	2.076	2.005	2.059	2.083	2.154	2.120	2.092	1.967	1.994	2.006	2.059	2.245
Mg	5.751	5.761	5.779	5.812	5.810	5.843	5.764	5.852	5.797	5.633	5.615	5.598	5.609	5.637	5.580	5.610	5.589	5.647	5.646	5.587	5.543	5.542	5.530	5.583	5.691
Ca	0.010	0.008	0.013	0.008	0.011	0.010	0.026	0.011	0.012	0.021	0.008	0.011	0.008	0.010	0.011	0.012	0.018	0.008	0.018	0.010	0.016	0.010	0.014	0.013	0.016
K	1.903	1.864	1.889	1.869	1.869	1.849	1.881	1.832	1.869	1.858	1.843	1.837	1.853	1.828	1.823	1.840	1.838	1.809	1.840	1.843	1.831	1.842	1.851	1.836	1.794
Na	0.000	0.012	0.000	0.000	0.041	0.000	0.000	0.000	0.049	0.013	0.021	0.003	0.140	0.000	0.006	0.000	0.028	0.067	0.050	0.015	0.041	0.012	0.000	0.026	0.000
Na	1.912	1.883	1.902	1.877	1.921	1.859	1.907	1.893	1.893	1.894	1.900	1.854	1.989	1.861	1.844	1.835	1.880	1.923	1.867	1.873	1.894	1.859	1.852	1.876	1.810
Cl																									
X Mg	0.377	0.388	0.378	0.388	0.384	0.382	0.380	0.394	0.383	0.372	0.362	0.374	0.367	0.368	0.359	0.367	0.373	0.381	0.376	0.374	0.355	0.360	0.363	0.369	0.394
X Fe	0.434	0.423	0.429	0.424	0.439	0.435	0.419	0.422	0.428	0.453	0.451	0.443	0.447	0.450	0.439	0.447	0.436	0.439	0.450	0.434	0.434	0.431	0.422	0.435	0.430
X Ti	0.024	0.025	0.020	0.017	0.016	0.014	0.012	0.014	0.018	0.083	0.090	0.090	0.090	0.094	0.095	0.090	0.087	0.088	0.084	0.096	0.100	0.098	0.097	0.093	0.071
X Al	0.164	0.163	0.171	0.174	0.159	0.166	0.185	0.168	0.169	0.091	0.095	0.090	0.095	0.086	0.105	0.094	0.101	0.088	0.091	0.093	0.109	0.107	0.114	0.100	0.102
Fe/Mg	0.535	0.521	0.532	0.526	0.533	0.532	0.524	0.517	0.528	0.549	0.555	0.542	0.549	0.550	0.550	0.549	0.539	0.535	0.545	0.537	0.550	0.545	0.538	0.541	0.522
Fe+Mg																									

PCA-93-84 biotite																									
	in contact							matrix					matrix												
	d							e					f												
	132	133	134	135	136	137	131-7	b1	b2	b1,2	c1	c2	c3	c4	c5	c1-5	5	g			h				
SiO2	3566	3566	3588	3522	3512	3641	3571	3499	3537	3518	3490	3436	3533	3496	3499	3491	3385	3351	52	53	51-3	61	62	63	61-3
Al2O3	1813	1844	1807	1861	1801	1821	1821	2037	2034	2035	1979	1905	1934	1954	1944	1943	1897	1989	1917	1934	2035	2040	2141	2072	
TiO2	368	383	382	398	400	364	379	157	165	161	397	393	400	389	384	393	509	276	354	383	237	244	233	238	
Cr2O	0.06	0.13	0.00	0.04	0.03	0.00	0.06	0.07	0.08	0.07	0.05	0.07	0.08	0.08	0.03	0.06	0.09	0.05	0.07	0.07	0.12	0.08	0.07	0.09	
FeO	1972	1921	2002	1970	1968	1931	1960	1752	1771	1761	1792	1827	1860	1811	1807	1820	1939	1919	1961	1940	1785	1781	1722	1763	
MnO	0.00	0.03	0.00	0.06	0.00	0.00	0.02	0.00	0.09	0.04	0.04	0.08	0.07	0.06	0.05	0.06	0.04	0.11	0.11	0.09	0.06	0.12	0.10	0.09	
MgO	9.51	9.53	9.68	9.63	9.38	9.76	9.65	10.14	10.13	10.14	8.40	8.46	8.65	8.69	8.49	8.54	9.08	10.45	9.04	9.52	8.91	9.08	8.86	8.95	
CaO	0.10	0.08	0.00	0.04	0.10	0.04	0.07	0.00	0.05	0.02	0.02	0.03	0.00	0.00	0.00	0.01	0.04	0.05	0.07	0.05	0.13	0.04	0.03	0.07	
K2O	9.39	9.30	9.34	9.28	9.32	9.39	9.34	9.80	9.69	9.75	9.48	9.57	9.67	9.83	9.62	9.63	8.50	7.71	8.70	8.30	9.19	9.47	9.70	9.45	
Na2O	0.00	0.14	0.00	0.00	0.00	0.00	0.02	0.00	0.42	0.21	0.44	0.23	0.38	0.25	0.31	0.32	0.28	0.19	0.37	0.28	0.34	0.50	0.46	0.43	
Cl	-	-	-	-	-	-	-	-	0.06	0.10	0.08	0.12	0.14	0.07	0.06	0.04	0.09	0.10	0.06	0.11	0.09	0.15	0.11	0.12	
Total	9625	9633	9681	9656	9570	9676	9646	9452	9563	9506	9513	9419	9619	9547	9488	9518	9543	9397	9565	9502	9428	9525	9614	9522	
Total	9625	9635	9681	9656	9570	9676	9646	9451	9561	9504	9510	9416	9617	9546	9487	9516	9541	9396	9563	9500	9425	9523	9612	9520	
Si	5.383	5.363	5.385	5.299	5.340	5.441	5.372	5.328	5.334	5.331	5.300	5.297	5.324	5.302	5.330	5.311	5.152	5.146	5.289	5.196	5.322	5.328	5.348	5.333	
Al	2.617	2.637	2.615	2.701	2.660	2.559	2.628	2.672	2.666	2.669	2.700	2.703	2.676	2.698	2.670	2.689	2.848	2.854	2.711	2.804	2.678	2.672	2.652	2.667	
	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	
Al	0.609	0.632	0.582	0.600	0.568	0.649	0.603	0.984	0.949	0.967	0.842	0.759	0.759	0.794	0.821	0.795	0.556	0.746	0.718	0.673	0.989	0.968	1.111	1.023	
Ti	0.418	0.433	0.431	0.450	0.457	0.409	0.429	0.180	0.187	0.183	0.453	0.455	0.453	0.444	0.440	0.449	0.583	0.318	0.404	0.435	0.272	0.278	0.261	0.270	
Cr	0.007	0.015	0.000	0.005	0.011	0.000	0.007	0.008	0.009	0.009	0.006	0.009	0.009	0.010	0.003	0.008	0.011	0.006	0.008	0.008	0.015	0.009	0.008	0.011	
Fe	2.489	2.416	2.513	2.479	2.502	2.413	2.466	2.232	2.233	2.232	2.276	2.356	2.344	2.297	2.302	2.315	2.469	2.465	2.488	2.474	2.282	2.255	2.148	2.228	
Mn	0.000	0.004	0.000	0.008	0.000	0.000	0.002	0.000	0.011	0.006	0.005	0.010	0.009	0.008	0.007	0.008	0.005	0.014	0.014	0.011	0.008	0.016	0.013	0.012	
Mg	2.139	2.136	2.165	2.159	2.125	2.174	2.163	2.303	2.278	2.290	1.902	1.944	1.943	1.964	1.927	1.936	2.060	2.391	2.046	2.166	2.031	2.050	1.970	2.017	
	5.663	5.636	5.691	5.701	5.663	5.645	5.670	5.707	5.667	5.687	5.484	5.533	5.517	5.517	5.500	5.511	5.684	5.940	5.678	5.767	5.597	5.576	5.511	5.561	
Ca	0.016	0.013	0.000	0.006	0.016	0.006	0.011	0.000	0.008	0.004	0.004	0.005	0.000	0.000	0.000	0.002	0.006	0.009	0.012	0.009	0.022	0.007	0.004	0.011	
K	1.808	1.784	1.788	1.731	1.808	1.790	1.793	1.904	1.865	1.884	1.837	1.881	1.859	1.902	1.870	1.870	1.650	1.511	1.685	1.615	1.792	1.829	1.846	1.822	
Na	0.000	0.041	0.000	0.000	0.000	0.000	0.006	0.000	0.122	0.061	0.130	0.068	0.111	0.072	0.093	0.095	0.082	0.058	0.110	0.083	0.101	0.147	0.132	0.127	
	1.824	1.838	1.788	1.788	1.824	1.797	1.610	1.904	1.995	1.949	1.971	1.954	1.970	1.974	1.963	1.967	1.738	1.578	1.807	1.708	1.915	1.983	1.982	1.960	
Cl	-	-	-	-	-	-	-	-	0.015	0.026	0.021	0.032	0.037	0.017	0.014	0.011	0.022	0.025	0.017	0.027	0.023	0.039	0.029	0.031	
X Mg	0.378	0.379	0.380	0.379	0.375	0.385	0.382	0.404	0.402	0.403	0.347	0.351	0.352	0.356	0.350	0.351	0.362	0.403	0.360	0.375	0.363	0.368	0.357	0.363	
X Fe	0.440	0.429	0.442	0.435	0.442	0.428	0.435	0.391	0.394	0.392	0.415	0.426	0.425	0.416	0.419	0.420	0.434	0.415	0.438	0.429	0.408	0.404	0.390	0.401	
X Ti	0.074	0.077	0.076	0.079	0.081	0.072	0.076	0.032	0.033	0.032	0.083	0.082	0.082	0.080	0.080	0.081	0.103	0.054	0.071	0.076	0.049	0.050	0.047	0.049	
X Al	0.108	0.112	0.102	0.105	0.100	0.115	0.106	0.172	0.167	0.170	0.154	0.137	0.138	0.144	0.149	0.144	0.098	0.126	0.126	0.117	0.177	0.174	0.202	0.184	
Fe/Mg	0.530	0.531	0.537	0.534	0.541	0.526	0.533	0.492	0.495	0.494	0.545	0.548	0.547	0.539	0.544	0.545	0.545	0.508	0.549	0.533	0.529	0.524	0.522	0.525	

PCA-93-84 plagioclase										matrix a 4			matrix b 5			in contact c 3			in contact d 3		
1.1	1.2	1.3	1.4	1.1-4	1.41	1.42	1.43	1.44	1.45	1.41-5	3.1	3.2	3.3	3.1-3	4.1	4.2	4.3	4.1-3	in cont		
Points	5.1	5.2	5.3	5.4	5.1-4	6.1	6.2	6.3	6.1-3												
SiO2	62.55	62.47	61.91	62.32	62.31	62.18	62.25	61.87	62.10												
Al2O3	24.01	24.16	23.98	24.22	24.07	24.40	24.28	24.30	24.33												
K2O	0.11	0.14	0.16	0.13	0.14	0.13	0.18	0.18	0.16												
CaO	4.89	4.89	4.91	5.04	4.93	5.13	5.04	5.14	5.10												
Na2O	9.17	9.24	8.88	8.85	9.04	9.02	8.95	9.04	9.00												
FeO	0.29	0.34	0.40	0.37	0.35	0.44	0.39	0.41	0.41												
Total	101.02	101.24	100.14	100.93	100.83	101.30	101.09	100.94	101.11												
Si	5.499	5.485	5.492	5.484	5.490	5.461	5.474	5.456	5.464												
Al	2.488	2.500	2.497	2.512	2.499	2.525	2.517	2.526	2.523												
	7.987	7.985	7.989	7.996	7.989	7.986	7.991	7.982	7.986												
K	0.012	0.016	0.018	0.014	0.015	0.014	0.021	0.021	0.019												
Ca	0.461	0.460	0.467	0.475	0.466	0.483	0.475	0.486	0.481												
Na	1.562	1.573	1.528	1.511	1.544	1.536	1.525	1.546	1.536												
	2.035	2.049	2.013	2.000	2.024	2.033	2.021	2.053	2.036												
Fe	0.021	0.025	0.029	0.027	0.026	0.032	0.029	0.031	0.031												
X An	0.227	0.224	0.232	0.238	0.230	0.238	0.235	0.237	0.236												
X Ab	0.768	0.768	0.759	0.756	0.762	0.756	0.755	0.753	0.754												
X Or	0.006	0.008	0.009	0.007	0.007	0.007	0.010	0.010	0.009												

PCA-93-84 ilmenite

points	a1	a2	a3	a4	a5	avg a	b1	b2	b3	b4	b5	avg b
TiO2	54.07	54.30	54.16	54.03	54.21	54.15	53.96	53.74	54.00	53.47	53.91	53.82
Cr2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	46.04	46.36	46.50	46.24	46.48	46.32	46.65	46.82	46.23	46.35	46.00	46.41
MgO	0.12	0.16	0.00	0.00	0.00	0.06	0.00	0.00	0.01	0.08	0.00	0.02
MnO	0.23	0.24	0.17	0.21	0.16	0.20	0.22	0.16	0.15	0.16	0.12	0.16
Total	100.46	101.06	100.83	100.48	100.85	100.74	100.83	100.72	100.39	100.06	100.03	100.41
Ti	1.015	1.013	1.014	1.015	1.015	1.014	1.011	1.009	1.015	1.010	1.010	1.012
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	1.015	1.013	1.014	1.015	1.015	1.014	1.011	1.009	1.015	1.010	1.016	1.012
Fe	0.961	0.962	0.968	0.966	0.967	0.965	0.972	0.978	0.966	0.974	0.965	0.971
Mg	0.004	0.006	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.003	0.000	0.001
Mn	0.005	0.005	0.004	0.004	0.003	0.004	0.005	0.003	0.003	0.003	0.003	0.003
	0.970	0.973	0.972	0.970	0.971	0.971	0.977	0.981	0.973	0.980	0.967	0.975
X Fe	0.990	0.989	0.996	0.995	0.997	0.993	0.995	0.997	0.996	0.993	0.997	0.996
X Mg	0.005	0.006	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.003	0.000	0.001
X Mn	0.005	0.005	0.004	0.005	0.003	0.004	0.005	0.003	0.003	0.003	0.003	0.004
X Ti	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Fe/Fe+Mg	0.995	0.994	1.000	1.000	1.000	0.998	1.000	1.000	1.000	0.997	1.000	0.999
activity	0.990	0.989	0.996	0.995	0.997	0.993	0.995	0.997	0.996	0.993	0.997	0.996

FS-136c-94 biotite																			
Point	inclusion										in contact					in contact			
	a										b					c			
	1.1	1.2	1.3	1.4	1.5	1.6	1.1-6	2.1	2.2	2.3	2.4	2.5	2.1-5	3.1	3.2	3.3	3.4	3.5	3.1-5
SiO2	35.88	35.52	35.41	35.29	35.36	35.56	35.50	35.37	35.64	35.64	34.40	35.91	35.39	34.97	35.48	34.87	34.95	35.20	35.09
Al2O3	22.09	21.45	21.63	21.60	21.30	21.79	21.64	20.14	20.66	20.19	20.05	20.31	20.27	20.58	20.18	20.58	20.17	21.10	20.52
TiO2	3.44	3.58	3.57	3.47	3.38	3.54	3.50	3.36	3.56	3.53	3.49	3.92	3.57	2.92	3.18	2.99	3.42	3.04	3.11
Cr2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	17.50	18.04	17.82	17.40	17.78	17.92	17.74	21.34	21.04	21.45	20.49	21.27	21.12	20.87	21.26	20.83	21.09	20.70	20.95
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.01	0.00	0.03	0.02	0.04	0.00	0.00	0.08	0.07	0.04
MgO	9.09	9.27	9.41	9.12	9.40	9.47	9.29	7.81	7.89	8.02	7.99	8.04	7.95	8.32	8.00	8.14	8.05	7.80	8.06
K2O	8.72	8.98	9.00	8.91	8.93	8.94	8.91	8.98	9.21	9.30	8.87	9.23	9.12	9.08	9.09	8.96	9.11	8.91	9.03
CaO	0.00	0.01	0.01	0.00	0.00	0.06	0.01	0.09	0.00	0.03	0.00	0.04	0.03	0.00	0.02	0.14	0.06	0.04	0.05
Na2O	0.00	0.35	0.01	0.16	0.30	0.22	0.17	0.00	0.10	0.13	0.62	0.17	0.20	0.25	0.00	0.53	0.26	0.31	0.27
Cl	0.06	0.06	0.08	0.04	0.08	0.06	0.06	0.29	0.32	0.35	0.27	0.38	0.32	0.26	0.26	0.31	0.34	0.35	0.30
Total	96.78	97.26	96.94	95.99	96.53	97.56	96.84	97.46	98.42	98.65	96.18	99.30	98.00	97.29	97.47	97.35	97.53	97.52	97.43
Total-O	96.77	97.25	96.92	95.98	96.51	97.55	96.83	97.39	98.35	98.57	96.12	99.21	97.93	97.23	97.41	97.28	97.45	97.44	97.36
Si	5.272	5.233	5.225	5.246	5.244	5.214	5.239	5.301	5.280	5.287	5.226	5.284	5.276	5.246	5.312	5.235	5.247	5.257	5.259
Al	2.728	2.767	2.775	2.754	2.756	2.786	2.761	2.699	2.720	2.713	2.771	2.716	2.724	2.754	2.688	2.765	2.753	2.743	2.741
	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	1.097	0.958	0.986	1.032	0.968	0.980	1.004	0.860	0.888	0.818	0.817	0.806	0.838	0.884	0.873	0.877	0.816	0.971	0.884
Ti	0.380	0.397	0.396	0.388	0.377	0.390	0.388	0.379	0.397	0.394	0.399	0.433	0.400	0.330	0.358	0.337	0.386	0.342	0.351
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe	2.150	2.223	2.198	2.164	2.205	2.197	2.190	2.674	2.607	2.661	2.603	2.618	2.633	2.619	2.662	2.615	2.648	2.585	2.626
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.001	0.000	0.004	0.003	0.005	0.000	0.000	0.010	0.009	0.005
Mg	1.992	2.035	2.070	2.022	2.078	2.070	2.045	1.746	1.742	1.775	1.810	1.764	1.767	1.860	1.784	1.821	1.802	1.737	1.801
	5.619	5.613	5.650	5.606	5.628	5.637	5.626	5.670	5.634	5.649	5.629	5.625	5.641	5.698	5.677	5.650	5.662	5.644	5.666
K	1.634	1.687	1.695	1.690	1.690	1.673	1.678	1.717	1.741	1.760	1.719	1.732	1.734	1.737	1.736	1.716	1.744	1.698	1.726
Ca	0.000	0.001	0.001	0.000	0.000	0.009	0.002	0.014	0.000	0.005	0.000	0.006	0.005	0.000	0.003	0.023	0.009	0.007	0.008
Na	0.000	0.101	0.003	0.046	0.088	0.061	0.050	0.000	0.029	0.037	0.182	0.049	0.059	0.074	0.000	0.154	0.077	0.090	0.079
	1.634	1.789	1.699	1.736	1.778	1.743	1.730	1.731	1.770	1.802	1.901	1.787	1.798	1.811	1.739	1.893	1.830	1.795	1.814
Cl	0.015	0.015	0.019	0.011	0.020	0.015	0.016	0.074	0.080	0.087	0.070	0.094	0.081	0.065	0.066	0.080	0.088	0.088	0.077
XMg	0.355	0.363	0.366	0.361	0.369	0.367	0.363	0.308	0.309	0.314	0.322	0.314	0.313	0.326	0.314	0.322	0.318	0.308	0.318
XFe	0.383	0.396	0.389	0.386	0.392	0.390	0.389	0.472	0.463	0.471	0.462	0.465	0.467	0.460	0.469	0.463	0.468	0.458	0.463
XTi	0.068	0.071	0.070	0.069	0.067	0.069	0.069	0.067	0.070	0.070	0.071	0.077	0.071	0.058	0.063	0.060	0.068	0.061	0.062
XAl	0.195	0.171	0.175	0.184	0.172	0.174	0.178	0.152	0.158	0.145	0.145	0.143	0.149	0.155	0.154	0.155	0.144	0.172	0.156
Fe/Mg	0.519	0.522	0.515	0.517	0.515	0.515	0.517	0.605	0.599	0.600	0.590	0.597	0.598	0.585	0.599	0.589	0.595	0.598	0.593

PS-136c-94 plagioclase

Points	matrix a			matrix b		
	1.1	1.2	1.3	2.1	2.2	2
SiO ₂	62.83	63.94	62.87	64.63	65.70	2.1.2
Al ₂ O ₃	23.59	23.22	23.75	23.37	22.31	65.17
K ₂ O	0.16	0.12	0.06	0.13	0.00	22.84
CaO	4.13	3.66	4.21	3.86	3.00	0.07
Na ₂ O	8.44	9.32	8.96	9.26	9.70	3.43
FeO	0.08	0.15	0.15	0.09	0.11	9.48
Total	99.23	100.41	100.00	101.34	100.82	0.10
						101.08
Si	5.583	5.618	5.555	5.625	5.727	5.676
Al	2.470	2.405	2.474	2.397	2.292	2.345
	8.050	8.023	8.029	8.022	8.019	8.021
K	0.018	0.014	0.007	0.015	0.000	0.008
Ca	0.393	0.344	0.398	0.360	0.280	0.320
Na	1.454	1.587	1.535	1.562	1.639	1.601
	1.865	1.945	1.940	1.937	1.919	1.928
Fe	0.006	0.011	0.011	0.006	0.008	0.007
X An	0.211	0.177	0.205	0.186	0.146	0.166
X Ab	0.780	0.816	0.791	0.806	0.854	0.830
X Or	0.010	0.007	0.004	0.008	0.000	0.004

PS-169-94 garnet

	R1	R2	R2	R2
	g	h	i	
	1	4	4	4
Point	4.2	4-3,4,15,16	4.10-1	
SiO ₂	36.83	37.14	37.49	
Al ₂ O ₃	21.19	21.21	21.39	
TiO ₂	0.00	0.00	0.01	
Cr ₂ O ₃	0.00	0.00	0.01	
FeO	34.64	34.26	33.93	
MnO	1.14	1.09	0.83	
MgO	3.92	4.62	5.16	
CaO	0.98	0.88	0.93	
Total	98.70	99.20	99.74	
Si	5.974	5.975	5.974	
Al	0.026	0.025	0.026	
	6.000	6.000	6.000	
Al	4.025	3.996	3.993	
Ti	0.000	0.000	0.001	
Cr	0.000	0.000	0.001	
	4.025	3.996	3.995	
Fe	4.699	4.610	4.523	
Mn	0.157	0.149	0.112	
Mg	0.949	1.109	1.226	
Ca	0.170	0.152	0.159	
	5.975	6.019	6.019	
XCa	0.028	0.025	0.026	
XMg	0.159	0.184	0.204	
XFe	0.786	0.766	0.751	
XMn	0.026	0.025	0.019	
Fe/	0.832	0.806	0.787	
Fe+Mg				

PS-169-94 biotite

	cont										cont										
	a					b					4					3					
Point	11	12	13	14	15	16	17	18	11-7	11-4	16-8	21	22	23	24	25	26	27	28	29	210
SiO2	35.73	36.10	35.35	35.82	35.14	35.96	36.42	35.54	35.76	35.76	35.97	35.33	36.40	35.65	35.37	36.44	35.64	35.48	35.70	35.80	35.45
Al2O3	20.11	20.10	19.73	19.98	19.91	20.30	21.13	19.53	20.10	19.98	20.32	19.59	20.08	19.79	19.02	19.65	18.82	21.48	21.83	19.86	20.35
TiO2	2.08	2.09	1.94	2.10	1.13	2.12	2.21	2.36	2.00	2.05	2.23	2.67	2.70	2.77	3.93	3.83	4.32	1.22	1.26	2.14	2.20
Cr2O3	0.04	0.03	0.02	0.00	0.00	0.02	0.00	0.03	0.02	0.02	0.02	0.00	0.01	0.02	0.02	0.00	0.03	0.08	0.06	0.03	0.06
FeO	18.34	18.25	18.24	17.93	20.15	17.97	16.99	18.01	18.24	18.19	17.66	15.99	15.86	15.38	15.90	15.96	16.37	18.81	18.52	19.38	19.46
MnO	0.08	0.02	0.01	0.01	0.06	0.00	0.00	0.00	0.02	0.03	0.00	0.04	0.02	0.01	0.02	0.05	0.00	0.13	0.06	0.06	0.09
MgO	10.29	10.71	10.36	10.65	9.34	10.51	9.34	10.05	10.16	10.50	9.97	11.68	12.05	11.57	11.33	11.65	10.78	9.70	8.90	9.68	9.58
K2O	0.12	0.12	0.16	0.09	0.13	0.14	0.09	0.18	0.13	0.12	0.14	0.20	0.13	0.04	0.16	0.05	0.06	0.15	0.15	0.14	0.14
CaO	9.05	9.11	8.95	9.11	8.95	9.24	8.51	8.80	8.97	9.06	8.85	8.57	8.94	8.98	8.54	8.81	8.77	8.90	8.14	9.07	9.04
Na2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cl	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	95.89	96.53	94.76	95.69	94.81	96.26	94.69	94.50	95.39	95.72	95.15	94.07	96.29	94.21	94.29	96.44	94.79	95.95	94.62	96.16	96.37
Total	95.89	96.53	94.76	95.69	94.81	96.26	94.69	94.50	95.39	95.72	95.15	94.07	96.29	94.21	94.29	96.44	94.79	95.95	94.62	96.16	96.37
Si	5.356	5.362	5.359	5.364	5.374	5.353	5.444	5.391	5.375	5.360	5.396	5.330	5.355	5.359	5.325	5.351	5.352	5.310	5.375	5.373	5.313
Al	2.644	2.638	2.641	2.636	2.626	2.647	2.556	2.609	2.625	2.640	2.604	2.670	2.645	2.641	2.675	2.649	2.648	2.690	2.625	2.627	2.687
Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	0.905	0.881	0.885	0.891	0.964	0.916	1.166	0.883	0.936	0.891	0.988	0.815	0.836	0.866	0.700	0.752	0.683	1.100	1.248	0.886	0.907
Ti	0.235	0.234	0.221	0.237	0.130	0.238	0.248	0.269	0.227	0.232	0.252	0.302	0.299	0.313	0.445	0.423	0.488	0.138	0.143	0.242	0.248
Cr	0.005	0.004	0.002	0.000	0.000	0.003	0.000	0.003	0.002	0.003	0.002	0.000	0.002	0.002	0.002	0.000	0.003	0.010	0.007	0.003	0.007
Fe	2.297	2.267	2.313	2.246	2.577	2.237	2.124	2.284	2.293	2.281	2.215	2.018	1.951	1.933	2.003	1.960	2.056	2.354	2.332	2.432	2.439
Mn	0.010	0.003	0.002	0.002	0.008	0.000	0.000	0.000	0.003	0.004	0.000	0.006	0.003	0.001	0.002	0.006	0.000	0.016	0.008	0.007	0.012
Mg	2.297	2.372	2.342	2.377	2.128	2.333	2.082	2.272	2.275	2.347	2.229	2.626	2.642	2.592	2.543	2.550	2.413	2.163	1.997	2.166	2.140
Mg	5.749	5.761	5.765	5.753	5.807	5.727	5.620	5.711	5.737	5.757	5.686	5.767	5.733	5.707	5.695	5.691	5.643	5.781	5.735	5.736	5.753
K	0.020	0.019	0.025	0.015	0.021	0.022	0.014	0.029	0.021	0.020	0.022	0.033	0.021	0.006	0.026	0.008	0.010	0.024	0.024	0.023	0.023
Ca	1.728	1.727	1.731	1.740	1.747	1.754	1.622	1.703	1.719	1.732	1.693	1.649	1.677	1.722	1.641	1.651	1.681	1.699	1.564	1.737	1.729
Na	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Na	1.748	1.746	1.756	1.755	1.768	1.776	1.636	1.732	1.740	1.751	1.715	1.682	1.726	1.728	1.667	1.659	1.691	1.723	1.588	1.760	1.752
Cl	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
XMg	0.400	0.412	0.406	0.413	0.366	0.407	0.370	0.398	0.397	0.408	0.392	0.455	0.461	0.454	0.447	0.448	0.428	0.374	0.348	0.378	0.372
XFe	0.400	0.394	0.401	0.390	0.444	0.391	0.378	0.400	0.400	0.396	0.389	0.350	0.340	0.339	0.352	0.344	0.364	0.407	0.407	0.424	0.424
XTi	0.041	0.041	0.038	0.041	0.022	0.042	0.044	0.047	0.040	0.040	0.044	0.052	0.052	0.055	0.078	0.074	0.086	0.024	0.025	0.042	0.043
XAl	0.157	0.153	0.154	0.155	0.166	0.160	0.207	0.155	0.163	0.155	0.174	0.141	0.146	0.152	0.123	0.132	0.121	0.190	0.218	0.154	0.158
Fe/(Fe+Mg)	0.500	0.489	0.497	0.486	0.548	0.489	0.505	0.501	0.502	0.493	0.499	0.435	0.425	0.427	0.441	0.435	0.460	0.521	0.539	0.529	0.533

