

A Geochemical and Isotopic Investigation of Metasedimentary Rocks from the North Caribou Greenstone Belt, Western Superior Province, Canada

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ABSTRACT

The North Caribou Greenstone Belt (NCGB) lies at the core the granitoid-dominant North Caribou Terrane (NCT). Two sedimentary assemblages; the Eyapamikama (ELS) and Zeemal-Heaton Lake (ZHA) form the core of the NCGB.

Geochemistry of garnets from the orogenic Au deposit at Musselwhite suggest that the auriferous fluids have a contribution of metamorphic fluids and mineralization consisted of prolonged, multi-stage periods. Chemical zoning suggests changes in the influx of chalcophile and lithophile elements and that Au/sulphide ratios during nucleation were lower relative to later growth events.

Zircons from the ELS and ZHA suggest a c. 100 My hiatus in the onset of sedimentation, with the ZHA showing younger, “Timiskaming-type” ages. Age distributions from each assemblage reflect proximal, igneous sources. Nd isotopic compositions of the ZHA suggest a mixture of ancient and contemporaneous sources which are similar to external TTG rocks. Deplete mantle model ages of the ZHA rocks indicate a Mesoarchean inheritance.

RÉSUMÉ

La ceinture de roches vertes North Caribou (NCGB) se trouve au coeur de la terrane du même nom (NCT) dominée par des granitoides. Deux assemblages sédimentaires; le Lac Eyapamikama (ELS) et le Lac Zeemal-Heaton (ZHA) forment le noyau du NCGB.

La géochimie de grenats provenant du gîte d'or orogénique de Musselwhite, suggère que les fluides aurifères avaient une composante métamorphique et que la minéralisation fut prolongée durant plusieurs périodes. La zonation chimique de ces grenats suggère des changements dans l'influx d'éléments chalcophiles et lithophiles, ainsi qu'un bas ratio Au/sulfures pendant la nucléation relativement aux événements de croissance subséquents.

Des zircons provenant de ELS et ZHA montrent une interruption de 100 Ma dans la sédimentation, avec le ZHA montrant des âges plus récents de type «Timiskaming». La distribution d'âges de chaque assemblage reflète des sources ignées à proximité. La composition isotopique en Nd du ZHA suggère un mélange de sources contemporaines, similaire aux TTG entourant la ceinture. Des âges modèles du manteau appauvri des roches provenant du ZHA indiquent une signature Mésoachéenne.

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First and foremost, I would like to extend my sincerest thanks and gratitude to my two supervisors, Drs. Keiko Hattori and David A. Schneider for their support, help and critical comments which greatly improved my work throughout my time at the University and while I was away. Thanks to Keiko for helping with the neodymium sample preparation, even when things didn't always work out. Thanks to David for showing me zircon separation techniques and spending time with me preparing the grain mounts, even though there were a lot of air bubbles in the epoxy cast.

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To my office mates and friends David Lowe and Fabio Stern; thanks for keeping the office a place for work – most of the time. I enjoyed our tectonic discussions, stories about Newfoundland and its geology. Thanks to my other great friends Fritz Griffith, John Jamieson and Matt Herod.

Thanks to my family for their moral support and encouragement during these three years. And finally special thanks to my girlfriend – now fiancée for moving to Ottawa, understanding why I had to sometimes stay late at night at school and holding down the place while I was away for field work, field schools and conferences.

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- Sample maps of Akow Lake, Forester Lake and Markop Lake areas

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INTRODUCTION

Preamble

In the last thirty years, the discussion surrounding the origin of Au mineralization in Archean greenstone belts has grown substantially. Of particular interest is the source of the hydrothermal fluids responsible for carrying the gold in solution and the temporal relationships between Au deposition and major crustal compression and deformation events. Researchers have proposed various sources (cf., Ridley et al., 2000), however metamorphic (Fyfe and Kerrich; 1982, Kerrich and Cassidy; 1994; Jia and Kerrich, 2000) and magmatic (Wood et al., 1986; Burrows and Spooner, 1987) fluids are the most debated ones.

The timing of Au mineralization with respect to peak metamorphism and crustal heating (e.g., magma emplacement) is also critical to the understanding of orogenic Au deposits and has long been a debate among geologists. These deposits generally form under upper greenschist to amphibolite facies conditions and temperatures of 540 to 600°C and depths of 10-15 km (Kerrich and Cassidy, 2004). Stüwe (1998) presents contrasting models for the timing of Au mineralization relative to metamorphism at various crustal depths. Of them, is the ‘deep-earlier’ model where deeper levels of the crust achieve peak metamorphism prior to shallower crustal levels.

Detrital zircons within metasedimentary basins in Archean greenstones provide valuable clues to the tectonic and depositional history of these ancient terranes. Moreover, the importance of understanding these greenstone belts becomes greater when they host significant Au and/or base metal endowments (e.g., Abitibi: Corfu, 1991; Hemlo-Heron: Davis and Lin, 2003; Vermilion: Lodge et al., 2013; **Fig. i**). Furthermore, geochemistry of metasedimentary rocks

become important in these terranes as they provide evidence of the tectonic setting in which they were deposited. There has been a long standing debate over the source of siliciclastic sediments in Archean greenstone as the maturity of these rocks range from low to very high (e.g., Donaldson and de Kemp, 1998). Such high maturity (i.e., quartz arenites) implies crustal recycling was present during the cratonization of Archean terranes and the provenances were not entirely from mafic and felsic metavolcanics.

PREVIOUS WORK

Mapping of the NCGB was first conducted by Satterly (1941). Later, workers carried out reconnaissance mapping in the 1960s (e.g., Emslie 1962), which was coeval with the discovery of Au-bearing quartz veins in the Opapimiskan Lake area by Harold and Allan Musselwhite. Further regional mapping continued throughout the 1970s (e.g., Thurston et al., 1979) and more detailed mapping into the 1980s (e.g., Sage and Breaks, 1982; Andrews et al., 1981; de Kemp, 1987). Breaks et al. (2001) have provided the latest map of the belt (**Fig. ii**).

Geochemical studies of garnet from orogenic Au deposits have received relatively little attention by researchers. The first chemical compositions of garnets were obtained by Otto (2002) for geobarometric calculations of auriferous rocks at Musselwhite. Moran (2008) provided major element transects of garnet porphyroblasts from the mine, however interpretations from these results were not drawn. However, detailed mapping by Geusebroek and Duke (2004) of underground workings at the Lupin mine, Nunavut, show that the size and abundance of garnet crystals increase adjacent to the iron formation. The success of garnet as a tracer of mineralization has been explored in other deposits such as skarn (Beinn an Dubhaich;

Smith et al., 2004) and SEDEX (Broken Hill; Spry et al., 2007 and St. Eugene; Pattison and Seitz, 2012).

Since the first geochronological study in the late 1980s by de Kemp (1987), the data repository for absolute ages of rocks within the NCGB and surrounding granitoids has grown immensely. High precision zircon U-Pb data obtained by de Kemp (1987) determined the oldest supracrustal rocks of the NCGB occur within the Keeyask Lake ($< 2978 \pm 3.0$ Ma) and Agutua Arm assemblages (2981 ± 1.8 Ma) in the western NCGB. Likewise, the Weagamow Batholith, which occurs immediately west of the Keeyask Lake assemblage, was dated at 2990 ± 1.8 Ma (de Kemp, 1987). Younger ages obtained by de Kemp (1987) include the North Caribou Batholith at 2869.3 ± 3.6 Ma and the Schade Lake Gneiss Complex at 2856 ± 1.8 Ma.

After mining production started at Musselwhite in 1997, researchers focused their work on obtaining precise ages of rocks in and around the mine. Davis and Stott (2001) reported an age for a rhyolitic tuff, outcropping west of the mine, within the South Rim metavolcanics, at 2981.9 ± 0.8 Ma and a volcanoclastic rhyolite from the North Rim metavolcanics at 2870 ± 2 Ma (**Fig. ii**). Davis and Stott (2001) also returned ages for the ELS metasedimentary rocks and a quartz arenite clast within the ZHA of < 2870 Ma and c. 2853 Ma, respectively. Magmatic rocks dated by Davis and Stott (2001) include the large North Caribou Batholith at 2864 ± 1.1 Ma.

Biczok et al. (2012) report several ages for lithologies within Musselwhite and plutons around the mine. Deposition of the Au-hosting banded iron-formation has been bracketed by footwall (c. 2982.4 ± 0.8 Ma) and hanging wall (c. 2972.4 ± 1.6 Ma) felsic tuffs (Biczok et al., 2012). However, more recent zircon U-Pb dating by McNicoll et al. (2013) suggests the BIF and metavolcanics are structurally overturned with ages from top to bottom ranging from c. 2978 to

2850 Ma. These ages are much older than the syn-orogenic granites surrounding the mine dated from 2729.4 ± 7.1 Ma to 2723.1 ± 0.8 Ma (Biczok et al., 2012). Sm-Nd dating of auriferous garnets from the main Au-hosting BIF zone suggests that mineralization occurred at 2690 ± 9 Ma. However, these data also suggest the mineralizing event(s) may range from c. 2717 Ma to c. 2664 Ma (Biczok et al., 2012).

The most recent, and comprehensive, study of the external granitoids within the NCT was carried out by Van Lankvelt et al. (2013). Zircon U-Pb results from this study indicate three main episodes of magmatism in the NCGB; a Mesoarchean (c. 3100 – 2900 Ma) inheritance, a large scale magmatism from 2880 – 2830 Ma and hydrothermal event from c. 2760 – 2680 Ma (Van Lankvelt, 2013; Van Lankvelt et al., 2013). The latest stage of zircon growth (i.e., recorded in the rims) shows chemical characteristics (REE and Th/U ratios) akin to their respective igneous cores (Van Lankvelt et al., 2013).

Geochronology of fabric-aligned monazites and zircons and detailed analysis of crustal-scale shear zoned by Kalbfleisch (2012) suggest a protracted history of metamorphism, deformation and shear zone reactivation spanning from 2.86 to 2.44 Ga.

THESIS OBJECTIVES

The objectives of this thesis were two-fold: the first objective was to address the potential of using minor and trace elements of garnet at Musselwhite to record ore-forming fluids. This is reported in Chapter 1.

The second objective was to determine the provenances and depositional history of sedimentary basins using U-Pb zircon ages, whole rock Nd isotopes and multi-element geochemistry. This is reported in Chapter 2.

STRUCTURE OF THE THESIS

The results of major and trace element chemical studies of garnet from the auriferous zones at Musselwhite, presented in Chapter 1, suggest that metamorphic fluids from deep crustal levels were involved in Au mineralization at the deposit scale. From the zonation patterns in the garnets and by using the results from pervious geochronological work for NCGB (Biczok et al., 2012) and other metamorphic terranes in the Western Superior Province (Heaman et al., 2011), it is possible to suggest that Musselwhite experienced a ‘deep-earlier’ metamorphic evolution; where the lower crust experienced peak metamorphism, prior to shallower levels.

Detrital zircon U-Pb data in Chapter 2 show a distinct hiatus in sedimentation with the onset of deposition of the ZHA commencing 100 My after the ELS. Both basins reflect proximal source regions, provided by pervious geochronological work, with the ELS containing a prominent c. 2800-2900 Ma signature and the ZHA containing c. 2670 to 2875 Ma signature. Mesoarchean (3.0 to 3.4 Ga) zircons occur in both basins, however are more extensive in the ELS. Furthermore, Nd isotopic compositions of the ZHA metasedimentary rocks are comparable to surrounding external granitoids, which, along with whole rock data, further underpins a proximal provenance. Ages obtained from the ZHA samples yielded similar ages to those from the Timiskaming assemblage in the Abitibi greenstone belt (**Fig. i**), which is spatially associated with Au deposits. The U-Pb ages of the ZHA metasedimentary rocks are presented in Chapter 3, with discussion of the possibility that these rocks may have ages and sedimentological features similar to the Timiskaming assemblage of the Abitibi greenstone belt.

STUDY AREA

The North Caribou Greenstone Belt (NCGB) is located in the centre of the North Caribou Terrane (NCT) of Ontario's western Superior Province (**Fig. i**). The NCT is one of many terranes and subprovinces within the Superior Province. Despite being the largest terrane, the NCT has received limited attention from researchers mainly due to its remote location. The NCGB is an attractive study area due its complex tectonic evolution and rich Au endowment from the Musselwhite mine. The NCGB (**Fig. ii**) consists of four to eight lithotectonic supracrustal assemblages. In short, they are the Agutua Arm, Keeyask Lake, McGruer and Eyapamikama Lake (ELS) assemblages. The ELS can be subdivided into the ELS-proper and Zeemal-Heaton assemblage (ZHA). Together, these two sedimentary basins account for ~ 50 % of the surface of the supracrustal rocks in the NCGB (Breaks et al., 2001). The North (NRV) and South Rim (SRV) metavolcanic units and the Opapimiskan Lake metavolcanic unit, which hosts the Musselwhite deposit, belong to the McGruer assemblage (**Fig. ii**).

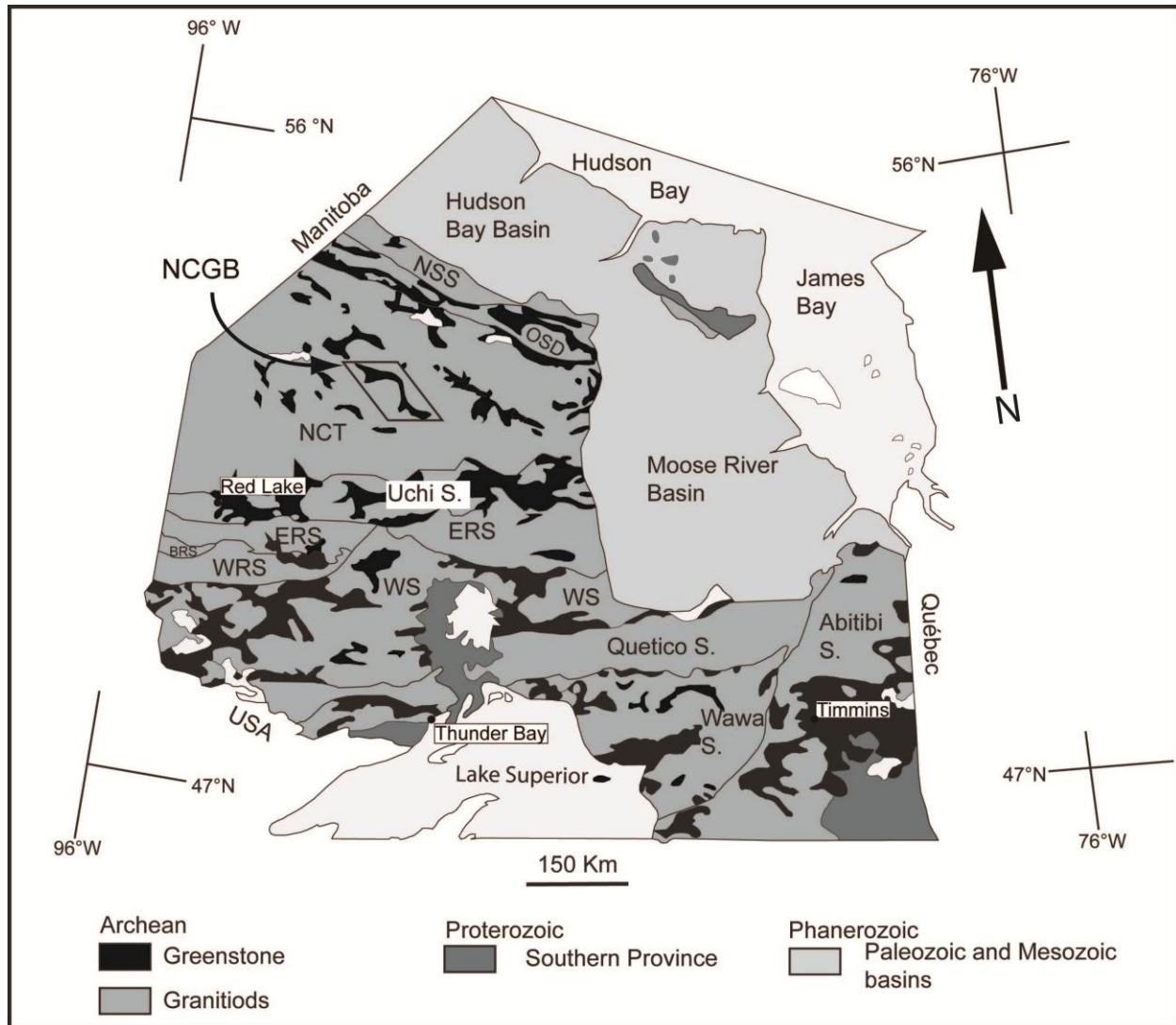


Figure i: Simplified geological map of the western Superior Province (WSP) modified after Breaks et al. (2001). The black box indicates the location of the North Caribou Greenstone Belt (NCGB; Fig. ii), within the North Caribou Terrane (NCT). Other WSP subprovinces: BRS; Bird River Province, ERS; English River Subprovince, S; Subprovince and WS; Wawa Subprovince.

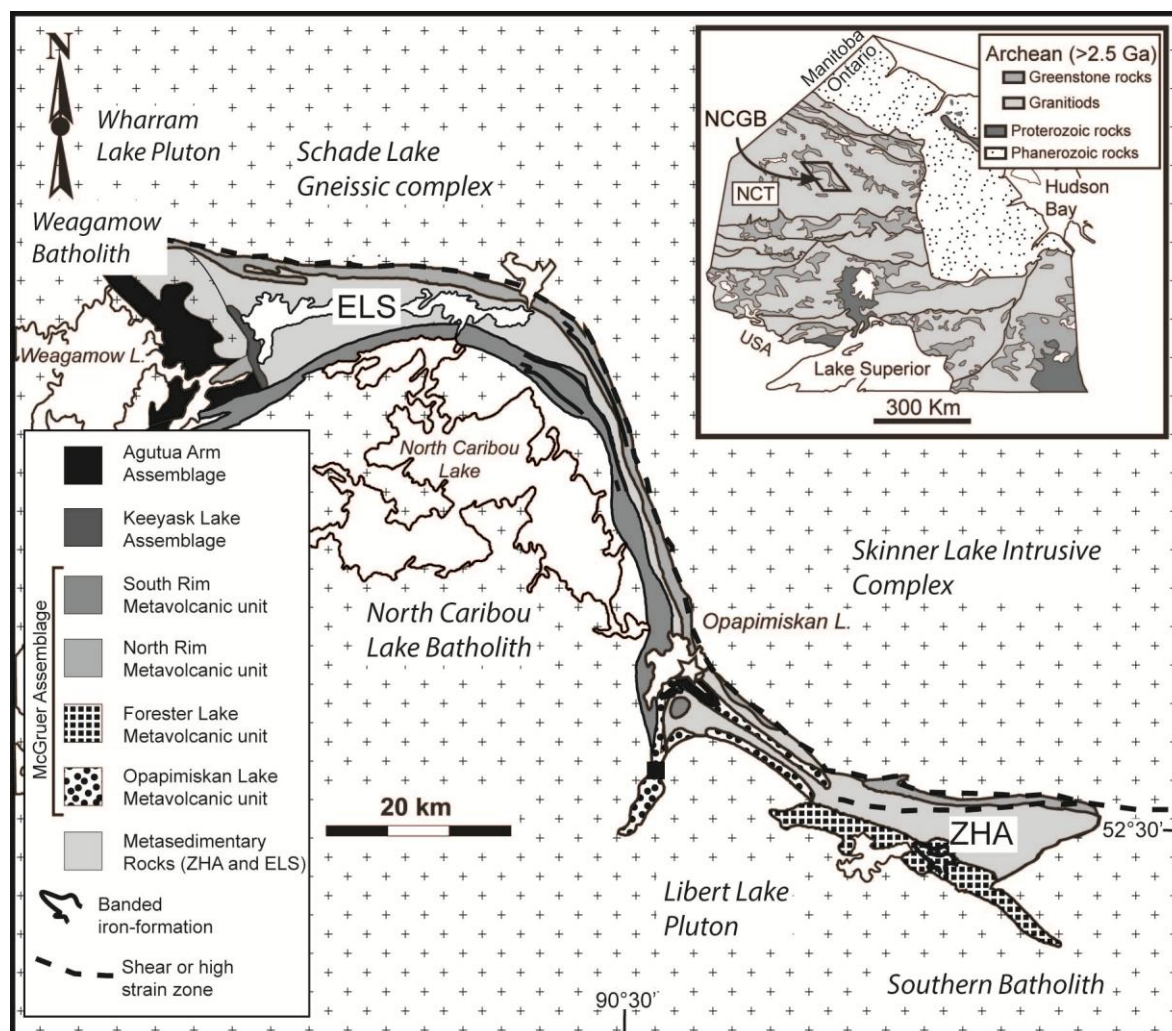


Figure ii: Geological map of the NCGB, its major assemblages – including the ZHA and ELS - and location of several major plutons. White star on the south shore of Opapimiskan Lake shows the location of the Musselwhite mine.

STATEMENT OF ORIGINAL CONTRIBUTION

This thesis provides new U-Pb isotopic data of detrital zircons and whole-rock geochemistry for metasedimentary rocks of the ZHA and ELS. It also presents new trace and major element abundances of garnets from the Musselwhite mine.

Fieldwork for this study was carried out during the summers of 2010 (June to August) and 2011 (2 weeks in June). Samples were collected by the author, Ms. Kalbfleisch and Ms. Van Lankvelt. Ms. Cossette collected major element abundances from one garnet sample discussed in

Chapter 1 and the results of which were previously reported in her unpublished undergraduate report at the University of Ottawa (cf., Cossette, 2011).

All rock samples were prepared by the author with the exception of thin and thick sections. Multi-element analyses of the rocks presented in Chapter 2 were carried out at Activation Laboratories in Ancaster, Ontario, and fused disc XRF analyses (i.e., major elements) were prepared by the author and Dr. Kell at the University of Ottawa.

The results and conclusions of Chapter 1, “*Garnet as a tracer for Au mineralization in an orogenic Au deposit; Evidence from the Musselwhite mine, North Caribou greenstone belt, WSP of Canada*” were presented in an oral presentation, by the author, at the 2012 GAC-MAC meeting in St. John’s, Newfoundland Labrador (**Appendix A4b**). The results and conclusions of Chapter 2, “*Geological Development of the North Caribou Greenstone belt, Recorded in Mesoarchean Sedimentary Rocks, Western Superior Province of Canada,*” were presented in a poster presentation at the 2011 GSA meeting in Minneapolis, Minnesota (**Appendix A4a**). The results and conclusions of Chapter 3, “*Timiskaming-type sedimentary rocks in the North Caribou greenstone belt, Western Superior Province of Canada,*” were presented in an oral presentation, by Dr. Hattori, at the 2013 GAC-MAC meeting in Winnipeg, Manitoba (**Appendix A4c**).

Chapter 1

Garnet as a tracer for Au mineralization in an orogenic Au deposit; Evidence from the Musselwhite mine, North Caribou greenstone belt, Western Superior Province of Canada.

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Abstract

The origin of auriferous fluids was constrained based on trace element concentrations of almandine garnets in auriferous schists from the Musselwhite mine; a banded iron-formation (BIF) hosted orogenic Au deposit, in the North Caribou Greenstone Belt (NCGB) of the western Superior Province (WSP). Garnet grains record at least two episodes of crystal growth: pre to syn Au mineralization and syn to post Au mineralization. The cores exhibit steep shallow to flat (HREE)_{CN} slopes with concave-down shape and steep positive in LREE. In addition, they show slightly positive Eu anomalies ($\text{Eu}/\text{Eu}^* = 0.45$ to 4.60) relative to the rims ($\text{Eu}/\text{Eu}^* = 0.12$ to 4.14), however the highest value obtained is from the rim of the main garnet-grunerite schist ore zone. The rims of the garnet porphyroblasts show weak to moderately negative slopes in HREE and significantly heterogeneous patterns in LREE. Differences in chalcophile and siderophile (i.e., Au) element concentrations between the cores and rims of garnet porphyroblasts, and the sulphides associated with Au, suggest that Au/sulphide ratios during the growth of garnet were lower in early stage of garnet growth than during later stages. Our data suggest that the fluid involved in Au mineralization was derived, in part, from a metamorphic source and mineralization may have occurred during extensive hydrothermal activity.

Introduction

A long standing debate has existed regarding the source of the mineralizing, hydrothermal fluids responsible for forming orogenic Au deposits. As well, the timing of Au introduction into upper crustal levels and relative timing relative to regional metamorphism is still outstanding. The debate revolves around either a system dominated by a metamorphic (i.e., Fyfe and Kerrich; 1982, Kerrich and Cassidy; 1994; Jia, 2000) or magmatic source (i.e., Wood et al., 1986;

Burrows and Spooner, 1987). To a lesser degree, meteoric or mantle derived fluids have been proposed for orogenic Au deposits (cf., Pitcarin et al., 2006). Furthermore, the timing of Au deposition relative to regional metamorphism is not well constrained; ranging from pre to post-metamorphism (Hagemann and Cassidy, 2000; Dubé and Gosselin, 2007). To constrain the debate, we present major and trace element chemistry of garnet crystals from auriferous rocks from Musselwhite, compare the compositions with those from barren samples outside the deposit and discuss the hydrothermal history of the deposit. Garnet is an appropriate mineral for such a study because it 1) commonly exhibits major element zonation, reflecting changes in temperature and pressure (Spear et al., 1991), and 2) is ubiquitous as a stable and/or meta-stable phase in rocks of various protoliths that were metamorphosed under upper greenschist facies or higher grade.

Garnet has been used to evaluate fluid/rock interactions in orogenic Au deposits. Geusebroek and Duke (2004) concluded the abundance and size of garnet provide an effective vector of Au mineralization in the banded iron-formation at the Lupin mine, Northwest Territories. More broadly, garnet has been proven to be an effective exploration tool and/or recorder of hydrothermal activity in several other mineralized terranes such as sediment-hosted polymetallic (Spry et al., 2007; Pattison and Seitz, 2012) and U-rich skarn (Smith et al., 2004) deposits.

The results from stable isotope work on silicate and sulfide minerals at Musselwhite by Otto (2002) suggest metamorphic and magmatic sources, respectively. Issac (2008) duplicated the analysis of Otto (2002) on silicate minerals and returned the same results; suggesting a metamorphic and magmatic source, yet indicating a stronger magmatic signature. Detailed microscopic work by Kolb (2010) on sulfides and silicate minerals at Musselwhite revealed native Au as inclusions in garnet porphyroblasts and within quartz-filled fractures with grains.

The occurrence of such would indicate Au precipitation during pre to syn-nucleation of garnet and post-peak deposition. Hence, the second objective of this study is to build a temporal model for Au mineralization from the intragranular chemical variation in auriferous garnet porphyroblasts in concert with published geochronological data of major well known metamorphic events in the WSP.

We interpret the chemistry of garnet from Musselwhite to reflect, in part, a fluid from a metamorphic source and garnet porphyroblasts that show significant intragranular compositional variation from core to rim. These variations are suggested to record changes in fluid composition during the growth of garnet from a mainly closed system (low water/rock ratio) to an open system (high water/rock ratio).

Geological Setting

The Musselwhite deposit is located within the North Caribou Greenstone Belt (NCGB; **Fig. 1-1A**) of the North Caribou Terrane (NCT; **Fig. 1-1inset**) of the WSP in Canada. The NCGB contains c. 3.0 Ga supracrustal rocks. The age of these rocks suggests that the NCT acted as a nucleus during the accretion of smaller terranes to form the Superior Province (Thurston et al., 1991). The docking between the Island Lake Domain (the north of the NCGB) and the NCGB itself took place at c. 2707 Ma (Thurston et al., 1991). The NCGB, a metavolcanic-metasedimentary greenstone-granitoid belt, has experienced a protracted history metamorphism, magmatism and deformation. The earliest record of deformation was documented in metavolcanic rocks which stratigraphically over and underlie the Musselwhite at > 2.87 Ga as result of TTG magmatism (Percival, 2007). Similar ages of c. 2.86 Ga are recorded in amphibolite facies rocks distal to the deposit (Kalbfleisch, 2012). Major episodes of crustal

melting are reflected in plutonic events that span from c. 2.73 to 2.668 Ga (Wyman et al., 2011). Gold mineralization is currently constrained by a 2-point regression (matrix and garnet), Sm-Nd “hydrothermal garnet” age from Musselwhite at 2690 Ma (Biczok et al., 2012). Although, Biczok et al. (2012) interpret this age to be the age of Au mineralization, an age of c. 2717 Ma can also be generated using the matrix and another garnet porphyroblast. Likewise, a lower intercept age of 2664 Ma can be generated using only the garnet porphyroblast analyses (Biczok et al., 2012).