PS-169-94 plagioclase

matrix a													matrix b												
6													4												
1.1 1.2 1.3 1.4 1.5 1.6 1.1-6													2.1 2.2 2.3 2.4 2.5 2.1-5												
31 32 33 34 35 36 37 38													31 32 33 34 35 36 37 38												
Points	62.14	63.29	62.48	62.56	62.92	62.09	62.58	63.10	63.55	63.90	63.53	63.56	63.53	60.98	60.51	59.92	62.88	63.13	63.53	63.49	64.01				
SiO2	23.47	23.69	23.41	23.85	24.11	23.74	23.71	23.18	23.40	23.54	23.41	23.48	23.40	24.59	24.35	24.22	22.82	23.33	23.16	23.43	23.49				
Al2O3	0.42	0.46	0.47	0.41	0.35	0.39	0.42	0.38	0.42	0.26	0.33	0.30	0.34	0.42	0.30	0.34	0.16	0.34	0.24	0.25	0.26				
K2O	4.09	4.27	4.28	4.21	4.32	4.31	4.5	4.60	4.45	4.43	4.49	4.38	4.47	6.21	6.25	6.14	4.25	4.57	4.44	4.58	4.42				
CaO	9.20	8.97	8.99	8.47	8.60	8.52	8.79	8.51	8.96	9.21	8.81	9.00	8.90	7.51	7.49	7.84	8.94	8.52	8.79	8.85	8.75				
Na2O	0.11	0.00	0.04	0.00	0.07	0.01	0.04	0.00	0.04	0.02	0.04	0.09	0.04	0.18	0.22	0.26	0.09	0.04	0.09	0.12	0.01				
FeO	99.43	100.68	99.67	99.50	100.37	99.06	99.79	99.77	100.82	101.36	100.61	100.81	100.67	99.89	99.12	98.72	99.14	99.93	100.25	100.72	100.94				
Total	5.541	5.563	5.554	5.552	5.540	5.541	5.549	5.590	5.580	5.579	5.584	5.578	5.582	5.427	5.427	5.408	5.604	5.583	5.600	5.577	5.598				
Si	2.467	2.454	2.453	2.495	2.502	2.497	2.478	2.421	2.422	2.422	2.425	2.429	2.424	2.580	2.575	2.576	2.398	2.432	2.406	2.426	2.421				
Al	8.008	8.017	8.007	8.047	8.042	8.038	8.037	8.021	8.002	8.001	8.009	8.007	8.006	8.007	8.002	7.984	8.002	8.015	8.006	8.003	8.019				
K	0.048	0.052	0.053	0.047	0.039	0.045	0.047	0.043	0.047	0.029	0.037	0.033	0.038	0.048	0.035	0.039	0.019	0.039	0.027	0.028	0.029				
Ca	0.390	0.402	0.408	0.400	0.407	0.412	0.403	0.436	0.418	0.414	0.422	0.412	0.420	0.592	0.600	0.594	0.406	0.433	0.419	0.431	0.414				
Na	1.591	1.529	1.549	1.458	1.468	1.474	1.512	1.462	1.526	1.559	1.501	1.532	1.516	1.295	1.302	1.372	1.545	1.461	1.502	1.508	1.484				
Fe	2.029	1.983	2.010	1.905	1.914	1.931	1.962	1.941	1.991	2.002	1.960	1.977	1.974	1.935	1.937	2.005	1.970	1.933	1.948	1.967	1.927				
Fe	0.008	0.000	0.003	0.000	0.005	0.001	0.003	0.000	0.003	0.002	0.003	0.006	0.003	0.013	0.016	0.020	0.007	0.003	0.007	0.009	0.001				
X An	0.192	0.203	0.203	0.210	0.213	0.213	0.206	0.225	0.210	0.207	0.215	0.208	0.213	0.306	0.310	0.296	0.206	0.224	0.215	0.219	0.215				
X Ab	0.784	0.771	0.771	0.765	0.767	0.763	0.770	0.753	0.766	0.779	0.766	0.775	0.768	0.689	0.672	0.684	0.784	0.756	0.771	0.767	0.770				
X Or	0.024	0.026	0.026	0.025	0.020	0.023	0.024	0.022	0.024	0.014	0.019	0.017	0.019	0.025	0.018	0.019	0.010	0.020	0.014	0.014	0.015				
incl cont													incl cont												
c d 4													e f 6												
31-3 34-8													5 41-5 46-11												
Points	60.47	63.41	62.52	63.69	62.98	61.54	61.92	62.50	62.88	61.82	63.13	63.07	62.40	62.53	62.63	62.53	62.40	62.53	62.63	62.53	62.63				
SiO2	24.39	23.25	23.82	24.31	24.25	24.07	24.23	23.64	23.83	23.24	23.14	23.75	23.28	24.14	24.10	24.10	23.75	23.28	24.14	24.10	24.10				
Al2O3	0.35	0.25	0.70	0.70	0.59	0.67	0.67	0.30	0.28	0.33	0.32	0.22	0.33	0.67	0.59	0.59	0.33	0.67	0.59	0.59	0.59				
K2O	6.20	4.45	5.24	5.49	5.63	5.22	5.59	4.45	4.49	4.45	3.95	4.52	4.47	5.43	5.28	5.28	4.47	5.43	5.28	5.28	5.28				
CaO	7.61	8.77	8.25	8.05	8.00	8.23	8.35	8.50	8.87	8.73	9.29	8.94	8.95	8.18	8.23	8.23	8.94	8.95	8.18	8.23	8.23				
Na2O	0.22	0.07	0.18	0.13	0.09	0.18	0.11	0.15	0.25	0.14	0.08	0.20	0.07	0.14	0.13	0.13	0.07	0.14	0.13	0.13	0.13				
FeO	99.24	100.20	100.71	102.37	101.54	99.91	100.87	99.56	100.60	98.71	99.91	100.70	99.50	101.08	100.85	100.85	99.91	99.50	101.08	100.85	100.85				
Total	5.421	5.592	5.516	5.520	5.504	5.476	5.465	5.551	5.537	5.547	5.590	5.546	5.556	5.496	5.503	5.503	5.546	5.556	5.496	5.503	5.503				
Si	2.577	2.417	2.477	2.483	2.498	2.525	2.521	2.475	2.473	2.459	2.416	2.462	2.444	2.501	2.500	2.500	2.462	2.444	2.501	2.500	2.500				
Al	7.998	8.009	7.993	8.003	8.002	8.001	7.986	8.026	8.010	8.006	8.006	8.008	8.000	7.997	8.004	8.004	8.006	8.000	7.997	8.004	8.004				
K	0.041	0.028	0.079	0.077	0.066	0.076	0.076	0.034	0.032	0.037	0.036	0.025	0.037	0.075	0.066	0.066	0.036	0.037	0.075	0.066	0.066				
Ca	0.595	0.421	0.496	0.509	0.527	0.498	0.529	0.425	0.424	0.428	0.375	0.426	0.426	0.512	0.498	0.498	0.375	0.426	0.512	0.498	0.498				
Na	1.323	1.500	1.411	1.353	1.355	1.420	1.428	1.463	1.515	1.519	1.595	1.525	1.545	1.393	1.404	1.404	1.595	1.545	1.393	1.404	1.404				
Fe	1.959	1.949	1.986	1.939	1.948	1.994	2.033	1.922	1.971	1.984	2.005	1.976	2.008	1.980	1.967	1.967	2.005	2.008	1.980	1.967	1.967				
Fe	0.016	0.005	0.013	0.010	0.006	0.014	0.008	0.011	0.019	0.011	0.006	0.015	0.005	0.010	0.010	0.010	0.006	0.015	0.005	0.010	0.010				
X An	0.304	0.216	0.250	0.263	0.271	0.250	0.260	0.221	0.215	0.216	0.187	0.216	0.212	0.259	0.253	0.253	0.187	0.216	0.212	0.259	0.253				
X Ab	0.675	0.770	0.710	0.698	0.696	0.712	0.702	0.761	0.769	0.766	0.795	0.772	0.769	0.704	0.714	0.714	0.769	0.795	0.769	0.704	0.714				
X Or	0.021	0.015	0.040	0.040	0.034	0.038	0.037	0.018	0.016	0.019	0.018	0.013	0.018	0.038	0.033	0.033	0.018	0.018	0.013	0.038	0.033				

PCA-200-85 garnet

Point	1.22	1.23	1.1	1.2	1.4	1.3	1.5	1.6	1.7	1.8	1.9	1.10	1.12	1.13	1.14	1.15	1.11	1.16	1.17	1.18	1.19
SiO ₂	37.82	37.78	38.28	38.49	38.06	38.17	37.90	38.49	38.14	38.19	38.33	38.24	38.08	37.82	38.39	38.25	38.93	38.58	38.09	37.98	38.01
Al ₂ O ₃	21.17	21.28	21.17	21.39	21.21	21.16	21.48	21.59	21.45	21.20	21.51	21.46	21.31	21.33	21.58	21.37	21.91	21.39	21.41	21.32	21.28
TiO ₂	0.08	0.02	0.05	0.07	0.00	0.01	0.00	0.00	0.06	0.02	0.12	0.09	0.15	0.03	0.02	0.13	0.02	0.13	0.16	0.04	0.14
Cr ₂ O ₃	0.06	0.09	0.16	0.14	0.02	0.04	0.02	0.09	0.09	0.10	0.15	0.05	0.08	0.12	0.06	0.07	0.09	0.12	0.19	0.01	0.12
FeO	31.86	29.98	31.23	30.14	29.85	29.53	29.09	29.80	29.52	29.41	29.43	29.19	29.39	29.44	29.99	29.89	29.46	30.32	30.50	30.70	31.19
MnO	0.34	0.34	0.30	0.35	0.28	0.30	0.35	0.22	0.28	0.38	0.39	0.40	0.39	0.29	0.26	0.31	0.31	0.39	0.42	0.39	0.35
MgO	6.24	7.54	6.85	7.45	7.54	7.57	7.72	7.73	7.51	7.49	7.54	7.65	7.56	7.44	7.51	7.32	7.61	7.42	7.18	7.03	7.08
CaO	1.88	1.98	1.97	2.41	2.25	2.32	2.40	2.39	2.27	2.28	2.50	2.54	2.54	2.46	2.15	2.03	2.56	1.99	2.00	1.93	1.97
Total	99.48	99.03	100.04	100.52	99.21	99.10	98.99	100.32	99.35	99.11	100.00	99.65	99.56	98.95	99.96	99.40	100.94	100.42	100.00	99.43	100.16
Si	5.990	5.963	6.006	5.986	5.990	6.006	5.963	5.980	5.984	6.008	5.976	5.978	5.969	5.966	5.989	6.003	5.998	6.003	5.965	5.985	5.960
Al	0.010	0.037	0.000	0.014	0.010	0.000	0.037	0.020	0.016	0.000	0.024	0.022	0.031	0.034	0.011	0.000	0.002	0.000	0.035	0.015	0.040
	6.000	6.000	6.006	6.000	6.000	6.006	6.000	6.000	6.000	6.008	6.000	6.000	6.000	6.000	6.000	6.003	6.000	6.003	6.000	6.000	6.000
Al	3.943	3.923	3.916	3.908	3.925	3.925	3.948	3.935	3.951	3.932	3.930	3.933	3.908	3.932	3.958	3.954	3.979	3.924	3.918	3.946	3.894
Ti	0.010	0.002	0.006	0.008	0.000	0.001	0.000	0.000	0.007	0.002	0.014	0.011	0.018	0.004	0.002	0.015	0.002	0.015	0.019	0.005	0.017
Cr	0.008	0.011	0.020	0.017	0.002	0.005	0.002	0.011	0.011	0.012	0.018	0.006	0.010	0.015	0.007	0.009	0.011	0.015	0.024	0.001	0.015
	3.960	3.936	3.941	3.933	3.927	3.931	3.950	3.946	3.969	3.946	3.962	3.950	3.935	3.951	3.968	3.978	3.992	3.953	3.961	3.952	3.925
Fe	4.220	3.957	4.098	3.920	3.929	3.886	3.828	3.872	3.873	3.869	3.837	3.816	3.853	3.884	3.913	3.923	3.796	3.945	3.995	4.046	4.090
Mn	0.046	0.045	0.040	0.046	0.037	0.040	0.047	0.029	0.037	0.051	0.052	0.053	0.052	0.039	0.034	0.041	0.040	0.051	0.056	0.052	0.046
Mg	1.473	1.774	1.602	1.727	1.768	1.775	1.810	1.790	1.756	1.756	1.752	1.782	1.766	1.749	1.746	1.712	1.748	1.721	1.676	1.651	1.654
Ca	0.319	0.335	0.331	0.402	0.379	0.391	0.405	0.398	0.382	0.384	0.418	0.425	0.427	0.416	0.359	0.341	0.423	0.332	0.336	0.326	0.331
	6.064	6.115	6.076	6.111	6.114	6.092	6.096	6.091	6.054	6.068	6.065	6.083	6.110	6.091	6.053	6.024	6.017	6.065	6.072	6.081	6.126
XCa	0.053	0.055	0.055	0.066	0.062	0.064	0.066	0.065	0.063	0.063	0.069	0.070	0.070	0.068	0.059	0.057	0.070	0.055	0.055	0.054	0.054
XMg	0.243	0.290	0.264	0.283	0.289	0.291	0.297	0.294	0.290	0.289	0.289	0.293	0.289	0.287	0.288	0.284	0.290	0.284	0.276	0.272	0.270
XFe	0.696	0.647	0.674	0.642	0.643	0.638	0.628	0.636	0.640	0.638	0.633	0.627	0.631	0.638	0.646	0.651	0.631	0.651	0.658	0.665	0.668
XMn	0.008	0.007	0.007	0.008	0.006	0.007	0.008	0.005	0.006	0.008	0.008	0.009	0.008	0.006	0.006	0.007	0.007	0.008	0.009	0.009	0.008
Fe/	0.741	0.691	0.719	0.694	0.690	0.686	0.679	0.684	0.688	0.688	0.687	0.682	0.686	0.689	0.691	0.696	0.685	0.696	0.704	0.710	0.712
Fe+Mg																					

PCA-200-85 garnet

Point	2.9	2.10	2.11	2.12	2.13	2.14	2.15	2.16	2.17	2.18	2.19	2.20	2.21	2.22	2.23	2.24	2.25	2.26	2.27	2.28
SiO ₂	38.58	38.23	38.50	38.79	38.58	38.50	38.63	38.29	38.43	38.34	38.54	38.51	38.50	38.49	38.36	38.04	38.05	38.13	38.08	38.34
Al ₂ O ₃	21.57	21.74	22.00	21.54	21.41	21.46	21.99	21.39	21.47	21.85	21.45	21.31	21.59	21.70	21.52	21.39	22.00	22.24	21.94	22.19
TiO ₂	0.07	0.03	0.07	0.00	0.00	0.00	0.13	0.05	0.12	0.01	0.12	0.11	0.09	0.01	0.05	0.05	0.03	0.00	0.00	0.06
Cr ₂ O ₃	0.12	0.05	0.02	0.00	0.00	0.09	0.13	0.11	0.12	0.11	0.08	0.10	0.14	0.11	0.11	0.11	0.05	0.00	0.00	0.06
FeO	29.41	29.60	29.72	29.42	29.98	29.77	29.68	29.75	30.06	30.27	30.25	30.31	30.15	30.58	30.13	31.02	29.26	29.34	30.03	29.22
MnO	0.31	0.28	0.41	0.29	0.30	0.35	0.39	0.24	0.40	0.33	0.41	0.38	0.41	0.43	0.33	0.32	0.39	0.32	0.36	0.45
MgO	7.69	7.68	7.45	7.94	7.59	7.94	7.84	7.61	7.80	7.68	7.38	7.59	7.72	7.52	7.36	6.97	7.77	7.83	7.44	8.00
CaO	2.11	2.02	1.97	1.99	1.91	2.00	1.99	1.91	1.94	1.94	2.01	1.90	1.99	1.96	2.06	2.00	1.80	1.80	1.71	1.85
Total	99.88	99.66	100.15	99.98	99.77	100.11	100.82	99.37	100.39	100.57	100.30	100.25	100.65	100.80	99.92	99.95	99.35	99.66	99.56	100.17
Si	6.007	5.972	5.982	6.026	6.024	5.991	5.963	6.002	5.975	5.951	6.001	6.000	5.972	5.970	5.992	5.971	5.952	5.943	5.962	5.944
Al	0.000	0.028	0.018	0.000	0.000	0.009	0.037	0.000	0.025	0.049	0.000	0.000	0.028	0.030	0.008	0.029	0.048	0.057	0.038	0.056
	6.007	6.000	6.000	6.026	6.024	6.000	6.000	6.002	6.000	6.000	6.001	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
Al	3.959	3.976	4.012	3.945	3.941	3.928	3.964	3.953	3.910	3.950	3.938	3.914	3.920	3.937	3.956	3.930	4.009	4.028	4.010	3.999
Ti	0.008	0.004	0.008	0.000	0.000	0.000	0.015	0.006	0.014	0.001	0.014	0.013	0.010	0.001	0.006	0.006	0.004	0.001	0.000	0.006
Cr	0.015	0.006	0.002	0.000	0.000	0.011	0.016	0.014	0.015	0.013	0.010	0.012	0.017	0.013	0.014	0.014	0.007	0.000	0.000	0.007
	3.982	3.986	4.023	3.945	3.941	3.939	3.995	3.973	3.939	3.965	3.962	3.940	3.948	3.952	3.975	3.950	4.020	4.029	4.010	4.012
Fe	3.830	3.867	3.862	3.822	3.915	3.874	3.831	3.900	3.909	3.930	3.940	3.950	3.911	3.966	3.936	4.072	3.828	3.824	3.932	3.789
Mn	0.041	0.037	0.054	0.038	0.040	0.046	0.051	0.032	0.053	0.043	0.054	0.050	0.054	0.056	0.044	0.043	0.052	0.042	0.048	0.059
Mg	1.784	1.788	1.725	1.838	1.766	1.841	1.803	1.778	1.807	1.777	1.713	1.762	1.785	1.738	1.713	1.631	1.811	1.820	1.737	1.849
Ca	0.352	0.338	0.328	0.331	0.320	0.333	0.329	0.321	0.323	0.323	0.335	0.317	0.331	0.326	0.345	0.336	0.301	0.300	0.287	0.308
	6.011	6.036	5.971	6.032	6.040	6.095	6.023	6.035	6.102	6.080	6.054	6.087	6.093	6.087	6.038	6.092	5.992	5.986	6.004	6.005
X _{Ca}	0.059	0.056	0.055	0.055	0.053	0.055	0.055	0.053	0.053	0.053	0.055	0.052	0.054	0.054	0.057	0.055	0.050	0.050	0.048	0.051
X _{Mg}	0.297	0.296	0.289	0.305	0.292	0.302	0.299	0.295	0.296	0.292	0.283	0.290	0.293	0.286	0.284	0.268	0.302	0.304	0.289	0.308
X _{Fe}	0.637	0.641	0.647	0.634	0.648	0.636	0.636	0.646	0.641	0.646	0.651	0.649	0.642	0.652	0.652	0.668	0.639	0.639	0.655	0.631
X _{Mn}	0.007	0.006	0.009	0.006	0.007	0.008	0.008	0.005	0.009	0.007	0.009	0.008	0.009	0.009	0.007	0.007	0.009	0.007	0.008	0.010
Fe/(Fe+Mg)	0.682	0.684	0.691	0.675	0.689	0.678	0.680	0.687	0.684	0.689	0.697	0.691	0.687	0.695	0.697	0.714	0.679	0.678	0.694	0.672

[illegible]

PCA-200-85 biotite

Point	matrix a															matrix b												
	2.8	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.1-8	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.1-8	8	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9
SiO2	36.02	35.26	36.06	35.73	36.06	36.23	36.12	36.15	35.93	35.98	35.97	36.62	36.25	36.12	35.74	36.02	35.97	36.08	36.59	36.16	36.36	36.45	36.54	36.63	36.72	36.81	36.90	37.00
Al2O3	18.53	18.11	17.93	17.94	18.22	18.12	17.94	19.33	18.11	18.22	17.86	17.49	17.74	17.68	17.74	17.52	17.37	17.70	18.27	18.27	18.22	17.96	18.02	18.11	18.20	18.29	18.38	18.47
TiO2	4.09	4.01	4.01	4.13	4.19	4.17	4.04	3.04	4.09	4.83	4.74	5.21	4.96	4.71	5.08	5.10	4.74	4.92	4.05	4.23	4.11	4.05	4.14	4.23	4.32	4.41	4.50	4.59
Cr2O3	0.13	0.00	0.10	0.11	0.07	0.11	0.03	0.02	0.08	0.12	0.10	0.10	0.13	0.17	0.05	0.14	0.04	0.11	0.06	0.15	0.14	0.06	0.14	0.23	0.32	0.41	0.50	0.59
FeO	17.58	17.42	17.65	17.33	17.31	17.20	17.29	16.72	17.40	16.93	16.73	16.74	16.67	17.13	16.85	16.86	17.25	16.90	17.27	17.01	17.20	17.54	17.88	18.22	18.56	18.90	19.24	19.58
MnO	0.12	0.00	0.01	0.11	0.10	0.02	0.03	0.10	0.06	0.03	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.03	0.05	0.13	0.22	0.31	0.40	0.49	0.58	0.67
MgO	10.73	10.38	10.57	10.48	10.60	10.47	10.49	10.08	10.53	10.20	10.13	10.31	10.18	10.99	10.24	10.04	10.52	10.33	10.57	10.37	11.07	10.90	11.24	11.58	11.92	12.26	12.60	12.94
K2O	0.03	0.10	0.05	0.03	0.01	0.06	0.00	0.08	0.04	0.13	0.10	0.02	0.03	0.10	0.02	0.00	0.00	0.05	0.11	0.07	0.10	0.12	0.21	0.30	0.39	0.48	0.57	0.66
CaO	9.72	9.58	9.61	9.67	9.78	9.85	9.69	9.71	9.70	9.98	9.60	9.86	9.84	9.64	9.65	9.73	9.86	9.77	9.39	9.47	9.73	9.59	9.93	10.27	10.61	10.95	11.29	11.63
Na2O	0.00	0.21	0.00	0.00	0.09	0.00	0.00	0.02	0.04	0.13	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.02	0.00	0.00	0.05	0.00	0.09	0.18	0.27	0.36	0.45	0.54
Cl	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	96.95	95.07	95.99	95.53	96.43	96.23	95.63	95.25	95.98	96.55	95.25	96.35	95.80	96.59	95.37	95.41	95.75	95.88	96.31	95.71	96.77	96.86	96.95	97.04	97.13	97.22	97.31	97.40
Total	96.95	95.07	95.99	95.53	96.43	96.23	95.63	95.25	95.98	96.55	95.25	96.35	95.80	96.59	95.37	95.41	95.75	95.88	96.31	95.71	96.77	96.86	96.95	97.04	97.13	97.22	97.31	97.40
Si	5.349	5.348	5.408	5.386	5.381	5.413	5.429	5.430	5.388	5.363	5.416	5.451	5.429	5.376	5.382	5.423	5.412	5.406	5.441	5.415	5.401	5.411	5.420	5.429	5.438	5.447	5.456	5.465
Al	2.651	2.652	2.592	2.614	2.619	2.587	2.571	2.570	2.612	2.637	2.584	2.549	2.571	2.624	2.618	2.577	2.588	2.594	2.559	2.585	2.599	2.589	2.600	2.609	2.618	2.627	2.636	2.645
Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	0.593	0.587	0.579	0.575	0.587	0.604	0.607	0.853	0.590	0.564	0.587	0.520	0.561	0.479	0.532	0.532	0.493	0.533	0.643	0.632	0.546	0.565	0.574	0.583	0.592	0.601	0.610	0.619
Ti	0.457	0.457	0.452	0.468	0.470	0.469	0.457	0.343	0.461	0.541	0.537	0.583	0.559	0.527	0.575	0.577	0.536	0.555	0.453	0.476	0.459	0.452	0.461	0.470	0.479	0.488	0.497	0.506
Cr	0.015	0.000	0.012	0.013	0.008	0.013	0.004	0.002	0.009	0.014	0.012	0.012	0.015	0.020	0.006	0.017	0.005	0.013	0.007	0.018	0.016	0.007	0.016	0.025	0.034	0.043	0.052	0.061
Fe	2.183	2.210	2.214	2.185	2.160	2.149	2.173	2.100	2.182	2.110	2.107	2.084	2.088	2.132	2.122	2.123	2.170	2.117	2.148	2.130	2.137	2.178	2.187	2.196	2.205	2.214	2.223	2.232
Mn	0.015	0.000	0.001	0.014	0.013	0.003	0.004	0.013	0.007	0.004	0.003	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.004	0.006	0.016	0.025	0.034	0.043	0.052	0.061	0.070
Mg	2.375	2.347	2.363	2.355	2.357	2.331	2.350	2.256	2.354	2.266	2.273	2.287	2.272	2.438	2.298	2.253	2.359	2.306	2.342	2.314	2.411	2.420	2.429	2.438	2.447	2.456	2.465	2.474
Mg	5.639	5.601	5.621	5.610	5.596	5.568	5.594	5.568	5.604	5.500	5.518	5.486	5.494	5.598	5.534	5.502	5.563	5.524	5.593	5.575	5.615	5.629	5.638	5.647	5.656	5.665	5.674	5.683
K	0.005	0.016	0.008	0.005	0.002	0.010	0.000	0.013	0.006	0.021	0.016	0.003	0.005	0.016	0.003	0.000	0.000	0.008	0.018	0.011	0.016	0.019	0.028	0.037	0.046	0.055	0.064	0.073
Ca	1.842	1.854	1.839	1.860	1.862	1.877	1.858	1.861	1.856	1.898	1.844	1.872	1.880	1.831	1.854	1.869	1.893	1.868	1.781	1.809	1.844	1.816	1.825	1.834	1.843	1.852	1.861	1.870
Na	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Na	1.846	1.870	1.847	1.865	1.864	1.887	1.858	1.874	1.862	1.918	1.860	1.876	1.885	1.847	1.857	1.869	1.893	1.876	1.799	1.821	1.860	1.835	1.844	1.853	1.862	1.871	1.880	1.889
Cl	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
XMg	0.421	0.419	0.420	0.420	0.421	0.419	0.420	0.405	0.420	0.412	0.412	0.417	0.414	0.436	0.415	0.409	0.424	0.417	0.419	0.415	0.436	0.428	0.437	0.446	0.455	0.464	0.473	0.482
XFe	0.387	0.395	0.394	0.389	0.386	0.386	0.388	0.377	0.389	0.384	0.382	0.380	0.380	0.381	0.383	0.386	0.390	0.383	0.384	0.392	0.381	0.387	0.396	0.405	0.414	0.423	0.432	0.441
XTi	0.081	0.082	0.080	0.083	0.084	0.084	0.082	0.062	0.082	0.098	0.097	0.106	0.102	0.094	0.104	0.105	0.096	0.100	0.081	0.085	0.082	0.080	0.089	0.098	0.107	0.116	0.125	0.134
XAl	0.105	0.105	0.103	0.102	0.105	0.108	0.109	0.153	0.105	0.103	0.106	0.095	0.102	0.086	0.096	0.097	0.089	0.097	0.115	0.113	0.097	0.100	0.109	0.118	0.127	0.136	0.145	0.154
Fe/	0.479	0.485	0.484	0.481	0.478	0.480	0.481	0.482	0.481	0.482	0.481	0.477	0.479	0.467	0.480	0.485	0.479	0.479	0.478	0.479	0.466	0.475	0.484	0.493	0.502	0.511	0.520	0.529
Fe+Mg	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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	matrix c							in contact d							matrix e			matrix f	
	125	126	127	121-7	141	142	143	144	145	146	147	141-7	a1	a2	a3	a1-3	b1	b2	b1,2
Point	125	126	127	121-7	141	142	143	144	145	146	147	141-7	a1	a2	a3	a1-3	b1	b2	b1,2
SiO2	36.50	36.32	36.30	36.34	35.67	36.66	36.78	36.46	35.34	35.78	36.10	36.39	35.11	35.37	35.57	35.35	35.80	36.97	36.39
Al2O3	18.10	17.83	17.70	18.01	19.94	18.67	19.06	18.87	18.29	18.48	17.51	19.14	18.40	18.54	18.63	18.52	20.00	21.16	20.58
TiO2	4.05	4.03	4.11	4.09	1.64	1.63	1.65	1.55	2.32	2.21	3.98	1.62	4.18	4.10	4.30	4.19	2.91	3.56	3.24
Cr2O3	0.07	0.09	0.08	0.09	0.04	0.07	0.04	0.00	0.10	0.06	0.08	0.04	0.09	0.07	0.04	0.07	0.03	0.04	0.04
FeO	16.89	17.56	17.54	17.29	16.87	17.12	16.88	16.36	16.79	16.90	17.48	16.81	16.70	16.77	16.77	16.75	16.46	14.45	15.46
MnO	0.00	0.01	0.01	0.03	0.00	0.03	0.00	0.00	0.05	0.00	0.02	0.01	0.05	0.03	0.07	0.05	0.05	0.09	0.07
MgO	11.03	10.85	10.86	10.81	11.77	12.31	12.58	12.64	12.74	12.63	11.34	12.33	9.95	9.90	10.09	9.98	9.02	8.26	8.64
K2O	0.04	0.08	0.09	0.09	0.07	0.00	0.02	0.01	0.04	0.02	0.07	0.03	0.03	0.01	0.00	0.01	0.00	0.05	0.03
CaO	9.49	9.67	9.58	9.56	9.47	9.67	9.64	9.73	9.50	9.57	9.59	9.63	9.53	9.90	9.70	9.71	9.14	8.95	9.05
Na2O	0.00	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.09	0.00	0.01	0.43	0.13	0.40	0.32	0.21	0.20	0.21
Cl	-	-	-	-	-	-	-	-	-	-	-	-	-	0.18	0.19	0.20	0.19	0.14	0.14
Total	96.17	96.44	95.97	96.32	95.47	96.16	96.68	95.62	95.17	95.74	96.18	95.98	94.85	95.01	95.77	95.14	93.76	93.87	93.82
Total-O	96.17	96.44	95.97	96.32	95.47	96.16	96.68	95.62	95.17	95.74	96.18	95.98	94.61	94.97	95.72	95.10	93.73	93.84	93.79
Si	5.431	5.419	5.401	5.417	5.343	5.459	5.436	5.443	5.332	5.362	5.403	5.420	5.345	5.366	5.350	5.354	5.444	5.526	5.485
Al	2.569	2.581	2.599	2.583	2.657	2.541	2.584	2.557	2.668	2.638	2.597	2.580	2.655	2.634	2.650	2.646	2.556	2.474	2.515
	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	0.607	0.555	0.531	0.583	0.864	0.737	0.757	0.765	0.586	0.627	0.493	0.781	0.646	0.681	0.653	0.660	1.029	1.254	1.142
Ti	0.453	0.452	0.464	0.459	0.185	0.183	0.183	0.174	0.263	0.249	0.448	0.181	0.479	0.468	0.486	0.478	0.333	0.400	0.367
Cr	0.008	0.011	0.009	0.011	0.005	0.008	0.005	0.000	0.012	0.007	0.009	0.004	0.011	0.008	0.005	0.008	0.004	0.005	0.005
Fe	2.102	2.191	2.201	2.155	2.113	2.132	2.086	2.043	2.119	2.118	2.189	2.094	2.126	2.127	2.109	2.121	2.093	1.807	1.950
Mn	0.000	0.001	0.001	0.004	0.000	0.004	0.000	0.000	0.006	0.000	0.003	0.001	0.007	0.004	0.008	0.006	0.007	0.011	0.009
Mg	2.446	2.413	2.428	2.401	2.627	2.732	2.771	2.812	2.865	2.821	2.530	2.736	2.258	2.240	2.262	2.253	2.044	1.840	1.942
	5.616	5.623	5.634	5.612	5.794	5.796	5.802	5.794	5.851	5.822	5.672	5.796	5.527	5.528	5.523	5.526	5.510	5.317	5.414
K	0.006	0.013	0.014	0.014	0.011	0.000	0.003	0.002	0.006	0.003	0.011	0.004	0.005	0.001	0.000	0.002	0.001	0.008	0.005
Ca	1.802	1.841	1.834	1.818	1.810	1.837	1.818	1.853	1.829	1.830	1.831	1.829	1.851	1.916	1.860	1.876	1.772	1.707	1.740
Na	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.126	0.037	0.116	0.093	0.062	0.057	0.060
	1.808	1.853	1.848	1.832	1.821	1.837	1.821	1.855	1.835	1.833	1.843	1.833	1.982	1.954	1.976	1.971	1.835	1.772	1.804
Cl	-	-	-	-	-	-	-	-	-	-	-	-	-	0.046	0.050	0.048	0.037	0.035	0.036
XMg	0.436	0.429	0.431	0.428	0.453	0.471	0.478	0.485	0.490	0.485	0.446	0.472	0.409	0.405	0.410	0.408	0.371	0.346	0.359
XFe	0.374	0.390	0.391	0.384	0.365	0.368	0.360	0.353	0.362	0.364	0.386	0.361	0.385	0.385	0.382	0.384	0.380	0.340	0.360
XTi	0.081	0.080	0.082	0.082	0.032	0.031	0.032	0.030	0.045	0.043	0.079	0.031	0.087	0.085	0.088	0.086	0.060	0.075	0.068
XAl	0.108	0.099	0.094	0.104	0.149	0.127	0.130	0.132	0.100	0.108	0.087	0.135	0.117	0.123	0.118	0.119	0.187	0.236	0.211
Fe/Mg	0.462	0.476	0.475	0.473	0.446	0.438	0.430	0.421	0.425	0.429	0.464	0.434	0.485	0.487	0.482	0.485	0.506	0.495	0.501

PCA-200-85 ilmenite

	3	3	3	3	3	4	1	1	1	1	4
	54.32	54.37	54.99	54.90	54.65	53.71	53.74	53.99	53.80	53.30	53.71
TiO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr2O3	45.69	45.49	45.32	44.89	45.35	46.25	46.46	46.45	46.35	45.74	46.25
FeO	0.07	0.00	0.00	0.00	0.02	0.05	0.07	0.14	0.00	0.00	0.05
MgO	0.39	0.45	0.37	0.44	0.41	0.32	0.33	0.30	0.32	0.31	0.32
MnO	100.47	100.31	100.68	100.23	100.42	100.33	100.60	100.88	100.47	99.35	100.33
Total	1018	1020	1026	1028	1023	1011	1010	1011	1012	1013	1011
Ti	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cr	1.018	1.020	1.026	1.028	1.023	1.011	1.010	1.011	1.012	1.013	1.011
Fe	0.953	0.949	0.940	0.935	0.944	0.967	0.971	0.967	0.969	0.967	0.969
Mg	0.003	0.000	0.000	0.000	0.001	0.005	0.003	0.005	0.000	0.000	0.002
Mn	0.008	0.010	0.008	0.009	0.009	0.006	0.007	0.006	0.007	0.007	0.007
	0.963	0.959	0.948	0.944	0.954	0.979	0.980	0.979	0.976	0.974	0.977
X Fe	0.989	0.990	0.992	0.990	0.990	0.988	0.990	0.988	0.993	0.993	0.991
X Mg	0.003	0.000	0.000	0.000	0.001	0.005	0.003	0.005	0.000	0.000	0.002
X Mn	0.009	0.010	0.008	0.010	0.009	0.006	0.007	0.006	0.007	0.007	0.007
Fe/Fe+Mg	0.997	1.000	1.000	1.000	0.999	0.995	0.997	0.995	1.000	1.000	0.998
X Ti	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
activity	0.989	0.990	0.992	0.990	0.990	0.988	0.990	0.988	0.993	0.993	0.991

[illegible]

PS-332-94 garnet	R1		C		j		4		4.1		4.2		4.3		4.4		4.5		R1	
	i	2	i	4	j	4	j	4	i	4.1	i	4.2	i	4.3	i	4.4	i	4.5	k	5
Point		5.56		5.1-4		4.1		4.2		4.1		4.2		4.3		4.4		4.5		4.1-5
SiO2		38.11		37.84		37.24		37.40		37.24		37.40		37.41		36.93		37.29		37.25
Al2O3		21.51		21.54		21.45		21.48		21.45		21.48		21.35		21.53		21.46		21.45
TiO2		2.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
Cr2O3		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
FeO		34.15		33.62		33.72		33.56		33.50		33.56		33.50		33.16		33.01		33.39
MnO		0.89		0.74		0.80		0.92		0.85		0.92		0.85		0.83		0.82		0.84
MgO		5.04		5.41		5.04		4.94		5.17		4.96		5.17		4.96		5.13		5.05
CaO		1.13		1.12		1.12		1.12		1.14		1.12		1.14		1.15		1.13		1.13
Total		100.81		100.27		99.37		99.42		99.42		99.42		99.42		98.56		98.84		99.12
Si		6.007		5.983		5.959		5.977		5.976		5.977		5.976		5.949		5.980		5.968
Al		0.008		0.017		0.041		0.023		0.024		0.023		0.024		0.051		0.020		0.032
		6.015		6.000		6.000		6.000		6.000		6.000		6.000		6.000		6.000		6.000
Al		3.988		3.998		4.005		4.022		3.997		4.022		3.997		4.037		4.035		4.019
Ti		0.000		0.000		0.000		0.000		0.000		0.000		0.000		0.000		0.000		0.000
Cr		0.000		0.000		0.000		0.000		0.000		0.000		0.000		0.000		0.000		0.000
		3.988		3.998		4.005		4.022		3.997		4.022		3.997		4.037		4.035		4.019
Fe		4.502		4.446		4.511		4.486		4.476		4.486		4.476		4.468		4.427		4.474
Mn		0.118		0.100		0.109		0.124		0.114		0.124		0.114		0.113		0.111		0.114
Mg		1.185		1.276		1.202		1.177		1.231		1.177		1.231		1.191		1.226		1.205
Ca		0.190		0.190		0.192		0.191		0.195		0.191		0.195		0.198		0.194		0.194
		5.994		6.012		6.014		5.978		6.016		5.978		6.016		5.970		5.958		5.987
XCa		0.032		0.032		0.032		0.032		0.032		0.032		0.032		0.033		0.033		0.032
XMg		0.198		0.212		0.200		0.197		0.205		0.197		0.205		0.199		0.206		0.201
XFe		0.751		0.740		0.750		0.750		0.744		0.750		0.744		0.748		0.743		0.747
XMn		0.020		0.017		0.018		0.021		0.019		0.021		0.019		0.019		0.019		0.019
Fe/		0.792		0.777		0.790		0.792		0.784		0.792		0.784		0.790		0.783		0.788
Fe+Mg																				

cont

Point	11	12	13	14	15	16	18	18	11-5	16.8	17	22	23	24	22-4	31	32	33	34	35	31-5	41	42
SiO2	35.28	35.53	35.67	35.56	37.27	35.44	35.01	35.86	35.23	34.56	35.48	35.65	35.37	35.50	35.92	35.01	35.29	35.37	34.64	35.25	35.50	35.72	
Al2O3	18.63	18.69	19.51	19.15	19.45	17.64	17.56	19.09	17.60	17.47	18.88	18.71	18.81	18.80	18.38	18.22	18.66	18.37	18.13	18.35	19.04	19.27	
TiO2	3.66	3.63	3.16	3.38	3.32	5.10	5.07	3.43	5.09	4.90	2.67	2.88	2.69	2.75	3.75	3.83	3.19	4.02	4.04	3.77	2.30	2.20	
Cr2O3	0.09	0.00	0.00	0.05	0.03	0.06	0.07	0.03	0.07	0.08	0.00	0.00	0.09	0.01	0.03	0.00	0.06	0.00	0.03	0.01	0.02	0.00	
FeO	18.33	17.95	17.78	18.04	17.04	17.61	17.50	17.83	17.56	17.47	17.03	17.48	16.94	17.15	18.63	17.89	17.04	17.59	18.79	17.99	17.23	17.10	
MnO	0.11	0.02	0.03	0.10	0.01	0.12	0.03	0.05	0.08	0.00	0.00	0.01	0.02	0.01	0.00	0.06	0.02	0.00	0.03	0.02	0.04	0.00	
MgO	9.43	9.61	9.71	9.70	8.95	9.17	9.13	9.48	9.15	9.49	10.39	10.48	10.19	10.35	9.92	9.75	10.54	10.03	9.52	9.95	10.55	10.94	
K2O	0.16	0.13	0.13	0.03	0.20	0.14	0.06	0.13	0.10	0.16	0.08	0.10	0.13	0.10	0.09	0.09	0.11	0.02	0.04	0.07	0.03	0.08	
CaO	0.10	0.04	0.00	0.00	0.59	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Na2O	9.59	9.52	9.37	9.61	9.22	9.42	9.44	9.46	9.43	9.21	9.39	9.57	9.15	9.37	9.36	9.46	9.43	9.58	9.20	9.41	9.50	9.41	
Cl	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Total	95.38	95.12	95.36	95.62	96.08	94.70	93.87	95.51	94.29	93.34	93.92	94.97	93.31	94.07	96.05	94.37	94.28	95.01	94.40	94.82	94.21	94.72	
Total	95.38	95.12	95.36	95.62	96.08	94.70	93.87	95.51	94.29	93.34	93.92	94.97	93.31	94.07	96.05	94.37	94.28	95.01	94.40	94.82	94.21	94.72	
Si	5.354	5.385	5.372	5.361	5.531	5.396	5.381	5.401	5.389	5.344	5.414	5.399	5.426	5.413	5.397	5.358	5.374	5.363	5.320	5.362	5.408	5.401	
Al	2.646	2.615	2.628	2.639	2.469	2.604	2.619	2.599	2.612	2.656	2.586	2.601	2.574	2.587	2.603	2.642	2.626	2.637	2.680	2.638	2.592	2.599	
8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	
Al	0.687	0.723	0.835	0.765	0.933	0.562	0.563	0.789	0.563	0.528	0.811	0.738	0.827	0.792	0.652	0.645	0.723	0.647	0.601	0.654	0.826	0.835	
Ti	0.418	0.414	0.357	0.383	0.371	0.584	0.586	0.389	0.585	0.570	0.306	0.328	0.310	0.315	0.424	0.441	0.365	0.458	0.467	0.431	0.264	0.250	
Cr	0.011	0.000	0.000	0.006	0.003	0.008	0.009	0.004	0.009	0.010	0.000	0.010	0.001	0.004	0.000	0.007	0.000	0.004	0.001	0.002	0.002	0.000	
Fe	2.326	2.275	2.239	2.275	2.115	2.243	2.250	2.246	2.247	2.260	2.173	2.214	2.173	2.187	2.341	2.290	2.170	2.230	2.413	2.289	2.195	2.162	
Mn	0.014	0.002	0.004	0.012	0.001	0.016	0.004	0.007	0.010	0.000	0.000	0.001	0.003	0.001	0.000	0.007	0.003	0.000	0.004	0.003	0.005	0.000	
Mg	2.133	2.171	2.181	2.179	1.981	2.083	2.091	2.129	2.087	2.188	2.364	2.366	2.331	2.354	2.222	2.224	2.391	2.266	2.179	2.256	2.397	2.465	
5.589	5.585	5.616	5.620	5.404	5.496	5.503	5.563	5.500	5.556	5.654	5.657	5.657	5.645	5.652	5.639	5.614	5.652	5.605	5.665	5.635	5.689	5.712	
K	0.025	0.021	0.021	0.004	0.033	0.023	0.010	0.021	0.017	0.026	0.013	0.017	0.022	0.017	0.015	0.014	0.018	0.003	0.006	0.011	0.005	0.013	
Ca	0.029	0.012	0.000	0.000	0.171	0.000	0.000	0.042	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Na	1.856	1.840	1.801	1.849	1.746	1.830	1.851	1.818	1.841	1.817	1.828	1.848	1.790	1.822	1.794	1.848	1.832	1.853	1.802	1.826	1.847	1.814	
1.910	1.873	1.822	1.853	1.950	1.853	1.853	1.861	1.882	1.857	1.843	1.841	1.865	1.812	1.839	1.809	1.862	1.850	1.856	1.808	1.837	1.852	1.827	
Cl	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
XMg	0.382	0.389	0.388	0.388	0.367	0.379	0.380	0.383	0.379	0.394	0.418	0.418	0.413	0.416	0.394	0.396	0.423	0.404	0.385	0.400	0.421	0.432	
XFe	0.416	0.407	0.399	0.405	0.391	0.408	0.409	0.404	0.408	0.407	0.384	0.391	0.385	0.387	0.415	0.408	0.384	0.398	0.426	0.406	0.386	0.379	
XTi	0.075	0.074	0.064	0.068	0.069	0.106	0.106	0.070	0.106	0.103	0.054	0.058	0.055	0.056	0.075	0.079	0.065	0.082	0.076	0.046	0.046	0.044	
XAl	0.123	0.129	0.149	0.136	0.173	0.102	0.102	0.142	0.102	0.095	0.143	0.130	0.147	0.140	0.116	0.115	0.128	0.115	0.106	0.116	0.145	0.146	
Fe/	0.522	0.512	0.507	0.511	0.516	0.518	0.518	0.513	0.518	0.508	0.479	0.483	0.482	0.482	0.513	0.507	0.476	0.496	0.525	0.504	0.478	0.467	
Fe+Mg																							

PS-332-94 biotite		cont	s-incl	matrix					matrix				matrix				matrix				matrix			
		f	g	h					i				j				k							
		3	1	5					4				3											
Point		4.3	4.1-3	6.1	6.2	6.3	6.4	6.5	6.1-5	9.1	9.2	9.3	9.4	9.1-4	8.1	8.2	8.3	8.1-3	7.1	7.2	7.3	7.1-3		
SiO2	35.46	35.56	35.99	34.77	35.64	35.92	35.62	35.10	35.41	36.33	35.85	35.50	36.37	36.01	36.35	34.34	36.92	35.87	35.91	35.82	35.22	35.65		
Al2O3	19.41	19.24	18.15	17.98	18.44	18.40	18.60	18.48	18.38	19.09	18.74	18.63	19.06	18.88	19.19	18.72	19.64	19.18	19.13	18.89	19.11	19.04		
TiO2	2.24	2.25	4.36	4.33	4.80	4.44	4.78	4.66	4.60	4.58	4.68	4.51	4.45	4.56	2.64	2.68	2.80	2.71	4.03	4.62	4.12	4.26		
Cr2O3	0.00	0.01	0.02	0.00	0.07	0.03	0.00	0.11	0.04	0.12	0.09	0.05	0.08	0.09	0.10	0.16	0.07	0.11	0.07	0.12	0.10	0.10		
FeO	16.96	17.10	17.74	17.16	17.20	17.71	16.95	16.50	17.10	17.28	17.36	17.36	17.46	17.37	17.36	16.67	17.05	17.03	17.86	18.08	17.09	17.68		
MnO	0.00	0.01	0.00	0.01	0.01	0.04	0.00	0.00	0.01	0.06	0.08	0.04	0.12	0.08	0.09	0.14	0.07	0.10	0.08	0.10	0.12	0.10		
MgO	10.78	10.76	9.54	9.63	9.52	9.82	9.06	8.75	9.36	9.76	9.85	9.16	9.97	9.69	11.07	10.61	11.13	10.94	9.45	9.22	8.95	9.21		
K2O	0.11	0.07	0.16	0.10	0.13	0.07	0.13	0.18	0.12	0.10	0.00	0.07	0.02	0.05	0.01	0.09	0.00	0.03	0.00	0.06	0.08	0.05		
CaO	0.03	0.01	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.63	9.58	9.28	9.71	9.55	9.52	8.97	9.67	9.39	9.44	9.52	9.16	9.37		
Na2O	9.45	9.45	9.42	9.16	9.15	9.41	9.04	8.98	9.15	0.34	0.52	0.40	0.61	0.47	0.47	0.35	0.29	0.37	0.47	0.45	1.39	0.77		
Cl	-	-	-	-	-	-	-	-	-	0.12	0.13	0.11	0.12	0.12	0.09	0.12	0.16	0.12	0.09	0.08	0.72	0.30		
Total	94.44	94.46	95.43	93.14	94.96	95.84	94.18	92.76	94.18	97.41	96.88	95.11	97.97	96.84	96.89	92.85	97.80	95.85	96.53	96.96	96.06	96.52		
Total-O	94.44	94.46	95.43	93.14	94.96	95.84	94.18	92.76	94.18	97.38	96.85	95.09	97.94	96.82	96.87	92.82	97.76	95.82	96.51	96.94	95.90	96.45		
Si	5.379	5.396	5.425	5.368	5.379	5.399	5.408	5.408	5.390	5.362	5.334	5.373	5.348	5.354	5.391	5.319	5.407	5.372	5.362	5.337	5.323	5.341		
Al	2.621	2.604	2.575	2.632	2.621	2.611	2.592	2.592	2.610	2.638	2.666	2.627	2.652	2.646	2.609	2.681	2.593	2.628	2.638	2.663	2.677	2.659		
	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000		
Al	0.849	0.837	0.650	0.639	0.660	0.643	0.737	0.765	0.689	0.682	0.620	0.696	0.652	0.663	0.745	0.736	0.797	0.759	0.728	0.655	0.728	0.704		
Ti	0.256	0.257	0.495	0.503	0.545	0.501	0.546	0.540	0.527	0.508	0.524	0.513	0.492	0.509	0.295	0.312	0.309	0.305	0.453	0.517	0.468	0.479		
Cr	0.000	0.001	0.003	0.000	0.008	0.003	0.000	0.013	0.005	0.014	0.011	0.006	0.009	0.010	0.012	0.020	0.008	0.013	0.009	0.014	0.012	0.012		
Fe	2.152	2.170	2.237	2.216	2.171	2.223	2.152	2.126	2.178	2.132	2.160	2.197	2.147	2.159	2.153	2.159	2.088	2.133	2.230	2.253	2.160	2.214		
Mn	0.000	0.002	0.000	0.001	0.002	0.005	0.000	0.000	0.002	0.007	0.010	0.006	0.014	0.009	0.011	0.019	0.009	0.013	0.010	0.012	0.015	0.012		
Mg	2.438	2.433	2.143	2.216	2.142	2.196	2.050	2.010	2.123	2.147	2.184	2.067	2.185	2.146	2.448	2.450	2.431	2.443	2.102	2.048	2.016	2.055		
	5.695	5.699	5.528	5.575	5.528	5.571	5.485	5.454	5.523	5.490	5.509	5.485	5.499	5.496	5.664	5.696	5.642	5.667	5.532	5.499	5.399	5.477		
K	0.018	0.012	0.025	0.016	0.022	0.011	0.020	0.029	0.020	0.016	0.000	0.011	0.003	0.008	0.002	0.015	0.000	0.006	0.000	0.009	0.014	0.008		
Ca	0.008	0.003	0.015	0.000	0.000	0.000	0.000	0.000	0.000	1.814	1.818	1.792	1.822	1.812	1.801	1.773	1.806	1.793	1.798	1.810	1.766	1.791		
Na	1.828	1.830	1.811	1.805	1.762	1.801	1.752	1.766	1.777	0.099	0.150	0.117	0.174	0.135	0.134	0.106	0.083	0.108	0.136	0.131	0.406	0.224		
	1.854	1.844	1.851	1.821	1.784	1.812	1.772	1.795	1.797	1.929	1.968	1.920	1.999	1.954	1.937	1.894	1.889	1.907	1.934	1.950	2.186	2.023		
Cl	-	0.000	-	-	-	-	-	-	-	0.029	0.033	0.028	0.030	0.030	0.023	0.032	0.040	0.032	0.023	0.021	0.184	0.076		
XMg	0.428	0.427	0.388	0.397	0.387	0.394	0.374	0.369	0.384	0.391	0.396	0.377	0.397	0.390	0.432	0.430	0.431	0.431	0.380	0.372	0.373	0.375		
XFe	0.378	0.381	0.405	0.397	0.393	0.399	0.392	0.390	0.394	0.388	0.392	0.401	0.390	0.393	0.380	0.379	0.370	0.376	0.403	0.410	0.400	0.404		
XTi	0.045	0.045	0.090	0.090	0.099	0.090	0.100	0.099	0.095	0.093	0.095	0.094	0.089	0.093	0.052	0.055	0.055	0.054	0.082	0.094	0.087	0.088		
XAl	0.149	0.147	0.118	0.115	0.119	0.115	0.134	0.140	0.125	0.124	0.113	0.127	0.119	0.121	0.132	0.129	0.141	0.134	0.132	0.119	0.135	0.129		
Fe/	0.469	0.471	0.511	0.500	0.503	0.503	0.512	0.514	0.506	0.498	0.497	0.515	0.496	0.502	0.468	0.468	0.462	0.466	0.515	0.524	0.517	0.519		
Fe+Mg																								

PS-332-94 plagioclase

	matrix a						matrix b						matrix c						matrix d			
	1 1	1 2	1 3	1 4	1 5	1 6	1 1-6	2 1	2 2	2 3	2 4	2 5	2 6	2 1-6	3 1	3 2	3 1,2	4 1	4 2	4 5	4 6	4 1-6
Points	1 1	1 2	1 3	1 4	1 5	1 6	1 1-6	2 1	2 2	2 3	2 4	2 5	2 6	2 1-6	3 1	3 2	3 1,2	4 1	4 2	4 5	4 6	4 1-6
SiO2	62.33	62.45	62.18	61.98	63.14	62.73	62.47	63.14	63.71	63.40	63.91	63.58	63.48	63.54	62.43	61.99	62.21	61.96	62.20	61.85	63.48	62.37
Al2O3	23.48	23.46	23.37	23.15	23.73	23.74	23.49	23.99	24.15	23.95	24.06	23.75	24.01	23.99	23.52	23.53	23.53	23.48	23.42	23.58	23.38	23.47
K2O	0.25	0.31	0.38	0.31	0.33	0.23	0.30	0.27	0.31	0.37	0.41	0.36	0.36	0.35	0.11	0.15	0.13	0.08	0.13	0.18	0.13	0.13
CaO	4.63	4.71	4.63	4.67	4.69	4.71	4.67	4.81	4.72	4.89	4.87	4.73	4.78	4.80	4.76	4.77	4.77	4.77	4.75	4.83	4.16	4.63
Na2O	8.57	8.68	8.82	8.40	8.89	8.73	8.68	8.70	8.62	8.59	8.72	8.84	8.71	8.70	8.60	9.19	8.90	8.66	8.53	8.65	9.44	8.82
FeO	0.01	0.08	0.09	0.07	0.01	0.06	0.05	0.01	0.07	0.02	0.08	0.04	0.07	0.05	0.12	0.19	0.16	0.00	0.01	0.10	0.15	0.07
Total	99.27	99.69	99.47	98.58	100.79	100.20	99.67	100.92	101.58	101.22	102.05	101.30	101.41	101.41	99.54	99.82	99.68	98.95	99.04	99.19	100.74	99.48
Si	5.553	5.548	5.542	5.562	5.548	5.541	5.549	5.537	5.547	5.544	5.547	5.557	5.542	5.546	5.548	5.515	5.532	5.538	5.552	5.524	5.577	5.548
Al	2.466	2.457	2.455	2.449	2.457	2.472	2.459	2.479	2.478	2.469	2.461	2.447	2.471	2.468	2.463	2.467	2.465	2.474	2.464	2.483	2.421	2.461
	8.019	8.005	7.997	8.011	8.005	8.013	8.008	8.016	8.025	8.013	8.008	8.004	8.013	8.013	8.011	7.982	7.997	8.012	8.016	8.007	7.998	8.008
K	0.028	0.035	0.044	0.035	0.037	0.026	0.034	0.031	0.035	0.042	0.045	0.040	0.041	0.039	0.012	0.017	0.015	0.009	0.015	0.020	0.015	0.015
Ca	0.442	0.448	0.442	0.449	0.441	0.445	0.445	0.452	0.440	0.458	0.453	0.443	0.447	0.449	0.453	0.455	0.454	0.457	0.454	0.462	0.392	0.441
Na	1.480	1.495	1.524	1.462	1.515	1.495	1.495	1.480	1.454	1.456	1.467	1.498	1.474	1.472	1.483	1.586	1.535	1.502	1.476	1.497	1.609	1.521
	1.950	1.978	2.010	1.946	1.993	1.966	1.974	1.963	1.929	1.956	1.965	1.981	1.962	1.959	1.948	2.058	2.003	1.968	1.945	1.979	2.016	1.977
Fe	0.001	0.006	0.007	0.005	0.001	0.004	0.004	0.001	0.005	0.001	0.006	0.003	0.005	0.004	0.009	0.014	0.012	0.000	0.001	0.007	0.011	0.005
X An	0.227	0.226	0.220	0.231	0.221	0.226	0.225	0.230	0.228	0.234	0.231	0.224	0.228	0.229	0.233	0.221	0.227	0.232	0.233	0.233	0.194	0.223
X Ab	0.759	0.756	0.758	0.751	0.760	0.760	0.757	0.754	0.754	0.744	0.747	0.756	0.751	0.751	0.761	0.771	0.766	0.763	0.759	0.756	0.798	0.769
X Or	0.014	0.018	0.022	0.018	0.019	0.013	0.017	0.016	0.018	0.021	0.023	0.020	0.021	0.020	0.006	0.008	0.007	0.005	0.008	0.010	0.007	0.007