Deformation in the NCGB and Musselwhite has been marked by three major events as documented by Breaks et al. (2001) and Hall and Riggs (1986), respectively. The first event is rarely observed, although where it is seen, it is characterized by tight to isoclinal folds (Breaks et al., 2001). These folds were subsequently re-folded by the second event, which is punctuated by mesoscopic, vertical open folds with wavelengths between 0.3 to 3 m. The final event is marked by the penetrative development of crenulation cleavages overprinting the folds of the first and second deformation events. Potential reactivations of some of these structures were recently determined at 2.45 Ga determined by Kalbfleisch (2012) using total U-Th geochronology of *in-situ* monazite grains within upper-greenschist rocks along the greenstone-granitoid boundaries. To date, this age records the latest episodes of deformation within the NCGB.

Geology at the Musselwhite Mine

Gold mineralization (~ 5 Moz. Au as of December 31, 2010; Wyman et al., 2011) at Musselwhite is concentrated within two major banded-iron formations; the Northern Iron Formation (NIF) (**Fig. 1-2**) and Southern Iron Formation (SIF), both of which are hosted within the tholeiitic metavolcanic rocks of the Opapimiskan-Markop unit of the McGruer Assemblage

(Biczok et al., 2012). The NIF (**Fig. 1-2B**) hosts the majority of Au mineralization and is currently under production. The NIF consists of 6 major lithologies divided equally into a lower oxide dominant section and upper silicate dominant section (**Fig. 1-2A**). The transition from oxide to silicate dominant domains was described by Moran (2008) as a result of the onset or increase in clastic sedimentation (e.g., clay) contemporaneous with BIF formation. Thus, the protoliths for the NIF and SIF are chemical cherts, mudstones and pelites. From bottom to top, the oxide dominant section consists of pyrrhotite-bearing schist, laminated chert-grunerite [(Mg, Fe)₂(Mg, Fe)₅Si₈O₂₂(OH)₂] schists and amphibole+/- garnet schists. The upper most facies consists of silicate dominated rocks such as garnet-grunerite, garnet-biotite and garnet-hornblende schists (Biczok et al., 2012). The garnet-grunerite schist is the main auriferous unit, containing the highest Au grades, and is the target for further exploration in the NIF. The Au endowment controls of this high grade zone (garnet-grunerite schist) is not well understood, however Biczok et al. (2012) suggest the changes in redox conditions during deposition of the iron-formation may have played a critical as a “chemical trap” for mineralizing fluids. As mentioned above, this unit was dated by garnet Sm-Nd by Biczok et al. (2012) yielding the approximate age of Au mineralization.

Otto (2002) calculated that the mineralization in the NIF occurred under amphibolite facies conditions with temperatures ranging between ~540 to 600°C and pressures of 0.6 to 0.7 GPa based on Mg-Fe exchange equilibrium between garnet and other phases and, in doing so, provided the first quantitative chemical analysis of garnet at Musselwhite. Hall and Riggs (1986) determined the peak metamorphic conditions of the SIF to be ~530 to 550°C and 0.3 GPa.

Sampling

Five garnet-bearing rock samples were collected from underground at Musselwhite, diamond drill core and surface outcrop in the summer of 2010 (**Figs. 1A & 2A**). The underground samples (JD10-07 and JD10-11), both from the NIF, were collected from the garnet-grunerite schist (JD10-07) and the amphibole-garnet schist (JD10-11) (**Fig. 1-2A**). Although both lithologies are auriferous, the grunerite-garnet schist commonly contains higher Au concentrations in the deposit. In addition, one high grade (i.e., 35.48 g/t Au over 1m) auriferous sample (JD10-18) was collected from drill core north of Opapimiskan Lake on property held, at the time, by Premier Gold, now Premier Gold Mines Limited (**Fig. 1-1A**). This sample is believed to be stratigraphically equivalent to the grunerite-garnet schist at Musselwhite. Detailed petrographic examination confirms that sample JD10-18 shows similar mineralogy as grunerite-garnet schist at the mine. One sample was collected from an outcrop north of Opapimiskan Lake (**Fig. 1-1B**), which represents the garnet-biotite schist overlying the main garnet-grunerite schist at the mine (JD10-16A). Finally, sample JD10-90 was collected at Forester Lake, ~ 24 km east of Musselwhite. Breaks et al. (2001) described this rock as stratigraphically equivalent to the auriferous rocks at Musselwhite. This rock represents the Au-barren bearing sample for this study.

Petrography

Garnets in the garnet-grunerite schist (JD10-07 and JD10-18) are idioblastic and poikiloblastic with microscopic inclusions of quartz, grunerite and magnetite. The size of the garnet crystals from these rocks are the some of the largest at Musselwhite ranging from ~ 20 to 1 mm. Sample JD10-07 contains abundant coarse grained biotite (up to 2 mm) and is spatially associated with

actinolite which defines the main schistosity of the rock. Actinolite is commonly a retrograde product of common hornblende, and may potentially be associated with Au mineralization. The coarse grained nature of the biotite may suggest K alteration; however this alteration type is not pervasive at Musselwhite. Millimeter to centimeter thick granoblastic sulphide-bearing quartz bands occur within the matrix of these samples. The bands are parallel to the foliation and are colloquially referred to as “quartz floods” by Musselwhite geologists. Oxide and sulphide phases within these bands include magnetite, chalcopyrite, arsenopyrite and pyrrhotite and one occurrence of native gold. A paragenetic sequence in this sample is most likely an early magnetite formation (i.e., from the BIF) followed by sulphide minerals. In sample JD10-18, native gold grains (up to 30 μm) occur within a matrix of hornblende + grunerite + quartz and is spatially associated with pyrrhotite and magnetite. Ribbon quartz was noted along the foliation, which may indicate a lesser amount of silica flooding in comparison to sample JD10-07. Rims ($\sim 20 \mu\text{m}$ thick) of garnet poikiloblasts in this sample are inclusion-free.

The amphibole-garnet schist (JD10-11; **Fig. 1-3**) does not contain grunerite. This sample is dominated by a poikiloblastic garnet with a matrix composed of bluish-green amphibole (e.g., ferrotschermakite; Otto, 2002) + hornblende + biotite + quartz. The size of the garnet crystals within the same range as the garnet-grunerite schist, however the abundance of crystals is much less. Garnet contains inclusions of ilmenite, magnetite and chalcopyrite. Elemental mapping shows small inclusions of native gold, along with these sulfides (**Fig. 1-3**). Biotite is interpreted to occur as both a metamorphic and alteration phase. The metamorphic type is expressed as sheeted crystals, parallel to the main foliation and alteration grains occur proximal to pressure shadows around garnet. This suggests the growth of biotite post dates crystallization of common hornblende. Common hornblende is spatially associated with grunerite. In one location, grunerite

is mantled by hornblende, indicating common hornblende nucleation at the expense of grunerite. Sericite alteration is pervasive in this sample as fine aggregates are seen replacing subidioblastic plagioclase crystals.

The garnet-biotite schist sample (JD10-16A; **Fig.1-4**), which immediately overlies the garnet-grunerite schist, has a distinctly different mineral assemblage and texture compared to other auriferous samples. It contains chlorite and plagioclase together with garnet, hornblende and quartz. Two types of garnet are identified in JD10-16A; small porphyroblasts (< 2 mm) are generally xenoblastic, inclusion free and spatially associated with quartz + biotite gneissic bands. The second type of garnet (2-5 mm in size) is poikiloblastic with inclusions of quartz and white mica. White mica crystals are fine grained (~ 10-20 µm). Chlorite is spatially associated with biotite and likely to be an alteration phase of biotite. Native Au grains (~ 20 µm) were noted as inclusions in garnet poikiloblasts. Other inclusions are magnetite, chalcopyrite and pyrrhotite. Pyrrhotite also occurs in the quartz-rich matrix and mantles magnetite grains. Native gold is only seen spatially associated with chalcopyrite.

Summary of the Paragenetic sequences in the auriferous rocks

The two garnet-grunerite schists show an earlier magnetite phase, followed by chalcopyrite then pyrrhotite. None of these minerals were seen as inclusions in garnet porphyroblasts in the sample from Musselwhite, but all three were seen in the drill-hole sample, north of the Musselwhite mine. Arsenopyrite occurs only in the mine sample.

The paragenetic sequences for the garnet-biotite and amphibole schists are more complex, although both show gold as inclusions in garnets, thus indicating mineralization during and/or before crystallization of garnet porphyroblasts. The occurrence of sulfides, oxides and native Au

as inclusions in garnet sets these rocks apart from the garnet-grunerite schists (high Au grade zone). The garnet-biotite schist (hanging wall zone) only contains chalcopyrite and Au, while ilmenite and gold are inclusions within garnet in the amphibole-garnet schist.

The Au-barren sample (JD10-90) has a very simple mineral assemblage. This sample is composed of poikiloblastic garnet, actinolite, quartz and ilmenite, where the inclusions in garnet are quartz and actinolite. Garnet poikiloblasts (1-3 mm in size) are xenoblastic and show a post-kinematic growth history as the inclusions are parallel to foliation in the matrix. Quartz crystals within the matrix show a granoblastic texture. The lack of common hornblende and biotite suggests that the metamorphic history (i.e., P-T-t path) of the BIF outside Musselwhite may have been much different.

Analytical Methods

Major element composition of garnets, excluding JD10-18, was analyzed at the University of Ottawa using the JEOL 8230 SuperProbe electron microprobe analyzer (EPMA). Operating conditions were set at an acceleration voltage of 20.0 kV, a beam current of 2 nA and a beam diameter of 3 μm . Sample JD10-18 was analyzed at New Mexico Tech using a Camera SX-100 EPMA with an accelerating voltage of 15 kV and beam current of 20 nA. Element concentrations are reported in **Table 1-1 and Appendix A1a**. Fe (III) was not measured, however concentrations were calculated from Fe (II) abundances. All data are presented at a 95% confidence level and are the result of rim to rim automated line transects with 20-30 μm point spacing. Points along each transect were manually adjusted to avoid inclusions within the garnet. Four well characterized, in-house standards (almandine, diopside, tephroite $[\text{MnSiO}_4]$ and rutile) were analyzed in between analyses of garnet crystals from each sample to monitor

accuracy. All trace element abundances were determined by laser ablation-inductively coupled plasma-mass spectrometry (LA-ICPMS) methods at the Geological Survey of Canada in Ottawa. Concentrations were determined using a Photo-Machines Analyte 193 nm ArF excimer laser coupled to an Agilent 7700 quadrupole ICP-MS with a beam diameter of either 43 or 52 μm and a repetition rate of 16 Hz. Each ablation of 60 seconds was preceded by 45 seconds of background counting. Calibration and quality control during analyses of the unknowns were done by analyzing BCR-2G and GSD-1G synthetic glasses. Mean Ca concentrations from EPMA analyses were used as the internal standard due to its high abundances in silicate minerals (i.e., garnet) and similar fractionation to many lithophile elements (Jackson et al., 2008). The time-resolved signals for each analysis were reduced using the on-line GLITTER data reduction software of van Achterbergh et al. (2001). Attempts were made to ablate at least the core and rim for each crystal and to avoid inclusion-rich areas. Although the online time-resolved program GLITTER allows the user to select intervals of the signal in which to be integrated, inevitably some inclusions were ablated and best attempts were made to exclude those inclusions in order to maximize signal precision of the garnet matrix. Mineral abbreviations used below follow that of Whitney and Evans (2010).

Results: Garnet Chemistry

Major Element Chemistry

The most abundant major component of all garnet crystals is almandine ($X_{\text{Alm}} = 0.567 - 0.873$) (**Table 1-1**). Garnet crystals from the garnet-grunerite schist main host rock at Musselwhite (JD10-07) and drill core (JD10-18) have similar zoning patterns where concentrations of Mn and Mg are inversely correlated. The spessartine component decreases gradually ($X_{\text{Sps}} = 0.0019 -$

0.175) while pyrope component increases ($X_{\text{Py}} = 0.084 - 0.298$) towards the rims. The pyrope abundance is highest very close to the rim in a few crystals in JD10-18 and -07. Some of the highest andradite values from this study occur within this rock type. The drill core sample (JD10-18) shows X_{Adr} values ranging from 0.00 – 0.0118. Sharp increases in X_{Adr} occur proximal to the rims of several grains from the sample. One core analysis from JD10-07 yielded an andradite composition of $X_{\text{Adr}} = 0.0382$, however zoning from this end-member is not observed in the rest of the grain. Grossular zoning is observed in both samples, but is more prominent in JD10-18 with a gradual increase in X_{Grs} towards the rim ($X_{\text{Grs}} = 0.0141 - 0.206$). Small-scale (i.e., analysis-to-analysis) oscillatory zoning is observed in several component. For instance, Grt 1 contains growth bands of high almandine that correspond to relatively low concentrations of Ca and Mg. However, this relationship is the inverted for Grt 2 (**Appendix A1b**).

The amphibole-garnet schist (JD10-11) also exhibits notable zoning (**Fig. 1-3**), similar to the garnet-grunerite schist. The grossular component is elevated in the rims and spessartine component gradually decreases from core to rim (X_{Sps} range = 0.0466 – 0.149). The pyrope component is relatively homogeneous from core to rim and has the lowest contribution to the garnet composition ($X_{\text{Prp}} = 0.039 - 0.072$). The andradite component ranges from 0.0017 to 0.0106. The highest values measured occur within the rim zones and similar to the garnet-grunerite schist, the andradite component increases sharply here. Again, similar to the garnet-grunerite schist, oscillatory zoning is present with zones high grossular and low almandine occurring within the mid-crystal regions.

The garnet-biotite schist sample (JD10-16A; **Fig. 1-4**) exhibits the strongest major element zonation as each component varies throughout the crystal. Unlike the amphibole-garnet and garnet-grunerite schist samples, the almandine content in the garnet crystals from this sample

increases significantly from core to rim ($X_{\text{Alm}} = 0.612 - 0.783$). The almandine component decreases steadily at the very edge of the rim in some crystals. The highest andradite component from this study is evident from the cores of this rock type ($X_{\text{Adr}} = 0.00 - 0.0135$) (**Appendix A1b**). These trends contrast those of the main auriferous zone samples. Both spessartine ($X_{\text{Sps}} = 0.0365 - 0.181$) and grossular ($X_{\text{Grs}} = 0.0764 - 0.202$) components decrease continuously from core to rim, which is a characteristic pattern for this sample. The pyrope component is minor, yet gradually increases towards the rim ($X_{\text{Prp}} = 0.024 - 0.095$). In addition to the strong crystal-scale zoning, oscillatory zoning is present in these garnets with similar element relationships to the garnet-grunerite and amphibole-garnet schists. However, growth bands are not pervasive in all crystals and only occur within the cores.

Element zoning in garnet from the Au-barren sample (JD10-90) is weak, with the exception of gradational decrease in grossular ($X_{\text{Grs}} = 0.078 - 0.122$) and increase in pyrope ($X_{\text{Prp}} = 0.042 - 0.071$) towards the rims. The spessartine component is nearly absent in all garnet crystals and almandine and andradite compositions are homogeneous within both crystals ($X_{\text{Alm}} = 0.818 - 0.868$ and $X_{\text{Adr}} < 0.0052$).

Rare-Earth Element Abundances

Thirty six trace REE analyses, evenly divided between rims and cores, were conducted on several garnet crystals from all five samples (**Fig. 1-5A**). The results from the analyses are presented in **Table 1-2**. Significant intragranular variation is observed in almost every sample. For example, samples JD10-07 and JD10-18, the garnet-grunerite schists, have similar slope in LREE [$(\text{Sm/Ce})_{\text{CN}}$ ranging from 4.57 – 1220] with the highest values recorded in the rims (**Fig. 1-5B**). Cores from JD10-18 show a consistent and slightly concave down pattern for HREE, yet the mineralogically similar JD10-07 sample has more variability in both the HREE slope and Eu

anomaly $[(\text{Lu}/\text{Gd})_{\text{CN}} = 0.18 - 2.55; (\text{Eu}/\text{Eu}^*)_{\text{CN}} = 0.45 - 2.55]$ as both concave up and down patterns are present. Rim analyses are more variable, in particular in the drill core sample with flat to concave down patterns $[(\text{Lu}/\text{Gd})_{\text{CN}} = 0.59 - 8.87]$. On the contrary, rim HREE patterns from JD10-07 exhibit consistent concave up shapes with $(\text{Lu}/\text{Gd})_{\text{CN}}$ values ranging from 0.12 to 0.95. The highest, single Eu anomaly from this study $[(\text{Eu}/\text{Eu}^*)_{\text{CN}} = 6.52]$ occurs in the rim zone of sample JD10-07 (**Fig. 1-5**).

Garnet porphyroblasts from the amphibole-garnet schist (JD10-11) exhibit more intragranular REE zoning relative to grains of the garnet-grunerite schist (i.e., main host rock of the NIF). Heavy-REE slopes in the rims are shallow to steep [e.g., $(\text{Lu}/\text{Gd})_{\text{CN}}$ ranges from 1.11 to 5.35] relative to cores (e.g., 1.14 – 2.16; **Fig. 1-5A**). In addition, the rims show some of the highest positive Eu anomalies of all rim analyses in this study with $(\text{Eu}/\text{Eu}^*)_{\text{CN}}$ values ranging from 1 to 4.14 (**Figs. 1-5C & D**). Core analysis are less variable, yet have slightly higher positive Eu anomalies (e.g., 1.62 – 4.60). The upper limit of this range is similar to values attended by Spry et al. (2007) for garnets from the hanging wall rock at the Broken Hill deposit, although in their study, they do not differentiate between core and rim analyzes.

Similar intragranular variations are present in the garnet-biotite schist (JD10-16A). Cores are typically high in HREE compared to rims with positive slopes with $(\text{Lu}/\text{Gd})_{\text{CN}}$ values from 1.35 – 3.02. Reminiscent of garnet from the amphibole-garnet schist, positive Eu anomalies are, again, higher in cores of sample JD10-16A $[(\text{Eu}/\text{Eu}^*)_{\text{CN}} = 1.87 - 2.95]$ and do not overlap with rims values which attenuate to both negative and slightly positive values $[(\text{Eu}/\text{Eu}^*)_{\text{CN}} = 0.46 - 1.79]$. The Au-barren sample shows a remarkable difference in HREE patterns and Eu anomalies compared to auriferous samples (**Fig. 1-5C**). The HREE compositions in the rims are relatively homogeneous compared to auriferous rims $[(\text{Lu}/\text{Gd})_{\text{CN}}$ ranging from 0.36 – 2.51]. In addition, Eu

anomalies for both cores and rims record some of the lowest values in this study ranging between 0.55 – 2.2 and 0.65 – 2.95, respectively. A relative increase LREE is seen in garnet crystals from JD10-90, as $(\text{Sm/Ce})_{\text{CN}}$ values range from 0.90 to 22.57, which represent the ‘shallowest’ slopes obtained in this study. Such REE homogeneity in the Au-barren garnet schist comes as no surprise, considering major element variation from line transects showed limited to no zoning from core to rim.

Trace Element Composition

Garnet is well known as a repository for many high field strength elements, with several studies having determined end-member concentrations [i.e., uvarovite; $\text{Ca}_3\text{Cr}_2(\text{SiO}_4)_3$, goldmanite; $\text{Ca}_3\text{V}_2(\text{SiO}_4)_3$ and kimzeyite; $\text{Ca}_3(\text{Zr,Ti})_2(\text{Al, Fe,Si})_3\text{O}_{12}$; see Meagher (1982) and references therein]. Abundance of Ni (i.e., chalcophile) is not well known for garnet. Nevertheless, auriferous garnet crystals from Musselwhite, drill core and outcrop show abnormally high Ni concentrations, up to 8 ppm, especially within cores of garnet-grunerite samples (JD10-07 and JD10-18) (**Fig. 1-6A**). Corresponding rims are generally low in Ni (i.e., below detection limit of <1 ppm). Garnet from the garnet-biotite and garnet-amphibole schists show an inverse relationship in Ni zonation as higher abundances are seen in the rims (0.33 – 1.65 ppm) and lower in the cores (0.77 – 2.31 ppm). In comparison, rims from the Au-barren schists contain the highest Ni concentration (0.77 – 1.65 ppm) of all rims in this study. Likewise, the cores show very low Ni concentrations are generally below the lower detection limit of 1 ppm.

Intragranular Y zonation (**Fig. 1-5D**) is also present in the rims of auriferous garnet crystals. Garnets from the garnet-grunerite schist show high concentrations (<1 ppm to > 160 ppm). Cores exhibit low Y concentrations with no analysis exceeding 150 ppm and as low as 3 ppm. Rims of garnet crystals from the garnet-amphibole schist have a lower and less variable range Y (3 – 39

ppm), yet this range is higher than respective cores (3 – 15 ppm). This same trend occurs in the garnet from the garnet-biotite schist, although rims variation between rim and core concentration is less pronounced (5 – 118 ppm in the rims and 54 – 72 ppm in the cores). Again, garnet crystals from the Au-barren sample (JD10-90) show an inverse zonation pattern relative to auriferous garnet described above; cores exhibit higher, and more variable, Y concentrations (2 – 414 ppm) relative to their respective rims (~5 – 198 ppm).

Discussion

Intragranular variations; closed vs. open system

The composition of metamorphic garnet is dependent on many parameters, such as rock composition, temperature, pressure and oxygen fugacity (Spry et al., 2007 and references therein). Garnet crystals that form in a closed system should reflect the bulk composition of the rock (Spear et al., 1991). In contrast, in an open system, the compositions of metamorphic minerals are greatly affected by the fluid chemistry.

Similar to the intragranular major elements variations, variations in rare-earth element abundances are seen from core to rim across the auriferous garnets. Despite major overlap of the abundance of REE between the core and rim zones (**Fig. 1-5**), it is possible to assess the degree of REE mobility during closed and open system environments. The highest HREE concentrations (i.e., the upper limit of the core zone in **Fig. 1-5A**) are recorded in the core of the Au-barren schist sample. Given the lack of sulfides and Au and limited major element zonation, this schist provided us with the composition of metamorphic garnet formed in a closed system environment for which we can quantitatively compare with auriferous garnets. As well, the limited variation in the abundance of LREE [$(\text{Sm/Ce})_{\text{CN}} = 2\text{--}16$] in cores of these garnets, from the Au-barren

schist further support that the early stage of crystal growth occurred in a closed system (i.e., low water/rock ratios). Rims of garnet from auriferous rocks depict a different nature of hydrothermal activity. Here, the HREE in the rims show a flat to concave-up chondrite-normalized shape, which may suggest major decreases in HREE, in the system, during late stage garnet growth and Au mineralization. The steep slope in MREE (Gd to Ho) indicates greater fractionation of these elements into garnet porphyroblasts relative to HREE. The mobility of REE in fluids responsible for mineralization in orogenic Au deposits is still unknown, although the composition of fluids is generally CO₂ rich (Dubé and Gosselin, 2007). Based on this broad, universal composition for orogenic Au systems and that REE can be mobile in these fluids (cf., Samson and Wood, 2005) the low concentrations of HREE in rims of auriferous garnet crystals at Musselwhite may reflect changes in the fluid chemistry. Regardless of the source of the CO₂-rich fluid, the significant zoning observed in garnets from the auriferous rocks suggests fluids evolved during Au mineralization. This evolution can be conceptualized as a time dependent systems, where fluid interactions with the underlying mafic and minor felsic metavolcanics and metasedimentary rocks varied from an earlier to subsequently later stage of mineralization (cf., Phillips, 1993). Such concepts have been applied to other deposits where Au mineralization is synchronous with syn to late metamorphism (i.e., Bleeker and Hall, 2007). The major element data presented here may suggest variation in the oxygen fugacity of the mineralizing fluids during late stages of crystal growth. The rims of the amphibole-garnet schist shows elevated andradite composition, which indicates the enrichment of Fe⁺³ in the system. Here, it is suggested that mineralization may have potentially been two-fold process involving closed and open (i.e., high water/rock ratios) system hydrothermal events.

Variation of REE abundances in garnet from ore zones in other deposits have been documented by several workers. Spry et al. (2007) noted variation in HREE patterns, LREE/HREE ratios and Eu anomalies in garnet from the host rocks at the well-known Broken Hill Pb-Zn-Ag deposit and attributed this variation to changes in oxygen fugacity, temperature and relative input of detrital and hydrothermal components. Moreover, garnet from rocks associated with the massive sulphide deposit show extremely show HREE slopes, which is uncommon for garnet. Smith et al. (2004) concluded that the observed positive Eu anomalies and high LREE-normalized patterns in garnet from the carbonates at Beinn an Dubhaich U-rich skarn aureole in Scotland, was a result of episodic infiltration of externally buffered batches of fluid. More recently, the validity of garnet as a ‘vector’ for mineralization in a sedimentary Pb-Zn deposit was tested by Pattison and Seitz (2012). They concluded, by based on thermodynamic and petrographic data from altered and unaltered rocks from the St-Eugene deposit, that garnet can be an effective vector if metamorphic conditions are within a specific range (~100°C and ~2-3 kbar). Although work by Pattison and Seitz (2012) do not indicate a fluid source for mineralization, it does support the cause for garnet as a tracer for mineralization. The work by Smith et al. (2004), Spry et al. (2007) and Pattison and Seitz (2012) strongly suggest garnet to be a useful tool in several deposits, but could not address the source of the mineralizing fluid. Likewise this study does not, nor cannot, definitively determine the origin of fluids responsible for Au precipitation at Musselwhite using only trace and REE abundance in garnet, but can infer a source and tectonic model for deposition.

The small-scale (i.e., micron-scale) oscillatory zoning observed in several garnet crystals from the auriferous zones may suggest variation to the fluid composition during Au mineralization. The exact cause of this zoning is not well known, however several studies suggest this oscillation

in the chemical composition garnet is a result of mixing of magmatic and metamorphic fluids (Clechenko and Valley, 2003) or variations in the fluid chemistry as a result of flow path deviation during mineralization (Yardley et al., 1991). Yardley et al. (1991) suggest that zoning could be used as a criterion for assisting the degree of extensive metasomatism in hydrothermal systems. Therefore, coupled with the REE variation, it is possible that major element oscillatory zoning of the garnets at Musselwhite reflects compositional variation to the fluid chemistry.

Significance of High Positive Eu anomalies and Ca in Garnet

Here we explore possible origins of the high Ca and positive Eu anomalies observed in rims of garnet in auriferous zone.

The first possibility is regional metamorphism of NIF and SIF and mafic volcanic rocks of the Opapimiskan Lake unit (**Fig. 1-1A**). During greenschist facies conditions, plagioclase changes to albite by releasing Ca^{2+} and Eu^{2+} (due to similar ionic size). Ca^{2+} and Eu^{2+} may have been incorporated into garnet porphyroblasts in the NIF and is reflected in the cores (**Fig. 1-5C**). Alternatively, the highest Eu anomalies occur within the rims of garnet porphyroblasts from the garnet-grunerite and garnet-amphibole schists. If the fluids that were derived within a system under greenschist facies, the cores of the garnet porphyroblasts would have high Ca and Eu composition, relative to the rims. Therefore, the metamorphic facies under which mineralization occurred must have been higher than greenschist. Geothermal and geobarometric work by Otto (2002) and Hall and Riggs (1986) at Musselwhite places mineralization in the amphibolite field of Brown (2008). As such, metamorphic fluids derived from devolatilization and dehydration phase reactions under amphibolite facies conditions are well suited to mobilize Ca, and most importantly Au (cf., Ridley and Diamond, 2000). These temperatures and pressures are akin to orogenic terranes. Likewise at these conditions, circulation of voluminous amounts of

hydrothermal fluid (i.e., high water/rock ratio) through the metavolcanics in the NCGB could easily mobilized Ca and other mobile elements into high strain zones. This mobilization may have resulted in Ca metasomatism in the rims of the garnet. As mentioned, several rim analyses from the amphibole-garnet and garnet-grunerite schists show high andradite compositions, relative to the Au-barren schist. Likewise, these rims yielded high Eu anomalies, which suggest reducing conditions for mineralization. In such a scenario, there should be limited or no evidence of andradite variation from core to rim. This may suggest that during late stages of Au mineralization, the proportion of reducing fluids was much greater than oxidizing. As a corollary, a few rims from these garnets do exhibit slightly positive and negative Eu anomalies (**Fig. 1-5D**), which may indicate buffering of the fluid composition. The reducing, CO₂-rich nature of these fluids is favourable for the formation of large Au-only deposits (Phillips and Evans, 2004).

Timing of Au mineralization relative to metamorphism

The timing of Au mineralization is estimated to be between 2717 to 2690 Ma based on Nd isotope compositions of garnet and matrix of garnet-grunerite schist by Biczok et al (2012). Considering that the LREE concentrations of garnet are highly variable (**Figs. 1-5B & C**), as previously discussed, the geochemical variation in garnet porphyroblasts from Musselwhite may have been contemporaneous with metamorphic fluid production from amphibolite and granulite metamorphic terranes in the WSP; approximately 300 km northwest of the NCGB. Heaman et al. (2011) yielded two zircon U-Pb ages of c. 2716 Ma and 2694.6 ± 0.6 Ma, which they attribute to represent peak amphibolite and granulite metamorphism in the Pikwitonei Granulite Domain (PGD), respectively. The latter age is strikingly similar to the range of ages for mineralization reported by Biczok et al. (2012) and similar to granulite ages of many other terranes in the WSP

(cf., Corfu, 1987). The age of amphibolite metamorphism in the PGD pre-dates the collision of the Oxford-Stull Domain, and the NCT (Thurston et al., 1991). This slight difference in age between the collision of the NCGB and Oxford-Stull Domain and the onset of amphibolite metamorphism in the PGD agrees with the “deep-earlier” model of Stüwe (1998) where the lower crust achieves peak metamorphic conditions prior to the upper crust due to external heating for either magmatic underplating or magmatic heating in the mid-crust. The geothermal gradient to produce such a large heat source would have to be relatively high (50 °C/km; Stüwe, 1998) and is not unrealistic for Neoarchean geodynamics. Despite our interpretation that the fluid evolved in the formation of the Musselwhite deposit was of a metamorphic source, a word of caution is in order. If the relative timing of mineralization follows that of Stüwe (1998), we cannot unequivocally conclude Au-bearing fluids were entirely derived from a metamorphic source given that the model evolves internal heating. This heat was most likely derived from several magmatic events in the NCT (cf., Van Lankvelt et al., 2013), the evidence for which is the ubiquitous occurrence of large TTG-granitoid bodies surrounding the NCGB.

Sulphide association with Au mineralization

Sulphide rich, Au-bearing pods within garnet porphyroblasts in the garnet-amphibole schist consists of ilmenite, chalcopyrite and magnetite (**Fig. 1-6A**). It is unclear from this study if magnetite constitutes a metamorphic mineral or a relict mineral during the formation of Algoma-type BIFs (cf., Klein, 2005), however the occurrence of ilmenite is believed to be a metamorphic mineral. Ilmenite has been previously documented as a greenschist facies mineral as inclusions within garnet by Jiang et al. (1996). It should be noted here, that as a testament to this metamorphic origin, ilmenite is the only oxide phase in the Au-barren schist sample. The absence of magnetite in this rock may exclude it from being a stratigraphic equivalent to the

garnet-grunerite schist at Musselwhite, as previously proposed by Breaks et al. (2001). However, the mineral assemblage is strikingly similar to that of the amphibole-garnet schist and so this Au-barren schist may potentially be part of this silicate facies. Chalcopyrite appears to mantle gold in this sample. Therefore a possible paragenetic sequence would be the crystallization of ilmenite + gold + garnet – in the presence of magnetite – following a chalcopyrite phase. The garnet-biotite schist sample also has a very similar sequence (**Fig. 1-6C**), although the inclusions within garnet from this sample do not contain ilmenite, but rather pyrrhotite.

With the exception of magnetite, inclusion assemblages within garnets from the garnet-grunerite schist (**Fig. 1-6D**) are quite different from those in the garnet-amphibolite and garnet-biotite schist. In place of the common sulphides is quartz and grunerite. Despite these sulphide-free garnet poikiloblasts, the occurrence of pyrrhotite + arsenopyrite + chalcopyrite assemblages within the quartz bands may give insight into fluid temperatures responsible for Au precipitation (cf., Ridley et al., 2000).

The occurrence of chalcopyrite, magnetite and ilmenite inclusions within garnet in the garnet-grunerite schists (**Figs. 1-6B & D**) may indicate an earlier mineralizing event at upper greenschist to lower amphibolite conditions. The relatively homogeneous REE concentrations in the cores of garnet would coincide with this event as hydrothermal circulation within the BIF was not intense (**Fig. 1-7A**). On the contrary, the occurrence of Au associated with arsenopyrite, pyrrhotite and minor pyrite within late quartz floods may potentially be an indicator of high temperature fluids. Ridley et al. (2000) have documented similar assemblages for their “diopside-class” orogenic Au deposits, which were formed from fluids with temperatures ranging from 500 - 700°C. This range is consistent with calculation by Otto (2002) for the Musselwhite deposit (~540 to 600°C). Furthermore, such assemblages have been documented in

orogenic Au deposits of the Yilgarn Craton in Australia, in particular the Kings Cross and Hopes Hill deposits (cf., Ridley et al., 2000), which are low and high temperatures deposits, respectively. This has implications for Au mineralization at Musselwhite in that the lack of arsenopyrite as inclusions in garnet and the abundance of magnetite-chalcopyrite and gold suggest fluid temperatures were lower relative to fluids responsible for mineralization in the post-peak metamorphic event(s). The transition from low to high water/rock ratios during mineralization may, perhaps, be marked by the drastic variation in REE signatures found the cores and rims of auriferous garnet porphyroblasts.

A note on garnet partitioning of chalcophile and lithophile elements during Au and sulphide deposition

In addition to garnet porphyroblasts being an effective recorder of the type of mineralizing fluid(s) involved in orogenic Au deposits, there is also a chemical difference between lithophile and chalcophile element concentrations from core to rim (**Fig. 1-6A**). The high Ni (e.g., chalcophile) and low Mg (e.g., lithophile) content recorded in the cores of garnet suggest that during pre- to syn-nucleation of garnet, the system did not contain an abundance of sulfides. Therefore, despite garnet being a repository for lithophile elements, Ni preferentially partitioned into garnet as other repository phases such as clinopyroxene and olivine are absent in the garnet-grunerite schist rocks. This may be attributed to fluid being undersaturated in reduced sulfur. On the contrary, during post-peak metamorphic mineralization, Ni concentrations in the rims of garnet are low, while Mg concentrations are subdued. We interpret this to be spatially associated with co-sulfide Au mineralization, where the fluids were saturated in sulphides and the partitioning of chalcophile elements into sulphide phases were much greater than silicates. The late quartz bands which are characteristic of high grade ore rocks contain abundant pyrrhotite,

arsenopyrite and minor pyrite; all of these phases would partition Ni and other chalcophile elements in the presence of silicates (**Fig. 1-7B**).

Conclusions

The data here suggest that Au mineralization at Musselwhite occurred in multiple mineralizing events. Fluids derived from a metamorphic source involving an unequivocal pre to syn amphibolite grade Au precipitation events. Record of this event is captured in the normalized REE patterns of the cores of garnet crystals from Musselwhite; high HREE/LREE and shallow LREE slopes. The relatively low $(Eu/Eu^*)_{CN}$ values may suggest that during this time of crystallization, hydrothermal circulation may not have been very intense and the dehydration generated fluids derived from the lower crust, or fluids that stripped metals and mobile elements from the surrounding mafic volcanic rocks, contributed only a minimal proportion of the Au in the deposit. Extremely variable chemical abundances in rims of garnet poikiloblasts may record an environment with higher water/rock ratios and more intense hydrothermal fluid infiltration. Most noticeable is the high Eu anomalies and extremely heterogeneous LREE slopes. This gross variation in chemistry suggests extensive fluid-rock interactions and subsequent modification of the original metamorphic fluid source. The micro-scale oscillatory zoning of end-member compositions, within the rim regions of garnet, may support this fluid chemistry variation.

Our time-dependent model for Au mineralization is based on data collected in this study and relative timing of mineralization (e.g., Stüwe, 1998) and absolute (e.g., Heaman et al., 2011 and Biczok et al., 2012) ages of metamorphic events in the WSP (**Fig. 1-7B**). Utilizing this wealth of data, we propose Au mineralization at Musselwhite is an example of the “deep-earlier” model of Stüwe (1998) and may potentially be contemporaneous with amphibolite (c. 2694 Ma) and

granulite (c. 2679 Ma) events from deep crustal levels which agrees with the timing of the collision of the NCT with the Oxford Stull Domain (Thurston et al., 1991 and Biczok et al., 2012). However, it is impossible to resolve the absolute source of auriferous fluids considering the models of Stüwe (1998) involve internal heating of the crust and therefore, fluids could be derived from magmatic sources. To this end, we can only conclude, based on the chemical evidence from the auriferous garnet at Musselwhite, that mineralizing fluids were, in part, a product of a metamorphic source.

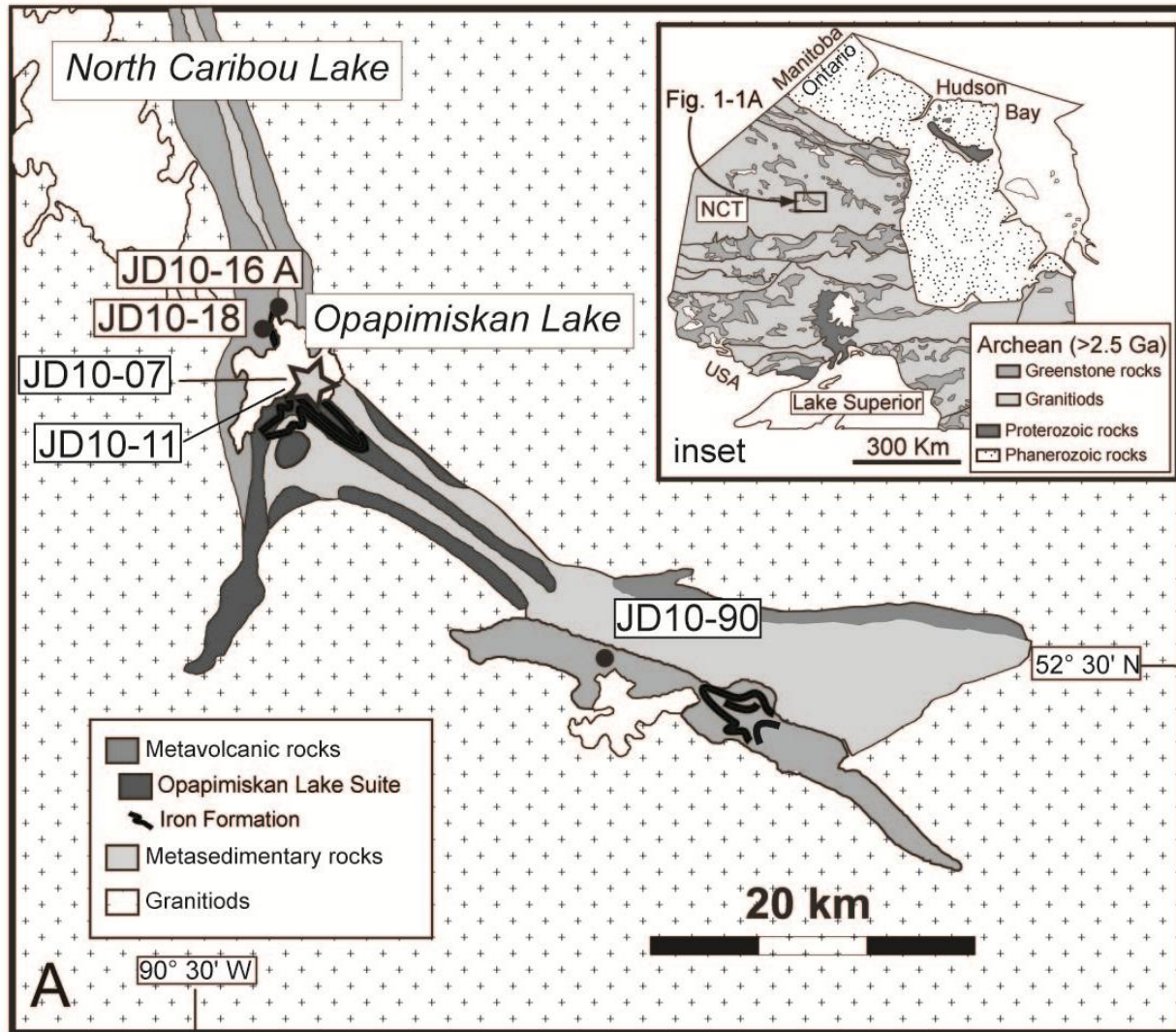


Figure 1-1: *inset*) Simplified map of the WSP showing several major terranes and subprovinces. The NCGB (black box) is located in the center of the NCT. See Figure 1-1A for a detailed map of the NCGB. BRS; Bird River Subprovince, ERS; English River Subprovince; S.; Subprovince and WS; Wawa Subprovince. Map modified after Breaks, et al. (2001). A) Simplified geological map of the eastern NCGB showing the four major lithological assemblages, surrounding plutonic rocks, and sample Musselwhite mine (grey star) is located on the south shore of Opapimiskian Lake.

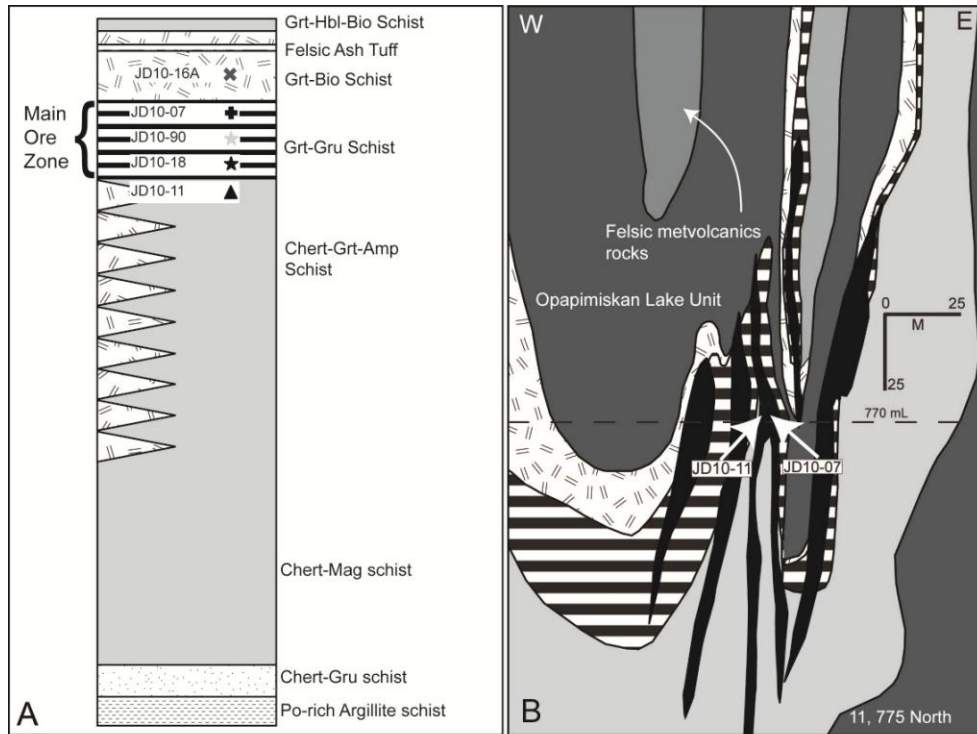


Figure 1-2: A) Schematic stratigraphic section of the NIF; silicate dominant units comprise the upper portion of the NIF, while the lower portion is oxide-dominant. Section modified from Cheatle (2006). Samples from this study were collected from the silicate-dominant units. Symbols identify each sample in the geochemical plots below. The true thickness of the NIF varies from 25 to 50 m (Biczok et al., 2012). B) Cross section of the NIF at the 770 meter level showing the location for the underground samples collected from the garnet-grunerite schist and grunerite-biotite-garnet schist. Colours and patterns used here are the same as Fig.1-2A. Black zones show high grade Au zones hosted predominantly within the garnet-grunerite schist unit. Units of the NIF are the same as shown in Figure 1-2A. Mafic metavolcanics (green), shown over and underlying the NIF. The overlying unit is capped by less voluminous felsic metavolcanics. Cross section is facing mine north.

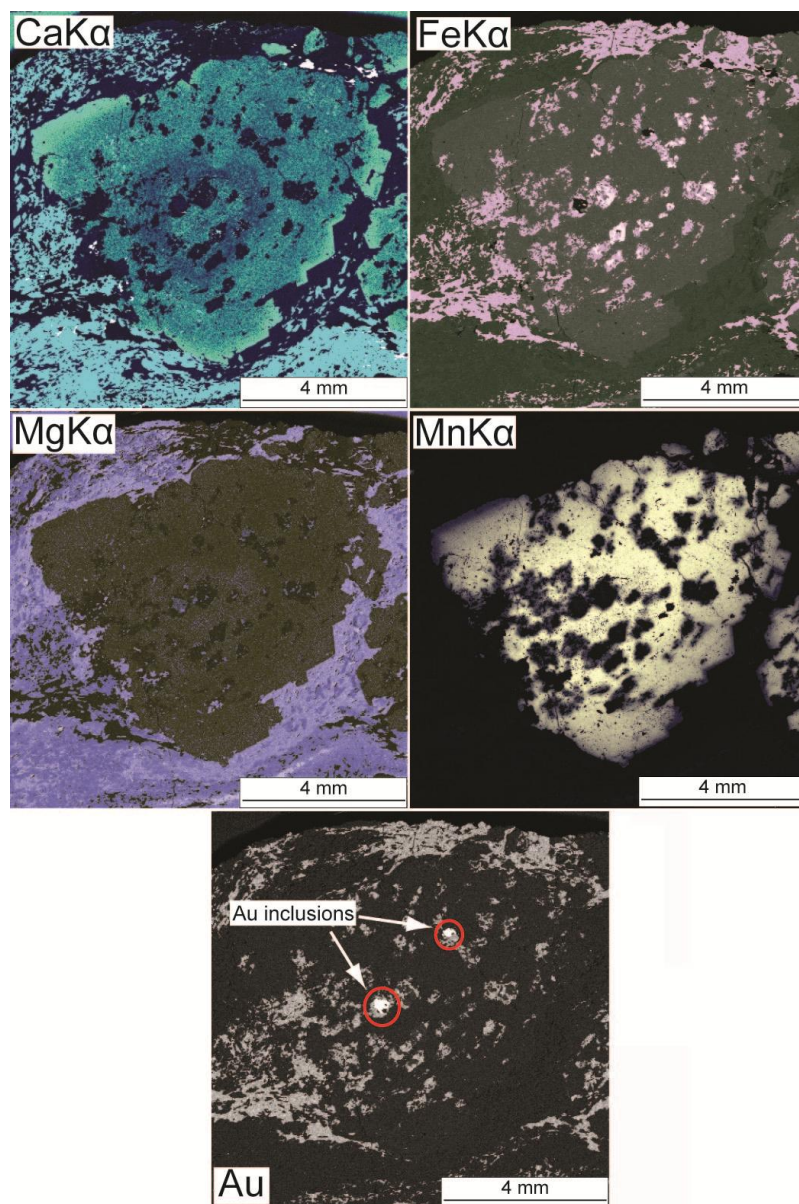


Figure 1-3: X-ray maps of a garnet porphyroblasts from the weakly auriferous amphibole-garnet schist (JD10-11) which underlies the garnet-grunerite schist (Fig. 1-2B). Intensity of the colour is proportional to the cation mapped. Note only Ca enrichment occurs with the rim of the garnet. If changes in pressure and temperature are due to regional metamorphism, which would have resulted in this enrichment, than zonation in this portion of the garnet would have been evident in other cations mapped. The Au map shows the occurrence of grains as inclusions within the core and outer core of garnet, which agrees with Kolb (2010) that mineralization, occurred during pre to syn nucleation of garnet.

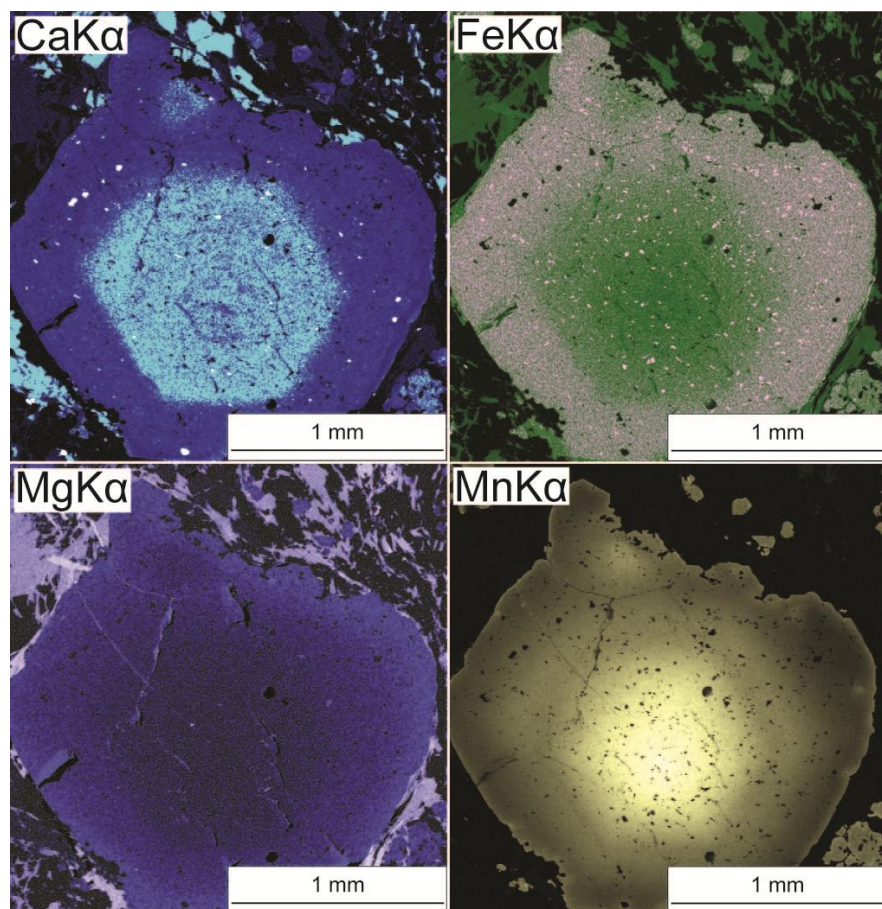


Figure 1-4: X-ray maps of a garnet porphyroblast from the auriferous garnet- biotite schist samples (JD10-16A). Cation zoning exhibit a typical prograde metamorphic pattern; the core is enriched in Mn, Fe and Ca and depleted in this rim.

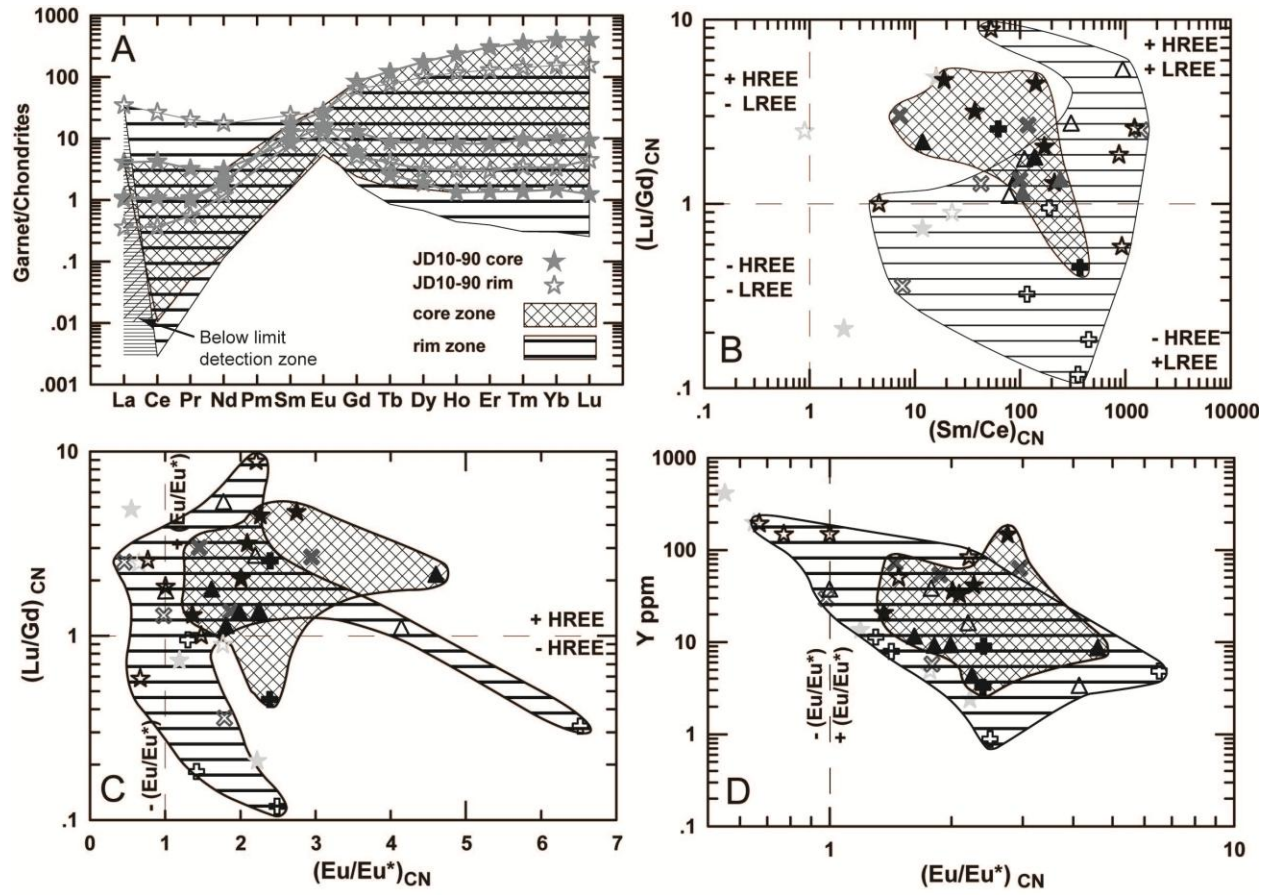


Figure 1-5: A) Chondrite-normalized rare-earth element plot showing the core and rim zones for auriferous garnet compared to the barren sample. Symbols for each sample are given in Fig. 1-2A. Chondrite values from Sun and McDonough (1989). B) HREE slope vs. LREE plot. C) HREE slope vs. $(Eu/Eu^*)_{CN}$ and D) Y vs. $(Eu/Eu^*)_{CN}$.