PS-332-94 ilmenite

Points	1.1	1.2	1.3	1.4	1.5	avg 11	2.2	2.3	2.4	avg 12
TiO2	52.33	51.75	51.64	52.56	52.34	52.07	54.05	53.23	53.71	53.66
Fe2O3	0.00	1.57	1.41	0.79	0.31	1.02	0.03	0.00	0.00	0.00
FeO	46.83	45.73	45.75	46.64	46.77	46.23	45.44	44.95	45.56	45.32
MgO	0.00	0.37	0.20	0.10	0.00	0.17	0.57	0.56	0.72	0.62
MnO	0.24	0.20	0.22	0.21	0.37	0.25	0.21	0.17	0.21	0.20
Total	99.40	99.64	99.22	100.30	99.79	99.74	100.27	98.91	100.20	99.79
Ti	1.000	0.985	0.987	0.994	0.996	0.991	1.013	1.012	1.009	1.011
Fe+3	0.000	0.030	0.027	0.015	0.006	0.020	0.000	0.000	0.000	0.000
	1.000	1.015	1.014	1.009	1.002	1.010	1.013	1.012	1.009	1.011
Fe+2	0.995	0.968	0.973	0.981	0.990	0.978	0.947	0.951	0.951	0.950
Mn	0.005	0.004	0.005	0.005	0.008	0.006	0.004	0.004	0.005	0.004
Mg	0.000	0.014	0.008	0.004	0.000	0.007	0.021	0.021	0.027	0.023
	1.000	0.986	0.986	0.990	0.998	0.990	0.972	0.976	0.983	0.977
X Ti	1.000	0.970	0.973	0.985	0.994	0.981	1.000	1.000	1.000	1.000
X Fe +	0.000	0.030	0.027	0.015	0.006	0.019	0.000	0.000	0.000	0.000
X Fe +	0.995	0.982	0.987	0.991	0.992	0.988	0.974	0.974	0.967	0.972
X Mn	0.005	0.004	0.005	0.005	0.008	0.006	0.004	0.004	0.005	0.004
X Mg	0.000	0.014	0.008	0.004	0.000	0.007	0.022	0.022	0.027	0.024
activity	0.995	0.953	0.961	0.976	0.986	0.969	0.974	0.974	0.967	0.972

Ppoint	R1											R1											R2										
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.111	1.8.12	1.13.16.18	c	4										
SiO2	38.51	37.98	38.05	38.42	38.40	38.11	37.71	38.07	38.53	38.02	37.53	37.68	38.03	37.73	37.35	37.20	36.94	37.11	38.02	37.88	37.32	37.32	1.13.16.18										
Al2O3	21.55	21.40	21.65	21.61	21.49	21.35	21.41	21.55	21.71	21.24	21.06	21.37	21.86	20.93	21.36	21.23	21.19	21.33	21.31	21.46	21.40	21.40	37.32										
TiO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.01	0.00	0.00	0.03	0.03											
Cr2O3	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.05	0.03	0.00	0.00	0.04	0.04											
FeO	34.40	33.81	33.65	33.78	33.44	33.20	33.57	33.22	33.61	33.38	33.85	33.35	33.73	33.31	32.94	32.73	32.81	33.03	34.13	33.29	33.08	33.08											
MnO	1.73	1.63	1.47	1.34	1.60	1.47	1.69	1.75	1.48	1.45	1.72	1.76	1.63	1.48	1.53	1.69	1.66	1.70	1.73	1.76	1.67	1.67											
MgO	4.91	5.22	5.39	5.44	5.70	5.29	5.26	5.13	5.36	5.37	4.69	4.76	5.41	5.46	5.50	5.47	4.99	5.17	4.80	4.95	5.26	5.26											
CaO	0.97	0.92	1.02	1.16	1.11	0.94	0.91	0.94	0.89	0.93	0.92	0.95	0.97	0.90	0.95	1.03	1.00	0.88	0.95	0.95	0.97	0.97											
Total	102.07	100.96	101.23	101.75	101.85	100.36	100.55	100.66	101.58	100.39	99.77	99.87	101.63	99.81	99.63	99.42	98.73	99.26	100.92	100.27	99.76	99.76											
Si	6.012	5.989	5.973	5.996	5.987	6.023	5.970	6.004	6.015	6.013	6.003	6.003	5.949	6.010	5.956	5.950	5.955	5.949	6.008	6.004	5.951	5.951											
Al	0.000	0.011	0.027	0.004	0.013	0.000	0.030	0.000	0.000	0.000	0.000	0.000	0.051	0.000	0.044	0.050	0.045	0.051	0.000	0.000	0.049	0.049											
Ti	6.012	6.000	6.000	6.000	6.000	6.023	6.000	6.004	6.015	6.013	6.003	6.003	6.000	6.010	6.000	6.000	6.000	6.000	6.008	6.004	6.000	6.000											
Cr	3.966	3.965	3.978	3.971	3.936	3.976	3.966	4.007	3.994	3.959	3.971	4.014	3.980	3.930	3.970	3.951	3.982	3.980	3.969	4.011	3.973	3.973											
Fe	4.491	4.458	4.419	4.410	4.360	4.388	4.444	4.382	4.388	4.416	4.529	4.445	4.413	4.437	4.393	4.377	4.423	4.429	4.510	4.414	4.411	4.411											
Mn	0.229	0.218	0.195	0.177	0.211	0.197	0.226	0.234	0.195	0.194	0.232	0.238	0.216	0.199	0.207	0.228	0.227	0.231	0.231	0.236	0.226	0.226											
Mg	1.143	1.226	1.261	1.265	1.326	1.246	1.242	1.206	1.247	1.267	1.117	1.130	1.262	1.296	1.306	1.305	1.199	1.236	1.130	1.168	1.251	1.251											
Ca	0.163	0.156	0.171	0.195	0.185	0.159	0.154	0.160	0.149	0.157	0.157	0.161	0.163	0.154	0.162	0.176	0.172	0.150	0.160	0.161	0.165	0.											

PS-344-94 biotite

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PS-344-94 biotite

Point	matrix			
	6.1	6.2	6.3	6.4
SiO ₂	35.47	35.69	35.04	35.21
Al ₂ O ₃	19.25	19.57	18.79	19.26
TiO ₂	4.48	4.59	4.55	4.37
Cr ₂ O ₃	0.08	0.06	0.06	0.08
FeO	19.35	19.18	19.52	19.30
MnO	0.11	0.13	0.15	0.08
MgO	9.24	9.32	9.25	9.30
K ₂ O	0.00	0.01	0.00	0.00
CaO	9.40	9.33	9.53	9.47
Na ₂ O	0.51	0.22	0.24	0.48
Cl	0.03	0.02	0.05	0.02
Total	97.92	98.12	97.18	97.57
Total-O	97.91	98.12	97.17	97.57
Si	5.260	5.263	5.252	5.244
Al	2.740	2.737	2.748	2.756
	8.000	8.000	8.000	8.000
Al	0.625	0.664	0.571	0.625
Ti	0.499	0.510	0.513	0.489
Cr	0.010	0.007	0.007	0.009
Fe	2.400	2.366	2.447	2.404
Mn	0.014	0.016	0.019	0.011
Mg	2.043	2.048	2.068	2.065
	5.591	5.611	5.625	5.603
K	0.000	0.002	0.000	0.000
Ca	1.779	1.756	1.823	1.799
Na	0.147	0.063	0.071	0.139
	1.926	1.821	1.894	1.938
Cl	0.007	0.006	0.013	0.004
XMg	0.365	0.365	0.368	0.369
XFe	0.429	0.422	0.435	0.429
XTi	0.089	0.091	0.091	0.087
XAl	0.112	0.118	0.102	0.112
Fe/	0.540	0.536	0.542	0.538
Fe+Mg				

PS-348a-94 garnet

	122	123	124	125	126	127	129	130	131	132	133	134	135	136	137	138	139	140	141	R1 a	R1 b
Point	1.22	1.23	1.24	1.25	1.26	1.27	1.29	1.30	1.31	1.32	1.33	1.34	1.35	1.36	1.37	1.38	1.39	1.40	1.41	2	1
SiO ₂	38.26	38.51	38.98	39.22	39.68	39.41	37.49	37.81	38.11	37.87	38.08	38.29	38.43	37.96	37.93	37.63	37.98	38.26	38.21	122.2	1.10
Al ₂ O ₃	21.62	21.85	22.08	22.70	22.36	22.59	21.60	21.81	22.01	22.21	22.12	22.11	21.94	21.99	21.65	21.87	21.99	22.05	22.00	38.39	37.74
TiO ₂	-	-	-	-	-	-	0.03	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.04	0.00	0.04	0.03	0.03	21.74	21.43
Cr ₂ O ₃	-	-	-	-	-	-	0.07	0.03	0.00	0.00	0.03	0.00	0.07	0.00	0.04	0.01	0.06	0.07	0.01	0.00	0.00
FeO	30.01	29.82	27.06	27.46	29.26	27.81	28.99	28.46	29.14	28.86	28.43	27.91	27.68	27.58	28.22	27.93	27.55	28.36	27.87	29.92	29.22
MnO	0.42	0.30	0.28	0.17	0.24	0.25	0.55	0.45	0.49	0.50	0.47	0.48	0.44	0.33	0.52	0.53	0.49	0.59	0.45	0.36	0.23
MgO	7.23	7.65	9.76	9.52	8.49	9.39	8.56	8.57	8.76	8.98	9.05	9.61	9.22	9.74	9.08	9.23	9.24	9.12	9.24	7.44	7.72
CaO	1.50	1.56	1.45	1.60	1.49	1.49	1.52	1.56	1.72	1.74	1.82	1.67	1.74	1.76	1.78	1.73	1.88	1.78	1.67	1.53	1.33
Total	99.04	99.69	99.61	100.67	101.52	100.94	98.81	98.69	100.24	100.17	100.01	100.08	99.52	99.36	99.26	98.93	99.23	100.26	99.48	99.37	97.67
Si	6.018	6.005	5.998	5.973	6.034	5.993	5.904	5.938	5.908	5.870	5.899	5.907	5.956	5.895	5.922	5.888	5.910	5.910	5.931	6.012	6.001
Al	0.000	0.000	0.002	0.027	0.000	0.007	0.096	0.082	0.092	0.130	0.101	0.093	0.044	0.105	0.078	0.112	0.090	0.090	0.069	0.000	0.000
	6.018	6.005	6.000	6.000	6.034	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.012	6.001
Al	4.009	4.016	4.003	4.048	4.008	4.042	3.914	3.974	3.929	3.928	3.937	3.929	3.963	3.920	3.906	3.923	3.945	3.925	3.957	4.013	4.017
Ti	-	-	-	-	-	-	0.004	0.000	0.002	0.001	0.001	0.001	0.000	0.000	0.005	0.000	0.004	0.004	0.003	0.000	0.000
Cr	-	-	-	-	-	-	0.009	0.004	0.000	0.000	0.004	0.000	0.008	0.000	0.005	0.001	0.008	0.009	0.001	0.000	0.000
	4.009	4.016	4.003	4.048	4.008	4.042	3.927	3.978	3.931	3.929	3.942	3.930	3.971	3.920	3.916	3.924	3.957	3.938	3.961	4.013	4.017
Fe	3.948	3.889	3.482	3.497	3.721	3.537	3.819	3.737	3.778	3.742	3.683	3.601	3.588	3.582	3.685	3.656	3.586	3.684	3.617	3.919	3.886
Mn	0.055	0.040	0.036	0.022	0.031	0.033	0.073	0.060	0.064	0.066	0.061	0.063	0.057	0.043	0.069	0.070	0.065	0.077	0.059	0.048	0.031
Mg	1.694	1.777	2.238	2.161	1.925	2.128	2.008	2.005	2.023	2.075	2.090	2.211	2.131	2.255	2.112	2.153	2.143	2.101	2.137	1.736	1.830
Ca	0.253	0.260	0.240	0.262	0.243	0.243	0.256	0.262	0.285	0.290	0.302	0.277	0.290	0.293	0.298	0.290	0.313	0.295	0.278	0.257	0.226
	5.950	5.966	5.996	5.942	5.920	5.941	6.156	6.064	6.150	6.173	6.136	6.152	6.066	6.173	6.164	6.169	6.107	6.137	6.091	5.958	5.973
XCa	0.043	0.044	0.040	0.044	0.041	0.041	0.038	0.042	0.046	0.047	0.048	0.045	0.046	0.048	0.046	0.047	0.048	0.045	0.045	0.043	0.038
XMg	0.285	0.298	0.373	0.364	0.325	0.358	0.326	0.331	0.329	0.336	0.341	0.359	0.351	0.365	0.343	0.349	0.351	0.342	0.351	0.291	0.306
XFe	0.664	0.652	0.581	0.589	0.629	0.595	0.620	0.616	0.614	0.606	0.600	0.585	0.592	0.580	0.598	0.593	0.587	0.597	0.594	0.658	0.651
XMn	0.009	0.007	0.006	0.004	0.005	0.006	0.012	0.010	0.010	0.011	0.010	0.010	0.009	0.007	0.011	0.011	0.011	0.013	0.010	0.008	0.005
Fe/Mg	0.700	0.686	0.609	0.618	0.659	0.624	0.655	0.651	0.651	0.643	0.638	0.620	0.627	0.614	0.636	0.629	0.626	0.636	0.629	0.693	0.680

	R1	f	g	h	i	j
	3	2	1	4	2	5
Point	2.19	2.20	2.1-3	2.14-1	2.19-20	2.4-11
SiO ₂	37.54	37.33	38.09	38.65	37.60	37.44
Al ₂ O ₃	21.76	21.70	21.80	22.04	21.66	21.73
TiO ₂	0.07	0.00	0.00	0.00	0.03	0.04
Cr ₂ O ₃	0.05	0.00	0.00	0.00	0.02	0.03
FeO	29.20	28.98	30.23	29.24	28.78	29.09
MnO	0.52	0.48	0.29	0.22	0.47	0.50
MgO	8.58	8.42	7.34	7.93	8.77	8.50
CaO	1.51	1.45	1.31	1.47	1.48	1.48
Total	99.23	98.36	99.06	99.54	98.80	99.81
Si	5.889	5.903	5.991	6.012	5.910	5.896
Al	0.111	0.097	0.009	0.000	0.090	0.104
	6.000	6.000	6.000	6.012	6.000	6.001
Al	3.913	3.948	4.032	4.040	3.924	3.931
Ti	0.009	0.000	0.000	0.000	0.003	0.005
Cr	0.006	0.000	0.000	0.000	0.002	0.003
	3.928	3.948	4.032	4.040	3.929	3.938
Fe	3.831	3.833	3.976	3.804	3.785	3.832
Mn	0.069	0.064	0.038	0.029	0.062	0.067
Mg	2.006	1.984	1.722	1.839	2.056	1.995
Ca	0.254	0.245	0.220	0.245	0.248	0.250
	6.160	6.126	5.956	5.917	6.150	6.143
XCa	0.038	0.040	0.037	0.041	0.039	0.039
XMg	0.326	0.324	0.289	0.311	0.334	0.325
XFe	0.622	0.626	0.668	0.643	0.615	0.624
XMn	0.011	0.010	0.006	0.005	0.010	0.011
Fel	0.656	0.659	0.698	0.674	0.648	0.658
Fe+Mg						

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	incl a 2		incl b 2		incl c 2		incl d 2		incl e 2		s-incl f 2		s-incl g 2									
Point	1.1	1.2	1.1,2	1.3	1.4	1.3,4	1.5	1.6	1.5,6	1.7	1.8	1.7,8	1.9	1.10	1.9,10	1.11	1.12	1.11,1	1.13	1.14	1.13,1	1.15
SiO2	36.56	35.98	36.27	36.06	36.43	36.25	36.57	36.85	36.71	36.88	36.57	36.73	36.64	36.57	36.61	36.51	36.59	36.55	36.49	36.81	36.65	35.84
Al2O3	18.90	18.67	18.79	19.16	19.09	19.13	18.89	19.10	19.00	18.52	18.36	18.44	18.92	18.73	18.83	18.35	18.30	18.33	20.09	20.04	20.07	19.86
TiO2	4.43	4.52	4.48	5.24	4.84	5.04	4.64	4.46	4.55	5.33	5.42	5.38	4.22	4.45	4.34	5.73	5.49	5.61	4.28	4.42	4.35	2.98
Cr2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
FeO	13.19	13.05	13.12	12.57	12.40	12.49	13.77	13.85	13.81	10.84	10.85	10.85	10.82	11.12	10.97	14.10	13.51	13.81	10.24	10.11	10.18	14.41
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
MgO	13.52	13.47	13.50	13.15	13.66	13.41	13.25	13.26	13.26	14.81	14.68	14.75	15.54	15.48	15.51	12.38	12.74	12.56	14.69	15.18	14.94	12.99
K2O	9.28	9.19	9.24	9.38	9.16	9.27	9.30	9.50	9.40	9.54	9.42	9.48	9.02	9.06	9.04	9.24	8.67	8.96	9.54	9.13	9.34	9.12
CaO	0.13	0.06	0.10	0.05	0.09	0.07	0.10	0.00	0.05	0.10	0.05	0.08	0.08	0.01	0.05	0.08	0.16	0.12	0.00	0.10	0.05	0.19
Na2O	0.00	0.00	0.00	0.03	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.17	0.00	0.00	0.00	0.00
Cl	0.09	0.06	0.08	0.08	0.05	0.07	0.09	0.10	0.10	0.07	0.03	0.05	0.04	0.06	0.05	0.08	0.03	0.06	0.00	0.01	0.01	0.08
Total	96.10	95.00	95.55	95.72	95.72	95.72	96.61	97.12	96.87	96.09	95.38	95.74	95.28	95.48	95.38	96.80	95.49	96.15	95.33	95.80	95.57	95.47
Total	96.08	94.99	95.54	95.70	95.71	95.71	96.59	97.10	96.85	96.07	95.37	95.72	95.27	95.47	95.37	96.78	95.48	96.13	95.33	95.80	95.57	95.45
Si	5.347	5.323	5.335	5.287	5.322	5.305	5.334	5.348	5.341	5.343	5.336	5.340	5.334	5.324	5.329	5.332	5.374	5.353	5.299	5.303	5.301	5.302
Al	2.653	2.677	2.665	2.713	2.678	2.696	2.666	2.652	2.659	2.657	2.664	2.661	2.666	2.676	2.671	2.668	2.626	2.647	2.701	2.697	2.699	2.698
	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	0.604	0.579	0.592	0.597	0.610	0.604	0.582	0.615	0.599	0.505	0.494	0.500	0.579	0.538	0.559	0.491	0.542	0.517	0.739	0.705	0.722	0.765
Ti	0.487	0.503	0.495	0.578	0.532	0.555	0.509	0.487	0.498	0.581	0.595	0.588	0.462	0.467	0.475	0.629	0.607	0.618	0.467	0.479	0.473	0.332
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe	1.613	1.615	1.614	1.542	1.516	1.529	1.680	1.681	1.681	1.313	1.324	1.319	1.318	1.354	1.336	1.723	1.660	1.692	1.244	1.218	1.231	1.783
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mg	2.947	2.971	2.959	2.874	2.976	2.925	2.881	2.869	2.875	3.198	3.193	3.196	3.372	3.359	3.366	2.695	2.790	2.743	3.180	3.260	3.220	2.864
	5.651	5.668	5.660	5.591	5.634	5.613	5.652	5.652	5.652	5.597	5.606	5.602	5.731	5.738	5.735	5.538	5.599	5.569	5.630	5.662	5.646	5.744
K	1.732	1.734	1.733	1.755	1.707	1.731	1.730	1.759	1.745	1.762	1.754	1.759	1.676	1.683	1.680	1.722	1.625	1.674	1.767	1.677	1.722	1.722
Ca	0.020	0.010	0.015	0.008	0.015	0.012	0.016	0.001	0.009	0.016	0.007	0.012	0.012	0.001	0.007	0.013	0.025	0.019	0.000	0.015	0.008	0.030
Na	0.000	0.000	0.000	0.009	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.093	0.000	0.047	0.000	0.000	0.000	0.000
	1.752	1.744	1.748	1.772	1.722	1.747	1.746	1.760	1.753	1.779	1.761	1.770	1.688	1.684	1.686	1.828	1.650	1.739	1.767	1.692	1.730	1.752
Cl	0.022	0.016	0.019	0.019	0.013	0.016	0.022	0.024	0.023	0.018	0.006	0.012	0.010	0.016	0.013	0.021	0.008	0.015	0.000	0.003	0.002	0.019
XMg	0.522	0.524	0.523	0.514	0.528	0.521	0.510	0.508	0.509	0.571	0.570	0.570	0.588	0.585	0.587	0.487	0.498	0.492	0.565	0.576	0.570	0.499
XFe	0.285	0.285	0.285	0.276	0.269	0.272	0.297	0.297	0.297	0.235	0.236	0.235	0.230	0.236	0.233	0.311	0.296	0.304	0.221	0.215	0.218	0.310
XTi	0.086	0.089	0.087	0.103	0.094	0.099	0.090	0.086	0.088	0.104	0.106	0.105	0.081	0.085	0.083	0.114	0.108	0.111	0.083	0.085	0.084	0.058
XAl	0.107	0.102	0.105	0.107	0.108	0.108	0.103	0.109	0.106	0.090	0.088	0.089	0.101	0.094	0.097	0.089	0.097	0.093	0.131	0.125	0.128	0.133
Fe/	0.354	0.352	0.353	0.349	0.337	0.343	0.368	0.369	0.369	0.291	0.293	0.292	0.281	0.287	0.284	0.390	0.373	0.382	0.281	0.272	0.277	0.384
Fe+Mg																						

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	in contact h				in contact i				matrix j				in contact k				matrix l					
	1 16	1 15.1	1 17	1 18	1 17.1	2 1	2 2	2 3	2 4	2 1-4	3 2	3 3	3 4	3 5	3 1-5	4 1	4 2	4 3	4 1-3	5 1	5 2	5 3
Point	36.23	36.04	36.24	36.19	36.22	35.57	35.63	35.44	36.43	35.77	42.43	38.41	37.68	39.41	39.48	36.17	36.03	36.51	36.24	36.69	37.44	37.29
SiO2	20.53	20.20	19.67	20.21	19.94	18.91	19.55	18.73	19.09	19.07	16.79	19.49	20.58	20.23	19.27	17.90	17.73	18.06	17.90	19.04	19.17	19.11
Al2O3	2.94	2.96	4.02	3.99	4.01	5.15	5.28	5.22	5.42	5.27	2.53	1.82	1.82	0.73	1.73	5.25	5.55	5.43	5.41	1.72	1.90	1.84
TiO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Cr2O3	14.22	14.32	14.54	14.29	14.42	15.08	14.91	14.19	14.94	14.78	12.45	11.93	12.53	12.03	12.24	15.22	14.96	15.06	15.08	12.14	12.26	12.28
FeO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
MnO	13.12	13.06	12.69	12.36	12.53	11.85	11.60	11.50	11.79	11.69	12.83	14.17	15.07	15.28	14.34	11.93	11.75	12.29	11.99	15.54	15.40	15.60
K2O	9.31	9.22	9.55	9.57	9.56	9.50	9.40	9.25	9.70	9.46	8.38	9.02	8.08	9.01	8.62	9.66	9.56	9.62	9.61	8.51	9.40	9.47
CaO	0.09	0.14	0.10	0.01	0.06	0.01	0.06	0.03	0.00	0.03	0.18	0.21	0.24	0.17	0.20	0.18	0.11	0.17	0.15	0.28	0.20	0.18
Na2O	0.00	0.00	0.00	0.09	0.05	0.05	0.31	0.01	0.00	0.09	0.50	0.42	0.03	0.30	0.31	0.00	0.09	0.14	0.08	0.40	0.15	0.50
Cl	0.11	0.10	0.10	0.06	0.08	0.11	0.06	0.02	0.08	0.07	0.00	0.04	0.01	0.06	0.03	0.01	0.03	0.05	0.03	0.02	0.01	0.00
Total	96.55	96.01	96.91	96.77	96.84	96.23	96.80	94.39	97.45	96.22	96.09	95.51	96.04	97.22	96.22	96.32	95.81	97.33	96.49	94.34	95.93	96.31
Total-O	96.53	95.99	96.89	96.76	96.83	96.21	96.79	94.39	97.43	96.21	96.09	95.50	96.04	97.21	96.21	96.32	95.80	97.32	96.48	94.34	95.93	96.31
Si	5.291	5.297	5.295	5.283	5.289	5.262	5.230	5.311	5.307	5.278	6.065	5.577	5.423	5.603	5.667	5.350	5.353	5.337	5.347	5.415	5.448	5.418
Al	2.709	2.704	2.705	2.717	2.711	2.738	2.770	2.689	2.693	2.723	1.935	2.423	2.577	2.397	2.333	2.650	2.647	2.663	2.653	2.585	2.552	2.582
	3.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	0.824	0.795	0.682	0.761	0.722	0.559	0.612	0.619	0.584	0.594	0.894	0.913	0.913	0.993	0.928	0.471	0.458	0.449	0.459	0.727	0.736	0.690
Ti	0.322	0.327	0.441	0.438	0.440	0.573	0.583	0.589	0.594	0.585	0.272	0.199	0.197	0.078	0.187	0.584	0.620	0.597	0.600	0.191	0.208	0.202
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Fe	1.737	1.760	1.777	1.745	1.761	1.866	1.831	1.779	1.821	1.824	1.488	1.449	1.508	1.431	1.469	1.883	1.859	1.842	1.861	1.499	1.492	1.492
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Mg	2.857	2.861	2.763	2.689	2.726	2.613	2.537	2.569	2.560	2.570	2.734	3.067	3.234	3.238	3.068	2.629	2.602	2.678	2.636	3.419	3.340	3.378
	5.740	5.742	5.663	5.633	5.648	5.611	5.563	5.556	5.559	5.572	5.388	5.628	5.852	5.740	5.652	5.567	5.539	5.566	5.557	5.836	5.776	5.767
K	1.734	1.728	1.710	1.783	1.782	1.792	1.761	1.768	1.802	1.781	1.528	1.670	1.483	1.634	1.579	1.822	1.812	1.795	1.810	1.602	1.745	1.756
Ca	0.013	0.022	0.016	0.002	0.009	0.001	0.010	0.005	0.000	0.004	0.028	0.033	0.037	0.027	0.031	0.029	0.017	0.026	0.024	0.044	0.031	0.028
Na	0.000	0.000	0.000	0.024	0.012	0.016	0.088	0.003	0.000	0.027	0.140	0.119	0.007	0.083	0.087	0.000	0.026	0.040	0.022	0.115	0.041	0.142
	1.747	1.750	1.796	1.809	1.803	1.809	1.859	1.776	1.802	1.812	1.696	1.822	1.527	1.744	1.697	1.851	1.855	1.861	1.856	1.761	1.817	1.926
Cl	0.028	0.024	0.025	0.015	0.020	0.029	0.016	0.005	0.019	0.017	0.000	0.010	0.003	0.015	0.007	0.002	0.009	0.012	0.008	0.005	0.002	0.000
XMg	0.498	0.498	0.488	0.477	0.483	0.466	0.456	0.462	0.461	0.461	0.507	0.545	0.553	0.564	0.542	0.472	0.470	0.481	0.474	0.586	0.578	0.586
XFe	0.303	0.307	0.314	0.310	0.312	0.333	0.329	0.320	0.328	0.327	0.276	0.257	0.258	0.249	0.260	0.338	0.336	0.331	0.335	0.257	0.258	0.259
XTi	0.056	0.057	0.078	0.078	0.078	0.102	0.105	0.106	0.107	0.105	0.050	0.035	0.034	0.014	0.033	0.105	0.112	0.107	0.108	0.033	0.036	0.035
XAl	0.144	0.138	0.120	0.135	0.128	0.100	0.110	0.111	0.105	0.107	0.166	0.162	0.156	0.173	0.164	0.085	0.083	0.081	0.083	0.125	0.127	0.120
Fe/	0.378	0.381	0.391	0.394	0.392	0.417	0.419	0.409	0.416	0.415	0.352	0.321	0.318	0.306	0.324	0.417	0.417	0.408	0.414	0.305	0.309	0.306
Fe+Mg																						