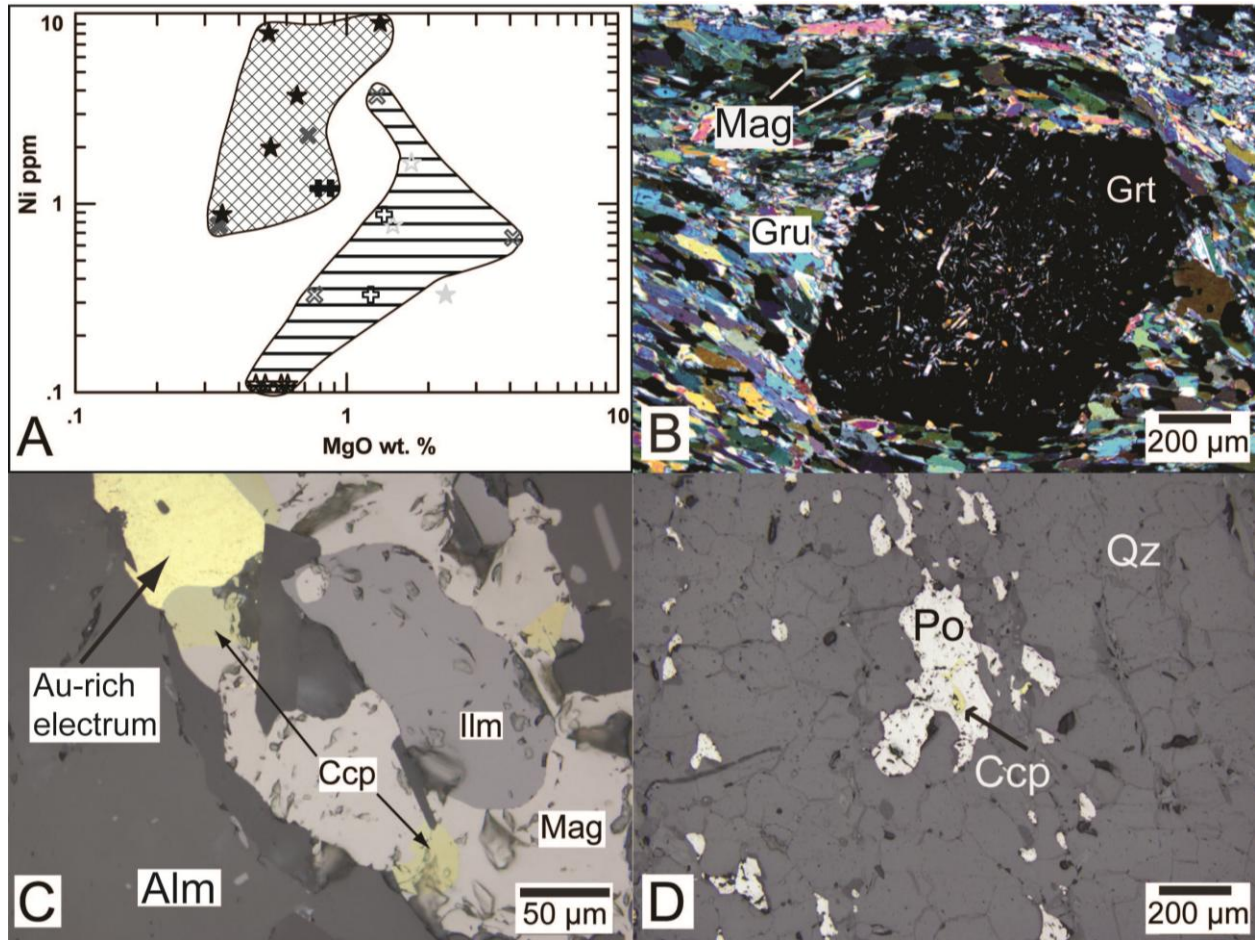


Figure 1-6: A) Ni vs. Mg showing a relationship between siderophile/chalcophile (Ni) and lithophile (Mg) partitioning in garnet. B) Cross-polarized photomicrograph of a garnet porphyroblasts from the grunerite-garnet (JD10-18) drill core schist sample. Inclusions are mainly grunerite +/- quartz and the matrix consists of sulphides (opaque), grunerite and hornblende. C) Reflected light photomicrograph of an ilmenite-magnetite-chalcopyrite-Au inclusions within an almandine poikiloblasts from the grunerite-biotite +/- garnet schist (JD10-16A). Same as the core inclusion from Figure 1-4A from the X-ray map. D) Chalcopyrite mantled by pyrrhotite with a quartz band in the grunerite-garnet schist sample (JD10-07).

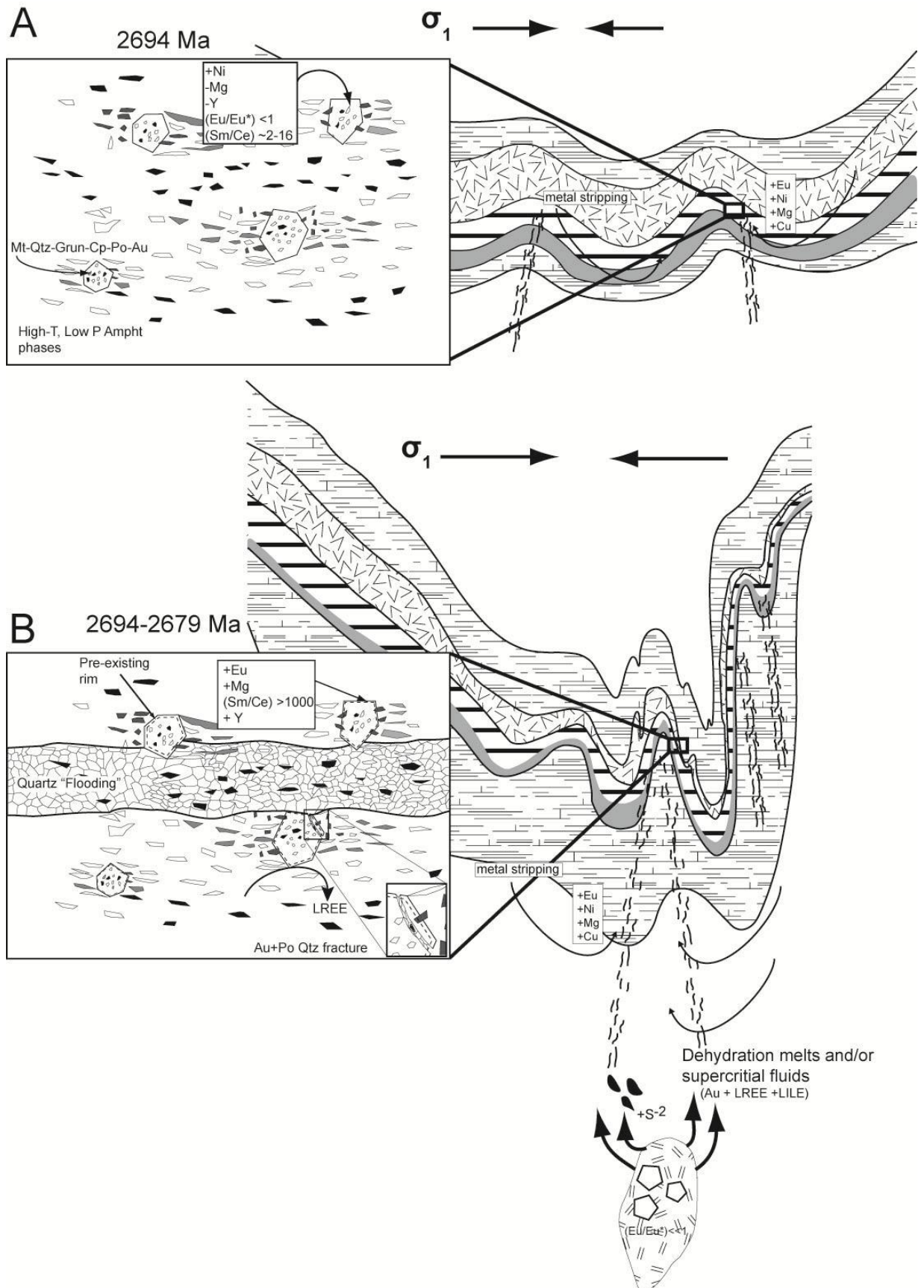


Figure 1-7: A) Schematic model showing the Au mineralization at Musselwhite. Gold deposition is contemporaneous with pre-to-syn nucleation of almandine porphyroblasts. This would represent the first phase of mineralization. Zircon U-Pb age of amphibolite grade metamorphism at 2694 Ma from the PGD north west of the NCGB from Heaman et al. (2011). At this time, high strain zones must have been established within the BIF and overlying mafic volcanics and served as a conduit for fluid migration. Metals may have been derived from these volcanic rocks during hydrothermal activity. Timing of the deposition of the NIF is between 2982 and 2972 Ma based on zircon U-Pb ages from the underlying and overlying volcanics (Biczok et al., 2012). B) Present day structural configuration of the NIF showing tight to isoclinal folding and steeply dipping high strain zones. The younger age of 2679 Ma is interpreted to be related to granulite grade metamorphism in the PGD (Heaman et al., 2011). Breakdown of hornblende and other hydrous phases during prograde phase reactions would result in the formation of a metamorphic (or supercritical) fluid in the lower crust. High positive Eu anomalies and growth of grossular-rich rims (Fig. 1-4A) of garnet porphyroblasts from auriferous rocks at Musselwhite would record this fluid migration. Extremely high $(Ce/Sm)_{CN}$ values, in the rims of garnet from the ore zone suggest that mobility of LREE during hydrothermal circulation during second phase of mineralization which is associated with quartz flooding and precipitation of Au in quartz-filled fractures in garnet, observed by Biczok et al. (2012).

Table 1-1: Mean electron microprobe analysis for garnet crystals. Mean = (Σ wt. %)/n.

Wt %	JD10-07 Grt 1			JD10-07 Grt 2			JD10-11 Grt 1			JD10-11 Grt 2			JD10-11 Grt 3			JD10-16A Grt 1		
	n = 38			n = 33			n = 33			n = 35			n = 40			n = 40		
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
SiO ₂	36.44	36.90	32.52	36.35	38.82	33.25	36.45	36.67	35.54	36.68	37.07	36.38	36.52	36.75	36.37	36.43	37.51	36.18
TiO ₂	0.20	4.20	0.03	0.08	0.17	0.02	0.12	1.27	0.06	0.11	0.38	0.00	0.14	0.39	0.06	0.08	0.38	0.02
Al ₂ O ₃	20.83	21.24	18.96	20.75	21.05	19.84	20.79	21.01	20.16	20.78	21.01	20.48	20.78	21.03	20.58	21.07	21.49	20.73
Cr ₂ O ₅	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Fe ₂ O ₃	1.02	2.08	0.00	1.70	7.75	0.00	1.47	1.97	1.07	1.36	1.86	0.43	1.78	2.08	1.32	1.74	2.15	0.00
FeO	36.39	37.29	35.66	35.83	37.43	28.35	30.10	30.82	29.52	31.33	33.47	29.73	30.15	31.31	29.09	30.90	34.21	26.72
MnO	0.29	1.24	0.09	0.90	2.33	0.17	6.11	6.64	4.55	3.73	4.91	2.33	5.44	6.44	3.88	4.50	8.10	1.64
MgO	1.58	2.16	0.71	1.19	2.02	0.80	1.29	1.60	1.08	1.46	1.61	0.99	1.31	1.42	1.18	1.27	2.43	0.60
CaO	3.30	3.69	2.92	3.62	6.07	3.04	3.97	4.83	3.34	4.87	7.11	4.26	4.52	5.49	4.00	4.62	6.28	2.71
Na ₂ O	0.10	0.07	0.00	0.02	0.16	0.00	0.01	0.04	0.00	0.01	0.04	0.00	0.01	0.06	0.00	0.01	0.06	0.00
K ₂ O	0.01	0.39	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.02	0.00
P ₂ O ₅	0.02	0.13	0.00	0.01	0.04	0.00	0.01	0.04	0.00	0.01	0.05	0.00	0.01	0.05	0.00	0.01	0.13	0.00
Sum	100.18			100.44			100.33			100.33			100.67			100.64		
Number of cations based on 12 oxygen atoms																		
Si	2.961	3.004	2.731	2.951	3.099	2.760	2.955	2.975	2.912	2.963	2.997	2.944	2.948	2.963	2.939	2.940	3.023	2.916
Ti	0.012	0.265	0.002	0.005	0.010	0.001	0.007	0.078	0.003	0.006	0.023	0.000	0.009	0.024	0.004	0.005	0.023	0.001
Al	1.994	2.030	1.876	1.986	2.006	1.867	1.986	2.002	1.947	1.978	1.995	1.953	1.978	1.995	1.959	2.004	2.039	1.981
Cr	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Fe ⁺³	0.062	0.131	0.000	0.104	0.484	0.000	0.090	0.119	0.065	0.083	0.113	0.026	0.108	0.126	0.080	0.106	0.130	0.000
Fe ⁺²	2.472	2.579	2.404	2.433	2.540	1.968	2.041	2.087	2.000	2.117	2.270	2.005	2.036	2.121	1.961	2.085	2.305	1.812
Mn	0.020	0.085	0.006	0.062	0.160	0.012	0.420	0.456	0.312	0.255	0.335	0.159	0.372	0.440	0.267	0.307	0.556	0.112
Mg	0.191	0.260	0.089	0.144	0.243	0.097	0.156	0.193	0.131	0.176	0.194	0.119	0.158	0.171	0.141	0.152	0.291	0.072
Ca	0.288	0.321	0.256	0.315	0.540	0.264	0.345	0.419	0.289	0.422	0.612	0.371	0.391	0.475	0.346	0.400	0.542	0.233
Na	0.016	0.567	0.000	0.003	0.025	0.000	0.002	0.007	0.000	0.002	0.006	0.000	0.002	0.010	0.000	0.002	0.009	0.000
K	0.002	0.044	0.000	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.002	0.000
P	0.001	0.010	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.002	0.000	0.001	0.009	0.000
Sum	8.02			8.00			8.002			8.002			8.003			8.003		
almandine	83.22	86.07	80.93	82.35	85.62	71.25	68.90	70.61	67.68	71.28	76.34	67.36	68.85	71.58	66.48	70.82	77.58	61.48
pyrope	6.41	8.74	2.97	4.87	8.62	3.28	5.28	6.48	4.42	5.91	6.56	4.03	5.34	5.77	4.79	5.17	9.87	2.44
grossular	9.34	10.51	7.39	10.11	15.72	8.46	11.10	13.56	9.37	13.59	19.67	11.97	12.48	15.06	11.15	12.85	17.50	7.51
spessartine	0.68	2.89	0.20	2.09	5.43	0.40	14.18	15.38	10.56	8.60	11.33	5.36	12.59	14.89	8.99	10.44	18.88	3.80
uvarovite	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
andradite	0.29	0.52	0.00	0.56	3.82	0.00	0.50	0.71	0.31	0.57	1.06	0.17	0.68	0.96	0.47	0.68	1.03	0.00

n/a; no analysis for this element.

Wt %	JD10-16A Grt 2			JD10-16A Grt 3			JD10-16A Grt 4			JD10-90 Grt 1			JD10-90 Grt 2			JD10-18 Grt 1		
	n = 40			n = 60			n = 30			n = 34			n = 65			n = 16		
	Mean	Max	Min.	Mean	Max	Min.	Mean	Max	Min.	Mean	Max	Min.	Mean	Max	Min.	Mean	Max	Min.
SiO ₂	36.32	36.74	35.82	36.50	36.78	36.23	36.43	36.75	36.16	36.66	37.33	36.26	36.56	36.90	34.57	35.99	36.15	35.76
TiO ₂	0.09	0.28	0.04	0.20	0.46	0.04	0.11	0.35	0.02	0.05	0.10	0.01	0.06	4.44	0.02	0.09	0.20	0.02
Al ₂ O ₃	21.03	21.60	20.67	21.03	21.62	20.69	21.03	21.34	20.71	21.10	21.51	20.79	21.12	21.34	20.33	20.31	20.57	20.02
Cr ₂ O ₅	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00	0.00	0.00	0.01	0.04	0.00
Fe ₂ O ₃	1.80	2.51	1.05	1.79	2.37	1.24	1.59	2.00	1.04	0.70	1.45	0.00	0.72	1.44	0.00	2.05	2.57	1.10
FeO	31.95	35.04	28.58	28.70	31.92	26.59	30.81	33.11	28.29	36.99	37.94	36.20	36.54	37.93	35.18	29.45	31.19	28.14
MnO	3.86	6.19	1.50	6.03	7.96	2.48	4.07	7.03	2.10	0.42	1.26	0.03	0.04	0.11	0.01	5.95	7.58	3.53
MgO	1.24	2.44	0.66	1.18	2.29	0.73	1.27	2.21	0.82	1.32	1.64	1.12	1.48	1.78	1.28	0.91	1.05	0.68
CaO	4.26	6.06	2.61	5.40	7.20	4.19	5.04	6.58	3.85	3.19	3.69	2.79	3.55	4.26	2.92	4.70	5.49	3.63
Na ₂ O	0.01	0.05	0.00	0.01	0.04	0.00	0.01	0.04	0.00	0.02	0.11	0.00	0.02	0.11	0.00	n/a	n/a	n/a
K ₂ O	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	n/a	n/a	n/a
P ₂ O ₅	0.01	0.04	0.00	0.01	0.04	0.00	0.01	0.04	0.00	0.03	0.07	0.00	0.03	0.07	0.00	n/a	n/a	n/a
Sum	100.40			100.53			100.21			100.49			100.14			99.24		
Number of cations based on 12 oxygen atoms																		
Si	2.937	2.969	2.893	2.937	2.960	2.919	2.944	2.957	2.928	2.969	3.009	2.935	2.961	2.987	2.781	2.950	2.973	2.935
Ti	0.006	0.017	0.002	0.012	0.028	0.002	0.007	0.021	0.001	0.003	0.006	0.001	0.008	0.269	0.001	0.005	0.013	0.001
Al	2.004	2.052	1.970	1.994	2.030	1.972	2.003	2.022	1.984	2.014	2.048	1.995	2.018	2.038	1.928	1.962	1.984	1.933
Cr	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.001	0.003	0.000
Fe ⁺³	0.110	0.153	0.064	0.108	0.143	0.076	0.097	0.121	0.063	0.043	0.088	0.000	0.044	0.088	0.000	0.126	0.158	0.068
Fe ⁺²	2.161	2.368	1.934	1.930	2.140	1.782	2.082	2.235	1.915	2.505	2.558	2.457	2.470	2.553	2.386	2.019	2.132	1.936
Mn	0.264	0.424	0.102	0.411	0.546	0.167	0.279	0.483	0.143	0.029	0.087	0.002	0.003	0.008	0.000	0.413	0.526	0.244
Mg	0.149	0.293	0.080	0.142	0.272	0.089	0.153	0.264	0.099	0.160	0.197	0.135	0.183	0.214	0.156	0.111	0.128	0.083
Ca	0.369	0.526	0.226	0.466	0.618	0.358	0.436	0.569	0.335	0.277	0.318	0.243	0.313	0.370	0.253	0.412	0.480	0.318
Na	0.002	0.007	0.000	0.002	0.007	0.000	0.001	0.006	0.000	0.004	0.017	0.000	0.004	0.017	0.000	n/a	n/a	n/a
K	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.001	0.000	n/a	n/a	n/a
P	0.001	0.003	0.000	0.001	0.003	0.000	0.001	0.003	0.000	0.002	0.005	0.000	0.002	0.005	0.000	n/a	n/a	n/a
Sum	8.003			8.003			8.002			8.006			8.006			8.04		
almandine	73.42	80.34	65.52	65.47	72.63	60.54	70.56	75.76	64.69	84.33	85.55	82.63	83.20	84.60	81.22	68.32	72.49	65.65
pyrope	5.06	9.99	2.72	4.81	9.26	3.00	5.20	8.94	3.34	5.37	6.66	4.51	6.17	7.23	5.21	3.75	4.37	2.82
grossular	11.85	16.85	7.23	14.89	19.47	11.53	14.05	18.26	10.83	9.12	10.66	7.99	10.27	12.05	8.32	13.07	15.10	10.12
spessartine	8.98	14.38	3.49	13.93	18.48	5.71	9.45	16.35	4.84	0.97	2.94	0.07	0.09	0.26	0.01	13.97	17.71	8.30
uvarovite	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	0.02	0.00
andradite	0.65	1.04	0.27	0.81	1.35	0.53	0.69	1.07	0.37	0.19	0.39	0.00	0.23	0.52	0.00	0.85	1.18	0.39
n/a; no analysis for this element.																		

Table 1-1: continued

Wt %	JD10-18 Grt 2			JD10-18 Grt 3			JD10-18 Grt 4			JD10-18 Grt 5			JD10-18 Grt 6		
	n = 10			n = 10			n = 15			n = 15			n = 15		
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
SiO ₂	35.92	36.14	35.37	35.95	36.33	35.69	35.99	36.27	35.68	36.10	36.41	35.89	36.19	36.39	36.03
TiO ₂	0.07	0.12	0.00	0.09	0.15	0.00	0.10	0.20	0.01	0.09	0.13	0.03	0.07	0.14	0.01
Al ₂ O ₃	20.39	20.50	20.20	20.38	20.67	20.20	20.44	20.82	19.75	20.51	20.68	20.35	20.52	20.85	20.28
Cr ₂ O ₅	0.01	0.04	0.00	0.02	0.07	0.00	0.01	0.04	0.00	0.01	0.05	0.00	0.03	0.07	0.00
Fe ₂ O ₃	2.40	2.81	2.04	2.46	3.29	2.09	2.60	3.58	2.17	2.38	2.80	2.08	2.28	2.77	1.82
FeO	28.95	30.60	28.23	28.17	31.27	25.77	31.21	32.09	30.24	31.93	32.70	30.86	31.25	31.80	30.73
MnO	5.64	6.49	3.68	6.53	8.37	3.35	5.25	5.60	3.64	4.80	5.14	3.64	4.60	5.21	3.05
MgO	0.92	1.13	0.85	0.85	1.13	0.72	1.02	1.49	0.81	1.07	1.14	0.95	0.99	1.16	0.84
CaO	5.24	5.55	4.94	5.28	5.60	4.98	3.73	5.22	3.01	3.56	5.37	3.01	4.42	5.18	4.05
Na ₂ O	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
K ₂ O	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
P ₂ O ₅	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sum	99.29			99.48			100.08			100.21			100.13		
Number of cations based on 12 oxygen atoms															
Si	2.939	2.951	2.916	2.937	2.953	2.917	2.932	2.946	2.918	2.938	2.945	2.923	2.942	2.955	2.932
Ti	0.004	0.007	0.000	0.005	0.009	0.000	0.006	0.013	0.001	0.006	0.008	0.002	0.004	0.009	0.000
Al	1.966	1.987	1.951	1.962	1.980	1.947	1.963	1.987	1.900	1.967	1.981	1.954	1.966	1.983	1.946
Cr	0.001	0.003	0.000	0.001	0.005	0.000	0.001	0.002	0.000	0.001	0.003	0.000	0.002	0.004	0.000
Fe ⁺³	0.148	0.174	0.126	0.152	0.202	0.128	0.159	0.220	0.133	0.146	0.171	0.127	0.139	0.169	0.112
Fe ⁺²	1.980	2.096	1.929	1.924	2.126	1.761	2.127	2.190	2.052	2.173	2.217	2.104	2.125	2.164	2.086
Mn	0.391	0.449	0.255	0.452	0.579	0.230	0.362	0.389	0.249	0.331	0.355	0.249	0.317	0.358	0.208
Mg	0.112	0.138	0.103	0.104	0.136	0.088	0.124	0.181	0.099	0.130	0.138	0.115	0.120	0.140	0.102
Ca	0.459	0.487	0.431	0.462	0.491	0.436	0.325	0.453	0.263	0.310	0.465	0.262	0.385	0.448	0.353
Na	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
K	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
P	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sum	8.05			8.05			8.05			8.05			8.05		
almandine	67.30	71.41	65.41	65.40	72.31	60.24	72.39	74.23	69.63	73.83	75.30	71.47	72.11	73.19	71.01
pyrope	3.82	4.71	3.50	3.53	4.64	2.98	4.21	6.15	3.35	4.40	4.67	3.91	4.09	4.74	3.45
grossular	14.48	15.24	13.68	14.54	15.16	13.61	10.22	14.30	8.00	9.79	14.76	8.32	12.16	14.19	11.09
spessartine	13.27	15.23	8.70	15.36	19.81	7.84	12.32	13.19	8.53	11.23	12.02	8.44	10.74	12.19	7.11
uvarovite	0.00	0.02	0.00	0.01	0.03	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.01	0.03	0.00
andradite	1.09	1.33	0.91	1.12	1.57	0.96	0.82	1.19	0.62	0.72	1.04	0.54	0.86	1.08	0.64
n/a; no analysis for this element.															

Table 1-1: continued

Wt %	JD10-18 Grt 3			JD10-18 Grt 4			JD10-18 Grt 5			JD10-18 Grt 6		
	n = 10			n = 15			n = 15			n = 15		
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
SiO ₂	35.95	36.33	35.69	35.99	36.27	35.68	36.10	36.41	35.89	36.19	36.39	36.03
TiO ₂	0.09	0.15	0.00	0.10	0.20	0.01	0.09	0.13	0.03	0.07	0.14	0.01
Al ₂ O ₃	20.38	20.67	20.20	20.44	20.82	19.75	20.51	20.68	20.35	20.52	20.85	20.28
FeO	30.39	33.30	28.72	33.55	34.24	32.28	34.07	34.72	33.05	33.30	33.99	33.00
MnO	6.53	8.37	3.35	5.25	5.60	3.64	4.80	5.14	3.64	4.60	5.21	3.05
MgO	0.85	1.13	0.72	1.02	1.49	0.81	1.07	1.14	0.95	0.99	1.16	0.84
CaO	5.28	5.60	4.98	3.73	5.22	3.01	3.56	5.37	3.01	4.42	5.18	4.05
Na ₂ O	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
K ₂ O	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
P ₂ O ₅	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cr ₂ O ₅	0.0179	0.0700	0.0000	0.0094	0.0360	0.0000	0.0125	0.0470	0.0000	0.0255	0.0690	0.0000
Sum	99.48			100.08			100.21			100.13		
Number of cations based on 12 oxygen atoms												
Si	2.956	2.969	2.942	2.952	2.964	2.940	2.956	2.962	2.945	2.959	2.972	2.951
Ti	0.005	0.009	0.000	0.006	0.013	0.001	0.006	0.008	0.002	0.005	0.009	0.000
Al	1.974	1.991	1.961	1.976	2.000	1.918	1.979	1.992	1.966	1.978	1.996	1.957
Fe	2.089	2.276	1.980	2.301	2.358	2.203	2.333	2.367	2.248	2.277	2.308	2.261
Mn	0.455	0.584	0.232	0.365	0.391	0.251	0.333	0.357	0.250	0.318	0.361	0.210
Mg	0.105	0.137	0.089	0.125	0.182	0.099	0.130	0.139	0.116	0.121	0.141	0.102
Ca	0.465	0.495	0.439	0.328	0.456	0.266	0.312	0.468	0.264	0.387	0.451	0.355
Na	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
K	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
P	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cr	0.001	0.005	0.000	0.001	0.002	0.000	0.001	0.003	0.000	0.002	0.004	0.000
Sum	8.05			8.05			8.05			8.05		

n/a; no analysis for this element.

Table 1-1: continued

Table 1-2: Trace element results from LA-ICPMS analysis of garnet crystals.