PS-348a-94 plagioclase

PS-348a-94 plagioclase															
Points	matrix a				matrix b				matrix c						
	1 1	1 2	1 3	1 4	1 1-4	2 1	2 2	2 3	2 1-3	3	3 1	3 2	3 3	3 4	3 1-4
SiO2	62.13	61.14	61.42	60.84	61.38	59.85	59.55	60.36	59.92	59.60	59.24	59.70	59.70	59.68	59.56
Al2O3	26.00	25.44	25.78	25.67	25.72	25.22	25.26	25.32	25.17	25.12	25.18	25.19	25.19	25.45	25.23
K2O	0.18	0.25	0.28	0.17	0.22	0.27	0.29	0.31	0.29	0.33	0.32	0.36	0.36	0.40	0.35
CaO	6.77	6.74	6.65	6.78	6.74	6.61	6.38	6.48	6.49	6.34	6.67	6.34	6.34	6.51	6.46
Na2O	7.77	7.58	7.57	7.52	7.61	7.56	7.50	7.46	7.50	7.37	7.53	7.51	7.51	7.93	7.58
FeO	0.00	0.00	0.00	0.00	0.00	0.10	0.09	0.07	0.09	0.02	0.15	0.00	0.00	0.12	0.07
Total	102.85	101.15	101.70	100.98	101.67	99.61	99.07	99.70	99.46	98.75	99.09	99.10	99.10	100.09	99.25
Si	5.370	5.376	5.368	5.356	5.368	5.351	5.349	5.384	5.361	5.365	5.332	5.359	5.359	5.323	5.345
Al	2.648	2.636	2.656	2.664	2.651	2.658	2.674	2.630	2.654	2.665	2.671	2.665	2.665	2.676	2.669
	8.018	8.012	8.024	8.020	8.019	8.009	8.023	8.014	8.015	8.030	8.003	8.024	8.024	7.999	8.014
K	0.020	0.028	0.030	0.020	0.025	0.031	0.034	0.036	0.033	0.038	0.036	0.041	0.041	0.045	0.040
Ca	0.626	0.634	0.624	0.640	0.631	0.633	0.614	0.620	0.622	0.611	0.643	0.610	0.610	0.622	0.622
Na	1.302	1.292	1.282	1.284	1.290	1.310	1.306	1.290	1.302	1.281	1.314	1.307	1.307	1.372	1.319
	1.948	1.954	1.936	1.944	1.946	1.974	1.954	1.946	1.957	1.930	1.993	1.958	1.958	2.039	1.981
Fe	0.000	0.000	0.000	0.000	0.000	0.007	0.007	0.005	0.006	0.001	0.011	0.000	0.000	0.009	0.005
X An	0.321	0.324	0.322	0.329	0.324	0.321	0.314	0.319	0.318	0.317	0.323	0.312	0.312	0.305	0.314
X Ab	0.668	0.661	0.662	0.660	0.663	0.664	0.668	0.663	0.665	0.664	0.659	0.668	0.668	0.673	0.666
X Or	0.010	0.014	0.015	0.010	0.013	0.016	0.017	0.018	0.017	0.020	0.018	0.021	0.021	0.022	0.020

Appendix D: Mineral assemblages of amphibolite gneisses

HB - hornblende

BT - biotite

QTZ - quartz

PL - plagioclase

RUT - rutile

ILM - ilmenite

CHL - chlorite

TI - titanite

CPX - clinopyroxene

SER - sericite

Sample	HB	BT	QTZ	PL	GT	RUT	ILM	CHL	TI	CPX	SER	DOMAIN
PS-7A-93	*		*	*	*							1A
PS-26-93	*	*	*	*	*		*					1A
PS-27A-93	*	*	*	*	*	*	*	*	*		*	2
PS-29A-93	*			*		*	*		*			2
PS-50B-94	*		*	*	*		*					1B
PS-51A-94	*	*	*	*	*		*					1B
PS-52-94	*		*	*	*		*		*			1B
PS-63-94	*	*	*	*			*		*	*		1B
PS-109-94	*	*	*	*			*	*			*	1A
PS-115-94	*	*	*	*	*		*					1A
PS-229-94	*	*		*	*				*			1A
PS-248-94	*		*	*	*	*	*					1A

Appendix E: Mineral analyses for amphibolite gneisses

PS-26-93 garnet	R2	c	R1	d	e	f	ALL
Points	2.10	2.11	2.3.4	2.5.6	2.8.9	2.1.11	
SiO ₂	37.29	36.95	37.74	37.21	37.38	34.24	
Al ₂ O ₃	20.80	20.96	21.30	21.36	21.35	19.43	
TiO ₂	0.02	0.07	0.01	0.03	0.02	0.02	
FeO	27.86	27.42	28.37	28.33	27.73	25.70	
MnO	2.83	2.68	2.40	2.38	2.72	2.39	
MgO	3.98	4.02	3.84	3.95	3.83	3.54	
CaO	6.30	6.49	6.51	6.33	6.44	5.91	
Total	99.08	98.59	100.16	99.58	99.46	91.22	
Si	5.976	5.943	5.974	5.931	5.956	5.459	
Al	0.024	0.057	0.026	0.070	0.045	0.041	
	6.000	6.000	6.000	6.000	6.000	6.000	
Al	3.905	3.917	3.949	3.943	3.964	3.611	
Ti	0.002	0.009	0.001	0.004	0.003	0.002	
	3.907	3.926	3.949	3.946	3.967	3.942	
Fe	3.734	3.688	3.757	3.775	3.696	3.427	
Mn	0.384	0.365	0.321	0.321	0.367	0.322	
Mg	0.950	0.964	0.907	0.938	0.910	0.841	
Ca	1.083	1.118	1.104	1.081	1.098	1.009	
	6.151	6.135	6.089	6.115	6.071	6.109	
X Fe	0.607	0.601	0.617	0.617	0.609	0.561	
X Mg	0.154	0.157	0.149	0.153	0.150	0.138	
X Ca	0.176	0.182	0.181	0.177	0.181	0.165	
X Mn	0.062	0.059	0.053	0.052	0.060	0.053	
Fe/Mg	0.797	0.793	0.806	0.801	0.803	0.736	

PS-26-93 hornblende

	in contact				inclusion				in contact				matrix			
	g				h				i				j			
Points	6.1	6.2	6.1,2	6.3	6.4	6.3,4	7.1	7.2	7.1,2	8.1	8.2	8.3	8.4	8.1-4		
SiO2	42.87	43.02	42.95	42.93	43.31	43.12	44.63	43.49	44.06	42.94	42.94	42.74	44.48	43.28		
Al2O3	11.77	11.81	11.79	11.95	12.02	11.99	10.15	11.22	10.69	11.38	11.43	11.98	10.68	11.37		
TiO2	1.63	1.65	1.64	1.87	1.48	1.68	1.35	1.23	1.29	1.65	1.62	1.55	1.20	1.51		
Cr2O	0.00	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
FeO	18.84	18.63	18.74	17.26	17.13	17.20	18.79	18.90	18.85	18.81	18.79	18.83	18.00	18.61		
MnO	0.37	0.41	0.39	0.28	0.37	0.33	0.41	0.44	0.43	0.44	0.36	0.41	0.40	0.40		
MgO	9.04	9.24	9.14	10.16	10.24	10.20	9.91	9.47	9.69	9.10	9.27	9.36	9.86	9.40		
CaO	10.78	10.86	10.82	10.95	10.87	10.91	10.89	10.80	10.85	11.08	11.10	10.61	10.81	10.90		
K2O	0.79	0.87	0.83	1.00	0.91	0.96	0.54	0.61	0.58	0.84	0.91	0.85	0.53	0.78		
NaO	0.86	1.36	1.11	1.29	1.09	1.19	1.04	1.04	1.04	0.75	1.21	0.96	0.92	0.96		
Cl	0.00	0.04	0.02	0.00	0.02	0.01	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00		
Total	96.95	97.92	97.44	97.69	97.44	97.57	97.71	97.22	97.47	96.99	97.63	97.29	96.88	97.20		
Total.	96.95	97.91	97.43	97.69	97.44	97.57	97.71	97.22	97.47	96.99	97.63	97.29	96.88	97.20		

Si	6.511	6.482	6.497	6.443	6.498	6.471	6.704	6.584	6.644	6.528	6.497	6.472	6.706	6.551
Al	1.489	1.518	1.504	1.557	1.502	1.530	1.296	1.416	1.356	1.472	1.503	1.528	1.294	1.449
	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000

Al	0.618	0.579	0.599	0.557	0.624	0.591	0.502	0.586	0.544	0.567	0.536	0.611	0.604	0.580
Ti	0.186	0.187	0.187	0.211	0.167	0.189	0.152	0.140	0.146	0.189	0.184	0.177	0.136	0.172
Cr	0.000	0.004	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe	2.394	2.348	2.371	2.167	2.150	2.159	2.361	2.393	2.377	2.392	2.378	2.384	2.270	2.356
Mn	0.048	0.052	0.050	0.035	0.047	0.041	0.053	0.056	0.055	0.056	0.046	0.052	0.051	0.051
Mg	2.047	2.075	2.061	2.273	2.291	2.282	2.219	2.136	2.178	2.062	2.091	2.114	2.216	2.121
	5.293	5.245	5.269	5.243	5.279	5.261	5.287	5.311	5.299	5.266	5.235	5.338	5.277	5.279

Ca	1.755	1.753	1.754	1.762	1.748	1.755	1.754	1.752	1.753	1.805	1.799	1.721	1.746	1.768
K	0.152	0.167	0.160	0.192	0.174	0.183	0.103	0.117	0.110	0.163	0.175	0.164	0.103	0.151
Na	0.252	0.397	0.325	0.374	0.316	0.345	0.304	0.305	0.305	0.222	0.356	0.283	0.268	0.282
	2.159	2.317	2.238	2.328	2.238	2.283	2.161	2.174	2.168	2.190	2.330	2.168	2.117	2.201

Cl	0.000	0.011	0.006	0.000	0.004	0.002	0.000	0.006	0.003	0.000	0.000	0.000	0.000	0.000
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X Fe	0.452	0.448	0.450	0.413	0.407	0.410	0.447	0.451	0.449	0.454	0.454	0.447	0.430	0.446
X Mg	0.387	0.396	0.391	0.434	0.434	0.434	0.420	0.402	0.411	0.392	0.399	0.396	0.420	0.402
X Ca	0.813	0.757	0.784	0.757	0.781	0.769	0.812	0.806	0.809	0.824	0.772	0.794	0.825	0.803
Fe/Mg	0.539	0.531	0.535	0.488	0.484	0.486	0.516	0.528	0.522	0.537	0.532	0.530	0.506	0.526

PS-26-93 plagioclase										in contact					matrix					matrix					matrix					matrix											
										a					b					c					d																
										5					6					3					3					3											
Point	1.1	1.2	1.4	1.5	1.1-5	2.1	2.2	2.3	2.4	2.5	2.6	2.1-6	3.1	3.2	3.3	3.1-3	4.1	4.2	4.3	4.1-3	matrix	d	3																		
SiO2	57.52	56.81	57.32	57.06	57.18	56.88	57.32	58.08	58.49	57.76	57.44	57.66	58.06	56.74	57.12	57.31	56.15	56.28	55.53	55.99																					
Al2O	27.25	26.74	26.42	26.58	26.75	26.97	27.30	26.79	27.12	27.88	27.52	27.26	27.12	26.95	26.80	26.96	28.12	27.94	27.96	28.01																					
K2O	0.14	0.10	0.07	0.10	0.10	0.13	0.17	0.12	0.18	0.17	0.10	0.15	0.15	0.20	0.12	0.16	0.07	0.16	0.20	0.14																					
CaO	8.53	8.57	7.88	8.39	8.34	8.78	8.51	8.50	8.54	9.15	9.01	8.75	8.76	8.61	8.57	8.65	9.66	9.37	9.46	9.50																					
Na2O	6.36	6.47	6.76	6.52	6.53	6.46	6.44	6.47	6.39	6.44	6.13	6.39	6.38	6.42	6.47	6.42	5.77	5.91	5.99	5.89																					
FeO	0.14	0.13	0.14	0.10	0.13	0.13	0.11	0.07	0.03	0.14	0.15	0.11	0.13	0.07	0.10	0.10	0.07	0.18	0.23	0.16																					
Total	99.94	99.82	99.59	98.75	99.03	99.35	99.85	100.03	100.75	101.54	100.35	100.31	100.60	98.99	99.18	99.59	99.84	99.84	99.37	99.68																					
Si	5.149	5.149	5.196	5.171	5.166	5.133	5.139	5.190	5.187	5.104	5.125	5.146	5.165	5.136	5.156	5.152	5.045	5.060	5.027	5.044																					
Al	2.875	2.857	2.823	2.839	2.849	2.869	2.885	2.822	2.835	2.903	2.894	2.868	2.844	2.875	2.851	2.857	2.878	2.860	2.983	2.974																					
Al	8.024	8.006	8.019	8.010	8.015	8.002	8.024	8.012	8.022	8.007	8.019	8.014	8.009	8.011	8.007	8.009	8.023	8.020	8.010	8.018																					
K	0.015	0.012	0.008	0.011	0.012	0.014	0.019	0.013	0.020	0.019	0.011	0.016	0.017	0.024	0.013	0.018	0.008	0.018	0.023	0.016																					
Ca	0.818	0.833	0.765	0.814	0.808	0.849	0.818	0.814	0.811	0.866	0.861	0.837	0.835	0.835	0.829	0.833	0.930	0.903	0.918	0.917																					
Na	1.105	1.137	1.189	1.145	1.144	1.131	1.120	1.122	1.098	1.104	1.060	1.106	1.101	1.127	1.133	1.120	1.006	1.030	1.052	1.029																					
Na	1.938	1.982	1.962	1.970	1.963	1.994	1.957	1.949	1.929	1.989	1.932	1.958	1.953	1.986	1.975	1.971	1.944	1.951	1.993	1.963																					
Fe	0.011	0.010	0.010	0.008	0.010	0.010	0.008	0.005	0.002	0.010	0.011	0.008	0.010	0.005	0.008	0.008	0.005	0.013	0.017	0.012																					
X An	0.422	0.420	0.390	0.413	0.411	0.426	0.418	0.418	0.420	0.435	0.446	0.427	0.428	0.420	0.420	0.423	0.478	0.463	0.461	0.467																					
X Ab	0.570	0.574	0.606	0.581	0.583	0.567	0.572	0.576	0.569	0.555	0.549	0.565	0.564	0.567	0.574	0.568	0.517	0.528	0.528	0.524																					
X Or	0.008	0.006	0.004	0.006	0.006	0.007	0.010	0.007	0.010	0.010	0.006	0.008	0.009	0.012	0.007	0.009	0.004	0.009	0.012	0.008																					
matrix																						matrix					matrix					matrix					matrix				
Point	5.2	5.1	5.3	5.1-3																		matrix					matrix					matrix									
SiO2	55.94	57.05	57.53	56.84																		matrix					matrix					matrix									
Al2O	26.95	27.23	27.77	27.32																		matrix					matrix					matrix									
K2O	0.15	0.15	0.11	0.14																		matrix					matrix					matrix									
CaO	9.15	8.78	8.97	8.97																		matrix					matrix					matrix									
Na2O	6.28	6.16	5.98	6.14																		matrix					matrix					matrix									
FeO	0.18	0.18	0.09	0.15																		matrix					matrix					matrix									
Total	98.65	99.55		99.55																		matrix					matrix					matrix									
Si	5.095	5.132	5.122	5.116																		matrix					matrix					matrix									
Al	2.894	2.887	2.914	2.898																		matrix					matrix					matrix									
Al	7.989	8.019	8.036	8.015																		matrix					matrix					matrix									
K	0.017	0.018	0.012	0.016																		matrix					matrix					matrix									
Ca	0.893	0.846	0.856	0.865																		matrix					matrix					matrix									
Na	1.109	1.074	1.032	1.072																		matrix					matrix					matrix									
Na	2.019	1.938	1.900	1.952																		matrix					matrix					matrix									
Fe	0.013	0.013	0.007	0.011																		matrix					matrix					matrix									
X An	0.442	0.437	0.451	0.443																		matrix					matrix					matrix									
X Ab	0.549	0.554	0.543	0.549																		matrix					matrix					matrix									
X Or	0.008	0.009	0.006	0.008																		matrix					matrix					matrix									

PS-29a-93 biotite		in contact		in contact	
		a		b	
		2	b1	2	b2
	B29A- B29A-			B29A- B29A-	
SiO2	34.42 34.52	34.47		34.43 34.45	34.44
Al2O3	15.31 15.10	15.21		15.94 15.41	15.68
TiO2	3.85 3.96	3.91		3.59 3.21	3.40
Cr2O3	0.00 0.00	0.00		0.00 0.02	0.01
FeO	24.95 24.98	24.97		25.67 25.55	25.61
MnO	0.05 0.01	0.03		0.05 0.03	0.04
MgO	7.18 7.23	7.21		6.98 7.13	7.06
CaO	0.13 0.15	0.14		0.15 0.05	0.12
K2O	8.71 8.57	8.64		8.67 8.83	8.75
NaO	0.08 0.00	0.04		0.12 0.22	0.17
Cl	0.06 0.08	0.07		0.13 0.10	0.12
Total	94.74 94.60	94.67		95.77 95.00	95.39
T_tal-	94.73 94.58	94.66		95.74 94.98	95.36
Si	5.45 5.464	5.455		5.403 5.455	5.429
Al	2.555 2.536	2.546		2.597 2.545	2.571
	8.000 8.000	8.000		8.000 8.000	8.000
Al	0.300 0.291	0.291		0.350 0.332	0.341
Ti	0.458 0.471	0.465		0.424 0.383	0.404
Cr	0.000 0.000	0.000		0.000 0.003	0.002
Fe	3.301 3.306	3.304		3.368 3.384	3.376
Mn	0.006 0.002	0.004		0.006 0.004	0.005
Mg	1.694 1.705	1.700		1.633 1.683	1.658
	5.759 5.765	5.762		5.781 5.789	5.785
Ca	0.022 0.025	0.024		0.033 0.008	0.021
K	1.757 1.730	1.744		1.736 1.784	1.760
Na	0.024 0.000	0.012		0.036 0.069	0.053
	1.803 1.755	1.779		1.805 1.831	1.833
Cl	0.015 0.022	0.019		0.033 0.027	0.030
X Fe	0.573 0.573	0.573		0.583 0.585	0.584
X Mg	0.294 0.296	0.295		0.282 0.291	0.287
X Al	0.052 0.049	0.050		0.061 0.057	0.059
X Ti	0.090 0.082	0.081		0.073 0.066	0.070
Fe/	0.661 0.660	0.660		0.673 0.668	0.671
Fe+Mg					

PS-29a-93 hornblende

	a					b					c				
	11	12	13	14	15	11-5	21	22	23	24	21-4	31	32	33	34
	5														5
SiO ₂	40.44	40.27	40.36	40.67	40.56	40.46	40.41	40.07	39.96	40.13	40.14	40.38	40.78	40.08	40.43
Al ₂ O ₃	13.39	13.15	13.08	13.27	13.45	13.27	13.30	13.50	13.63	13.48	13.48	13.77	13.60	13.32	13.24
TiO ₂	1.81	1.62	1.60	1.64	1.79	1.69	1.60	1.63	1.49	1.38	1.53	1.27	1.50	1.49	1.52
CR ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	23.08	23.26	23.06	23.04	23.16	23.12	23.19	22.85	23.06	23.17	23.07	22.88	23.12	22.99	23.06
MnO	0.08	0.01	0.02	0.00	0.06	0.03	0.04	0.05	0.05	0.13	0.07	0.00	0.00	0.03	0.00
MgO	5.87	5.87	5.89	5.82	6.11	5.91	6.19	6.07	5.80	5.84	5.98	5.89	6.03	5.58	6.04
CaO	11.20	11.14	11.04	11.07	11.16	11.12	11.01	10.98	11.03	11.14	11.04	11.12	11.01	11.13	10.83
Na ₂ O	1.19	1.26	1.22	1.14	1.35	1.23	1.12	1.17	1.06	1.06	1.10	1.00	1.20	1.16	1.12
CL	0.08	0.05	0.08	0.03	0.09	0.07	0.08	0.08	0.08	0.06	0.08	0.06	0.08	0.05	0.07
TOTAL	98.89	98.27	97.85	97.84	99.72	98.51	98.52	98.18	97.83	98.06	98.15	97.67	99.20	97.09	97.77
TOT-	98.87	98.26	97.83	97.83	99.70	98.50	98.50	98.16	97.81	98.05	98.13	97.66	99.18	97.08	97.75
Si	6.207	6.225	6.254	6.261	6.183	6.230	6.219	6.189	6.196	6.212	6.204	6.243	6.230	6.254	6.258
Al	1.793	1.775	1.746	1.719	1.817	1.770	1.781	1.811	1.804	1.788	1.796	1.757	1.770	1.746	1.742
	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	0.629	0.621	0.644	0.697	0.601	0.638	0.631	0.647	0.687	0.671	0.659	0.754	0.679	0.704	0.677
Ti	0.209	0.188	0.136	0.190	0.205	0.196	0.186	0.189	0.173	0.160	0.177	0.148	0.172	0.175	0.178
Fe	2.963	3.008	2.989	2.975	2.953	2.978	2.985	2.952	2.991	2.999	2.982	2.959	2.954	2.999	2.985
Mn	0.010	0.002	0.002	0.000	0.008	0.004	0.005	0.008	0.006	0.017	0.009	0.000	0.000	0.004	0.000
Mg	1.344	1.354	1.362	1.339	1.387	1.357	1.419	1.399	1.340	1.348	1.377	1.357	1.372	1.297	1.393
	5.155	5.173	5.183	5.201	5.154	5.173	5.226	5.195	5.197	5.195	5.203	5.218	5.177	5.179	5.233
Ca	1.842	1.845	1.834	1.831	1.824	1.835	1.816	1.817	1.833	1.848	1.829	1.843	1.802	1.860	1.796
K	0.234	0.248	0.242	0.225	0.262	0.242	0.221	0.231	0.210	0.209	0.218	0.198	0.234	0.231	0.220
Na	0.521	0.493	0.451	0.348	0.589	0.480	0.471	0.529	0.501	0.502	0.501	0.388	0.556	0.382	0.432
	2.597	2.586	2.527	2.404	2.675	2.558	2.508	2.577	2.544	2.559	2.547	2.429	2.592	2.473	2.448
CL	0.020	0.012	0.022	0.008	0.024	0.017	0.020	0.020	0.021	0.016	0.019	0.016	0.021	0.014	0.019
X Fe	0.575	0.581	0.577	0.572	0.573	0.576	0.571	0.568	0.576	0.577	0.573	0.567	0.571	0.579	0.570
X Mg	0.261	0.262	0.263	0.257	0.269	0.262	0.272	0.269	0.258	0.259	0.265	0.260	0.265	0.250	0.266
X Ca	0.709	0.713	0.726	0.762	0.682	0.718	0.724	0.705	0.721	0.722	0.718	0.759	0.695	0.752	0.734
Fe/Mg	0.575	0.581	0.577	0.572	0.573	0.576	0.571	0.568	0.576	0.577	0.573	0.567	0.571	0.579	0.570

PS-52-94 garnet

Points	1.1	1.2	1.14	1.3	1.4	1.5	1.13	1.6	1.12	1.7	1.11	1.8	1.9	1.10	1.15	1.16	1.17	1.18	1.19	1.20	R2 a 1
SiO2	38.33	38.32	38.56	38.14	38.44	38.39	38.57	38.20	38.28	37.59	37.98	38.40	38.38	38.09	38.60	38.54	38.32	38.30	38.70	38.40	1.1
Al2O3	21.39	21.28	21.84	21.50	21.52	21.39	21.63	21.46	21.34	21.48	21.45	21.67	21.66	21.37	21.82	21.65	21.65	21.34	21.64	21.37	38.33
TiO2	0.04	0.10	0.04	0.01	0.09	0.02	0.01	0.01	0.00	0.02	0.06	0.01	0.02	0.02	0.02	0.06	0.08	0.03	0.05	0.05	21.39
FeO	27.60	27.24	27.32	26.73	26.83	27.08	27.18	27.16	26.93	26.79	26.87	27.39	27.58	27.38	27.30	26.95	27.26	27.68	27.30	27.15	0.04
MnO	1.16	1.16	1.11	1.15	1.16	1.09	1.08	1.00	1.06	1.14	1.11	1.14	1.19	1.17	1.17	1.05	1.26	1.17	1.26	27.60	1.16
MgO	4.25	4.31	4.53	4.50	4.32	4.52	4.52	4.46	4.24	4.52	4.40	4.44	4.67	4.44	4.27	4.31	4.15	3.76	4.57	4.53	1.16
CaO	7.38	7.71	7.60	7.60	7.84	7.70	7.92	7.83	7.81	7.76	7.84	7.63	6.78	7.38	7.97	7.78	7.70	7.67	7.50	7.31	4.26
Total	100.16	100.12	100.80	99.63	100.20	100.19	100.91	100.12	99.66	99.30	99.71	100.68	100.28	99.85	101.15	100.34	100.42	99.95	101.02	100.02	7.38
Si	6.018	6.016	6.004	6.003	6.017	6.015	6.000	5.994	6.029	5.950	5.983	5.993	6.005	5.998	5.994	6.021	5.997	6.034	6.013	6.024	6.018
Al	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.050	0.017	0.007	0.000	0.002	0.006	0.000	0.003	0.000	0.000	0.000	0.000
Ti	0.018	0.016	0.004	0.003	0.017	0.015	6.000	6.000	6.029	6.000	6.000	6.000	6.005	6.000	6.000	6.021	6.000	6.034	6.013	6.024	6.018
Al	3.959	3.938	3.972	3.988	3.970	3.950	3.967	3.963	3.961	3.957	3.966	3.978	3.994	3.964	3.989	3.987	3.991	3.963	3.962	3.951	3.939
Ti	0.005	0.011	0.005	0.001	0.011	0.003	0.001	0.001	0.000	0.002	0.007	0.001	0.003	0.003	0.002	0.007	0.010	0.003	0.006	0.006	0.005
Fe	3.964	3.949	3.977	3.989	3.981	3.953	3.968	3.964	3.961	3.959	3.973	3.979	3.997	3.967	3.991	3.994	4.001	3.966	3.968	3.957	3.964
Mn	3.624	3.577	3.558	3.519	3.513	3.548	3.536	3.564	3.546	3.547	3.541	3.574	3.609	3.605	3.546	3.521	3.568	3.646	3.547	3.563	3.624
Mg	0.154	0.154	0.146	0.154	0.154	0.145	0.142	0.133	0.141	0.153	0.148	0.151	0.158	0.156	0.153	0.138	0.167	0.156	0.166	0.161	0.154
Ca	0.997	1.010	1.061	1.056	1.007	1.055	1.048	1.043	0.995	1.067	1.033	1.034	1.089	1.043	0.989	1.003	0.969	0.884	1.059	1.060	0.997
Fe	1.242	1.298	1.268	1.281	1.315	1.292	1.320	1.317	1.318	1.317	1.324	1.275	1.137	1.246	1.326	1.302	1.291	1.295	1.248	1.229	1.242
X Fe	6.017	6.039	6.023	6.010	5.989	6.040	6.046	6.057	6.000	6.084	6.046	6.034	5.993	6.050	6.014	5.964	5.995	5.981	6.020	6.013	6.017
X Mg	0.602	0.592	0.591	0.586	0.587	0.587	0.585	0.588	0.591	0.583	0.586	0.592	0.602	0.596	0.590	0.590	0.595	0.610	0.589	0.593	0.602
X Ca	0.166	0.167	0.174	0.176	0.168	0.175	0.173	0.172	0.166	0.175	0.171	0.171	0.182	0.172	0.164	0.168	0.162	0.148	0.176	0.176	0.166
X Mn	0.206	0.215	0.211	0.213	0.220	0.214	0.218	0.217	0.220	0.216	0.219	0.211	0.190	0.206	0.220	0.218	0.215	0.217	0.207	0.204	0.206
Fe/Mg	0.026	0.026	0.024	0.026	0.026	0.024	0.023	0.022	0.024	0.025	0.024	0.025	0.026	0.026	0.025	0.023	0.028	0.026	0.028	0.027	0.026
Fe+Mg	0.784	0.780	0.772	0.769	0.777	0.771	0.771	0.774	0.781	0.769	0.774	0.776	0.768	0.776	0.782	0.778	0.786	0.805	0.770	0.771	0.784

PS-52-94 hornblende														in contact														matrix													
e														f														g													
2														4														9													
Points	51	52	51,2	61	62	63	64	61-4	71	72	73	74	71-4																												
SiO2	40.41	42.12	41.27	42.04	41.50	41.53	41.97	41.76	42.40	42.35	41.64	41.69	42.02																												
Al2O3	14.03	12.11	13.07	11.92	11.52	11.57	11.93	11.74	11.73	11.89	12.25	11.56	12.11																												
TiO2	1.93	1.40	1.67	1.04	0.95	1.25	1.21	1.11	1.59	1.38	1.77		1.63																												
Cr2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01																												
FeO	19.55	19.63	19.59	22.02	21.61	21.35	21.17	21.54	20.35	20.08	20.29	20.27	20.25																												
MnO	0.26	0.22	0.24	0.27	0.19	0.19	0.19	0.21	0.15	0.16	0.25	0.20	0.19																												
MgO	8.18	9.21	8.70	8.26	8.09	8.28	8.36	8.25	8.77	8.80	8.87	8.63	8.77																												
CaO	10.58	10.63	10.61	10.66	10.45	10.33	10.56	10.50	10.76	10.77	10.86	10.66	10.76																												
K2O	0.73	0.49	0.61	0.54	0.47	0.50	0.50	0.50	0.49	0.56	0.64	0.63	0.58																												
NaO	1.87	1.56	1.72	1.56	1.58	1.66	1.58	1.60	1.36	1.59	2.33	1.94	1.81																												
Cl	0.05	0.04	0.05	0.07	0.02	0.04	0.07	0.05	0.07	0.07	0.11	0.10	0.09																												
Total	97.59	97.41	97.50	98.38	96.38	96.70	97.54	97.25	97.67	97.66	99.06	98.44	98.21																												
Total-O	97.58	97.40	97.49	98.36	96.38	96.69	97.52	97.24	97.65	97.64	99.04	98.42	98.19																												
Si	6.159	6.402	6.281	6.406	6.444	6.421	6.421	6.423	6.445	6.438	6.287	6.312	6.371																												
Al	1.841	1.598	1.720	1.594	1.556	1.579	1.579	1.577	1.555	1.562	1.713	1.688	1.630																												
	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000																												
Al	0.679	0.572	0.626	0.547	0.552	0.529	0.573	0.559	0.547	0.568	0.466	0.553	0.534																												
Ti	0.222	0.160	0.191	0.119	0.111	0.145	0.139	0.129	0.182	0.159	0.201	0.201	0.106																												
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002																												
Fe	2.492	2.496	2.494	2.805	2.807	2.761	2.708	2.770	2.587	2.553	2.561	2.567	2.567																												
Mn	0.033	0.028	0.031	0.035	0.024	0.025	0.024	0.027	0.019	0.021	0.032	0.026	0.025																												
Mg	1.857	2.088	1.973	1.875	1.872	1.908	1.905	1.890	1.988	1.995	1.996	1.947	1.982																												
	5.283	5.344	5.314	5.381	5.366	5.368	5.349	5.366	5.323	5.296	5.262	5.294	5.294																												
Ca	1.728	1.732	1.730	1.740	1.739	1.712	1.731	1.731	1.753	1.754	1.756	1.729	1.748																												
K	0.142	0.095	0.119	0.105	0.094	0.099	0.098	0.099	0.096	0.109	0.123	0.122	0.113																												
Na	0.553	0.461	0.507	0.481	0.476	0.498	0.469	0.476	0.401	0.469	0.683	0.570	0.531																												
X	2.423	2.288	2.356	2.306	2.309	2.309	2.298	2.306	2.250	2.332	2.562	2.421	2.391																												
Fe/	0.012	0.010	0.011	0.018	0.005	0.010	0.017	0.013	0.019	0.019	0.027	0.026	0.023																												
Cl																																									
X	0.472	0.467	0.469	0.521	0.523	0.514	0.506	0.516	0.486	0.482	0.487	0.485	0.485																												
X	0.352	0.391	0.371	0.348	0.349	0.355	0.356	0.352	0.373	0.377	0.379	0.368	0.374																												
X	0.713	0.757	0.734	0.755	0.753	0.741	0.753	0.751	0.779	0.752	0.685	0.714	0.731																												
X																																									
Fe/Mg	0.573	0.545	0.558	0.599	0.600	0.591	0.587	0.594	0.565	0.561	0.562	0.569	0.564																												

PS-52-94 plagioclase

Points	in contact						matrix				matrix				
	k						b				c				
	high	1.1	1.2	1.3	1.4	1.5	low	2.2	2.3	3.1	3.2	3.4	3.5	3.1-5	4
SiO ₂	51	58.15	52	53	54	55	56	51-6	61	62	63	61-3	71	72	73
Al ₂ O ₃	58.15	26.62	26.73	26.36	26.50	26.67	26.65	26.59	26.60	26.76	27.19	26.85	26.98	27.10	27.20
K ₂ O	0.13	0.13	0.13	0.12	0.06	0.15	0.09	0.11	0.06	0.06	0.05	0.06	0.15	0.43	0.22
CaO	8.12	8.14	8.06	8.06	8.06	8.09	8.32	8.13	8.39	8.59	9.09	8.69	8.83	8.64	8.84
Na ₂ O	6.51	6.38	6.65	6.58	6.58	6.88	6.64	6.61	6.24	6.04	6.23	6.17	6.37	6.10	6.16
FeO	0.12	0.22	0.31	0.23	0.23	0.15	0.18	0.20	0.34	0.21	0.27	0.27	0.40	0.35	0.41
Total	99.65	99.82	99.37	99.26	99.26	99.70	99.36	99.53	98.77	98.44	99.99	99.07	99.12	98.88	98.91
Si	5.211	5.208	5.208	5.206	5.206	5.185	5.177	5.20	5.175	5.157	5.125	5.152	5.111	5.109	5.093
Al	2.812	2.818	2.797	2.811	2.811	2.822	2.829	2.81	2.839	2.865	2.874	2.859	2.882	2.901	2.912
	8.023	8.026	8.005	8.017	8.017	8.007	8.006	8.01	8.014	8.022	7.999	8.012	7.993	8.010	8.005
K	0.015	0.014	0.014	0.007	0.007	0.017	0.011	0.01	0.007	0.007	0.006	0.007	0.017	0.050	0.025
Ca	0.779	0.780	0.778	0.777	0.778	0.778	0.803	0.78	0.815	0.836	0.873	0.841	0.858	0.841	0.860
Na	1.131	1.107	1.160	1.148	1.148	1.198	1.160	1.15	1.096	1.064	1.084	1.081	1.120	1.074	1.085
	1.925	1.901	1.952	1.932	1.932	1.993	1.974	1.95	1.918	1.907	1.963	1.929	1.995	1.965	1.971
Fe	0.009	0.016	0.024	0.017	0.017	0.011	0.013	0.02	0.026	0.016	0.020	0.021	0.030	0.026	0.031
X An	0.405	0.410	0.399	0.402	0.402	0.390	0.407	0.40	0.425	0.438	0.445	0.436	0.430	0.428	0.451
X Ab	0.588	0.582	0.594	0.594	0.594	0.601	0.588	0.59	0.571	0.558	0.552	0.561	0.561	0.547	0.544
X Or	0.008	0.007	0.007	0.004	0.004	0.009	0.006	0.01	0.004	0.004	0.003	0.003	0.009	0.025	0.013

high in contact

in contact

in contact

low

high

low

high

low

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low

ALL R2 C

	11	12	13	14	16	19	18	11	11	1-3,11	14,6,8	1-5,8-1	2,6	2,4	2,5	2,3	2,2	2,1	2,7	2,8	2,9	2,1-9	2,16-	2,35-
Points	37.44	37.12	36.98	37.10	37.48	37.84	37.52	37.70	37.36	37.23	37.45	37.39	37.90	37.62	37.77	37.29	37.66	37.71	37.86	37.39	37.58	37.64	37.76	37.53
SiO2	21.04	21.30	21.03	20.98	21.10	21.31	21.29	21.31	21.32	21.17	21.17	21.19	21.33	21.37	21.36	21.06	21.15	21.32	21.58	21.28	21.62	21.34	21.46	21.21
Al2O3	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.02	0.06	0.04	0.02	0.00	0.00	0.00	0.06	0.03	0.03	0.01	0.03
TiO2	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.02	0.00	0.01	0.00	0.01
Cr2O	27.76	27.56	27.63	27.79	27.90	27.51	27.49	27.77	27.38	27.58	27.74	27.64	27.38	27.41	27.64	27.23	27.08	27.14	27.28	27.28	27.17	27.29	27.24	27.44
FeO	2.25	2.28	2.31	2.24	2.21	2.36	2.40	2.34	2.21	2.26	2.30	2.29	2.45	2.44	2.45	2.44	2.49	2.25	2.48	2.50	2.59	2.45	2.44	2.45
MnO	5.08	5.42	5.27	5.09	5.65	5.64	5.41	5.60	5.43	5.30	5.44	5.40	5.58	5.66	5.52	5.21	5.38	5.32	5.41	5.35	5.29	5.41	5.40	5.37
MgO	5.22	5.16	5.20	5.07	4.96	5.15	4.89	5.16	5.15	5.18	5.02	5.11	5.43	5.39	5.11	5.56	5.22	5.61	5.60	5.31	5.61	5.43	5.56	5.34
CaO	98.79	98.84	98.50	98.28	99.30	99.81	99.00	99.88	98.86	98.75	99.12	99.03	100.09	99.96	99.90	98.81	98.98	99.35	100.22	99.19	99.89	99.60	99.89	99.36
Total	5.976	5.920	5.928	5.957	5.949	5.963	5.964	5.946	5.945	5.942	5.954	5.950	5.958	5.927	5.953	5.950	5.983	5.967	5.9	5.939	5.924	5.949	5.948	5.952
Si	0.024	0.080	0.072	0.043	0.051	0.037	0.036	0.054	0.055	0.058	0.046	0.050	0.042	0.073	0.047	0.050	0.017	0.033	0.061	0.076	0.051	0.052	0.049	
Al	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
AI	3.934	3.924	3.901	3.927	3.897	3.922	3.952	3.908	3.944	3.926	3.921	3.923	3.911	3.896	3.921	3.911	3.943	3.944	3.939	3.923	3.941	3.925	3.934	3.916
Ti	0.000	0.000	0.004	0.002	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.003	0.007	0.005	0.003	0.000	0.000	0.000	0.007	0.004	0.003	0.002	0.004
Cr	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.001	0.000	0.001	0.001	0.001	0.000	0.000	0.001	0.002	0.000	0.001	0.000	0.001
X	3.934	3.924	3.911	3.929	3.897	3.922	3.952	3.908	3.945	3.929	3.922	3.925	3.914	3.904	3.927	3.915	3.943	3.944	3.940	3.932	3.945	3.929	3.936	3.921
Fe	3.705	3.676	3.704	3.732	3.703	3.626	3.653	3.663	3.644	3.682	3.688	3.678	3.600	3.612	3.643	3.633	3.598	3.592	3.583	3.624	3.582	3.607	3.589	3.638
Mn	0.304	0.307	0.313	0.304	0.297	0.315	0.322	0.313	0.298	0.306	0.309	0.308	0.326	0.326	0.327	0.330	0.335	0.302	0.329	0.336	0.346	0.329	0.326	0.329
Mg	1.208	1.289	1.259	1.218	1.336	1.326	1.282	1.318	1.289	1.261	1.289	1.281	1.308	1.329	1.296	1.239	1.273	1.254	1.265	1.266	1.243	1.275	1.268	1.268
Ca	0.892	0.862	0.892	0.873	0.843	0.853	0.833	0.871	0.878	0.886	0.855	0.870	0.915	0.910	0.863	0.950	0.888	0.952	0.942	0.904	0.948	0.919	0.939	0.907
Fe+Mg	6.109	6.154	6.168	6.127	6.179	6.136	6.090	6.165	6.109	6.135	6.140	6.137	6.149	6.177	6.129	6.152	6.094	6.100	6.119	6.130	6.119	6.130	6.122	6.141
X Fe	0.607	0.597	0.601	0.609	0.599	0.591	0.600	0.594	0.597	0.600	0.601	0.599	0.586	0.585	0.594	0.591	0.590	0.589	0.586	0.591	0.585	0.588	0.586	0.592
X Mg	0.198	0.210	0.204	0.199	0.216	0.216	0.211	0.214	0.211	0.206	0.210	0.209	0.213	0.215	0.212	0.201	0.209	0.206	0.207	0.207	0.203	0.208	0.207	0.206
X Ca	0.146	0.143	0.142	0.142	0.136	0.142	0.137	0.141	0.144	0.144	0.139	0.141	0.148	0.145	0.139	0.153	0.146	0.156	0.154	0.145	0.154	0.149	0.153	0.146
X Mn	0.050	0.050	0.051	0.050	0.048	0.051	0.053	0.051	0.049	0.050	0.050	0.050	0.053	0.053	0.053	0.054	0.055	0.050	0.054	0.055	0.057	0.054	0.053	0.054
Fe/Mg	0.754	0.740	0.746	0.754	0.735	0.732	0.740	0.735	0.739	0.745	0.741	0.742	0.733	0.731	0.738	0.746	0.739	0.741	0.739	0.741	0.742	0.739	0.739	0.742

PS-115-94 biotite

PS-115-94 biotite		in contact						matrix				matrix					matrix								
		a						b				c					d								
		6						4				5					6								
SAMP	1.1	1.2	1.3	1.4	1.5	1.6	1.1-6	2.1	2.2	2.3	2.4	2.1-4	3.1	3.2	3.3	3.4	3.5	3.1-5	4.1	4.2	4.3	4.4	4.5	4.6	4.1-6
SiO2	35.96	39.60	35.61	35.90	35.86	35.81	36.46	35.78	36.24	36.34	36.25	36.15	35.82	36.17	35.53	35.74	35.61	35.77	36.07	35.84	36.06	36.25	36.40	36.06	36.11
Al2O3	15.74	16.73	15.75	15.94	15.69	15.76	15.94	15.87	15.98	16.03	16.36	16.06	15.75	18.26	15.83	15.97	15.72	16.31	16.06	16.05	15.94	16.36	16.30	15.94	16.11
TiO2	3.43	2.70	3.44	3.29	3.42	3.10	3.23	3.37	3.51	3.51	3.19	3.39	3.97	3.57	4.00	3.94	3.91	3.88	3.31	3.11	3.34	3.10	3.36	3.35	3.26
Cr2O3	0.04	0.00	0.04	0.00	0.07	0.02	0.03	0.04	0.01	0.03	0.00	0.02	0.09	0.03	0.02	0.03	0.00	0.03	0.02	0.00	0.00	0.04	0.00	0.05	0.02
FeO	18.49	16.83	18.69	18.56	18.59	18.65	18.30	18.67	18.51	18.68	17.96	18.46	18.59	16.79	18.45	18.73	18.77	18.27	18.21	18.47	18.67	18.20	18.91	18.60	18.51
MnO	0.09	0.20	0.30	0.16	0.13	0.34	0.20	0.23	0.17	0.22	0.20	0.20	0.41	0.22	0.28	0.26	0.08	0.25	0.21	0.27	0.16	0.14	0.18	0.21	0.19
MgO	12.68	10.38	12.74	13.08	12.74	12.60	12.37	12.79	13.01	12.94	12.69	12.86	12.67	11.19	12.49	12.62	12.43	12.28	13.21	12.90	13.05	12.98	12.95	12.92	13.00
CaO	0.02	0.61	0.01	0.00	0.02	0.13	0.13	0.00	0.00	0.00	0.03	0.01	0.01	0.10	0.00	0.03	0.00	0.03	0.00	0.15	0.03	0.00	0.00	0.00	0.03
K2O	8.18	6.74	8.23	8.26	8.17	7.92	7.92	8.31	8.20	8.56	8.28	8.34	8.45	7.43	8.40	8.29	8.34	8.18	8.19	7.96	8.28	8.24	8.41	8.32	8.23
Na2O	0.00	0.35	0.00	0.00	0.04	0.16	0.09	0.00	0.09	0.24	0.07	0.10	0.33	0.45	0.26	0.17	0.17	0.28	0.00	0.16	0.19	0.27	0.50	0.00	0.19
CL	0.13	0.08	0.14	0.13	0.09	0.12	0.12	0.10	0.17	0.14	0.13	0.14	0.18	0.15	0.09	0.12	0.09	0.13	0.14	0.11	0.10	0.14	0.16	0.06	0.12
TOTAL	94.76	94.22	94.95	95.32	94.82	94.61	94.79	95.16	95.89	96.69	95.16	95.73	96.27	94.36	95.35	95.90	95.12	95.41	95.42	95.02	95.82	95.72	97.17	95.51	95.77
TOT-	94.73	94.20	94.92	95.29	94.80	94.58	94.76	95.14	95.85	96.66	95.13	95.70	96.23	94.33	95.33	95.87	95.10	95.38	95.39	95.00	95.80	95.69	97.13	95.50	95.74
Si	5.470	5.891	5.425	5.434	5.456	5.463	5.524	5.432	5.448	5.435	5.473	5.447	5.395	5.442	5.392	5.391	5.415	5.407	5.440	5.436	5.433	5.449	5.418	5.445	5.437
Al	2.530	2.109	2.575	2.566	2.544	2.537	2.476	2.568	2.552	2.565	2.527	2.553	2.605	2.558	2.608	2.609	2.585	2.593	2.560	2.564	2.567	2.551	2.582	2.555	2.563
SUBT	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	0.292	0.826	0.253	0.277	0.270	0.298	0.370	0.272	0.279	0.260	0.385	0.299	0.191	0.680	0.223	0.230	0.233	0.312	0.295	0.306	0.264	0.348	0.278	0.282	0.286
Ti	0.392	0.302	0.394	0.375	0.392	0.356	0.368	0.385	0.397	0.394	0.362	0.385	0.450	0.404	0.456	0.447	0.447	0.441	0.375	0.355	0.378	0.350	0.376	0.381	0.369
Cr	0.004	0.000	0.005	0.000	0.008	0.003	0.003	0.005	0.001	0.004	0.000	0.003	0.011	0.004	0.002	0.004	0.000	0.004	0.003	0.000	0.000	0.005	0.000	0.006	0.002
Fe	2.352	2.095	2.381	2.350	2.365	2.380	2.320	2.371	2.327	2.337	2.268	2.325	2.342	2.112	2.341	2.363	2.387	2.309	2.297	2.343	2.352	2.288	2.354	2.349	2.331
Mn	0.012	0.026	0.038	0.020	0.017	0.044	0.026	0.029	0.021	0.027	0.025	0.026	0.052	0.029	0.037	0.033	0.010	0.032	0.027	0.034	0.021	0.017	0.023	0.026	0.025
Mg	2.875	2.303	2.893	2.951	2.889	2.866	2.794	2.893	2.915	2.884	2.857	2.887	2.844	2.509	2.824	2.837	2.817	2.766	2.970	2.917	2.931	2.910	2.875	2.907	2.918
SUBT	5.927	5.552	5.964	5.973	5.941	5.947	5.881	5.955	5.940	5.906	5.897	5.925	5.890	5.738	5.883	5.914	5.894	5.864	5.967	5.955	5.946	5.918	5.906	5.951	5.941
Ca	0.003	0.098	0.002	0.000	0.003	0.022	0.022	0.000	0.000	0.000	0.004	0.001	0.001	0.017	0.000	0.005	0.000	0.005	0.000	0.025	0.004	0.000	0.000	0.000	0.005
K	1.587	1.279	1.600	1.595	1.586	1.541	1.530	1.609	1.572	1.633	1.595	1.602	1.625	1.426	1.626	1.596	1.618	1.578	1.576	1.541	1.591	1.580	1.598	1.602	1.582
Na	0.000	0.102	0.000	0.000	0.011	0.047	0.027	0.000	0.027	0.068	0.021	0.029	0.096	0.133	0.077	0.048	0.051	0.081	0.000	0.048	0.054	0.080	0.143	0.000	0.054
SUBT	1.590	1.479	1.602	1.595	1.600	1.610	1.579	1.609	1.599	1.701	1.620	1.632	1.722	1.576	1.703	1.649	1.669	1.664	1.576	1.614	1.649	1.660	1.741	1.602	1.641
CL	0.033	0.020	0.036	0.033	0.023	0.031	0.030	0.026	0.043	0.035	0.035	0.035	0.045	0.039	0.024	0.030	0.022	0.032	0.037	0.029	0.025	0.036	0.041	0.016	0.031
X Mg	0.485	0.415	0.485	0.494	0.486	0.482	0.475	0.486	0.491	0.488	0.484	0.487	0.483	0.437	0.480	0.480	0.478	0.472	0.498	0.490	0.493	0.492	0.487	0.488	0.491
X Fe	0.397	0.377	0.399	0.393	0.398	0.400	0.394	0.398	0.392	0.396	0.385	0.392	0.398	0.368	0.398	0.400	0.405	0.394	0.385	0.393	0.396	0.387	0.399	0.395	0.392
X Al	0.049	0.149	0.042	0.046	0.045	0.050	0.063	0.046	0.047	0.044	0.065	0.050	0.032	0.119	0.038	0.039	0.040	0.053	0.049	0.051	0.044	0.059	0.047	0.047	0.050
X Ti	0.066	0.054	0.066	0.063	0.066	0.060	0.063	0.065	0.067	0.067	0.061	0.065	0.076	0.070	0.078	0.076	0.076	0.075	0.063	0.060	0.064	0.059	0.064	0.064	0.062
Fe+Mg	0.450	0.476	0.451	0.443	0.450	0.454	0.454	0.450	0.444	0.448	0.443	0.446	0.452	0.457	0.453	0.454	0.459	0.455	0.436	0.445	0.445	0.440	0.450	0.447	0.444

PS-115-94 biotite				matrix			
				e			
				4			
SAMP	5.1	5.2	5.3	5.4	5.1-4		
SiO ₂	35.80	36.13	36.38	36.02	36.08		
Al ₂ O ₃	16.00	16.01	16.07	16.10	16.04		
TiO ₂	3.11	3.23	3.20	3.26	3.20		
Cr ₂ O ₃	0.09	0.06	0.00	0.04	0.05		
FeO	18.86	18.86	18.77	18.58	18.77		
MnO	0.30	0.13	0.19	0.27	0.22		
MgO	12.81	12.81	12.90	12.64	12.79		
CaO	0.04	0.07	0.03	0.01	0.04		
K ₂ O	8.32	8.18	8.33	8.34	8.29		
Na ₂ O	0.07	0.00	0.04	0.06	0.05		
CL	0.16	0.10	0.15	0.12	0.13		
TOTA	95.56	95.58	96.06	95.46	95.66		
TOT-	95.52	95.56	96.03	95.43	95.63		
Si	5.424	5.453	5.465	5.447	5.447		
Al	2.576	2.547	2.535	2.553	2.553		
SUBT	8.000	8.000	8.000	8.000	8.000		
Al	0.281	0.301	0.310	0.317	0.302		
Ti	0.354	0.367	0.361	0.371	0.363		
Cr	0.011	0.007	0.000	0.004	0.005		
Fe	2.390	2.381	2.358	2.350	2.370		
Mn	0.038	0.016	0.025	0.035	0.028		
Mg	2.892	2.882	2.890	2.850	2.878		
SUBT	5.966	5.954	5.944	5.927	5.946		
Ca	0.007	0.011	0.004	0.001	0.006		
K	1.608	1.575	1.596	1.609	1.597		
Na	0.021	0.000	0.012	0.025	0.014		
SUBT	1.636	1.586	1.612	1.635	1.617		
CL	0.041	0.027	0.037	0.030	0.034		
X Mg	0.485	0.484	0.486	0.481	0.484		
X Fe	0.401	0.400	0.397	0.396	0.399		
X Al	0.047	0.051	0.052	0.053	0.051		
X Ti	0.059	0.062	0.061	0.063	0.061		
Fe/	0.452	0.452	0.449	0.452	0.452		
Fe+Mg							

PS-115-94 hornblende										matrix										matrix										matrix										matrix										matrix									
										a					b					c					d					e																													
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Points	11	12	13	11-3	45.33	45.44	45.81	45.53	44.93	45.01	44.97	45.00	45.40	45.34	44.91	45.16	44.82	44.86	44.90	44.70	45.20	44.97	44.91																																				
SiO2	11.05	10.98	10.98	11.00	10.87	10.57	10.72	10.99	10.84	10.79	10.99	10.90	10.78	10.55	10.74	10.46	10.59	10.64	10.63	10.63	10.63	10.63	10.63																																				
Al2O3	0.75	0.72	0.75	0.74	0.70	0.72	0.71	0.64	0.62	0.72	0.77	0.69	0.74	0.76	0.79	0.71	0.82	0.81	0.77	0.77	0.77	0.77	0.77																																				
TiO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00																																					
Cr2O	16.28	15.83	16.12	16.08	16.17	15.82	16.00	16.12	16.28	16.00	16.30	16.17	16.26	16.32	16.40	15.95	15.89	16.68	16.25	16.25	16.25	16.25	16.25																																				
FeO	0.43	0.46	0.41	0.43	0.41	0.48	0.45	0.48	0.40	0.48	0.50	0.46	0.47	0.51	0.49	0.42	0.48	0.50	0.48	0.48	0.48	0.48																																					
MnO	11.62	11.95	11.93	11.83	11.39	11.81	11.60	11.36	11.39	11.41	11.22	11.35	11.10	11.33	11.41	11.10	11.11	11.50	11.26	11.26	11.26	11.26	11.26																																				
MgO	10.85	11.09	10.93	10.96	10.91	10.79	10.85	10.79	10.76	10.94	10.74	10.81	11.03	10.77	10.86	10.74	10.94	10.50	10.81	10.81	10.81	10.81																																					
CaO	0.64	0.63	0.63	0.63	0.62	0.55	0.59	0.66	0.58	0.56	0.55	0.59	0.60	0.54	0.64	0.59	0.57	0.72	0.61	0.61	0.61	0.61																																					
K2O	1.78	1.84	1.77	1.80	1.66	1.74	1.70	1.73	1.62	1.64	1.72	1.68	1.57	1.55	1.70	1.75	1.62	1.81	1.67	1.67	1.67	1.67																																					
NaO	0.08	0.09	0.10	0.09	0.06	0.10	0.08	0.09	0.00	0.07	0.07	0.06	0.05	0.01	0.09	0.10	0.06	0.12	0.07	0.07	0.07	0.07																																					
Cl	98.81	99.03	99.43	99.09	97.72	97.59	97.66	97.86	97.89	97.95	97.77	97.87	97.42	97.20	98.02	96.52	97.28	98.25	97.46	97.46	97.46	97.46																																					
Total	98.79	99.01	99.41	99.07	97.71	97.57	97.64	97.84	97.89	97.93	97.75	97.86	97.41	97.20	98.00	96.50	97.27	98.22	97.44	97.44	97.44	97.44																																					
Si	6.666	6.661	6.685	6.671	6.681	6.694	6.688	6.683	6.723	6.715	6.675	6.699	6.691	6.705	6.671	6.729	6.738	6.675	6.701	6.701	6.701	6.701																																					
Al	1.334	1.339	1.315	1.329	1.319	1.306	1.313	1.317	1.277	1.285	1.325	1.301	1.309	1.295	1.329	1.271	1.262	1.325	1.299	1.299	1.299	1.299																																					
Al	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000																																					
Al	0.582	0.558	0.574	0.571	0.587	0.547	0.567	0.607	0.616	0.598	0.601	0.605	0.587	0.563	0.553	0.585	0.599	0.537	0.570	0.570	0.570	0.570																																					
Ti	0.083	0.080	0.083	0.082	0.079	0.081	0.080	0.071	0.069	0.080	0.086	0.077	0.083	0.086	0.088	0.080	0.092	0.091	0.087	0.087	0.087	0.087																																					
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000																																					
Fe	2.003	1.941	1.967	1.970	2.011	1.968	1.990	2.002	2.016	1.982	2.026	2.007	2.030	2.040	2.037	2.008	1.981	2.071	2.028	2.028	2.028	2.028																																					
Mn	0.054	0.057	0.051	0.054	0.052	0.061	0.057	0.060	0.050	0.060	0.063	0.058	0.059	0.065	0.061	0.054	0.060	0.062	0.060	0.060	0.060	0.060																																					
Mg	2.548	2.611	2.595	2.585	2.524	2.617	2.571	2.515	2.515	2.519	2.487	2.509	2.471	2.524	2.527	2.491	2.470	2.543	2.505	2.505	2.505	2.505																																					
Mg	5.270	5.247	5.270	5.262	5.253	5.274	5.264	5.255	5.266	5.239	5.263	5.256	5.230	5.278	5.266	5.218	5.202	5.304	5.250	5.250	5.250	5.250																																					
Ca	1.710	1.742	1.709	1.720	1.738	1.720	1.729	1.717	1.707	1.737	1.711	1.718	1.764	1.726	1.728	1.733	1.748	1.670	1.728	1.728	1.728	1.728																																					
K	0.121	0.119	0.118	0.119	0.117	0.104	0.111	0.125	0.110	0.105	0.105	0.111	0.114	0.103	0.120	0.113	0.108	0.137	0.116	0.116	0.116	0.116																																					
Na	0.506	0.523	0.502	0.510	0.478	0.503	0.491	0.497	0.465	0.470	0.496	0.482	0.455	0.448	0.489	0.511	0.467	0.521	0.482	0.482	0.482	0.482																																					
Na	2.337	2.384	2.329	2.350	2.333	2.327	2.330	2.339	2.282	2.312	2.312	2.311	2.333	2.277	2.337	2.357	2.323	2.328	2.326	2.326	2.326	2.326																																					
Cl	0.019	0.022	0.024	0.022	0.014	0.025	0.020	0.022	0.000	0.017	0.018	0.014	0.014	0.003	0.024	0.025	0.014	0.031	0.018	0.018	0.018	0.018																																					
X Fe	0.380	0.370	0.373	0.374	0.383	0.373	0.378	0.381	0.383	0.378	0.385	0.382	0.388	0.387	0.387	0.385	0.381	0.390	0.386	0.386	0.386	0.386																																					
X Mg	0.483	0.498	0.492	0.491	0.480	0.496	0.488	0.479	0.478	0.481	0.473	0.477	0.472	0.478	0.480	0.477	0.475	0.479	0.477	0.477	0.477	0.477																																					
X Ca	0.732	0.731	0.734	0.732	0.745	0.739	0.742	0.734	0.748	0.751	0.740	0.743	0.756	0.758	0.739	0.735	0.752	0.717	0.743	0.743	0.743	0.743																																					
Fe/	0.440	0.426	0.431	0.433	0.443	0.429	0.436	0.443	0.445	0.440	0.449	0.444	0.451	0.447	0.446	0.446	0.445	0.449	0.447	0.447	0.447	0.447																																					
Fe+Mg																																																											