Sample	V	Cr	Ni	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Th	U
JD10-90 G2C1	60.51	50.44	0.33	118.25	0.08	0.96	2.39	15.76	0.19	0.11	0.97	2.60	0.31	145	138	0.94	124	0.10	0.48	0.08	0.23	0.04	0.25	0.03	0.26	0.07	0.39	0.28
JD10-90 G1R1	63.79	56.16	0.77	178.46	0.00	1.08	197.93	371	0.57	0.27	8.25	16.17	1.94	8.28	3.63	160	13.30	2.86	25.34	6.62	2153	3.64	26.38	4.01	9.32	0.15	13.80	5.63
JD10-90 G1C1	65.14	51.74	0.00	149.45	0.97	0.44	414.06	164.81	0.76	0.54	0.25	0.66	0.10	0.88	2.65	157	17.42	4.59	44.85	13.24	50.52	9.09	68.39	10.30	3.37	0.18	176	2.09
JD10-90 G3R1	89.67	119	165	164.11	0.00	0.23	4.90	19.62	0.07	0.20	0.09	0.23	0.05	0.57	128	0.66	104	0.15	0.80	0.17	0.49	0.09	0.57	0.11	0.30	0.06	4.10	0.19
JD10-90 G3C1	61.30	50.70	0.00	147.58	0.00	0.20	13.62	29.83	0.29	0.07	0.26	0.66	0.10	0.94	196	0.86	2.66	0.33	2.17	0.47	135	0.25	176	0.24	0.57	0.10	2.29	0.57
JD10-11 G1R1	45.99	57.20	0.00	5.70	0.00	0.00	38.63	2.21	0.00	0.00	0.00	0.00	0.00	0.05	0.41	0.53	163	0.34	3.10	0.98	3.75	0.71	5.90	106	0.02	0.00	0.00	0.00
JD10-11 G1R2	103.00	132.34	0.00	7.39	0.00	0.03	3.38	6.24	0.04	0.00	0.00	0.02	0.01	0.36	0.36	0.48	0.37	0.04	0.33	0.07	0.25	0.04	0.33	0.05	0.09	0.01	0.02	0.04
JD10-11 G1C1	153.40	135.72	0.00	9.52	3.15	0.08	4.38	32.86	143	10.13	0.01	0.02	0.01	0.18	0.40	0.32	0.50	0.06	0.38	0.10	0.33	0.06	0.57	0.08	0.65	0.12	0.13	0.18
JD10-11 G1C2	132.10	231.66	0.00	7.92	0.05	0.05	11.61	7.59	0.08	0.20	0.00	0.01	0.01	0.15	0.47	0.38	109	0.16	1.17	0.26	0.94	0.17	1.29	0.24	0.12	0.01	0.02	0.05
JD10-11 G2R1	87.18	128.44	0.00	7.31	0.04	0.01	16.10	23.44	0.00	0.04	0.00	0.00	0.00	0.07	0.31	0.46	1.11	0.18	1.44	0.40	1.49	0.26	2.22	0.37	0.52	0.00	0.05	0.10
JD10-11 G2C1	98.82	119.08	0.00	8.02	0.00	0.01	9.30	28.45	0.02	0.03	0.00	0.01	0.01	0.20	0.55	0.43	0.84	0.13	0.91	0.24	0.70	0.11	0.85	0.14	0.59	0.01	0.09	0.15
JD10-11 G2C2	110.12	138	0.00	8.33	0.02	0.16	9.20	54.69	0.02	0.09	0.01	0.02	0.01	0.23	0.63	0.48	1.11	0.13	0.91	0.21	0.75	0.12	0.92	0.15	1.21	0.00	0.17	0.27
JD10-11 G3R1	98.48	131.56	0.00	8.77	0.00	0.00	37.60	5.82	0.00	0.00	0.00	0.02	0.00	0.13	0.57	0.42	2.33	0.44	3.78	1.07	3.47	0.51	3.22	0.50	0.08	0.00	0.01	0.01
JD10-11 G3C1	126	147	0.00	10.20	0.00	0.30	8.67	87.74	145	0.15	0.11	0.27	0.04	0.55	0.80	1.20	0.83	0.11	0.77	0.19	0.77	0.15	1.24	0.22	1.93	0.11	0.51	0.54
JD10-07 G2R1	74.41	12.64	0.33	13.51	0.00	0.01	7.97	2.69	0.01	0.01	0.00	0.01	0.02	0.59	136	0.61	132	0.17	1.07	0.19	0.45	0.05	0.28	0.03	0.06	0.01	0.00	0.03
JD10-07 G2R2	60.79	3.35	0.88	16.10	0.00	0.00	0.89	6.09	0.06	0.01	0.00	0.01	0.02	0.73	100	0.61	0.45	0.03	0.17	0.02	0.06	0.01	0.05	0.01	0.09	0.02	0.00	0.07
JD10-07 G2C1	31.70	10.06	1.21	78.22	0.00	3.80	9.09	527	0.15	0.04	0.01	0.05	0.02	0.41	0.73	0.58	0.80	0.09	0.85	0.25	1.02	0.21	1.57	0.25	10.46	0.08	1.55	4.11
JD10-07 G1R1	29.72	49.06	0.00	19.34	0.00	1.49	11.40	76.75	0.03	0.00	0.01	0.02	0.01	0.28	100	0.53	164	0.23	1.55	0.34	1.17	0.16	1.02	0.19	1.56	0.01	0.19	0.47
JD10-07 G1C1	58.14	75.79	1.21	10.26	0.00	0.01	3.25	6.49	0.04	0.00	0.00	0.01	0.01	0.32	0.65	0.53	0.75	0.08	0.45	0.08	0.25	0.04	0.27	0.04	0.11	0.05	0.00	0.05
JD10-07 G1R2	39.27	12.92	0.00	6.30	0.00	0.01	4.85	1.41	0.20	0.01	0.00	0.02	0.01	0.34	0.47	1.28	0.81	0.10	0.56	0.10	0.27	0.03	0.24	0.03	0.01	0.07	0.01	0.07
JD10-16A G3R1	77.52	70.20	0.33	16.82	0.22	2.05	5.77	35.50	0.30	0.00	0.16	0.52	0.10	0.75	100	0.73	165	0.19	0.95	0.19	0.48	0.07	0.47	0.07	0.78	0.02	0.24	0.23
JD10-16A G3C1	200.58	125.06	0.77	11.36	0.03	1.74	53.85	48.97	2.63	0.09	0.01	0.03	0.01	0.25	0.71	1.14	3.54	0.76	6.16	1.46	4.53	0.68	4.54	0.58	1.05	0.17	0.25	0.27
JD10-16A G2R1	427	473	0.66	71.45	0.00	0.01	117.90	101	0.18	0.00	0.00	0.01	0.01	0.37	2.28	0.83	10.33	2.11	17.49	4.65	15.39	2.33	17.53	3.16	2.14	0.02	0.09	0.50
JD10-16A G2C1	236	166.40	0.77	13.07	0.03	4.24	63.38	46.37	0.64	0.27	0.01	0.04	0.04	1.12	1.29	1.98	3.19	0.69	6.69	1.79	6.50	1.08	7.94	1.04	1.04	0.05	0.27	0.28
JD10-16A G4R1	174.59	151.58	3.74	33.51	0.51	0.05	29.53	779	12.66	4.84	0.02	0.09	0.03	0.46	0.92	0.59	3.15	0.56	3.83	0.89	2.98	0.44	3.29	0.49	11.67	0.87	3.11	8.78
JD10-16A G4C1	215.83	309.40	2.31	25.93	0.05	0.07	72.26	72.61	9.02	0.13	0.25	0.47	0.06	0.47	0.85	0.96	3.72	0.86	7.91	2.23	7.81	1.28	9.16	1.37	1.55	0.64	0.80	0.51
JD10-18 G7R1	2.79	0.75	0.11	3.99	0.01	0.02	193.80	0.97	0.00	0.00	0.00	0.00	0.00	0.12	0.81	0.84	8.11	2.01	16.98	3.76	9.39	1.01	5.12	0.58	0.00	0.00	0.00	0.00
JD10-18 G7C1	32.15	29.12	8.03	6.27	0.26	0.11	147.31	5.04	0.46	0.11	0.07	0.13	0.02	0.34	0.62	1.37	2.83	0.64	6.33	1.93	7.42	1.19	9.28	1.62	0.05	0.05	0.02	0.03
JD10-18 G3R1	8.14	34.32	0.11	3.43	0.01	0.01	83.18	2.44	0.00	0.01	0.00	0.02	0.01	0.13	0.25	0.66	1.85	0.51	5.75	1.81	7.64	1.39	11.45	2.00	0.02	0.00	0.00	0.00
JD10-18 G3C1	10.06	6.27	0.88	3.37	0.00	0.01	41.37	1.77	0.03	0.00	0.00	0.01	0.00	0.06	0.23	0.50	1.32	0.33	3.03	0.85	3.10	0.53	4.01	0.72	0.03	0.01	0.01	0.01
JD10-18 G2R1	5.02	2.96	0.11	3.31	0.06	1.01	50.26	2.13	0.00	0.06	0.43	0.51	0.06	0.37	0.59	0.82	3.28	0.60	5.03	1.23	3.58	0.47	2.81	0.40	0.00	0.00	0.00	0.00
JD10-18 G2C1	7.06	8.50	1.98	5.93	0.00	0.02	35.83	3.07	0.03	0.00	0.00	0.01	0.01	0.09	0.27	0.57	1.72	0.33	2.85	0.73	2.39	0.40	2.75	0.43	0.03	0.02	0.00	0.01
JD10-18 G1R1	3.72	1.56	0.00	3.81	0.00	0.00	148.70	0.98	0.00	0.00	0.00	0.00	0.00	0.14	0.56	0.75	4.70	1.20	12.57	3.59	11.05	1.45	8.06	1.06	0.02	0.00	0.00	0.00
JD10-18 G1C1	6.50	4.58	9.13	19.34	0.01	0.07	33.04	1.31	0.02	0.07	0.02	0.03	0.01	0.09	0.26	0.49	1.38	0.26	2.47	0.67	2.54	0.42	2.91	0.53	0.02	0.01	0.01	0.01
JD10-18 G6R1	3.74	20.02	0.11	4.18	0.00	0.00	147	1.27	0.00	0.00	0.00	0.00	0.01	0.15	0.81	0.75	6.03	1.43	15.10	4.35	14.40	2.10	13.41	1.89	0.04	0.00	0.00	0.01
JD10-18 G6C1	8.14	27.56	3.74	8.74	0.00	0.10	20.65	13.91	23.24	0.10	0.02	0.02	0.01	0.21	0.80	0.59	2.13	0.31	2.15	0.52	1.39	0.24	2.37	0.34	0.22	1.28	0.10	0.12

Notes: All values are given in ppm

G = grain analyzed

C = core of grain

R = rim of grain

Sample	(Sm/Ce) _{CN}	(Lu/Gd) _{CN}	(Lu/Ce) _{CN}	(Eu*) _{CN}	(Eu/Eu*) _{CN}	(Ce*) _{CN}	(Ce/Ce*) _{CN}
JD10-90 G2C1	2.12	0.21	0.30	7.53	2.22	3.65	1.16
JD10-90 G1R1	0.90	2.48	6.07	44.21	0.65	27.60	0.96
JD10-90 G1C1	16.01	4.86	381.69	5104	0.55	102	105
JD10-90 G3R1	22.57	0.90	12.29	6.70	1.77	0.45	0.81
JD10-90 G3C1	1185	0.73	8.78	12.87	1.19	109	0.99
JD10-11G1R1	948.22	5.35	14883.71	5.33	1.78	0.01	0.24
JD10-11G1R2	78.78	1.11	67.75	2.08	4.14	0.06	0.52
JD10-11G1C1	90.19	1.37	115.72	2.52	2.25	0.06	0.48
JD10-11G1C2	136.35	1.78	415.04	4.20	1.62	0.04	0.56
JD10-11G2R1	306.88	2.73	2199.40	3.73	2.20	0.01	0.72
JD10-11G2C1	241.21	1.35	368.58	3.85	1.99	0.03	0.46
JD10-11G2C2	106.24	1.14	159.73	4.74	1.81	0.06	0.60
JD10-11G3R1	109.70	1.76	589.13	7.54	1.00	0.01	2.58
JD10-11G3C1	1188	2.16	19.81	4.65	4.60	0.45	0.99
JD10-07 G2R1	449.53	0.18	59.73	7.64	1.42	0.09	0.22
JD10-07 G2R2	355.45	0.12	14.09	4.35	2.49	0.12	0.15
JD10-07 G2C1	62.14	2.55	129.41	4.35	2.40	0.12	0.66
JD10-07 G1R1	189.70	0.95	222.02	7.25	1.30	0.06	0.62
JD10-07 G1C1	370.72	0.45	143.63	3.94	2.39	0.05	0.25
JD10-07 G1R2	116.58	0.32	48.61	3.49	6.52	0.07	0.39
JD10-16A G3R1	7.63	0.36	3.36	7.29	1.79	0.88	0.98
JD10-16A G3C1	99.57	1.35	498.91	10.93	1.87	0.08	0.57
JD10-16A G2R1	1410.74	2.51	11995.17	32.58	0.46	0.04	0.25
JD10-16A G2C1	119.05	2.68	585.54	11.98	2.95	0.22	0.32
JD10-16A G4R1	42.55	1.29	140.09	10.65	0.98	0.18	0.80
JD10-16A G4C1	7.19	3.02	71.15	11.82	1.45	0.86	0.89
JD10-18 G7R1	926.37	0.59	4051.86	22.39	0.67	0.03	0.22
JD10-18 G7C1	19.01	4.71	305.15	8.92	2.75	0.26	0.82
JD10-18 G3R1	52.85	8.87	2619.06	5.32	2.21	0.05	0.61
JD10-18 G3C1	140.95	4.50	2664.35	3.98	2.27	0.03	0.35
JD10-18 G2R1	4.57	1.00	19.13	9.90	1.48	1.23	0.68
JD10-18 G2C1	170.42	2.04	1619.93	5.08	2.01	0.03	0.32
JD10-18 G1R1	870.81	1.85	9983.47	13.27	1.00	0.00	0.00
JD10-18 G1C1	37.10	3.18	471.28	4.20	2.09	0.07	0.65
JD10-18 G6R1	1223.34	2.57	17422.76	17.32	0.77	0.03	0.14
JD10-18 G6C1	211.80	1.30	545.23	7.78	1.36	0.12	0.21

Notes: All values are given in ppm

G = grain analyzed

C = core of grain

R = rim of grain

Table 1-2: continued

Chapter 2

Geological History of the North Caribou Greenstone Belt, Recorded in Mesoarchean
Sedimentary Rocks, Western Superior Province of Canada

Abstract

We present new zircon U-Pb geochronological, whole-rock Nd isotopic and geochemical data of late to early Neoarchean metasedimentary rocks from the North Caribou Greenstone Belt (NCGB) of the western Superior Province. Detrital zircons analyzed from these siliciclastic rocks show an approximately 190 Ma gap in the onset of sedimentation; with the older rocks occurring in the western basin, Eyapamikama Lake assemblage (ELS) yielding a minimum age of c. 2865 Ma, whereas the eastern basin, Zeemal-Heaton assemblage (ZHA) yielded an age of c. 2674 Ma. Despite an overlap in potential provenances from both basins, major age peaks - from relative probability plots - suggest the ELS basin sediment was sourced from early Neoarchean granitoids and/or felsic volcanics with minor Mesoarchean inheritance. On the contrary the ZHA detritus was sourced primarily from proximal mid- to late Neoarchean granitoids. Moreover, the Nd isotopic compositions of the ZHA rocks are near chondritic and display both negative and positive values (ϵ_{Nd} range = 0.9 to -1.76). Likewise, these data are comparable to those of the surrounding granitoids. The potential for these plutons as serving as the provenance is further highlighted by the low Zr/Sc and high incompatible element (e.g., Co, Cr, Ni) concentrations of the sediments, suggesting deposition in an active tectonic setting and limited degrees of sediment recycling. Calculated early Mesoarchean depleted mantle model ages (3.07 to 3.56 Ma) of the sediments suggest that these granitoids and felsic volcanics may have been derived from older crustal material.

Introduction

In the absence of biostratigraphy in Archean greenstone belts, unwinding the evolution and stratigraphy of sedimentary rocks within these ancient terranes, specifically in the Superior

Province, has been a contentious issue amongst greenstone belt researchers. With the advent of radiometric dating techniques, determining absolute ages of meta-sedimentary rocks has greatly improved our understanding of Archean geodynamic processes. However, since then, the majority of studies have focused their attention on belts in the southern Superior provinces (**Fig. 2-1 inset**), as these belts contain large Au and base metal endowments (e.g., Pontiac: Davis, 2002; Abitibi: Ayer et al., 2005; Hemlo: Davis and Lin, 2003). However, only a few studies have investigated the provenance of the sedimentary rocks using a large population of detrital zircons (e.g., Lodge et al., 2013). Understanding the development and source regions of siliciclastic dominant basins provides insight into crustal formation processes and greenstone belt construction. The importance of these studies is also to aid in the finger-printing of late to syn-orogenic, late Neoproterozoic age sedimentary rocks (e.g., “Timiskaming-type” sediments) which may have the potential to be associated with major orogenic Au deposits in the Superior Province. The NCGB is one such greenstone belt, as it hosts the multi-million ounce Musselwhite deposit (**Fig. 2-1A**)

The North Caribou Terrane (NCT), which hosts North Caribou Greenstone Belt (NCGB), is considered the nucleus of the WSP (Thurston et al., 1991) and is composed of a collage of several ~3.0 Ga greenstone belts. As with several other belts in the NCT, the NCGB is composed of distinct metavolcanic and metasedimentary lithotectonic assemblages. The overall structure of these belts have been described by Lin (2005) as synclinal “dome and keel” structures with TTG-type granitoids forming the domes (via vertical tectonism) and greenstone rocks (including metasedimentary facies) forming the keels (via horizontal tectonism). This model has been adopted and applied to several greenstone belts including the NCGB (cf., Kalbfleisch, 2012), however understanding the temporal relationships between tectonism, magmatism and

sedimentary protosources in these belts are not well known and still debated. Detailed mapping by de Kemp (1987) resulted in the recognition for c. 2.99 Ma quartz arenite units within the Keeyask Lake assemblage (**Fig. 2-1A**) and slightly younger Eyapamikama Lake Assemblage (ELS). Later mapping by Breaks et al. (2001) concluded that the ELS was continuous from west to east in the core of the NCGB, however earlier work by Thurston et al. (1991) divided the assemblage into the Zeemal-Heaton Lake Assemblage (ZHA) in the south, proximal to Musselwhite, and the northern ELS (north of Musselwhite; **Fig. 2-1A**).

This study, in conjunction with Chapter 3, attempts to reconstruct the maximum depositional age, source(s) and propose a tectonic setting for the ZHA and ELS. The results from the detrital zircons, suggest a hiatus of ~ 190 Ma between the onset of deposition (maximum deposition age) into the two basins, with the ZHA preceding the ELS. Zircon morphologies suggest the detritus was derived from surrounding granitoids and potentially felsic volcanics (now eroded). The ages of the youngest zircons from the ZHA are within range of “Timiskaming-type” rocks from other greenstone belts (e.g., Abitibi and Wawa subprovinces). Relative probability curves from the two basins differ significantly, suggesting varying provenances. Whole Nd isotope data and depleted mantle ages suggest the provenance of the ZHA rocks were a mix of both juvenile and evolved sources and show evidence of a Mesoarchean crustal signature, respectively. Bulk rock chemistry from both assemblages is indifferent, implying deposition occurred within an active tectonic setting. In an attempt to summarize these data, along with previous geochronological work, a tectonic model for the NCGB is presented.

Geology of the NCGB

The NCGB is located along the northern margin of North Caribou Terrane (NCT; **Fig 2-1 inset**). The NCT itself is believed to have served as the nucleus for cratonization of the western Superior Province from c. 2.72 to 2.68 Ma (Percival, 2007). However, the majority external plutonic rocks and supracrustal (volcanic and sedimentary) rocks within the NCGB pre-date this amalgamation (e.g., de Kemp, 1987; Davis and Stott, 2001, Biczok et al., 2012; Van Lankvelt, 2013). The NCGB (**Fig. 2-1A**) is composed of four major supracrustal assemblages. The oldest assemblages are the c. 3.0 Ga volcanic rocks of the Agutua Arm assemblage and the meta-sedimentary rocks of the Keeyask Lake assemblage (Donaldson and de Kemp, 1998). The McGruer assemblage is the most extensive and is comprised of mainly plume derived, ultramafic/mafic volcanics (Hollings and Kerrich, 1998) with subordinate felsic occurrences. The youngest assemblages are the mainly deep marine turbidite deposits of the ZHA and ELS.

The first sedimentological and geochronological study of the ELS and Keeyask Lake assemblage was carried out by de Kemp (1987). Results from detailed mapping (i.e., outcrop scale) of the ELS revealed a post-2960 Ma period of rapid uplift and erosion of Agutua Arm volcanics as a result of emplacement of large scale TTG-type granitoids. The consequence of this uplift was the rapid deposition of several polymictic conglomeratic beds with clasts of mainly trondjemitic tonalites and minor quartz-diorite, diorite and gabbro (de Kemp, 1987). Sediment input from immature sources (e.g., mafic and ultramafic volcanic rocks) is also present. De Kemp (1987) noted the occurrences of spinifex-texture komatiities and banded iron-formation clasts within these sedimentary rocks which show scour contact relationships with older deposits, and attributed it to turbidite deposition. Evidence for crustal reworking is present in the ELS. De Kemp (1987) suggests the occurrence of quartz arenite pebble and c. 3.0 Ga TTG-type granitoid

clasts in the upper section of the assemblage provide firm indication for multiple events of exhumation and erosion of felsic rocks surrounding the NCGB.

Mapping by Breaks et al. (2001) was not as detailed as work by de Kemp (1987), however similar rock types and stratigraphic features were documented. For example, Breaks et al. (2001) noted two groups of rocks within the ZHA; 1) quartz arenites and quartz wackes with minor volcaniclastic material and 2) poorly sorted immature wackes, conglomerates and mudstones. The quartz arenites and wackes comprise the bulk of the ZHA from east of Musselwhite mine to Obabigan Lake (sample site of JD10-71; **Fig 2-1A**). Breaks et al. (2001) suggested the primary source of these mature sediments were the surrounding intrusive felsic rocks, however they reserve the possibility of felsic volcanics as the provenance due to embayed, non-abraded quartz grains in these metasedimentary rocks. The second group of rocks in the ZHA described by Breaks et al. (2001) occur in the very eastern area of the NCGB, along Obabigan and Neawagank Lakes. Conglomeratic units from this group contain highly deformed quartzite and trondhjemite clasts with minor, yet significant, amounts of mafic, fuchsite altered ultramafic and felsic metavolcanic clasts. Breaks et al. (2001) suggest the occurrence of this extremely heterolithic clast composition indicates that sediments within the ZHA sampled not only the external TTG-type granitoids but also underlying, and older, metavolcanics from the McGruer assemblage.

Geochronological studies (i.e., zircon U-Pb) from plutonic, volcanic and siliciclastic rocks within and surrounding the NCGB is extensive (de Kemp, 1987; Davis and Stott, 2001; Wyman et al., 2011; Biczok et al., 2012 and references within; Kalbfleisch, 2012; Van Lankvelt, 2013). The ages obtained from a few of these studies are summarized in **Table 3-1**. As mentioned above, the earliest records of magmatism and volcanism are recorded mainly in the northwestern arm of the NCGB. The felsic volcanics of the Agutua Arm assemblage (2981.0 ± 1.8 Ma) and Weagamow

Batholith (2990 ± 1.8 Ma) represent the oldest rocks in the NCGB (de Kemp, 1987). de Kemp (1987) also returned an age 2958.7 ± 1.8 Ma for a tonalite clast within the ELS. Recent work by Biczok et al. (2012) and McNicoll et al. (2013) attained a slightly younger age for rhyolites from the Opapimiskan-Markop Lake unit (McGruer Lake assemblage; **Fig. 2-1A**) within the mine area of 2972.4 to 2982.4 Ma and 2978 Ma, respectively. These ages are much older than those obtained by Davis and Stott (2001) on felsic volcanic distal from the deposit (e.g., 2863 ± 1 Ma and 2870 ± 2 Ma).

More recently, Van Lankvelt (2013) obtained zircon U-Pb ages for several granitoids surrounding the NCGB. The oldest of these rocks is the Wharram Lake Pluton (**Fig. 2-1A**) dated at 2976 ± 15 Ma. Van Lankvelt (2013) identified a major period of magmatism from c. 2830 to 2880 Ma. The older phase of magmatism is recorded mainly south of NCGB within the North Caribou Batholith with ages ranging from 2872 ± 12 Ma to 2829 ± 13 Ma, while the younger granitoids (2844 ± 15 to 2828 ± 9 Ma) in the north (i.e., Skinner Lake Intrusive Complex) (Van Lankvelt, 2013). Biczok et al. (2012) obtained younger ages for smaller scale plutonic rocks proximal to the Musselwhite mine of c. 2730 ± 8 to 2723.1 ± 0.8 Ma.

Samples

Samples were collected during summer field work in 2010 and 2011. As outcrop exposure was limited, many of the samples were collected along lake shores and several along inland traverses. Despite complete overprinting from metamorphism and deformation, from the petrography, it is possible to determine some relict sedimentary features. The grain size ranges from medium to fine and sorting from well (i.e., homogeneous) to poor (i.e., heterogeneous). Medium (1-2 mm) and moderately to well sorted samples include JD10-94 (**Fig. 2-2A**), JD10-71, JD10-100,

NCB11-19 and NCB11-20. With the exception of JD10-94, all other samples in this sorting group contain both mono and polycrystalline quartz grains with pervasive undulose extinction. Sample JD10-94 shows the highest degree of sorting (most homogeneous grain size) with a framework composed of very fine grained (~0.25 mm) monocrystalline, irregularly-shaped quartz (~30%) and plagioclase (~30%) crystals. Two types of plagioclase grains were observed; percline twinned and oscillatory zoned grains. Idioblastic, very fine grained biotite (~15%) occurs along the interstices (i.e., microlithons) of quartz and plagioclase and form a very weak, discontinuous foliation domains. Detailed descriptions of JD10-71 and JD10-100 are presented in Chapter 3. These rocks from the ZHA show high quartz (~60 to 75%) and plagioclase (~10 to 20%) abundances. In general, these minerals form a partially (non-polygonal) recrystallized framework texture, in which microlithons are separated by euhedral chlorite + biotite foliation domains. Relict grain boundaries can still be observed and weakly outlined by fluid inclusion trails. Samples NCB11-34B, NCB11-01 (**Fig. 2-2C**), NCB11-30, NCB11-22B, JD10-42 (**Fig. 2-2B**) and JD10-48 are poorly sorted, fine to medium meta-quartzofeldspathic wackes and arenites. In particular, NCB11-34B and JD10-42 show medium grain (1-2 mm) subangular clasts of plagioclase and quartz within a fine grain matrix (1-0.5 mm) of quartz, chlorite and white mica. White mica crystals dominate the cleavage planes in NCB11-34B, which are irregular and do not show a main foliation direction. Both samples show mono and polycrystalline quartz. Plagioclase (20 %) grains exhibit both simple and polysynthetic twinning. Sample NCB11-01 shows similar texture to NCB11-34B and JD10-42, however, a few plagioclase grains show myrmekitic textures. As well, fine grained (0.5-0.25 mm) and minor (< 1%) epidote occur within the quartz + plagioclase framework. Grains are commonly mantled by chlorite. Samples JD10-89 (**Fig. 2-2D**) and JD10-56 are the less mature sample and contain an abundance of amphibole (up to

60%). The abundance of hornblende in sample JD10-56 (~ 30%) is coarse grained (1-1.5 mm) crystals along with medium grained recrystallized quartz grains (60%). Euhedral metamorphic biotite grains (10%) define a discontinuous, weakly developed foliation within the interstices of hornblende + quartz network. The origin of the amphibole is unclear, however, the grains may potentially be detrital. Acicular ferro-actinolite (~75 %) strongly overprints monocrystalline quartz grains in JD10-89. The origin of the ferro-actinolite is potentially metamorphic, thus indicating a metamorphic grade of greenschist. However, the occurrence of pyrrhotite (~5%) and xenoblastic calcite (~5%), may suggest a hydrothermal origin. Quartz grains show evidence of deformation as grains exhibit undulose extinction and grain boundary migration and bulging. These samples, along with JD10-94, were collected close to the contacts with metavolcanic rocks.

Sample Preparation and Analytical Methods

Rock preparations for Nd isotopic and whole rock geochemical analysis followed identical procedures. Samples were trimmed to remove weathered surfaces prior to crushing in a steel jaw crusher. Rock chips were then homogenized to a powder consistency in a ceramic pulveriser. Both steel plates and ceramic pulveriser assemblage were pre-contaminated with a small portion of each sample and then cleaned with alcohol between samples to minimize cross contamination.

Whole Rock Geochemistry

Major elements (**Table 2-1**) were determined by fused disc XRF methods at the University of Ottawa. Prior to analysis, 1 g of rock powder was added to 5 g of lithium tetraborate flux. The mixtures were heated to ~1100°C for 5 minutes in a platinum crucible. Trace elements were

determined at Activation Laboratories in Ancaster Ontario using total digestion (4-acid digestion) ICP/ICP-MS Ultratrace 6 lithogeochemistry analysis.