PS-115-94 plagioclase										matrix a 4				in contact b 3				matrix c 4				matrix d 6			
Points	1.1	1.2	1.3	1.4	1.1-4	2.1	2.2	2.3	2.1-3	3.1	3.2	3.3	3.4	3.1-4	4.1	4.2	4.3	4.4	4.5	4.6	4.1-6	4.7	4.8	4.9	4.10
SiO ₂	56.71	56.25	56.14	56.79	56.47	53.24	52.65	51.73	52.54	56.72	56.77	56.43	55.07	56.25	56.59	56.78	56.25	55.54	56.96	56.57	56.45	56.78	56.78	56.78	56.78
Al ₂ O ₃	27.78	27.85	27.37	27.60	27.65	30.00	29.90	30.98	30.29	27.94	28.00	28.14	28.87	28.24	27.90	28.14	27.90	28.01	27.64	27.44	27.84	27.64	27.64	27.64	27.64
K ₂ O	0.09	0.11	0.14	0.10	0.11	0.05	0.09	0.03	0.05	0.08	0.08	0.05	0.07	0.07	0.11	0.13	0.09	0.04	0.13	0.13	0.10	0.13	0.13	0.13	0.10
CaO	9.19	9.28	9.14	9.02	9.16	11.91	12.17	12.84	12.31	9.24	9.43	9.66	10.45	9.69	9.26	9.36	9.35	9.62	9.07	8.93	9.27	9.36	9.36	9.36	9.27
Na ₂ O	6.55	6.23	6.10	6.17	6.26	4.78	4.63	4.13	4.52	6.35	6.13	6.35	5.65	6.09	6.19	6.27	6.26	5.81	6.44	6.17	6.22	6.27	6.27	6.27	6.22
FeO	0.14	0.06	0.10	0.11	0.10	0.11	0.18	0.22	0.17	0.04	0.08	0.05	0.18	0.09	0.16	0.08	0.16	0.10	0.19	0.13	0.14	0.13	0.13	0.13	0.14
Total	100.46	99.78	98.99	99.79	99.75	100.09	99.62	99.93	99.88	100.37	100.49	100.56	100.29	100.43	100.21	100.96	100.01	98.12	100.43	99.37	100.02	100.43	100.43	100.43	100.02
Si	5.071	5.060	5.068	5.099	5.080	4.812	4.789	4.697	4.766	5.071	5.068	5.042	4.949	5.033	5.069	5.054	5.053	5.031	5.092	5.102	5.067	5.102	5.102	5.102	5.067
Al	2.928	2.953	2.923	2.921	2.932	3.196	3.206	3.316	3.239	2.944	2.947	2.964	3.058	2.978	2.946	2.952	2.954	2.990	2.912	2.917	2.945	2.917	2.917	2.917	2.945
K	7.989	8.013	8.011	8.020	8.012	8.008	7.995	8.013	8.005	8.015	8.015	8.006	8.007	8.011	8.015	8.006	8.007	8.021	8.004	8.019	8.012	8.019	8.019	8.019	8.012
Ca	0.010	0.013	0.017	0.011	0.013	0.005	0.010	0.003	0.006	0.009	0.009	0.005	0.008	0.008	0.013	0.014	0.010	0.005	0.014	0.015	0.012	0.015	0.015	0.015	0.012
Na	0.881	0.885	0.888	0.888	0.883	1.153	1.186	1.249	1.196	0.885	0.902	0.924	1.006	0.929	0.889	0.892	0.900	0.934	0.869	0.863	0.891	0.863	0.863	0.863	0.891
Fe	1.137	1.088	1.071	1.075	1.093	0.838	0.817	0.728	0.794	1.100	1.061	1.079	0.984	1.056	1.075	1.116	1.090	1.020	1.116	1.079	1.083	1.079	1.079	1.079	1.083
X An	0.434	0.448	0.449	0.444	0.444	0.578	0.589	0.631	0.599	0.444	0.457	0.460	0.504	0.466	0.450	0.441	0.450	0.477	0.435	0.441	0.449	0.441	0.441	0.441	0.449
X Ab	0.561	0.545	0.542	0.550	0.549	0.420	0.406	0.368	0.368	0.552	0.538	0.537	0.492	0.530	0.544	0.552	0.545	0.521	0.558	0.551	0.545	0.551	0.551	0.551	0.545
X Or	0.009	0.012	0.016	0.010	0.012	0.006	0.012	0.004	0.008	0.008	0.008	0.005	0.008	0.008	0.012	0.013	0.009	0.005	0.013	0.014	0.011	0.014	0.014	0.014	0.011

matrix e 4										matrix f 6				matrix g 8				matrix h 10				matrix i 12			
Points	5.1	5.2	5.3	5.4	5.1-4	6.1	6.2	6.3	6.4	6.5	6.6	6.1-6	7.1	7.2	7.3	7.4	7.5	7.6	7.1-6	8.1	8.2	8.3	8.4	8.5	8.6
SiO ₂	56.99	56.53	56.83	56.67	56.75	57.24	57.24	58.25	57.27	56.60	56.84	57.24	56.83	57.28	57.96	58.01	57.31	57.51	57.48	57.31	57.48	57.31	57.48	57.31	57.48
Al ₂ O ₃	27.84	27.02	27.88	27.97	27.68	27.61	26.74	26.40	27.09	27.68	27.5	27.18	27.70	27.91	27.10	27.19	27.44	27.95	27.55	27.44	27.55	27.44	27.55	27.44	27.55
K ₂ O	0.08	0.12	0.08	0.09	0.09	0.08	0.15	0.18	0.12	0.09	0.1	0.11	0.11	0.11	0.16	0.18	0.16	0.16	0.14	0.16	0.14	0.16	0.14	0.16	0.14
CaO	9.18	8.68	9.22	9.18	9.07	9.00	8.44	7.70	8.51	9.09	8.91	8.61	8.96	9.23	8.32	8.45	8.96	9.00	8.82	8.96	9.00	8.82	8.96	9.00	8.82
Na ₂ O	6.67	6.69	6.40	6.27	6.51	6.33	6.64	6.80	6.72	6.60	6.43	6.59	6.39	6.19	6.71	6.72	6.42	6.44	6.53	6.72	6.44	6.53	6.72	6.44	6.53
FeO	0.19	0.15	0.14	0.21	0.17	0.08	0.08	0.06	0.13	0.10	0.10	0.09	0.14	0.05	0.05	0.10	0.10	0.15	0.10	0.10	0.15	0.10	0.15	0.10	0.10
Total	100.95	99.19	100.55	100.35	100.27	100.34	99.29	99.39	99.84	100.16	99.92	99.82	100.13	101.07	100.30	100.65	100.39	101.21	100.62	100.39	101.21	100.62	100.39	101.21	100.62
Si	5.074	5.115	5.074	5.067	5.082	5.111	5.163	5.231	5.140	5.076	5.100	5.137	5.091	5.086	5.170	5.160	5.118	5.096	5.120	5.118	5.096	5.120	5.118	5.096	5.120
Al	2.922	2.982	2.934	2.948	2.922	2.906	2.942	2.794	2.867	2.926	2.915	2.875	2.924	2.921	2.848	2.851	2.889	2.920	2.892	2.889	2.920	2.892	2.889	2.920	2.892
K	7.996	7.997	8.008	8.011	8.004	8.017	8.005	8.025	8.007	8.002	8.015	8.012	8.015	8.007	8.018	8.011	8.007	8.016	8.012	8.007	8.016	8.012	8.007	8.016	8.012
Ca	0.009	0.014	0.010	0.011	0.011	0.009	0.018	0.020	0.014	0.010	0.008	0.008	0.012	0.013	0.018	0.020	0.018	0.018	0.016	0.018	0.016	0.018	0.016	0.018	0.016
Na	0.875	0.842	0.882	0.880	0.870	0.861	0.815	0.741	0.819	0.873	0.857	0.828	0.860	0.878	0.795	0.805	0.858	0.855	0.842	0.858	0.855	0.842	0.858	0.855	0.842
Fe	1.151	1.173	1.107	1.087	1.130	1.097	1.161	1.183	1.169	1.148	1.118	1.146	1.110	1.117	1.161	1.159	1.112	1.107	1.128	1.112	1.107	1.128	1.112	1.107	1.128
X An	0.430	0.415	0.441	0.445	0.433	0.438	0.409	0.381	0.409	0.430	0.432	0.417	0.434	0.437	0.403	0.406	0.432	0.432	0.424	0.432	0.432	0.424	0.432	0.432	0.424
X Ab	0.566	0.578	0.554	0.550	0.562	0.558	0.582	0.609	0.584	0.565	0.564	0.577	0.560	0.556	0.588	0.584	0.559	0.559	0.568	0.559	0.568	0.559	0.568	0.559	0.568
X Or	0.008	0.012	0.009	0.010	0.010	0.008	0.016	0.017	0.012	0.009	0.007	0.011	0.011	0.012	0.016	0.017	0.016	0.016	0.014	0.016	0.014	0.016	0.014	0.016	0.014

	R2	R1	C
1	1	1	1
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99	1	1	1
100	1	1	1

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PS-248-94 garnet												
	115	114	19	113	110	111	117	118	113	R1 d	R2 e	C f
Points	115	114	19	113	110	111	117	118	113	3	2	13
SiO2	38.00	37.68	37.24	37.89	37.36	37.29	36.85	37.61	37.92	37.49	37.51	14.17
Al2O3	21.22	21.29	20.98	21.31	21.19	20.98	20.90	21.32	21.24	21.26	21.16	21.16
TiO2	0.04	0.01	0.00	0.07	0.06	0.07	0.04	0.02	0.02	0.04	0.03	0.03
Cr2O3	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.01
FeO	28.89	29.66	29.86	29.24	28.96	28.69	27.83	29.00	28.38	28.98	29.10	29.10
MnO	1.26	1.33	1.37	1.12	1.06	1.13	1.02	1.16	1.03	1.11	1.20	1.20
MgO	4.30	4.37	4.41	4.36	4.62	4.55	4.39	4.71	4.46	4.67	4.44	4.44
CaO	6.17	5.37	4.96	6.38	5.86	5.88	6.58	6.14	6.61	6.00	5.82	5.82
Total	99.88	99.71	98.90	100.37	99.13	98.59	97.61	99.96	99.66	99.55	99.26	99.26
Si	6.007	5.981	5.974	5.971	5.955	5.974	5.958	5.947	5.997	5.951	5.97	5.97
Al	0.000	0.019	0.026	0.029	0.045	0.026	0.042	0.053	0.005	0.049	0.03	0.03
	6.007	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.001	6.000	6.00	6.00
Al	3.954	3.964	3.941	3.929	3.936	3.936	3.941	3.920	3.955	3.928	3.95	3.95
Ti	0.005	0.001	0.000	0.008	0.007	0.008	0.004	0.003	0.003	0.005	0.00	0.00
Cr	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.001	0.00	0.00
	3.959	3.965	3.941	3.937	3.945	3.944	3.945	3.923	3.958	3.934	3.95	3.95
Fe	3.819	3.937	4.007	3.853	3.860	3.843	3.763	3.835	3.754	3.848	3.88	3.88
Mn	0.169	0.178	0.186	0.149	0.143	0.153	0.140	0.155	0.137	0.149	0.16	0.16
Mg	1.012	1.034	1.056	1.025	1.098	1.086	1.058	1.109	1.052	1.104	1.05	1.05
Ca	1.045	0.913	0.853	1.078	1.001	1.010	1.140	1.040	1.120	1.021	0.93	0.93
	6.045	6.062	6.102	6.105	6.102	6.092	6.101	6.139	6.063	6.121	6.08	6.08
X Fe	0.632	0.649	0.657	0.631	0.633	0.631	0.617	0.625	0.619	0.629	0.64	0.64
X Mg	0.167	0.171	0.173	0.168	0.180	0.178	0.173	0.181	0.174	0.180	0.17	0.17
X Ca	0.173	0.151	0.140	0.177	0.164	0.166	0.187	0.169	0.185	0.167	0.16	0.16
X Mn	0.028	0.029	0.030	0.024	0.023	0.025	0.023	0.025	0.023	0.024	0.03	0.03
Fe/Mg	0.791	0.792	0.791	0.790	0.779	0.780	0.781	0.776	0.781	0.778	0.79	0.79

P.S-248-94 hornblende

Points	in contact a					matrix b				in contact c				matrix inclusion d				inclusion e				inclusion f			
	11	12	13	14	15	11-5	21	22	23	24	21-4	31	32	33	34	31-4	41	42	43	44	41-4	11	12	122	1212
SiO ₂	41.84	41.72	41.89	41.99	41.47	41.78	41.52	41.57	42.07	42.05	41.80	42.33	41.59	41.50	41.91	41.83	41.67	42.70	42.18	42.94	42.37	41.01	41.75	41.81	41.78
Al ₂ O ₃	12.32	12.63	11.75	11.91	11.89	11.99	11.93	11.85	11.61	11.75	11.79	11.37	11.87	11.54	11.62	11.60	11.71	11.70	12.19	11.53	11.78	13.60	13.00	12.93	12.97
TiO ₂	1.50	1.69	1.79	1.72	1.69	1.68	1.76	1.74	1.63	1.74	1.72	1.53	1.55	1.54	1.58	1.55	1.42	1.50	1.58	1.48	1.50	1.48	1.51	1.47	1.49
Cr ₂ O ₃	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	19.14	18.87	18.65	19.06	18.74	18.89	19.29	19.25	19.11	19.25	19.23	19.06	18.67	18.48	18.68	18.77	19.14	19.02	18.81	19.36	19.08	18.69	19.03	19.21	19.12
MnO	0.29	0.35	0.20	0.22	0.25	0.26	0.17	0.19	0.19	0.21	0.19	0.26	0.21	0.20	0.23	0.23	0.09	0.13	0.20	0.20	0.16	0.23	0.24	0.12	0.18
MgO	9.79	9.69	9.64	9.78	9.75	9.73	9.33	9.58	9.57	9.50	9.50	9.75	9.52	9.68	9.86	9.70	9.50	9.85	9.57	9.88	9.70	9.16	9.33	9.46	9.40
CaO	11.06	11.03	11.07	10.94	11.03	11.03	10.99	11.13	10.93	11.12	11.04	10.88	11.06	10.70	10.99	10.91	11.04	11.15	11.29	11.14	11.16	10.83	10.81	10.79	10.80
K ₂ O	0.77	0.80	0.81	0.81	0.73	0.78	0.80	0.77	0.77	0.75	0.77	0.74	0.76	0.69	0.75	0.74	0.63	0.73	0.76	0.70	0.71	0.57	0.67	0.61	0.64
NaO	1.72	1.47	1.61	1.37	1.35	1.50	1.45	1.45	1.66	1.75	1.58	1.34	1.34	1.25	1.60	1.38	1.26	1.79	1.31	1.27	1.41	1.41	1.75	1.76	1.76
Cl	0.08	0.10	0.08	0.08	0.06	0.08	0.07	0.10	0.04	0.06	0.07	0.10	0.07	0.06	0.06	0.07	0.01	0.07	0.08	0.08	0.06	0.06	0.12	0.11	0.12
Total	98.51	97.80	97.49	97.88	96.96	97.73	97.37	97.63	97.58	98.18	97.69	97.36	96.84	95.64	97.28	96.78	96.47	98.64	98.00	98.58	97.92	97.04	98.27	98.27	98.27
Total	98.49	97.78	97.47	97.86	96.95	97.71	97.35	97.61	97.57	98.17	97.68	97.34	96.82	95.63	97.27	96.77	96.47	98.62	97.98	98.56	97.91	97.03	98.24	98.25	98.25
Si	6.307	6.330	6.367	6.358	6.337	6.340	6.336	6.328	6.394	6.362	6.355	6.439	6.365	6.410	6.381	6.399	6.394	6.411	6.369	6.446	6.405	6.242	6.294	6.301	6.298
Al	1.693	1.670	1.633	1.642	1.663	1.660	1.664	1.672	1.606	1.638	1.645	1.561	1.635	1.590	1.619	1.601	1.606	1.589	1.631	1.554	1.595	1.758	1.706	1.699	1.703
	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	0.496	0.486	0.472	0.484	0.478	0.483	0.481	0.455	0.474	0.457	0.467	0.478	0.506	0.512	0.466	0.491	0.513	0.482	0.538	0.487	0.505	0.683	0.605	0.598	0.602
Ti	0.171	0.193	0.204	0.196	0.194	0.192	0.202	0.199	0.186	0.198	0.196	0.175	0.179	0.179	0.181	0.179	0.164	0.170	0.179	0.167	0.170	0.169	0.171	0.166	0.169
Cr	0.000	0.002	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.001	0.000	0.008	0.000	0.004
Fe	2.412	2.395	2.371	2.414	2.395	2.397	2.462	2.450	2.429	2.436	2.444	2.425	2.416	2.387	2.379	2.402	2.456	2.388	2.375	2.431	2.413	2.379	2.399	2.422	2.411
Mn	0.038	0.044	0.026	0.028	0.032	0.034	0.023	0.025	0.027	0.027	0.025	0.034	0.027	0.026	0.030	0.029	0.012	0.017	0.025	0.025	0.020	0.029	0.031	0.016	0.024
Mg	2.200	2.191	2.184	2.207	2.222	2.201	2.123	2.175	2.175	2.175	2.152	2.211	2.171	2.230	2.237	2.212	2.173	2.204	2.154	2.211	2.186	2.078	2.096	2.125	2.111
	5.317	5.311	5.257	5.329	5.321	5.307	5.298	5.304	5.281	5.261	5.286	5.323	5.299	5.334	5.293	5.312	5.318	5.261	5.274	5.321	5.294	5.338	5.310	5.327	5.319
Ca	1.786	1.793	1.803	1.775	1.805	1.792	1.797	1.816	1.779	1.803	1.799	1.774	1.813	1.771	1.794	1.788	1.816	1.794	1.827	1.793	1.808	1.767	1.747	1.742	1.745
K	0.148	0.155	0.157	0.157	0.142	0.152	0.156	0.150	0.149	0.144	0.150	0.144	0.149	0.136	0.147	0.144	0.123	0.140	0.147	0.135	0.136	0.112	0.130	0.118	0.124
Na	0.502	0.433	0.476	0.401	0.401	0.443	0.430	0.429	0.490	0.514	0.466	0.396	0.398	0.375	0.472	0.410	0.374	0.521	0.383	0.369	0.412	0.415	0.513	0.515	0.514
	2.436	2.381	2.436	2.333	2.348	2.367	2.383	2.395	2.418	2.461	2.414	2.314	2.360	2.282	2.413	2.342	2.313	2.455	2.357	2.297	2.356	2.294	2.390	2.375	2.383
Cl	0.020	0.026	0.021	0.020	0.016	0.021	0.017	0.025	0.011	0.016	0.017	0.026	0.018	0.016	0.016	0.019	0.004	0.017	0.021	0.021	0.016	0.015	0.032	0.028	0.030
X Fe	0.454	0.451	0.451	0.453	0.450	0.452	0.465	0.462	0.460	0.463	0.462	0.456	0.456	0.448	0.449	0.452	0.462	0.454	0.450	0.457	0.456	0.446	0.452	0.455	0.453
X Mg	0.414	0.413	0.415	0.414	0.418	0.415	0.401	0.410	0.411	0.407	0.407	0.415	0.410	0.418	0.423	0.416	0.409	0.419	0.408	0.416	0.413	0.389	0.395	0.399	0.397
X Ca	0.733	0.753	0.740	0.761	0.769	0.751	0.754	0.758	0.736	0.733	0.745	0.767	0.768	0.776	0.743	0.764	0.785	0.731	0.775	0.781	0.768	0.770	0.731	0.733	0.732
Fe/Mg	0.523	0.522	0.521	0.522	0.519	0.521	0.537	0.530	0.528	0.532	0.532	0.523	0.527	0.517	0.515	0.521	0.531	0.520	0.524	0.524	0.525	0.534	0.534	0.533	0.533

Fe+Mg

PS-248-94 plagioclase										matrix			matrix			matrix			matrix		
										a			b			c			d		
										4			3			4			4		
	1 1	1 2	1 3	1 4	1 1-4	2 1	2 2	2 3	2 1-3	3 1	3 2	3 3	3 4	3 1-4	4 1	4 2	4 3	4 4	4 1-4		
Points	56.26	56.78	56.86	56.46	56.59	56.18	55.65	56.88	56.24	56.00	55.03	54.87	55.88	55.45	56.12	55.67	55.61	55.89	55.82		
SiO2	27.66	27.91	27.49	27.12	27.55	27.36	27.15	27.52	27.34	28.03	28.19	27.58	27.30	27.78	26.96	27.25	27.20	26.82	27.06		
Al2O3	0.13	0.06	0.13	0.08	0.10	0.07	0.10	0.09	0.09	0.06	0.08	0.07	0.12	0.08	0.12	0.08	0.09	0.12	0.10		
K2O	9.46	9.55	9.20	8.99	9.30	9.36	8.97	9.51	9.28	9.77	10.20	9.78	9.54	9.82	9.02	9.37	9.13	8.93	9.11		
CaO	6.04	6.27	6.36	5.88	6.14	5.91	5.85	6.06	5.94	5.62	5.36	5.58	6.05	5.65	6.10	5.78	5.89	6.09	5.97		
Na2O	0.19	0.14	0.20	0.15	0.17	0.18	0.15	0.23	0.19	0.16	0.24	0.23	0.23	0.22	0.19	0.15	0.13	0.13	0.15		
FeO	99.74	100.71	100.24	98.68	99.81	99.06	97.87	100.29	99.07	99.64	99.10	98.11	99.12	98.99	98.51	98.30	98.05	97.98	98.21		
Total	5.057	5.065	5.094	5.122	5.087	5.087	5.094	5.092	5.091	5.044	4.995	5.028	5.069	5.034	5.109	5.080	5.085	5.114	5.097		
Si	2.935	2.935	2.903	2.900	2.919	2.921	2.930	2.904	2.918	2.976	3.016	2.978	2.919	2.972	2.894	2.931	2.932	2.893	2.913		
Al	8.003	8.000	7.997	8.022	8.006	8.008	8.024	7.996	8.009	8.020	8.011	8.006	7.988	8.006	8.003	8.011	8.017	8.007	8.010		
K	0.015	0.007	0.015	0.009	0.012	0.009	0.012	0.011	0.011	0.007	0.009	0.008	0.014	0.010	0.014	0.010	0.010	0.014	0.012		
Ca	0.913	0.912	0.884	0.874	0.878	0.908	0.880	0.913	0.900	0.943	0.992	0.960	0.928	0.956	0.880	0.916	0.894	0.876	0.892		
Na	1.054	1.084	1.105	1.034	1.069	1.037	1.039	1.052	1.043	0.982	0.943	0.991	1.065	0.995	1.077	1.023	1.045	1.080	1.056		
Fe	1.982	2.003	2.004	1.917	1.977	1.954	1.931	1.976	1.954	1.932	1.944	1.959	2.007	1.961	1.971	1.949	1.949	1.970	1.960		
Fe	0.014	0.010	0.015	0.011	0.013	0.014	0.012	0.017	0.014	0.012	0.018	0.018	0.017	0.016	0.015	0.012	0.010	0.010	0.012		
X An	0.461	0.455	0.441	0.456	0.453	0.465	0.456	0.462	0.461	0.488	0.510	0.490	0.462	0.488	0.446	0.470	0.459	0.445	0.455		
X Ab	0.532	0.541	0.551	0.539	0.541	0.531	0.538	0.532	0.534	0.508	0.485	0.506	0.531	0.507	0.546	0.525	0.536	0.548	0.539		
X Or	0.008	0.003	0.007	0.005	0.006	0.005	0.006	0.006	0.005	0.004	0.005	0.004	0.007	0.005	0.007	0.005	0.005	0.007	0.006		

Appendix F: Mineral assemblages of marbles and calc-silicate gneisses

QTZ - quartz
DI - diopside
CC - calcite
SC - scapolite
PHL - phlogopite
FO - forsterite
PL - plagioclase

TI - titanite
RUT - rutile
AM - amphibole
KF - K-feldspar
SP - spinel
AP - apatite
OP - opaques

Sample		QTZ	DI	CC	SC	PHL	FO	PL	TI	RUT	AM	KF	SP	AP	OP
PS-19-93	C-S	*	*					*	*		*				
PS-21B-93	C-S	*	*	*	*			*	*		*	*			
PS-15b-94	C-S	*	*		*				*						
PS-35-94	C-S	*	*	*					*						
PS-68-94	C-S	*	*			*		*	*		*				
PS-74B-94	MARB			*	*	*	*								
PS-86c-94	MARB			*				*			*				
PS-88A-94	MARB		*	*	*	*			*						
PS-88b-94	C-S	*	*			*		*							*
PS-132-94	C-S	*	*		*										
PS-203-94	C-S		*		*	*			*						
PS-223-94	MARB	*	*	*	*	*	*	*							
PS-235-94	C-S	*	*			*		*	*		*				
PS-238-94	MARB			*		*	*		*	*	*		*	*	
PS-257-94	C-S	*	*					*	*						*
PS-283-94	C-S	*	*		*			*	*						
PS-339-94	C-S	*	*		*			*	*						
PS-342-94	C-S	*	*		*			*	*						

Appendix G: Mineral analyses for marbles and calc-silicate gneisses

Diopside		PS-21b-93 calc-silicate gneiss										PS-238-94 marble										
		1.1	1.2	1.3	1.4	avg 1	2.1	2.1	2.3	avg 2	3.1	3.2	3.3	avg 3	4.1	4.2	4.3	avg 4	2.1	2.2	2.3	2.4
SiO2	51.14	51.38	51.50	51.16	51.30	51.33	50.99	50.52	50.95	51.31	51.66	51.57	51.51	49.93	50.39	50.62	50.31	53.38	54.10	54.25	52.42	53.54
Al2O3	0.69	0.82	0.69	0.72	0.73	0.69	0.64	0.74	0.69	0.44	0.44	0.54	0.47	0.91	0.71	0.81	0.81	2.96	2.45	2.59	4.50	3.13
TiO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.97	0.63	0.56	1.38	0.99
CR2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	16.32	15.79	15.04	15.77	15.73	15.33	14.87	15.34	15.18	12.51	12.79	12.30	12.53	15.91	15.90	15.37	15.73	0.41	0.45	0.43	0.46	0.44
MgO	8.26	8.55	8.85	8.40	8.52	8.62	8.86	8.70	8.73	10.54	10.44	10.65	10.54	8.03	8.28	8.51	8.27	17.49	18.05	18.29	17.00	17.71
MnO	0.13	0.24	0.18	0.18	0.18	0.14	0.22	0.21	0.19	0.03	0.07	0.12	0.07	0.25	0.25	0.16	0.22	0.00	0.00	0.00	0.00	0.00
CaO	23.59	23.75	23.83	23.52	23.67	23.65	23.67	23.57	23.63	23.71	23.90	23.82	23.81	23.14	23.31	23.36	23.27	25.72	25.44	25.64	25.37	25.54
Na2O	0.64	0.47	0.45	0.42	0.50	0.35	0.24	0.32	0.30	0.21	0.19	0.43	0.28	0.51	0.30	0.40	0.40	0.20	0.11	0.46	0.11	0.22
TOTA	100.77	101.00	100.54	100.17	100.62	100.11	99.49	99.40	99.67	98.75	99.49	99.44	99.23	98.68	99.14	99.23	99.02	101.13	101.23	102.22	101.24	101.46
Si	1.974	1.973	1.979	1.980	1.977	1.982	1.980	1.970	1.977	1.983	1.984	1.980	1.982	1.968	1.974	1.975	1.972	1.911	1.931	1.921	1.874	1.909
Al	0.026	0.027	0.021	0.020	0.024	0.018	0.020	0.030	0.023	0.017	0.016	0.020	0.018	0.032	0.026	0.025	0.028	0.089	0.069	0.079	0.126	0.091
	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Al	0.005	0.010	0.010	0.013	0.010	0.013	0.009	0.004	0.009	0.003	0.004	0.004	0.004	0.010	0.007	0.012	0.010	0.036	0.034	0.029	0.063	0.041
Ti	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.017	0.015	0.037	0.024
CR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE	0.527	0.507	0.483	0.510	0.507	0.495	0.483	0.500	0.493	0.404	0.411	0.395	0.403	0.524	0.521	0.502	0.516	0.012	0.013	0.013	0.014	0.013
MG	0.475	0.489	0.507	0.485	0.489	0.497	0.513	0.505	0.505	0.608	0.598	0.609	0.605	0.472	0.483	0.495	0.483	0.933	0.960	0.965	0.906	0.941
MN	0.004	0.008	0.006	0.006	0.006	0.005	0.007	0.007	0.006	0.001	0.002	0.004	0.002	0.009	0.008	0.005	0.007	0.000	0.000	0.000	0.000	0.000
CA	0.975	0.977	0.981	0.975	0.977	0.979	0.985	0.985	0.983	0.982	0.984	0.980	0.982	0.977	0.979	0.977	0.978	0.986	0.973	0.973	0.972	0.976
NA	0.048	0.035	0.033	0.032	0.037	0.026	0.018	0.024	0.023	0.016	0.014	0.032	0.021	0.039	0.022	0.030	0.030	0.014	0.007	0.032	0.008	0.015
	2.034	2.026	2.020	2.021	2.025	2.015	2.015	2.025	2.018	2.014	2.013	2.024	2.017	2.031	2.020	2.021	2.024	2.007	2.004	2.027	2.000	2.010
Fe/Fe+	0.526	0.509	0.488	0.513	0.509	0.499	0.485	0.498	0.494	0.399	0.407	0.393	0.400	0.526	0.519	0.504	0.516	0.013	0.012	0.013	0.015	0.014
X Ca	0.479	0.482	0.486	0.482	0.482	0.486	0.489	0.486	0.487	0.488	0.489	0.484	0.487	0.481	0.485	0.483	0.483	0.491	0.486	0.480	0.486	0.486

Scapolite

PS-21-94 calc-silicate gneiss

	1.1	1.2	1.3	1.4	avg 1	2.1	2.2	2.3	2.4	avg 2	3.1	3.2	3.3	3.4	avg 3	4.1	4.2	4.3	4.4	4.5	avg 4
SiO ₂	45.92	45.20	45.03	45.62	45.44	46.25	45.79	45.58	45.04	45.67	45.56	46.07	45.76	45.09	45.62	46.27	45.37	45.12	45.50	44.70	45.39
Al ₂ O ₃	27.81	27.53	27.61	27.71	27.67	27.71	27.79	27.92	27.69	27.78	27.50	28.02	28.20	27.91	27.91	27.74	27.88	28.15	27.61	27.01	27.68
FeO	0.15	0.27	0.00	0.13	0.14	0.07	0.11	0.03	0.03	0.06	0.06	0.09	0.10	0.09	0.09	0.19	0.11	0.20	0.13	0.15	0.16
MnO	0.00	0.02	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.04	0.01	0.02	0.04	0.03	0.00	0.02	0.02	0.00	0.00	0.01
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.01
CaO	18.33	17.64	18.31	17.92	18.05	17.99	18.04	18.08	18.48	18.15	18.10	18.32	19.03	18.83	18.57	18.63	18.24	18.69	18.28	17.98	18.36
Na ₂ O	3.49	3.73	3.47	3.64	3.58	3.80	3.54	3.33	3.73	3.60	3.61	3.18	3.08	3.62	3.37	3.41	3.59	3.45	3.49	3.61	3.51
K ₂ O	0.65	0.66	0.55	0.65	0.63	0.64	0.65	0.60	0.66	0.64	0.68	0.69	0.63	0.59	0.65	0.81	0.75	0.68	0.68	0.66	0.72
CL	0.75	0.78	0.67	0.76	0.74	0.82	0.79	0.79	0.74	0.79	0.80	0.78	0.79	0.69	0.77	0.83	0.78	0.68	0.77	0.72	0.76
TOTAL	97.10	95.83	95.64	96.43	96.25	97.29	96.71	96.33	96.42	96.69	96.35	97.16	97.61	96.86	97.00	97.88	96.74	96.99	96.50	94.83	96.59
TOT-	96.93	95.65	95.49	96.26	96.06	97.10	96.53	96.15	96.25	96.51	96.17	96.98	97.43	96.70	96.82	97.69	96.56	96.84	96.33	94.67	96.42

normalised to (Si + Al) = 12

Si	7.002	6.985	6.967	6.993	6.967	7.032	6.995	6.968	6.958	6.988	7.012	6.989	6.951	6.938	6.973	7.030	6.959	6.915	6.996	7.008	6.982
Al	4.998	5.015	5.035	5.007	5.014	4.968	5.004	5.031	5.042	5.011	4.989	5.011	5.049	5.062	5.028	4.969	5.041	5.085	5.004	4.992	5.018
	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
Fe	0.019	0.035	0.000	0.016	0.018	0.008	0.014	0.004	0.004	0.008	0.008	0.012	0.013	0.011	0.011	0.024	0.014	0.025	0.017	0.020	0.020
Mn	0.000	0.003	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.005	0.001	0.002	0.005	0.003	0.000	0.002	0.003	0.000	0.000	0.001
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.002
Ca	2.985	2.921	3.035	2.943	2.974	2.931	2.952	2.961	3.058	2.976	2.984	2.977	3.098	3.104	3.041	3.032	2.998	3.069	3.011	3.020	3.026
Na	1.032	1.118	1.041	1.081	1.068	1.121	1.048	0.986	1.117	1.068	1.076	0.937	0.907	1.079	1.000	1.004	1.067	1.026	1.041	1.097	1.047
K	0.126	0.130	0.108	0.128	0.123	0.124	0.127	0.117	0.131	0.125	0.134	0.134	0.121	0.116	0.126	0.157	0.146	0.133	0.134	0.133	0.141
	4.172	4.207	4.184	4.168	4.183	4.185	4.141	4.068	4.321	4.179	4.207	4.061	4.141	4.315	4.181	4.217	4.227	4.256	4.211	4.270	4.236
CL	0.193	0.204	0.176	0.197	0.193	0.211	0.204	0.204	0.194	0.203	0.207	0.200	0.203	0.179	0.197	0.215	0.202	0.178	0.200	0.191	0.197
EqAn	67	67	68	67	67	66	67	68	68	67	66	67	68	69	68	66	68	70	67	66	67

PS-223-94 marble

1.1	1.2	1.3	1.4	avg 1	2.1	2.2	2.3	avg 2
46.82	45.72	47.07	45.97	46.40	44.88	46.98	46.72	46.19
27.67	27.18	27.97	28.83	27.91	29.35	27.73	27.71	28.26
0.16	0.18	0.08	0.02	0.11	0.14	0.20	0.11	0.15
0.01	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.03
0.07	0.00	0.15	0.00	0.06	0.00	0.00	0.08	0.03
17.97	17.50	17.05	18.57	17.77	19.65	17.82	17.86	18.44
3.67	3.69	3.65	3.04	3.51	3.08	3.73	3.66	3.49
0.56	0.58	0.75	0.46	0.59	0.39	0.61	0.57	0.52
0.66	0.69	0.72	0.63	0.68	0.47	0.75	0.71	0.64
97.59	95.54	97.44	97.52	97.02	98.05	97.82	97.42	97.76
97.44	95.38	97.28	97.38	96.87	97.94	97.65	97.26	97.62

7.073	7.055	7.058	6.900	7.022	6.776	7.077	7.062	6.972
4.927	4.944	4.943	5.100	4.979	5.223	4.923	4.938	5.028
12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00

0.021	0.024	0.010	0.002	0.014	0.017	0.025	0.014	0.019
0.001	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.004
0.015	0.000	0.033	0.000	0.012	0.000	0.000	0.019	0.006
2.910	2.894	2.739	2.987	2.883	3.179	2.876	2.893	2.983
1.075	1.105	1.060	0.886	1.032	0.901	1.089	1.074	1.021
0.108	0.114	0.144	0.088	0.114	0.074	0.117	0.110	0.100
4.130	4.137	3.986	3.963	4.054	4.182	4.107	4.110	4.133

0.169	0.181	0.183	0.159	0.173	0.120	0.192	0.181	0.164
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64	65	65	70	66	74	64	65	68
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Plagioclase	PS-21b-93 calc-silicate																			
	11	12	13	avg 1	21	22	23	24	p2	31	32	33	34	p3	41	42	43	44	p4	
SiO2	45.10	45.54	44.64	45.09	44.76	44.82	45.56	44.69	44.96	52.85	48.72	48.19	51.26	48.46	63.17	46.59	45.68	45.19	45.82	
Al2O3	34.98	35.05	36.00	35.34	35.63	35.58	35.36	35.62	35.55	28.89	31.75	33.83	32.43	32.79	18.84	34.93	35.65	36.03	35.54	
K2O	0.00	0.11	0.04	0.05	0.00	0.06	0.02	0.05	0.03	5.43	0.76	0.14	0.00	0.45	15.38	0.03	0.00	0.00	0.01	
CaO	18.06	18.22	19.09	18.46	18.63	18.70	18.33	18.60	18.57	10.98	14.74	16.65	16.99	15.70	0.08	17.59	18.58	19.14	18.44	
Na2O	1.11	1.37	0.87	1.12	0.86	1.17	1.27	1.11	1.10	2.05	2.39	2.39	0.78	2.39	1.20	1.38	1.05	0.77	1.07	
FeO	0.03	0.00	0.22	0.08	0.02	0.09	0.09	0.00	0.05	0.00	0.02	0.10	0.05	0.06	0.10	0.00	0.00	0.05	0.02	
TOTAL	99.28	100.29	100.86	100.14	99.90	100.42	100.63	100.07	100.26	100.20	98.38	101.30	101.51	99.84	98.77	100.52	100.96	101.18	100.89	
Si	4183	4188	4094	4155	4132	4125	4175	4124	4139	4860	4527	4368	4586	4448	5918	4256	4169	4123	4133	
Al	3824	3800	3893	3839	3877	3860	3820	3874	3858	3131	3478	3614	3419	3546	2080	3761	3835	3874	3823	
	8007	7988	7987	7994	8009	7985	7995	7998	7997	7991	8005	7982	8005	7994	7998	8017	8004	7997	8006	
K	0.000	0.012	0.004	0.005	0.000	0.007	0.002	0.005	0.004	0.637	0.090	0.016	0.000	0.053	1.838	0.003	0.000	0.000	0.001	
Ca	1.795	1.795	1.876	1.822	1.843	1.845	1.800	1.839	1.832	1.082	1.468	1.617	1.629	1.543	0.008	1.722	1.817	1.871	1.803	
Na	0.200	0.244	0.155	0.200	0.153	0.208	0.225	0.198	0.196	0.366	0.430	0.420	0.135	0.425	0.219	0.244	0.186	0.136	0.189	
	1.995	2.051	2.035	2.027	1.996	2.060	2.027	2.042	2.031	2.085	1.988	2.053	1.764	2.021	2.065	1.969	2.003	2.007	1.993	
FE	0.003	0.000	0.017	0.007	0.001	0.007	0.007	0.000	0.004	0.000	0.001	0.008	0.004	0.005	0.008	0.000	0.000	0.004	0.001	
X An	0.900	0.875	0.922	0.899	0.923	0.896	0.888	0.901	0.902	0.519	0.738	0.788	0.923	0.763	0.004	0.875	0.907	0.932	0.905	
X Ab	0.100	0.119	0.076	0.098	0.077	0.101	0.111	0.097	0.096	0.176	0.216	0.205	0.077	0.210	0.106	0.124	0.093	0.068	0.095	
X Or	0.000	0.006	0.002	0.003	0.000	0.003	0.001	0.002	0.002	0.306	0.045	0.008	0.000	0.027	0.890	0.002	0.000	0.000	0.001	

Amphibole	PS-238-94 marble									
	H238-1.1	H238-1.2	H238-1.3	H238-1.4	avg 1	H238-3.1	H238-3.2	H238-3.3	H238-3.4	avg 3
SiO2	48.79	48.37	47.44	48.42	48.26	45.40	45.96	46.34	46.19	45.97
Al2O3	11.79	11.21	11.81	11.47	11.57	13.88	13.74	13.85	14.41	13.97
TiO2	1.02	0.85	1.12	0.99	1.00	1.43	1.35	1.42	1.50	1.43
CR2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	1.01	1.11	1.07	1.07	1.07	1.16	1.05	1.12	1.16	1.12
MnO	0.06	0.01	0.07	0.00	0.04	0.00	0.00	0.00	0.05	0.01
MgO	20.28	20.28	20.02	20.70	20.32	19.52	19.44	19.66	19.68	19.58
CaO	13.83	13.88	13.74	13.82	13.82	13.81	13.78	13.80	13.85	13.81
K2O	0.79	0.68	0.79	0.68	0.74	1.18	1.15	1.13	1.18	1.16
Na2O	0.92	0.73	1.10	0.97	0.93	1.05	0.93	1.34	1.50	1.21
CL	0.05	0.00	0.03	0.07	0.04	0.05	0.05	0.04	0.06	0.05
TOTAL	98.54	97.12	97.19	98.19	97.76	97.48	97.45	98.70	99.58	98.30
TOT-O	98.53	97.12	97.18	98.17	97.75	97.47	97.44	98.69	99.57	98.29
Si	6.707	6.742	6.631	6.687	6.692	6.362	6.427	6.408	6.343	6.385
Al	1.293	1.258	1.369	1.313	1.308	1.638	1.573	1.592	1.657	1.615
	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	0.617	0.584	0.576	0.554	0.583	0.655	0.691	0.665	0.675	0.672
Ti	0.105	0.089	0.118	0.103	0.104	0.151	0.142	0.147	0.154	0.149
CR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe	0.117	0.129	0.125	0.123	0.124	0.136	0.123	0.129	0.133	0.130
Mn	0.007	0.001	0.009	0.000	0.004	0.000	0.000	0.000	0.005	0.001
Mg	4.157	4.213	4.171	4.261	4.201	4.078	4.051	4.052	4.028	4.052
	5.003	5.016	4.999	5.041	5.015	5.020	5.007	4.993	4.995	5.004
Ca	2.038	2.073	2.058	2.045	2.054	2.074	2.064	2.044	2.037	2.055
K	0.138	0.122	0.141	0.120	0.130	0.212	0.205	0.199	0.207	0.206
Na	0.245	0.198	0.299	0.259	0.250	0.285	0.251	0.359	0.398	0.323
	2.421	2.393	2.498	2.424	2.434	2.571	2.520	2.602	2.642	2.584
CL	0.012	0.001	0.008	0.016	0.009	0.012	0.011	0.010	0.014	0.012
X Ca	0.842	0.866	0.824	0.844	0.844	0.807	0.819	0.786	0.771	0.795
Fe/Fe+Mg	0.027	0.030	0.029	0.028	0.029	0.032	0.029	0.031	0.032	0.031

PS-238-94 marble												
Forsterite												
SAMPLE	F238-1.1	F238-1.2	F238-1.3	F238-1.4	F238-1.5	avg 1	F238-2.1	F238-2.2	F238-2.3	avg 2		
SiO2	41.73	41.37	41.72	41.80	42.45	41.81	42.52	41.94	41.62	42.03		
MGO	54.63	54.31	54.84	54.82	54.73	54.67	55.14	54.23	54.61	54.66		
FeO	3.02	3.10	3.06	3.10	3.08	3.07	3.20	3.21	3.15	3.19		
MNO	0.00	0.02	0.08	0.05	0.02	0.03	0.10	0.06	0.00	0.05		
CAO	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.01	0.00	0.03		
NiO	0.00	0.00	0.08	0.00	0.00	0.02	0.04	0.06	0.00	0.03		
TOTAL	99.38	98.80	99.78	99.77	100.28	99.60	101.09	99.51	99.38	99.99		
Si	0.997	0.995	0.994	0.996	1.004	0.997	1.000	1.001	0.995	0.999		
	0.997	0.995	0.994	0.996	1.004	0.997	1.000	1.001	0.995	0.999		
MG	1.946	1.947	1.948	1.946	1.930	1.943	1.933	1.930	1.947	1.937		
FE	0.060	0.062	0.061	0.062	0.061	0.061	0.063	0.064	0.063	0.063		
MN	0.000	0.001	0.002	0.001	0.000	0.001	0.002	0.001	0.000	0.001		
CA	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.001		
Ni	0.000	0.000	0.002	0.000	0.000	0.000	0.001	0.001	0.000	0.001		
	2.006	2.010	2.013	2.009	1.991	2.006	2.001	1.996	2.010	2.002		
Forsterite	95.370	94.790	95.740	95.670	95.510	95.416	96.260	94.630	95.330	95.407		
Fayalite	4.260	4.370	4.340	4.410	4.370	4.350	4.540	4.540	4.470	4.517		

Appendix H: Mineral assemblages of ultramafic schists

Sample	OL	TR	CPX	OPX	PHL	SER	CHR	LOCATION
PS-7B-93	*	*	*		*	*		RINDA RIDGE (DOMAIN 1A)
PS-7C-93	*	*		*	*			RINDA RIDGE (DOMAIN 1A)
PS-7D-93	*	*			*	*		RINDA RIDGE (DOMAIN 1A)
PS-30-93	*	*	*	*	*	*	*	NORTH OF SLOCAN (HWY 6)
PS-146-93	*	*	*	*				RINDA RIDGE (DOMAIN 1A)

5 of/de 5

PM-1 3 1/2"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

PRECISIONSM RESOLUTION TARGETS

P-Tms

PEg?

VALG

VALG

VALG

VALG

VALG

uKgn

319
320 324 309 308
321 325 310
302 307 326 311
322 313
303 317
323 315
308 305
304 316

5c

4c

U N T A

S L O C A N

PGNS-1c

F O R E S T

R A N E

Map of
Scale
Date
Author

L L A

mJgd

R
O
S

• 338

Brigade

• 337

P-Tms

PEg?

Meta Peak
no 32

PGNS-1c

F O R E S T

uKgn

PEg?

P-Tms and granitic sills

PEg

Helo Peak
no 32

PGNS-1c

F O R E S T

O C A N

R A N G E S

R E S T

uKgn

20

28

24

25

PGNS-1c

VALG

VALG

uKgn

PGNS-1a

348
348
348
348

PGNS-1b

VALG

uKgn

0232

0231

uKgn

MAP 1: GEOLOGY OF PARAGNEISSES IN THE VALHALLA COMPLEX

LEGEND

Eocene - Paleocene

PEg Ladybird granite - leucocratic biotite quartz monzonite
to granite

Paleocene

Pgm Airy quartz monzonite - K-feldspar megacrystic biotite
+/- hornblende quartz monzonite

Cretaceous

PEg

PGNS-1c

THE TADAM...
THE TADAM...

O C A N F O R E S T

Mount
Hudson

Mount
Hudson

Gullin Lakes
n=72

uKgn

PGNS-1a

PGNS-1b

uKgn

uKgn

PGNS-1c

FOREST

uKgn

24
26

17
25

NS-1a-3

25

uKgn

STUDIAN
FOREST

CHALCO

NARROW

THE FARM

MAP 2: STRUCTURE OF PARAGNEISSES IN THE VALHALLA COMPLEX

LEGEND

Eocene - Paleocene

PEg Ladybird granite - leucocratic biotite quartz monzonite
to granite

Paleocene

Pgm Airy quartz monzonite - K-feldspar megacrystic biotite
+/- hornblende quartz monzonite

Cretaceous

uKgn Mulvey granodiorite - melanocratic biotite-hornblende
augen granodioritic gneiss with leucocratic veins

Middle Jurassic

mJgd Nelson batholith and satellites

Paleozoic and Triassic

P-Tms Nemo Lakes belt: polydeformed semipelite and pelite,
calcareous schist, amphibolite and ultramafic rocks

uKgn

232

231

233

PGNS-1c

11

uKgn

1005

1004

1003

100

101

98

99

97

96

85

1000

1001

1002

95

13

12

S

T

PEg

uKgn

11

FOREST

THEY PARADISE

1002

1001

Perris

Forty
Side

mJgd

PEg

LEGEND

Eocene - Paleocene

PEg Ladybird granite - leucocratic biotite quartz monzonite to granite

Paleocene

Fgm Airy quartz monzonite - K-feldspar megacrystic biotite +/- hornblende quartz monzonite

Cretaceous

uKgn Mulvey granodiorite - melanocratic biotite-hornblende augen granodioritic gneiss with leucocratic veins

Middle Jurassic

mJgd Nelson batholith and satellites

Paleozoic and Triassic

P-Tms Nemo Lakes belt: polydeformed semipelitic and pelitic, calcareous schist, amphibolite and ultramafic rocks

Neoproterozoic - Paleozoic?

PGNS-1c Valhalla assemblage (paragneiss)

11 Undivided rocks: pelitic schist, migmatitic schist, amphibolite gneiss, marble (m), calc-silicate gneiss, quartzite and ultramafic rocks

10a Quartzite, psammite

10b Semipelitic schist, psammite, argillaceous quartzite

9 Rinda marble

8a Rinda ridge composite unit: marble, calc-silicate gneiss, psammite semipelitic schist to pelitic schist, amphibolite gneiss, ultramafic rocks (8a-u)

8b Marble, calc-silicate gneiss, psammite to pelitic schist

7 Semipelitic to pelitic schist, psammite

6 Bannock Burn marble

5a Hoder Creek composite unit: psammite, pelitic schist, argillaceous quartzite, marble, calc-silicate gneiss, amphibolite gneiss

5b Semipelitic to pelitic schist, psammite

5c Semipelitic schist, psammite

4a Marble, calc-silicate gneiss

4b Demers marble

4c Marble, siliceous marble

3a Quartzite

3b Semipelitic to pelitic schist, migmatitic schist,

argillaceous quartzite

Middle Jurassic

mJgd Nelson batholith and satellites

Paleozoic and Triassic

P-Tms Nemo Lakes belt: polydeformed semipelite and pelite,
calcareous schist, amphibolite and ultramafic rocks

Neoproterozoic - Paleozoic?

PGNS-1c Valhalla assemblage (paragneiss)

PGNS-1b (age uncertain)

PGNS-1a (age uncertain)

FOLIATION: S2, S3

LINEATION (L2): STRETCHING,
PEBBLE ELONGATION

AXIAL PLANE

FOLD AXIS: S, U, W, Z

ALL FOLDS ARE THIRD GENERATION
EXCEPT WHERE NOTED

MAFIC DYKE

Stereograms represent poles to S2 foliation
planes for areas noted.

o 13

o 12

mJgd

PEg

SLOCAN FOREST

PEmE

RANGE

CAN RANGES

- 5a Hoder Creek composite unit: psammite, pelitic schist, argillaceous quartzite, marble, calc-silicate gneiss, amphibolite gneiss
- 5b Semipelitic to pelitic schist, psammite
- 5c Semipelitic schist, psammite

- 4a Marble, calc-silicate gneiss
- 4b Demers marble
- 4c Marble, siliceous marble

- 3a Quartzite
- 3b Semipelitic to pelitic schist, migmatitic schist, argillaceous quartzite
- 3c Quartzo-feldspathic gneiss, pelitic schist, calcareous quartzite (3c-cq)

- 2a Hird Lakes calc-silicate (2a-cs) - quartzite cobble metaconglomerate (2a-cg)
- 2b Marble

- 1 Quartzo - feldspathic gneiss

VAK Valhalla Assemblage intrude by K-feldspar megacrystic granite

VALC Valhalla Assemblage comprising >75% leucogranite

Paragneiss (age uncertain)

PGNS-1b

PGNS-1a

GEOLOGICAL CONTACT: MAPPED, ASSUMED

SLOCAN LAKE FAULT: MAPPED, ASSUMED

VALKYR SHEAR ZONE: MAPPED, ASSUMED

PEg

Pgm

I R K

O L U M B A

Ak

R A S H

P5g

PGNS-1c

Perry Ridge
n=35

34 ← 19

16 ← 22

15 ← 21

29 ← 30

mJgd

PEg

21
23

ISLOCAN FOREST

Pgm E

R A N G E

A N R A N G E S

FOLD AXIS: S, U, W, Z

ALL FOLDS ARE THIRD GENERATION
EXCEPT WHERE NOTED

MAFIC DYKE

Stereograms represent poles to S2 foliation
planes for areas noted.

CONTACT: MAPPED, ASSUMED

SLOCAN LAKE FAULT: MAPPED, ASSUMED

VALKYR SHEAR ZONE: MAPPED, ASSUMED

92
94° 90
91

27

28

45

51

Pgm

RAINING

RAINING

60
325 331 332
327 329 330

11

PGNS-1c

PEg

Pgm

KOKANE
(SLOCAN RAN)

Pgme

R A N G E

A N R A N G E S

PEg

mJgd

KOKAN
FOREST

KANDEAR
FOREST

KOKANEE RANGE
(SLOCAN RANGES)

SLOCAN LAKE FAULT: MAPPED, ASSUMED

VALKYR SHEAR ZONE: MAPPED, ASSUMED

GWILLIM CREEK SHEAR ZONES

BRITTLE NORMAL FAULT

60 Station number year 1994

•29 Station number year 1993

Map is modified from Reesor (1965), Parrish (1981, 1984) and Carr (1986).

SCALE 1:50000

PGNS-1c

PEg

PEg

mJgd

29 30

13 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

11 12

Pgm E

A N R A N G E

O G

PEg

mJgd

KOKANEE RANGE

(SLOCAN RANGE)

SLOCAN LAKE FAULT: MAPPED, ASSUMED

VALKYR SHEAR ZONE: MAPPED, ASSUMED

GWILLIM CREEK SHEAR ZONES

BRITTLE NORMAL FAULT

STATION LOCALITY

SCALE 1:50000

0

5 km

Cross-sections A, B, C through the Valhalla complex.

END

0 6-0 6-9/6

FIN