Sm-Nd isotopic Analysis

Separation of Sm and Nd (see **Table 2-2** for results) were carried out at the University of Ottawa on all samples, however successful separation of REE was only completed on those from the ZHA. Due to complications with proper separation of isotopes, samples collected in 2011 are not discussed in this study. Further work is planned to be carried out on these samples. All other samples were analyzed at Carleton University using a Thermo-Finnigan Triton thermal ionization mass spectrometer. Samples were mixed with 3 μL of H_3PO_4 prior to being mounted onto a double Re filament wheel changer. Each solution was dried onto the filament by progressively heating the filament from 1.1 to 1.9 A. Accuracy of each analysis was monitored with an in-house standard, as well as JR-1 rock standard. The in house standard ($^{143}\text{Nd}/^{144}\text{Nd}$ value of 0.511 849 +/- 10 at 2 σ) was analyzed periodically throughout the sample runs. This standard is equivalent to La Jolla (Tanaka et al., 2000). Detailed description of the sample preparation procedure is presented in **Appendix A2**.

U-Pb zircon Analysis

Liberated and polished zircons were analyzed by LA-ICP-MS methods at the University of New Brunswick using Resonetics M-50-LR 193 nm Excimer laser connected to Aglient 7700x quadrupole ICP-MS. The operating conditions were a focused laser beam size of 24 μm diameter, a repetition rate of 4 Hz, and energy attenuation of 3 J/cm^2 . The calibration used FC-1 (Paces and Miller, 1993) and references of 91500 and NIST 610 synthetic glass were used to calculate U

and Th concentrations. The use of Iolite (Paton et al., 2011) and VizualAge (Petrus and Kamber, 2012) programs allowed for rapid integration of the time versus signal strength for each analysis.

The results (**Appendix A3b**) with high common Pb ($> 2\%$ ^{204}Pb) and high discordance ($> 30\%$) in $\text{Pb}^{207}/\text{Pb}^{206}$ were also removed, following the previous work for Archean zircons by Gehrels (2012). With the exception of sample NCB11-34B, only a small proportion of the total grains analyzed from each sample were removed due to high discordance and/or high ^{204}Pb . Relative age probability plots were generated using Isoplot/Ex 3.00 (Ludwig, 2003) using the final $^{207}\text{Pb}/^{206}\text{Pb}$ ages and their associated internal standard error (2σ). Cumulative probability plots were generated using the same data as the relative age plots using CUMULATIVE PROB PLOT Excel program of Gehrels (2012). Detailed analytical procedures, including sample preparation, are described in **Appendix A3a**.

Results

Whole Rock Geochemistry

Despite similar major element compositions for the ELS and ZHA (**Fig. 2-3** and **Table 2-1**), the degree of textural maturity of the samples does correlate to the composition. For instance, the highest SiO_2 (~ 80 to 70 wt. %) abundances are found in the most texturally mature meta-psammities (e.g., JD10-71, NCB11-34B and JD10-100), with the exception of JD10-42 (poorly sorted meta-feldspathic schist) (**Fig. 2-3**). On the contrary, samples proximal to the surrounding metavolcanic rocks (i.e., least mature sedimentary rocks), show the lowest concentrations (~ 51 to 61 wt. % SiO_2). These rocks exhibit the highest FeO (~ 16 to 5 wt. %) and CaO (~ 4 to 10 wt. %) concentrations. There is no positive correlation between the high CaO and LOI content. Trace element ratios for the ZHA and ELS rocks are relatively similar. For the ZHA, Th/Sc and Zr/Sc

ratios range from 0.1 to 1.4 and 3.2 to 42.4, respectively (**Fig. 2-4A**). Likewise, the ELS samples show a similar range, although the Zr/Sc ratio is much lower (i.e., 2.4 to 24.4).

Sm-Nd Isotopes

The age of deposition for all samples used to determine initial isotopic abundances, with the exception of JD10-71 and JD10-100, was 2850 Ma (**Fig. 2-5**). This age was previously reported by Davis and Stott (2001) for the ZHA. The ages for JD10-71 and JD10-100 will be discussed below. The results from the analysis of metasedimentary rocks of the ZHA show relatively restricted ϵ_{Nd} range from 0.9 to -1.76 with initial $^{143}\text{Nd}/^{144}\text{Nd}$ ratios ranging from 0.5088502 to 0.509080 (see **Table 2-2**). Based on the maturity of the samples and their proximity to mafic volcanics, it is possible to separate the samples into two groups; those with $\epsilon_{\text{Nd}} > 0$ and those with $\epsilon_{\text{Nd}} < 0$. The first group consists of the mature samples which were sampled within the core of the ZHA or distal from a mafic volcanic rock. The depleted mantle ages (T_{DM}) for these rocks range from 3.07 to 3.1 Ga. The second group consists of metasedimentary rocks with $\epsilon_{\text{Nd}} < 0$ which were sampled proximal to mafic metavolcanic – metasedimentary contacts. The T_{DM} age range for this group is slightly older from 3.12 to 3.56 Ga.

The isotopic abundances obtained from this study are very similar to abundances of granitoids and felsic volcanics rocks surrounding the NCGB (**Fig. 2-5**). Wyman et al. (2011) found that these rocks (c. 2730 to 2980 Ma) had ϵ_{Nd} values showing both juvenile and evolved signatures.

U-Pb isotopes

A complete table of all U/Pb ratios, discordance percents and Th/U values are presented in **Appendix A3b**. Concordia plots of these analyses are shown in **Figures 2-6 C – F**.

The Obabigan Lake metapelite yielded 52 zircons, all of which were analyzed with only fifteen rejected analyses after filtering (**See Appendix A3a**). The majority of the grains are sub-angular (34 %) to sub-rounded (38%). Twelve grains are rounded and 2 were fragmental. The shapes of the grains vary from equant to acicular, with the majority (52 %) being elongate-columnar. Stubby-columnar grains account for 29% of the sample, while 4% are acicular. Three grains are near equant. The main size range is fine grained (106-150 μm) accounting for 38% of the sample. Both coarse (200-250 μm) and medium (150-200 μm) grained size populations account for 30% of the sample. Despite yielding the least number of zircons ($n=37$) in this study, the metapelite (JD10-71), returned four major age-distribution peaks (**Fig. 2-6A**), with two of them contributing the majority to the cumulative age probability (**Fig. 2-6B**). The youngest and first major peak occurs at c. 2732 Ma derived from 6 grains and two grains at c. 2710 Ma and 2760 Ma. The second major peak occurs at c. 2878 Ma ($n=7$) with a slightly younger (within error), yet significant population at 2848 Ma. An early Neoproterozoic component at 2990 Ma was detected along with three zircons yielding ages between c. 2975 ± 24 to 2999 ± 24 Ma. These grains range from sub-rounded to well-rounded. The maximum age of deposition for the Obabigan Lake sample is constrained by the youngest zircon analyzed, yielding an age of 2723 Ma.

The Heaton Lake meta-psammite (JD10-100) yielded the most zircons for this study: 105. Eighty-five grains were analyzed, with 22 rejected after filtering. Most of the grains are evenly distributed among the sub-angular and sub-rounded types; 33% to 36%, respectively. Only a small proportion is rounded (16%) or angular (12%). Elongate-columnar grains account for the bulk of the sample (60%), while stubby-columnar grains are the second most abundant (32%). Only 4 grains were acicular and 2 were fragmental. Most of the zircons (41%) were medium grained (150-200 μm), while the fine and coarse grained fractions accounted for 33% and 26%,

respectively. The colours of the grains vary from opaque, reddish brown to medium, transparent pink. The largest fraction seems to contain the deepest coloured grains, while the most transparent are the smallest.

The meta-psammite from Heaton Lake shows broader range in population spanning ~ 400 My (i.e., 2674 ± 29 Ma to 3132 ± 36 Ma) from 67 zircons (**Fig. 2-6A**). The first major contribution of sediments is represented by peak at 2720 Ma ($n=12$). This age is ~ 20 Ma younger than the Obabigan Lake rocks; however the youngest detrital zircon dated from the Heaton Lake sample was 2674 Ma. The largest peak occurs at 2874 Ma ($n=28$), with an overlapping shoulder peak at 2839 Ma, which is very similar to those found in Obabigan Lake metapelite. However, a late Neoproterozoic signature (c. 2956 Ma; $n=5$) is present in this sample as well as a prominent 3039 Ma one. An early Mesoproterozoic component is present with the occurrence of a 3126 Ma grain.

The meta-K-feldspar psammite sample (NCB11-01) from the westernmost portion of the ELS yielded 60 zircons, all of which were mounted, imaged and analyzed. Of that number 15 zircons were rejected after data filtering. Approximately half (55%) of the detrital grains in this sample are medium sized ($150 - 200 \mu\text{m}$) with 33% and 13% comprising the fine ($100-150 \mu\text{m}$) and coarse ($200-250 \mu\text{m}$) grained population, respectively. The shapes range from equant (18%; $l:w \sim 1$) to stubby-columnar (40%; $2 > l:w > 1$) with the stubby-columnar grains comprising the bulk of the shape population. Unlike the detrital zircons from the ZHA, only a minor ($n = 11$; 18%) component of the grains from this sample show elongate-columnar shapes. Likewise, only two grains are acicular ($l:w \gg 2$). Unfortunately, a significant number ($n=12$; 20%) of the grains were fragmental, therefore their shapes could not be properly assessed. The degrees of rounding of the zircons range from angular to well-rounded with the majority (28%) of them belonging to the sub-angular population. The remaining grains are near equally divided ($\sim 20\%$) into the

angular to rounded groups. A small portion (n=5) are well-rounded. The colours of the grains are mainly medium, translucent reddish-pink (~60%), while the remaining are transparent to opaque, deep reddish-brown. The lighter coloured (reddish-pink) grains are generally angular to sub-angular and medium to fine grained, while the deeper coloured grains are small and more rounded. Uranium-Pb isotopic results ($^{207}\text{Pb}/^{206}\text{Pb}$) from the 45 zircons analyzed from this sample show a single, dominant age population at c. 2986 Ma (**Figs. 2-6 A & B**). The “sharpest” of this peak (**Fig. 2-6 B**) is a result of 15 zircons (~33% of the total) yielding $^{207}\text{Pb}/^{206}\text{Pb}$ ages between c. 2981 to 2989 Ma (2σ errors: 10 to 20 Ma). A slightly older shoulder occurs adjacent to this peak, which consists of 10 zircons ranging with ages c. 3000 to 3022 Ma. Less prominent ages population occur at c. 3069 from 3 grains ($^{206}\text{Pb}/^{207}\text{Pb}$ ages = 3065 – 3070 Ma) and 3100 ± 7 Ma from the oldest zircon analyzed. The youngest zircon was age dated at 2951 ± 12 Ma.

As previously mentioned, analyses of zircons from the meta-quartzofeldspathic psammite sample (NCB11-34B) of the central portion of the ELS (**Fig.2-1A**) resulted in a significant number of rejected zircons (42 in total). However, from a total of 93 grains analyzed, 52 analyses were near concordant and contained < 2% common Pb. Similar to the western ELS sample (NCB11-01), the majority of the zircons (42%) from this sample are medium grained (150 – 200 μm), however, a much larger proportion (35%; n=33) are coarse grained (200-250 μm). Only 21 grains fall within the fine grained (100-150 μm) category. The shapes of the detrital zircons range from equant to acicular, with the majority of them occurring as elongate-columnar (44%) and stubby-columnar (23%). Eleven grains are acicular, while only four are equant. This distribution is quite different compared to NCB11-01, however, similar to zircons from NCB11-01, 17 of the grains from this sample are fragmental. The two ELS zircon sample have very similar distributions of rounding; again, the majority of the grains are sub-angular (30%) to sub-

rounded (23%). An equal quantity (n=18) of zircons occur as angular and rounded grains. Only two grains are well-rounded. The age-distribution from the meta-quartzofeldspathic psammite (NCB11-34B) is the most complex of the 4 samples in this study (**Fig. 2-6 A**), with ages ranging from 2856 Ma to 3069 Ma. The youngest group of zircons (i.e., > 2900 Ma; n = 10) occurs at 2866 Ma with a slightly smaller group (n=8) at 2893 Ma. The majority of the zircons (~ 22) span approximately 100 My, with a main (n=8) age population at c. 2973 Ma and an ‘older’ shoulder population at c. 3000 Ma (n=6). A slightly broader age population (n=10) occurs at c. 3058 Ma. Similar to NCB11-01, late Mesoarchean zircons are present in this sample, from two zircons dated at 3129 and 3226 Ma.

Discussion

Two Basins: Evidence from detrital zircons

The detrital zircon age distributions found in the ZHA and ELS (**Figs. 2-7A & B**) suggest the main provenances of the two basins were distinct and therefore, together record ~ 600 My of uplift and erosion of plutonic and volcanic rocks in the NCGB. The youngest source area is recorded from ~ 2674 to 2730 Ma from the ZHA metasedimentary rocks (**Figs. 2-6A & 3-3A**). The significant accumulation of zircons of this age is strikingly similar to the nearby Libert Lake Pluton, a foliated granite - from the Opapimiskan Lake area - Skinner Lake and Southern Plutons. However, as will be discussed in Chapter 3, it is premature to conclude only a plutonic source, as these zircons may have been derived from now eroded felsic volcanics within the McGruer Assemblage. The overlap in age of these granitoids and the detrital age peak in the ZHA rocks suggest that these intrusions were exposed shortly after a period from approximately 2674 to 2723 Ma (i.e., maximum age of deposition for the Heaton and Obabigan Lake

sediments). The docking of the Island Lake Domain with the NCT at ~ 2707 Ma (Thurston et al., 1991) is cotemporaneous with these age peaks. This would suggest the sediments were deposited in an active tectonic setting. Evidence for such is seen in the low Th/Sc ratios from whole rock chemistry (**Fig. 2-4A**), as Th is concentrated in mature sediment, whereas Sc (more compatible) is concentrated in immature sediments. However, the largest age peaks in both samples from the ZHA occur from c. 2839 to 2874 Ma (**Fig. 2-6B**). This age range is similar to U-Pb zircon ages for the emplacement of tonalites in the Opapimiskan Lake area (2857 Ma from Biczok et al., 2012) and tonalitic to granitic granitoids of the south Skinner Lake Intrusive Complex (2844 Ma from Van Lankvelt et al., 2011). These rocks are proximal to the ZHA, however, similar ages are reported for the Schade Lake Gneissic Complex in the northern NCGB at 2841 Ma and 2858 Ma (Van Lankvelt, 2013). The large accumulation of 2839 to 2874 Ma zircons within the ZHA metasedimentary rocks suggests the protosource for the sediment were these large and extensive granitic rocks and potentially their coeval volcanic centers. Furthermore, such pronounced age peaks at this time would indicate a period (pre- 2674 to 2723 Ma) of exhumation via rapid erosion of these plutons.

Although they are not a significant proportion of the total zircon population ($< 10\%$; **Fig. 2-6B**), a late to mid-Archean (i.e., 2900 to 3400 Ma) provenance is present in both ZHA and ELS metasedimentary rocks. For instance, the Heaton Lake meta-psammite contains a broad age peak at ~ 2956 Ma ($n=6$; **Fig. 2-6A**) and several grains > 3000 Ma ($n=9$). Likewise, the Obabigan metapelite contains four grains > 2900 Ma (i.e., 2920 ± 29 to 2999 ± 24 Ma). Zircons from both these groups show a range of sizes and shapes, however all the grains are sub-rounded to well-rounded. The high degree of rounding suggests these are recycled grains and have experienced extensive abrasion via transportation or tectonic processes. Van Lankvelt et al. (2013) recorded

the presence of minor amounts of inherited zircons from the North Caribou Batholith (2913 ± 11 to 3132 ± 7 Ma) and Skinner Lake Intrusive Complex (2932 ± 8 to 2996 ± 10 Ma) (**Fig. 2-1A**). Likewise, Biczok et al. (2012) yielded a similar age (2972.4 ± 1.6 Ma) for a thin felsic tuff horizon which overlies the NIF at Musselwhite. These plutonic and felsic bodies are proximal to the ZHA and therefore may be the provenance for the sediment. Furthermore, Th/U values of these mid-Archean detrital grains are > 0.1 and are within range of typical igneous zircons (Hoskin and Schaltegger, 2003).

The relative probability curves for the ELS samples (NCB11-34B and NCB11-01) are remarkably different than those for the ZHA zircons. The maximum age of sedimentation for the eastern ELS is constrained by the youngest zircon dated at 2856 ± 12 Ma from the meta-quartzofeldspathic psammite (NCB11-34B; **Fig. 2-1A**). However, the maximum age of deposition in the western ELS is ~ 100 My older (2951 ± 12 Ma). Much like the ZHA, the potential provenances for the ELS are more complex. The most probable provenance for this ~ 2856 Ma age is the Schade Lake gneissic complex dated at 2858 ± 5 Ma (Van Lankvelt, 2013), however similar ages were also recorded in the North Caribou Batholith from Biczok et al. (2012) (2857 to 2870 Ma) and Van Lankvelt et al. (2012) (2854 ± 8 Ma). The implications for such similar detrital and igneous ages would be the crustal residence time of the terrigenous sediment was relatively short, and therefore erosion and transportation may have occurred rapidly. Evidence for short lived sediment transportation is seen in the grain morphologies. The meta-quartzofeldspathic psammite contains the largest proportion of angular to sub-angular grains in this study (42%). The largest accumulation of sediment for the eastern ELS occurred at c. 2972 to 2977 Ma. Potential provenance for this age population is the nearby Wharram Pluton at 2967 ± 15 Ma (**Fig. 2-1A**) (cf., Van Lankvelt, 2013). The felsic volcanic rocks overlying the

ore zone at Musselwhite has a similar age (c. 2972 Ma; Biczok et al., 2012). The relatively angular to sub-angular nature of these grains suggests transportation was short and is in favor for a proximal source. The provenance of zircons > 3000 Ma is not very well represented in the NCGB. The majority (~50 %) of these Mesoarchean grains are sub-rounded to rounded which may indicate they 1) have experienced multiple phases of magmatic re-absorption and therefore are inherited cores or 2) are highly abraded, due to sediment transport processes, and their protosources are completely eroded. In light of the lack of magmatic ages > 3000 Ma, to this end, it is only possible to conclude they are inherited cores. The restricted age population (c. 2981 - 2989 Ma) from the meta-K feldspar psammite (NCB11-01) is similar to the age of the felsic volcanic of the Agutua Arm Assemblage (c. 2981 ± 1.8 Ma) and within error of the age of Weagamow Batholith (2990 ± 1.8 Ma), both dated by de Kemp (1987). The degree of rounding from detrital zircons from this age population is variable, however, several grains (~37%) are angular and a few of those yielded ages within range of these protosources (2980 to 2981 Ma and 2989 to 2993 Ma). These data strongly suggest erosion of the Agutua Arm and Keeyask Assemblage and Weagamow Batholith are the provenance for the western ELS. Similar to the eastern ELS sample, protosources of zircons which range from c. 3000 to 3012 Ma (n=12) cannot be properly assessed. However, grains which yielded the oldest ages in this are generally subrounded to rounded. Likewise, the zircons > 3050 Ma (n=4) are all rounded to well-rounded. Therefore, these Mesoarchean zircons are most likely inherited grains.

Neodymium and whole-rock geochemistry: Evidence of provenance and crustal reworking

Sm-Nd isotopic compositions of sedimentary rocks are commonly used to determine the source region of the detritus (Goldstein et al., 1984). As well, depleted mantle models ages (T_{DM}) provide quantitative insight in the crustal residence time of the detritus (Taylor and McLennan,

1985) and therefore can be useful for determining the source of sediments derived from these rocks. The ϵ_{Nd} values for the ZHA samples are mainly centered on chondritic values yet show both positive and negative composition. The meta-sedimentary rocks which are proximal to the mafic dominated North Rim and South Rim metavolcanic units generally show a negative ($\epsilon_{\text{Nd}} < 0$) crustal signature. This would suggest the provenance of these sediments may have been sourced from recycled crust material or remelting of evolved crust. The Meso- to Paleoproterozoic T_{DM} ages for these rocks (3.12 to 3.56 Ga) further support this interpretation as it infers a crustal residence time much older than the maximum deposition ages. These immature meta-sedimentary rocks show elevated compatible element concentrations (e.g., Cr, Co and V; **Table 2-1; Figs. 2-4 A&B**). Therefore, it is suggested that their provenance may contain a significant mafic component. The remaining samples (JD10-42 and JD10-48), which show $\epsilon_{\text{Nd}} > 0$, are generally more mature rocks (i.e., meta-psammities to meta-feldspathic schists) and their provenance is most likely from mantle-dominant derived igneous rocks. The T_{DM} model ages for these samples (3.07 to 3.12 Ga) suggest a much shorter crust residence time. **Figure 2-5** shows the results of Sm-Nd analyses along with previous work by Wyman et al. (2011) on external plutons surrounding the NCGB. From this plot, it is evident that there are several potential source regions for the ZHA. Excluding samples JD10-71 and JD10-100, $\epsilon_{\text{Nd}}^{t=2850 \text{ Ma}}$ values for all other metasedimentary rocks in this study overlap the closest with the Western foliated tonalite ($\epsilon_{\text{Nd}} = -1.2$ to -1.6) and Skinner Lake pluton ($\epsilon_{\text{Nd}} = -0.3$ to 1.4). This trend in the Nd isotopic data is consistent with detrital zircon results as the ZHA shows a strong ~ 2850 Ma provenance (**Fig. 2-6A**). Despite a much older age, the Southern volcanic rocks from Wyman et al. (2011), dated at 2980 Ma ($\epsilon_{\text{Nd}} = -0.1$ to 1.0) may have also been a source of detritus for the ZHA. The Heaton Lake (JD10-100) and Obabigan Lake (JD10-71) samples each contain a zircon dated at 2988 Ma

and 2975 Ma (**Appendix A3b**), respectively. As mentioned, potential late Neoproterozoic proto-sources for the meta-psammite Heaton Lake and metapelite Obabigan Lake rocks are the Libert Lake and the foliated granite from the Opapimiskan Lake and/or their coeval volcanic centers (**Fig. 2-5**). The results from the Sm-Nd analysis show the Libert Lake pluton samples from Wyman et al. (2011) trend towards more negative ϵ_{Nd} values, relative to the metasedimentary rocks from this study. However, these rocks plot between the Libert Lake pluton and the one eastern foliated tonalite dated at 2730 Ma ($\epsilon_{\text{Nd}} = 1.9$) from Wyman et al. (2011) (**Fig. 2-5**). The isotopic and age relationship here suggests the latest detritus to be deposited into the basin (e.g., ZHA) was a result of a mixture between these two sources.

Depleted mantle models Ages

Depleted mantle models provide some measure, at best, for the crustal process and continent growth. The T_{DM} ages for the ZHA are consistent with the current understanding of continental growth in the WSP. At least two periods of growth can be interpreted from these rocks.

The first period from 3.07 to 3.12 Ga represents a time of dominantly mantle-derived melting. These ages were determined from the compositionally most mature samples (**Fig. 2-3**), which yielded the highest ϵ_{Nd} values. This correlation between sediment maturity and isotopic compositions suggests the ~ 100 Ma time period represents additions of juvenile crust. This is consistent with current understandings that several greenstone belts in the NCT were constructed on a ~ 3.0 Ga sialic basement (Percival, 2007). This range of mantle model ages is consistent with detrital zircons from the Heaton and Obabigan Lake samples as both rocks contain multi-cycle > 3.0 Ga grains. The occurrence of plutonic or felsic volcanic rock within this age range are limited, however single spot zircon ages of 3094 ± 15 and 3132 ± 17 Ma for NCB granites

have been recorded by Van Lankvelt (2013). These rocks may have been exhumed portions of basement rocks.

The much older second period from 3.12 to 3.56 Ga suggests the presence of a late Paleoarchean crustal signature. The detrital zircon data from either the ELS or ZHA do not show crustal rocks this old in the NCGB; however mantle model ages from this time are not uncommon in the WSP. Henry et al. (2000) calculated T_{DM} of 3.47 Ga for evolved, (i.e., $\epsilon_{Nd} = -3.3$) 3.0 Ga tonalitic gneisses from the Winnipeg River Subprovince (see **Fig. i**). Despite this very low ϵ_{Nd} value from their study, the immature meta-sedimentary rocks from the NCGB did not yield such values. The slightly negative ϵ_{Nd} values, however, suggests extensive contamination of crustal material within the source regions of these rocks. The most likely candidate for this old crustal signature is the North Superior Superterrane, which has been suggested to contain the oldest continental crust (up to 3.7 Ga; Skulski et al., 2000) in the WSP. Two possibilities exist that would explain this contamination. The first possibility and most favourable, would be that the basement rocks of the Northern Superior Superterrane under lie, or were contaminated by, the basement rocks of the NCT. This would imply the granitoids and volcanic rocks of the NCGB would have formed from an evolved source ($\epsilon_{Nd} < 0$). The second possibility is highly transported sediment derived from supracrustal rocks formed or deposited from the North Superior Superterrane. If so, such sediments found in the ZHA and ELS would be very mature, both mineralogically (e.g., meta-quartzites) and chemically (high silica content). **Figure 2-4A** suggests the bulk of the meta-sedimentary rocks from the ZHA and ELS were deposited within an active tectonic environment, thus resulting in limited weathering. Likewise, zircons from this provenance would be well rounded as a result of extensive transportation. As previously discussed, the external grain morphology of Mesoarchean zircons from the ELS and ZHA are all well-rounded to rounded

grains. Therefore it is possible that proximal sources to the NCGB may have been completely eroded. As well, geochemical (**Fig. 2-3**) and petrographic evidence (**Figs. 2-2A & B**) does not favour the second possibility.

Proposed model for the evolution of the NCGB

Figure 2-7 shows a proposed model for the evolution of the NCGB based on detrital zircons, Nd isotopic and whole rock geochemistry. The emergence of the oldest supracrustal rocks (**Fig. 2-7A**) is confined mainly to the western extent of the belt, with the deposition of the Agutua Arm volcanics and Keeyask sediments at c. 2980 Ma with the most probable provenance being the 2990 Ma Weagamow Batholith (de Kemp, 1987). However the SRV in the western and eastern portion of the NCGB contain mafic and felsic volcanic rocks of similar age. Shortly thereafter, the deposition of sediment into the western ELS occurred no earlier than c. 2951 Ma (NCB11-01). The occurrence of plutonic rocks of this age is limited in the NCGB. However, the tonalite clast from the ELS dated by de Kemp (1987) is very similar (c. 2957 Ma). The largest supply of sediment into the western ELS came from a c. 2981 to 2989 Ma source (**Fig. 2-6 A**) which may have been the Weagamow Batholith or Agutua Arm Assemblage. This age gap suggests sediment from these provenances were in “storage” for ~30 Ma or were recycled. Zircons within this age bracket are mainly (63%) sub-rounded to rounded which suggests abrasion during transportation. The Wharram and Schade Lake Plutons may not have been exhumed at this time considering their magmatic ages pre-date the maximum deposition the ELS. Basin formation, from incipient rifting or tectonic switching, may have facilitated basin formation in the NCGB. Evidence for an active tectonic margin is demonstrated through the geochemical signatures of the samples (**Fig. 2-4B**).

As suggested by de Kemp (1987), the external plutons may have served as highlands surrounding the NCGB from 2900 to 2800 Ma (**Fig. 2-7B**). During this time, deposition of sediment into the eastern ELS occurred at c. 2856 Ma. Unlike the deposition of the western sediments (NCB11-01), sediment supply into the eastern basin was most likely rapid given the abundance of angular zircons, the poor sorting for detrital grains and low Zr/Sc ratios from the whole rock geochemistry data. The probable sources of this first cycle detritus came from the near-by North Caribou Batholith to the south and the Schade Lake Gneissic Complex to the north. Exposure of the Wharram Lake pluton (2967 ± 15 Ma; Van Lankvelt, 2013) may have been extensive at this time, as the largest accumulation zircons from the eastern ELS (**Fig. 2-6B**) is from c. 2972 to 2977 Ma. At the time of deposition, these rocks were exhumed and may very well have been topographic highs in the area. Likewise, the felsic volcanics (2972 Ma; Biczok et al., 2012), which form the hanging wall zone at Musselwhite, may contributed limited sediment to the ELS given the minor occurrence of rounded zircons in this age population (i.e., c. 2972 to 2977 Ma). This model agrees with depositional setting proposed by de Kemp (1987) and documented by Breaks et al. (2001). Biczok et al. (2012) interpreted the tectonic setting of the NCGB during this time (c. 2870 Ma) to be a supra-subduction zone setting on the margin of a proto-continent. Such an environment is favorable for rapid deposition of siliciclastic detritus.

The latest phase of major plutonism (**Fig. 2-7C**) is mainly recorded in the eastern portion of the NCGB from the Skinner Lake, Libert Lake and Southern plutons (**Fig. 2-1A**). In order for these rocks, or their volcanic equivalences, to have been the provenance of the ZHA, they must have exhumed by at least 2723 Ma (**Fig. 2-7C**). The mechanism of exhumation for these rocks is not well understood, however their emplacement ages post date the docking of the Island Lake Domain and NCT. In addition, the overall orientation of foliation in the eastern NCGB is sub-

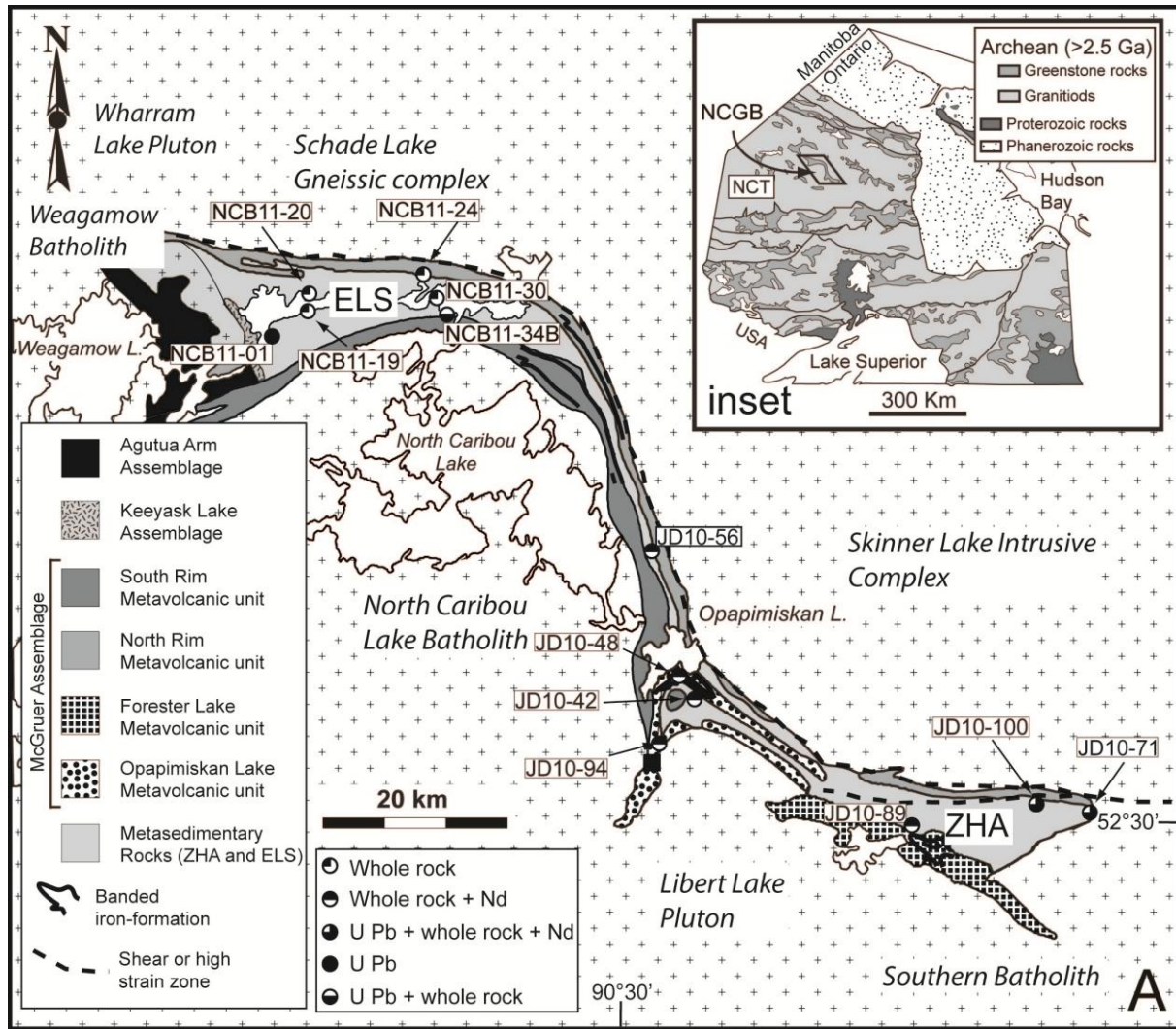
vertical to vertical and striking east-west (Kalbfleisch, 2012). These fabrics and the geochronology of the granitoids, indicate an active, convergent margin setting; one which is dominated by horizontal tectonics similar to present day convergent margins. Geochemistry signatures of the ZHA samples overlap with those of ELS, which suggests basin accumulation occurred in similar tectonic environments. The dominant immaturity (**Fig. 2-3**) and slightly evolved isotopic signature (**Fig. 2-4A**) of the meta-wackes from the ZHA suggest the surrounding mafic volcanics provided a significance proportion of the detritus. However, rhyolites from the Opapimiskan Lake Assemblage, proximal to the Musselwhite mine, have also yielded similar ages of 2720 Ma (per.comm., J. Biczok, 2012). The small size (~100 to 150 μm), stubby and subhedral shape of several zircons from the Heaton Lake meta-psammite (JD10-100) could be attributed to reworking for volcanic material during felsic eruptions. Similar shaped zircons have been reported by Davis and Lin (2003) of reworked felsic volcaniclastic rocks from the Hemlo greenstone belt.

The maximum age of deposition from the Heaton Lake meta-psammite at 2674 ± 29 Ma pre-dates the suggested age of mineralization at Musselwhite by ~25 Ma. However, given the error associated with this age deposition, sedimentation into this area would be pre- to syn-Au mineralization (see **Fig. 3-6**). Thus the Heaton-Zeemal Assemblage could be considered a “Timiskaming-type” unit within the NCGB (Chapter 3).

Conclusions

Whole rock Nd isotopic values for the Zeemal-Heaton Assemblage and U-Pb analysis of detrital zircons from both the Zeemal-Heaton and Eyapamikama Lake Assemblages suggest a c. 600 Ma period of tectonism and continental growth in the NCGB. The ϵ_{Nd} values for the ZHA show a

mixed signature of both positive and negative signatures. These values are comparable to those of large plutons surrounding the NCGB. Depleted mantle model ages range from 2900 to 3220 Ma, which suggests that supracrustal rocks from NCGB were formed from recycled crust or were derived from melting of older crustal material. Trace element ratios (e.g., Th/Sc and Zr/Sc) of metasedimentary rocks from the ZHA and ELS indicate terrigenous sediments were deposited within an active tectonic basin. Rocks from the ZHA with high abundances of compatible elements and negative isotopic signatures that are proximal to metavolcanics, suggest the provenance contained an appreciable proportion of basalt and/or ultramafic detritus. However, their respective detrital zircon age populations indicate that the onset of sedimentation differs by c. 95 Ma, with the ELS forming first. Age populations from this basin correlate well with ages from Wharram Lake, Schade Lake, and Weagamow Batholiths and the felsic volcanics of the Agutua Arm Assemblage. The difference in temporal deposition of the two basins agrees with previous interpretations from Thurston et al. (1991) and contradicts those from Breaks et al. (2001).



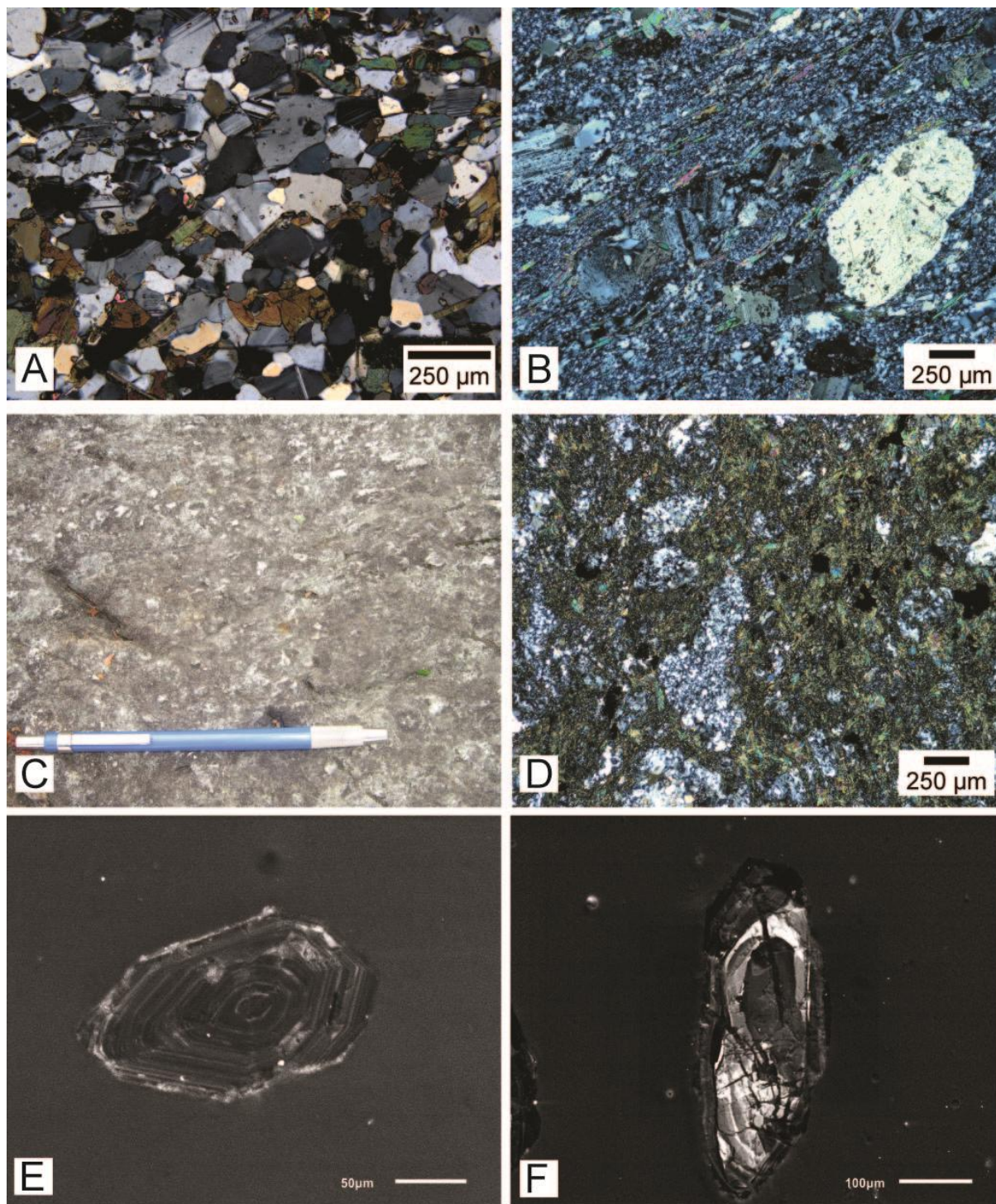


Figure 2-2: A) Sample JD10-94 showing recrystallized quartz and feldspar grains. B) Sample JD10-42 (meta-quartzofeldspathic psammite) showing a fine grained quartz + feldspar rich matrix with larger grains of plagioclase and K-feldspar. C) Field photo of sample NCB11-01 (meta-K feldspar psammite). D) Immature arenite proximal to mafic volcanics of the North Rim Metavolcanics. E) Backscatter SEM image of a detrital zircon from the ZHA unit (JD10-71). F) Backscatter SEM image of a detrital zircon from the ELS units (NCB11-01).

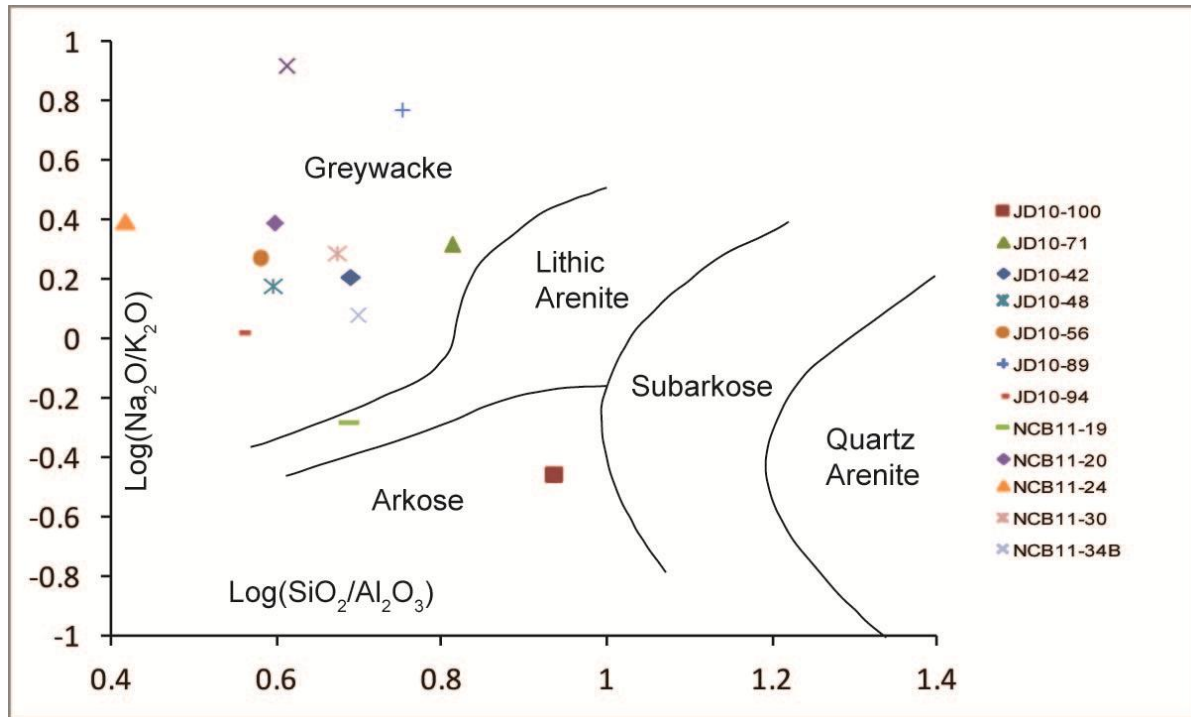


Figure 2-3: Major element discrimination plot of the metasedimentary rocks from the ELS and ZHA. Lithology fields from Pettijohn (1987).

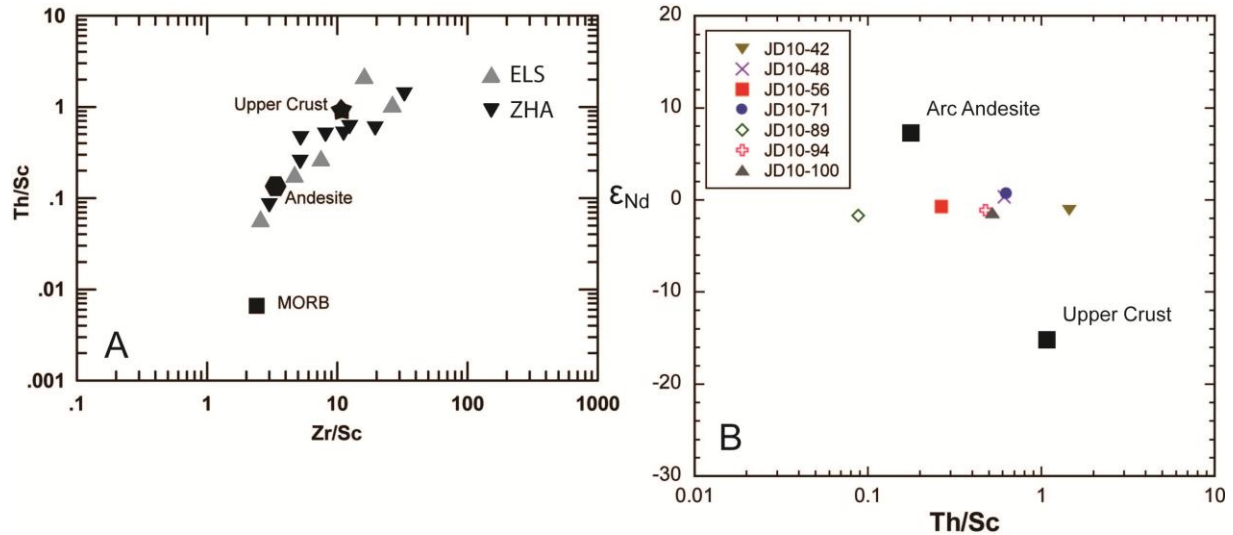


Figure 2-4: Tectonic discrimination plots from Nd and trace element data. A) Zr/Th vs Sc/Zr and B) ϵ_{Nd} vs Sc/Th . Reference composition data from McLennan et al. (1993).

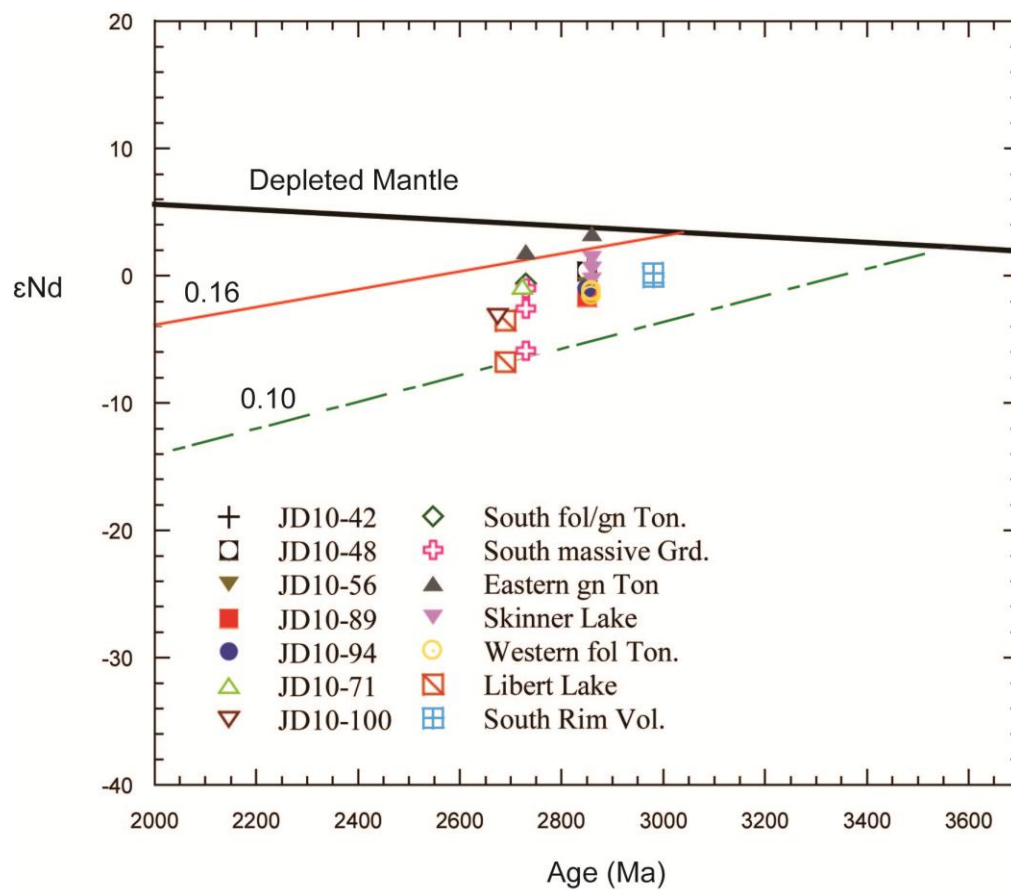


Figure 2-5: ϵ_{Nd} vs. age of samples from this study along with samples from granitoids from Wyman et al. (2010). Initial Nd compositions of samples without U-Pb data were calculated at 2850 after Davis and Stott (2001).

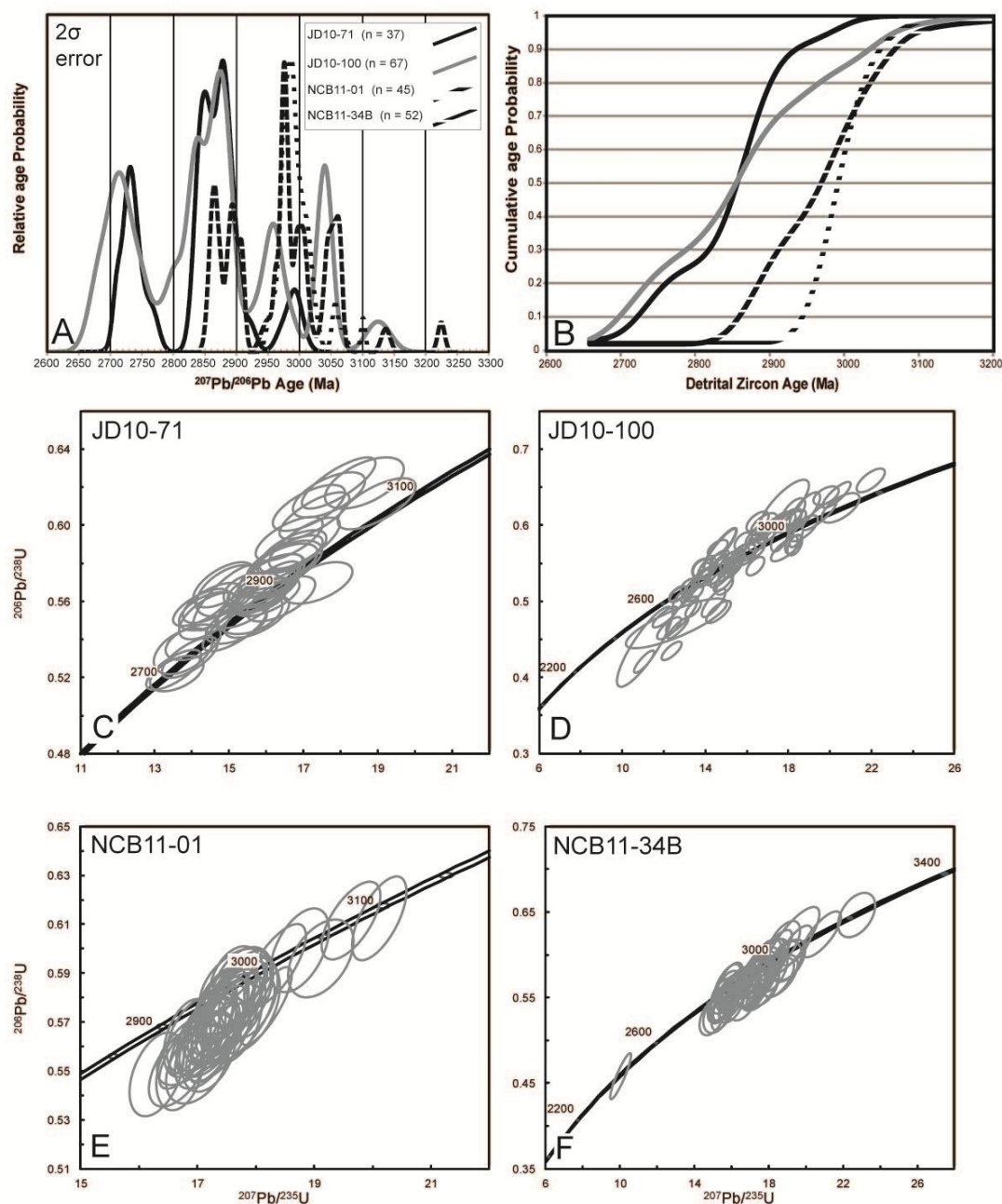
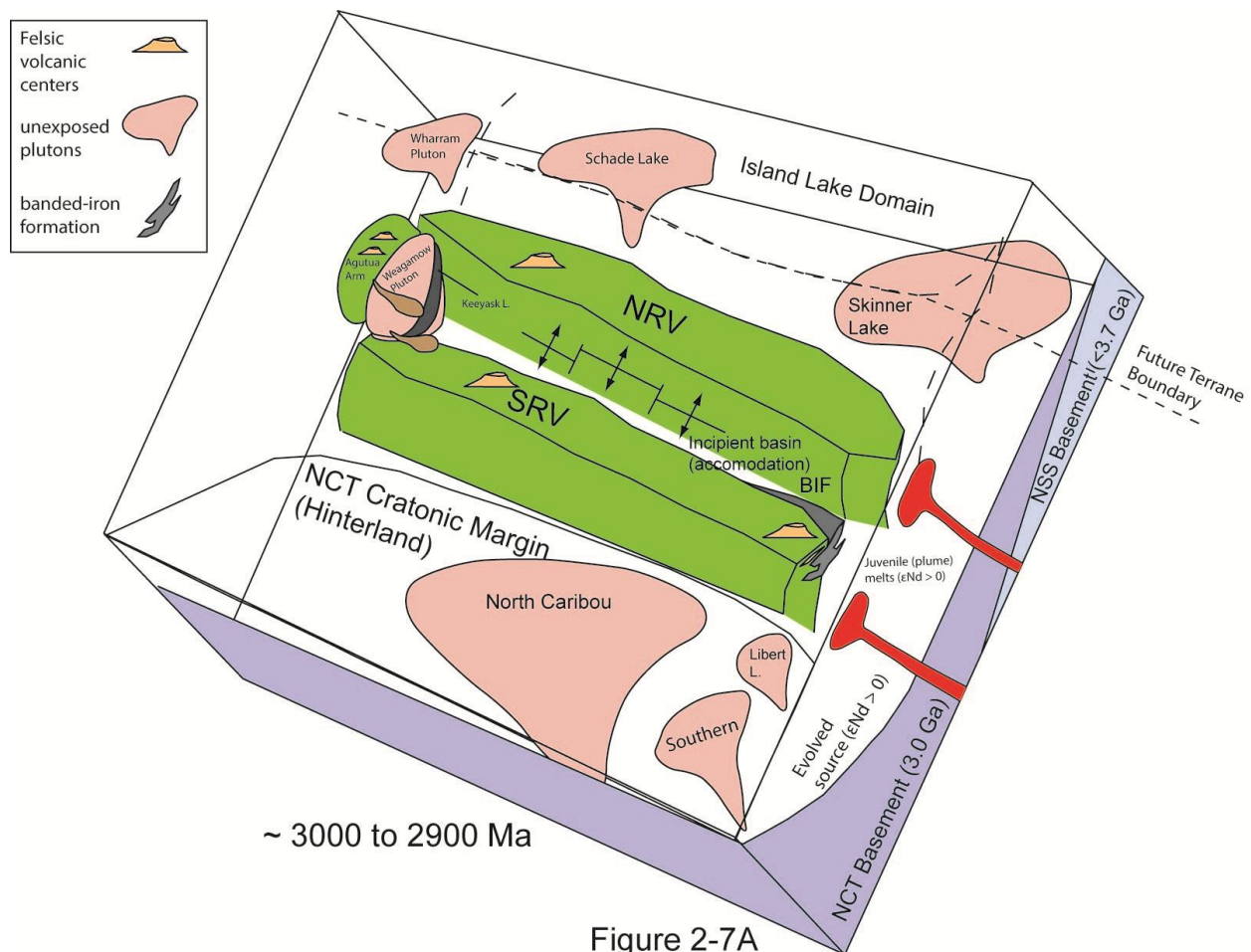


Figure 2-6: A) Relative age probability vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages generated using ISOPLOT 3 of Ludwig (2003) and B) Cumulative age probability vs. $^{207}\text{Pb}/^{206}\text{Pb}$ Age constructed using Excel add-on program CUMULATIVE PROB PLOT of Gehrels (2012). C-F) Concordia plot of all zircon analyses used in Figures 2-6 A & B.



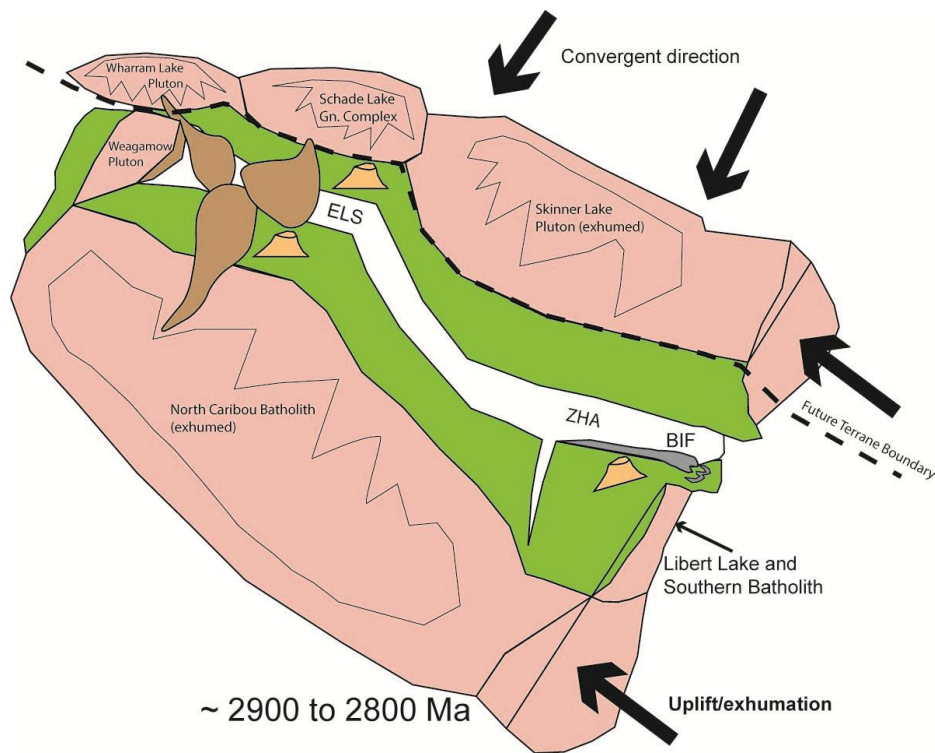


Figure 2-7B

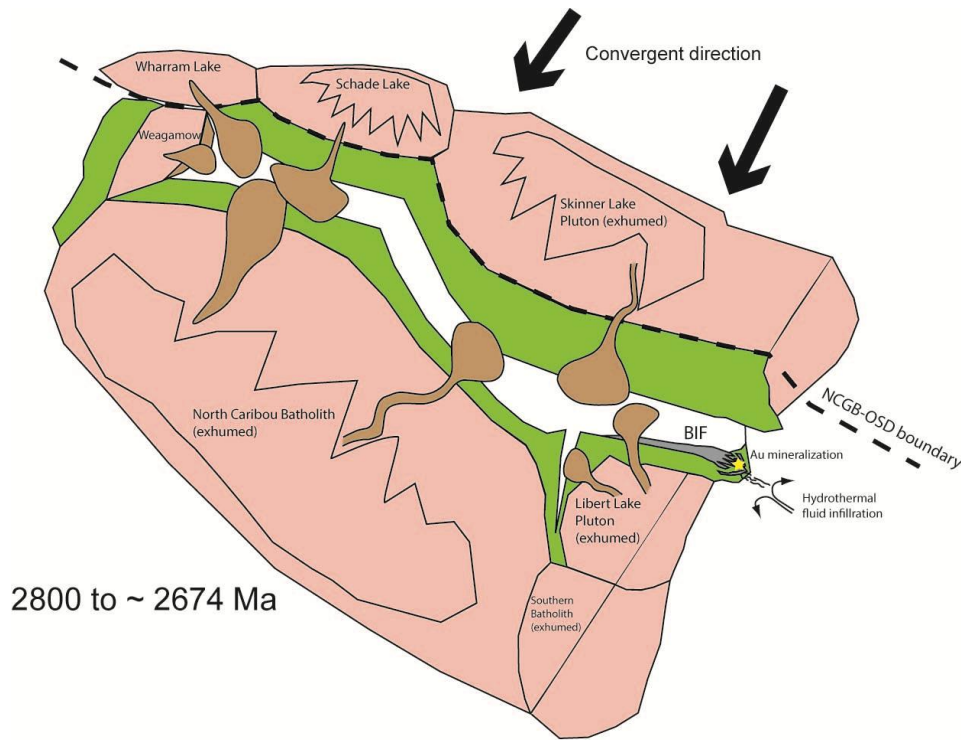


Figure 2-7C

Figure 2-7 A-C: Cartoon sketches of a proposed tectonic setting for the NCGB. A) Deposition of the first supracrustal rocks were the Agutua Arm Assemblage and Keeyask Lake Assemblage rocks at c. 2981 and 2980 Ma, respectively. The onset of deposition of sediments into the western proportion of the basin occurred < 2951 Ma. The most likely sources regions were the Weagamow Batholith or the felsic volcanic of the Agutua Arm metavolcanics. The plume derived mafic/ultramafic volcanic of the Opapimiskan assemblage (cf., Hollings and Kerrich, 1999) may have been sourced from older and evolved crustal material. B) From c. 2900 to 2800 Ma, uplift and erosion of large scale plutons initiated the deposition of immature detritus in the eastern ELS at c. 2856 Ma. The provenances for the first cycle detritus were most likely the North Caribou Batholith and Schade Lake Gneissic Complex. The prominent c. 2972 to 2977 Ma age population within the eastern ELS sample (NCB11-34B) may have been sourced from the Wharram Lake Pluton. C) The onset of sediment deposition into the ZHA occurred ~ 120 My (JD10-71 at < 2723 Ma) after commencement of sedimentation into the ELS. Zircons of this age population were mostly sourced from the Libert Lake and Southern Plutons. However, the large accumulation of zircons with ages ranging from c. 2839 to 2874 Ma are similar to the Skinner Lake Pluton and the small-scale tonalite intrusions in the Opapimiskan Lake area. The maximum age of deposition (c. 2723 Ma) of this sample pre dates the docking for the Island Lake Domain (c. 2707 Ma), suggesting these sediments were deposited in an active tectonic margin. This setting is ideal for rapid erosion of felsic volcanic arcs, and so, the provenances for these late Archean zircons could be now eroded volcanic centers. Likewise, the youngest zircons from the ZHA (c. 2674 to 2688 Ma) may have been sourced such felsic volcanic or from late Archean granites dykes proximal to the Musselwhite mine (cf., Biczok et al., 2012). The maximum age of deposition of both ZHA samples are within range (and error) of the proposed timing of Au mineralization at the mine (cf., Biczok et al., 2012).

Table 2-1: Major and trace element whole rock data.

Sample	JD10-42	JD10-48	JD10-56	JD10-71	JD10-89	JD10-94	JD10-100	NCB11-19	NCB11-20	NCB11-24	NCB11-30	NCB11-34B
Major Element (Wt. %)												
SiO ₂	71.07	66.09	61.55	75.56	51.72	61.23	80.51	72.07	58.08	53.59	66.74	70.73
TiO ₂	0.57	0.43	0.71	0.36	0.58	0.73	0.33	0.25	0.58	0.95	0.52	0.40
Al ₂ O ₃	14.58	16.81	16.21	11.66	9.18	17.06	9.37	14.85	14.70	20.57	14.20	14.20
Fe ₂ O ₃ ^(T)	3.01	4.37	7.42	4.17	15.44	5.67	4.78	4.66	9.08	13.81	7.27	3.79
MnO	0.04	0.05	0.11	0.08	0.33	0.13	0.05	0.07	0.24	0.22	0.13	0.08
MgO	0.77	1.72	3.25	1.85	11.00	2.14	1.35	4.19	10.35	3.00	5.29	1.42
CaO	1.55	3.68	6.49	1.87	10.37	6.54	0.63	0.38	4.23	3.98	2.12	3.81
Na ₂ O	4.97	3.95	2.57	2.86	1.04	3.08	0.73	1.15	1.70	2.58	2.29	2.93
K ₂ O	3.12	2.66	1.39	1.39	0.18	2.96	2.09	2.21	0.70	1.05	1.19	2.46
P ₂ O ₅	0.12	0.13	0.20	0.07	0.06	0.26	0.06	0.04	0.12	0.08	0.08	0.05
LOI	1.53	2.82	1.78	2.05	4.21	1.46	2.63	4.40	9.79	1.94	4.22	5.73
Trace Elements (ppm)												
Sc	6.1	9.1	17.2	9.1	25.1	17.6	9.1	7.3	17.2	47.9	21.1	4.2
V*	41.0	59.0	10.10	53.0	159.0	126.0	65.0	36.0	108.0	248.0	126.0	62.0
Cr*	5.0	41.0	74.0	169.0	278.0	197.0	118.0	110.0	906.0	436.0	677.0	110.0
Co*	6.0	16.0	24.0	19.0	59.0	2.10	22.0	14.0	51.0	58.0	44.0	11.0
Ni*	9.0	18.0	33.0	57.0	112.0	56.0	33.0	66.0	369.0	93.0	186.0	61.0
Cu	9.4	7.3	60.7	30.7	151.0	54.8	35.6	13.1	41.5	38.5	89.4	26.1
Zn*	48.0	51.0	83.0	72.0	143.0	79.0	43.0	108.0	121.0	81.0	79.0	53.0
Cs	2.18	2.88	1.96	1.53	0.13	4.93	3.21	1.54	2.03	5.58	1.76	1.64
Rb	106.2	75.8	53.8	48.4	2.01	81.3	66.1	68.8	26.7	22.5	40.1	54.1
Sr	309	159	169	236	25	242	78.9	70.4	91.8	163	108	101
Ba	947	484	371	477	29.2	650	380	385	95.0	272	262	480
Nb	0.714	2.84	0.051	2.32	2.72	0.052	3.95	6.95	2.90	2.24	3.58	4.60
Zr*	260	146	148	102	80	174	76	91	114	115	78	102
Hf	4.59	3.86	1.92	2.62	1.71	1.87	1.82	3.11	2.58	2.65	2.21	2.4
Y	20.9	12.4	18.9	10.4	20.2	20.9	5.97	14.7	11.9	15.8	10.7	8.86
Ta	39.4	19.9	26.1	21.9	7.14	41	115	44.4	21.6	13.8	15.9	18.5
Ce	91.1	37.1	50.4	40.8	14.6	82.6	21.8	9.11	42.3	28.8	31.5	46.6
Pr	9.7	1.06	5.97	4.63	1.81	10.7	2.53	10.4	4.73	3.37	3.69	3.87
Nd	33.2	13.5	20	15.3	6.74	37.1	8.3	34.8	16.2	12.4	13.1	12.9
Sm	5.61	2.54	3.5	2.62	1.71	6.33	1.52	5.91	3.01	2.65	2.63	2.3
Eu	1.23	0.691	1.04	1.04	0.686	0.614	1.54	0.746	0.72	0.612	0.527	0.408
Gd	4.59	2.23	3.54	2.21	2.41	5.08	1.32	3.21	2.26	2.24	1.9	1.57
Tb	0.616	0.305	0.506	0.302	0.402	0.622	0.202	0.415	0.322	0.306	0.211	0.209
Dy	3.37	1.83	3.13	1.61	2.92	3.53	1.01	1.97	1.61	2.24	1.47	1.25
Ho	0.715	0.406	0.709	0.302	0.704	0.726	0.202	0.414	0.322	0.51	0.316	0.209
Er	1.88	1.12	1.82	0.907	2.01	1.87	0.607	1.14	0.86	1.33	0.843	0.732
Tm	0.306	0.203	0.304	0.101	0.302	0.207	0.051	0.207	0.107	0.204	0.105	0.105
Yb	1.84	1.12	1.82	0.907	1.91	1.66	0.607	1.24	0.86	1.32	0.948	0.731
Lu	0.306	0.203	0.303	0.101	0.302	0.207	0.051	0.207	0.107	0.204	0.105	0.105
Pb	2.08	7.21	16.1	20.6	0.252	8.51	11.6	28.7	14.3	19.3	13.5	28.3
Th	8.88	5.89	4.56	5.75	2.21	8.40	4.76	14.80	4.41	2.65	3.58	4.18
U	2.04	1.42	1.01	1.81	0.503	1.97	1.21	3.94	1.29	0.816	1.26	5.33
Be	1.33	0.305	0.303	0.101	0.050	0.519	0.050	1.24	0.537	1.02	0.948	0.732
Li	16.9	75	24.3	17.6	12.4	86.6	24.7	44.8	59.2	90.4	43.5	20.1
As	0.051	11.8	0.051	2.22	0.05	0.052	0.405	0	8.70	22.9	10.5	29.8
Se	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.311	0.54	0.050	0.105	0.105
Sb	0.102	2.230	0.506	0.403	0.704	0.050	0.911	0.207	0.54	0.408	0.105	1.15
Ge	0.204	0.102	0.202	0.050	0.901	0.104	0.050	0.050	0.215	0.816	0.105	0.050
Mo	0.051	0.051	0.051	0.202	0.05	0.052	1.32	1.97	0.538	1.12	0.843	0.732
Ag	0.153	0.025	0.121	0.081	0.025	0.025	0.025	0.124	0.0752	0.0612	0.074	0.136
Cd	0.102	0.051	0.101	0.201	0.201	0.104	0.051	0	0.215	0	0	0.105
Ta	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.415	0.430	0.102	0.526	0.836
Tl	0.643	0.883	0.283	0.292	0.025	0.249	0.445	0.591	0.290	0.326	0.295	0.387
Bi	0.184	0.01	0.01	0.192	0.01	0.114	0.233	0.301	0.140	0.0816	0.232	0.282
W	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.415	0.43	0.102	0.527	0.836

Major elements analyzed by fused disc XRF and normalized to 100% volatile free. * = Concentration from XRF. Italics = below detection limit (d.l.). Values reported are one half d.l. LOI = Loss on ignition.

Trace elements analyzed by 4-acid digestion ICP-MS

Table 2-2: Sm-Nd data.

Sample	Datum	UTM Zone	Easting	Northing	Lithology	Age (Ma)	Sm [§]	Nd	¹⁴⁷ Sm/ ¹⁴⁴ Nd	¹⁴³ Nd/ ¹⁴⁴ Nd	$\epsilon_{Nd}^{\dagger}$	f (Sm/Nd)	T _{DM} * (Ga)
JD10-100	NAD 27	15	360991	5820283	Meta-psammite	^a 2674	1.09	6.3	0.104904	0.510929 ± 8	-1.76	-0.4667	3.09
JD10-42	NAD83	15	678740	5829548	Fine grained meta- feldspathic schist	2850	5.00	31.09	0.097283	0.510813 ± 5	0.9	-0.5054	3.09
JD10-48	NAD 83	15	676360	5832584	Meta- quartzofeldspathic schist	2850	1.94	10.77	0.108999	0.511006 ± 5	0.4	-0.4459	3.1
JD10-56	NAD 83	15	672730	5844298	Metapelite	2850	3.06	16.71	0.112368	0.511014 ± 4	-0.71	-0.4287	3.12
JD10-71	NAD 27	15	312516	5819109	Metapelite	^a 2723	2.62	11.56	0.104986	0.510946 ± 5	-0.87	-0.4663	3.07
JD10-89	NAD 83	15	702902	5818976	Fine grained meta- psammite (strongly altered)	2850	5.98	1.57	0.155196	0.511770 ± 11	-1.71	-0.2110	3.56
JD10-94	NAD 83	15	673810	5825668	Metapelite	2850	4.99	6.3	0.102639	0.510813 ± 10	-1.08	-0.4782	3.18

^a Ages are maximum age of deposition.

[§] Concentrations in ppm from bulk rock analysis.

[†] $\epsilon_{Nd}^{\dagger}$ values calculated with present day CHUR ¹⁴³Nd/¹⁴⁴Nd of 0.512638 from Wasserburg et al. (1981) normalized to ¹⁴⁶Nd/¹⁴⁴Nd = 0.7219. Present day CHUR ¹⁴⁷Sm/¹⁴⁴Nd of 0.1967 based on ¹⁴³Nd/¹⁴⁴Nd values of Jacobsen and Wasserburg (1980).

* T_{DM} values calculated using present day depleted mantle ratios ¹⁴³Nd/¹⁴⁴Nd and ¹⁴⁷Sm/¹⁴⁴Nd of 0.51315 and 0.2137, respectively. Values are from Michard et al. (1985).

Chapter 3

Timiskaming-type sedimentary rocks in the North Caribou greenstone belt, Western Superior
Province of Canada

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Abstract

The 2.7-3.0 Ga North Caribou Greenstone Belt (NCGB) contains the largest orogenic, shear zone hosted gold deposit in the Western Superior Province (WSP) of Canada; the Musselwhite deposit. The Zeemal-Heaton assemblage (ZHA), the youngest lithotectonic assemblage in the NCGB, is flanked to the north and south by discontinuous mafic and minor felsic metavolcanic rocks of older assemblages. The distribution of these rocks is bounded to the north by the sub-vertical, east-west trending North Caribou-Totogan Shear Zone (NCTSZ) which marks the boundary between the North Caribou Terrane (NCT) and the Island Lake Domain. U-Pb ages of detrital zircons from the siliciclastic rocks of the ZHA are presented here. The meta-psammitic schist from the Heaton Lake area (~ 40 km east of Musselwhite) yielded detrital zircon U-Pb ages between 2674 and 2712 Ma. Farther east (~7 km from Heaton Lake), metapelitic schists along the shores of Obabigan Lake show detrital zircon ages between 2723 and 2745 Ma. Since the sedimentation is younger than the ages of igneous zircon grains, the data suggest the deposition was most likely around 2674 Ma. The ages are similar to those of other “Timiskaming-type” sedimentary rocks in the eastern and southern Superior Province, which occur in close, spatial relationship with large gold-deposits. The slightly older ages of zircons from the Obabigan Lake area suggest the sedimentation was episodic and/or the provenances of detritus varied with time. The youngest zircons from the ZHA are comparable to the Sm-Nd age of ~ 2690 Ma of hydrothermal garnet at Musselwhite as well as the docking age of the Island Lake Domain with the North Caribou Terrane. The data suggest that the deposition of the sedimentary rocks was broadly synchronous with the major shear, deformation and the gold mineralization.

Introduction

In the Superior Province, young sedimentary rocks overlie previously metamorphosed and deformed volcanic rocks of greenstone belts. These rocks generally form the youngest lithological unit in greenstone belts and are referred to as Timiskaming-type rocks (Thurston et al., 1991). Deposition of Timiskaming-type siliciclastic sedimentary rocks is presumed to be synorogenic and typically consist of basal polymictic, clasts-sorted conglomerate which grade into deep-water turbidites (e.g., greywackes, siltstones and mudstones) (Bleeker, 2012). Conglomeratic beds of Timiskaming-type sediments are believed to be deposited during crustal-scale compression, as fluvial fans deposits (Bleeker, 2012). The occurrences of these rocks are mainly confined in the southern Superior, in particular within the Abitibi Subprovince (**Fig. 3-1 inset**). Their distributions, which delineate major deformation zones, are spatially associated with orogenic Au deposits. Examples include the Timiskaming assemblage along the Cadillac-Larder Lake Break shear zone (Corfu et al., 1991; Bleeker, 2012) which is spatially associated with large Au deposits such as Kerr Addison, Kirkland Lake and Sigma-Lamaque mines (cf., Dubé and Gosselin, 2007) and the Timmins mining camp along the Porcupine-Destor Fault Zone (cf., Bleeker, 2012). The occurrences of Timiskaming-type sediments are poorly documented in the WSP.

Here, we present recent detrital zircon analyses from samples from the North Caribou Greenstone Belt (NCGB) of the WSP, evaluate the provenance of these meta-sedimentary rocks and discuss the timing relationship between the sedimentation into the basins and Au mineralization in the Musselwhite.

Geology and Geochronology of the NCGB

The NCGB lies at the center of the NCT (**Fig. 3-1 inset**), which is considered to have served as the nucleus for accretion and amalgamation of the Superior Province (Percival, 2007). The belt is flanked by the North Caribou Batholith - which constitutes the core of the NCT - to the south and the Island Lake Domain (ILD) to the north. The boundary between the NCGB and the ILD is marked by several vertical to sub vertical shear zones (cf., Breaks et al., 1991; Kalbfleisch, 2012). Of particular interest to this study is the North Caribou-Totogan shear zone (NCTSZ; **Fig. 3-1A**). Similar to other Archean greenstone belts, the NCGB consists of assemblages of mafic to ultramafic (+/- felsic) metavolcanic and metasedimentary rocks. These rocks have undergone extensive deformation, which resulted in synclinal “dome-and-keel” regional structures (Lin, 2013), where younger sedimentary rocks are found at the core of the syncline and volcanics along the margins. However, recent geochronology U-Pb dating of the metavolcanics in the NCGB has revealed significant age differences between the metavolcanics bounding the sedimentary core. Two distinct sedimentary basins form the core of the NCGB (Thurston et al., 1991); the Eyapamikama in the northwest and the Zeemal-Heaton Assemblage (ZHA) in the southeast (**Fig. 3-1A**). The Opapimiskan-Markop unit hosts the two main Au-bearing iron formations of the Musselwhite deposit (Fig. 3 of Biczok et al., 2012; **Fig.1-2B**). The chemical sedimentary rocks and the deposition of the clastic material hosting the main ore zones have been bracketed to be between 2982 and 2972 Ma by U-Pb zircon ages from felsic volcanic rocks over and underlying the Opapimiskan-Markop unit (Biczok et al., 2012).

Geochronological studies on rocks from the NCGB and surrounding granitoids is extensive and spans ~ 300 Ma (**Table 3-1**; see *Previous Work* sub-section of *Introduction*) with clear spatial variation. It has long been believed that the western portion of the belt contained the oldest rocks.

Dating of metasedimentary and metavolcanic rocks in the western arm of the NCGB was done by de Kemp (1987), who recorded ages of c. 2.98 Ga. However, recent work by Biczok et al. (2012) yielded similar ages for volcanic rocks within the Musselwhite mine (i.e., 2.98 to 2.97 Ma). Kalbfleisch (2012) recognized a prominent and robust metamorphic event at c. 2.86 Ma from zircons from amphibolite-facies metasedimentary rocks in the eastern NCGB. Likewise, Van Lankvelt (2013) recorded similar ages (i.e., 2.86 to 2.73 Ma) for TTG-type granitoids surrounding the NCGB. Felsic volcanic rocks in the central portion of the belt were also dated at 2.87 Ga by Davis and Stott (2001). They also reported a granitic boulder clast of 2853 Ma from a conglomeratic bed from the ZHA. The youngest ages are from late, pegmatitic dykes that cross cut metavolcanics proximal to Musselwhite. Biczok et al. (2012) yield ages of 2668 Ma from these dykes. There is no evidence that indicates these dykes intrude the ZHA, however mine geologists have documented them in drill core underlying the deposit (Biczok et al., 2012). The age of Au mineralization at Musselwhite is ambiguous, however Nd isotopic ages from garnet crystals from the auriferous zone suggests an age 2690 ± 9 Ma (Biczok et al., 2012). Nevertheless, isochron ages vary from 2664 to 2717 Ma. This adds a severe degree of uncertainty to the actual age of mineralization.

The sedimentary stratigraphy of the NCGB has been described by previous authors (i.e., de Kemp, 1987; Donaldson and de Kemp, 1998; Breaks et al., 2001) with efforts concentrated on the sequence stratigraphy of the ELS. The overall structure of the ELS is a fining upward sequence; the basal rocks are boulder-sized, fan deposited polymictic conglomerates, which grade into intercalated arkosic arenites, wackes and mudstone siltstone laminations (Breaks et al., 2001). In some locations in the western NCGB, A-B-E type Bouma structures (cf., Bouma, 1962) are still preserved, thus providing evidence of turbidite fan deposits (Breaks et al., 2001).

The ZHA, described as the eastern ELS by Breaks et al. (2001), is mainly comprised of two lithofacies; 1) mature quartz wackes and arenites with subordinate volcanoclastic beds and 2) poorly sorted, immature wackes, conglomerates and mudstones (Breaks et al., 2001).

The metamorphism in the NCGB has been described in detail by Breaks and Bartlett (1991), Breaks et al. (1991) and Breaks et al. (2001). The NCGB exhibits an Abukuma type low pressure, high temperature metamorphic trend. The highest grade rocks (i.e., garnet-zone) are located on the northern margin of the NCGB, whereas rocks on the southern margin near the North Caribou Batholith (**Fig. 3-1A**) are predominately within the biotite zone with the exception of a narrow amphibolite grade contact aureole demarcating the intrusive contact of the North Caribou Batholith with the NCGB. Regional metamorphic conditions in the NCGB have reached 550°C and 0.3 GPa (Breaks et al., 2001). Similar temperatures (540-600 °C) and slightly higher pressures of 0.7 GPa were calculated by Otto (2002) for rocks within the mine.

Samples

Samples for this study were collected during field work in the summer of 2010 and sample sites are shown in **Figure 3-1A** and listed in **Table 3-2**. Outcrop exposure of the ZHA metasedimentary rocks is mainly confined to shorelines of the Zeemal, Heaton and Obabigan Lakes.

JD10-100: Heaton Lake meta-psammitic schist

Weathered surfaces of the metasedimentary rocks are generally lighter in colour than that of the volcanic rocks (**Fig. 3-2A**). The Heaton Lake outcrop is pinkish white and contains disaggregated smoky white quartz lenses set in a fine grain quartz + muscovite matrix with minor biotite. The wisps of sheet silicates define a steeply dipping, near vertical WNW-ESE

striking foliation. On the unweathered surface, muscovite-rich cleavage domains (~1 to 0.5 mm) are separated by translucent ~ 1 mm microlithons of grey quartz. From the petrography, this sample (**Fig. 3-2B**) shows a moderate grain size distribution of quartz (70%) + K-feldspar (20%) ± plagioclase. Quartz grains are both mono and polycrystalline. The monocrystalline grains are equate, medium sized (0.5 to 1 mm) and angular. The polycrystalline grains, however, are equate, very fine grained (0.25 to 0.125 mm) and subidioblastic to xenoblastic. Discontinuous and individual wisps of biotite (10%) crystals are generally seen along the boundaries between the two types of quartz. Such spatial association may indicate a detrital origin. Minor amounts of biotite do occur as randomly oriented crystals, which are partially replaced by chlorite. Biotite grains show radiation damage probably due to inclusions of very small zircon grains which are unidentifiable in thin section. Potassium feldspar grains are free from exsolution lamellae. Garnet (< 1%) does occur within the quartz + feldspar matrix. One grain is extremely xenoblastic with a highly irregular shape and its boundaries seem to be controlled by the interstices of the polycrystalline quartz + feldspar matrix. The xenoblastic nature of this grain suggests a late, potentially hydrothermal origin. Therefore, the metamorphic grade of this sample is within the biotite-zone and chemically plots within the “arkose” field of the discrimination plot of Pettijohn et al. (1987) (**Fig. 2-3**).

JD10-71: Obabigan Lake metapelitic schist

Weathered surface of the Obabigan Lake sample is light greyish black, while the unweathered surface is greyish white (**Fig. 3-2C**). The outcrop shows no primary sedimentary structures due to well developed, sub-vertical WNW-ESE trending foliation. Fine grained (1-2 mm) quartz grains are abundant (~ 70%) with subordinate biotite and K-feldspar. In thin section, the sample shows contrasting textures to that of the Heaton Lake meta-psammitic schist. The quartz (65 %)

grains in the Obabigan sample are dominantly medium grain (0.5 to 1 mm). No polycrystalline grains were observed. The shapes of the grains vary from subidioblastic (i.e., recrystallized) to xenoblastic. Relict cement is not evident in between grains, however < 1 mm sized fluid and/or mineral inclusions outline the relict grain boundaries. Biotite grains seem to occur along the grain boundaries monocrystalline domains (**Fig. 3-2D**). Again, rims of biotite appear to be replaced by chlorite. Minor sericite occurs on Na-rich laminae in the K-feldspar (25 %) grains. One large (~250 μm) zircon grain (**Fig. 3-2A**) was observed in the quartz + K-feldspar matrix and its long axis is parallel to the main fabric. An anhedral, irregularly shaped garnet does occur in the section and is texturally similar to that of the Heaton meta-psammitic schist. Trace (< 1%) pyrite is observed to be mantled by pyrrhotite (~1%). Despite similar textures to Heaton Lake, the Obabigan Lake schist contains more phyllosilicates (e.g., biotite, chlorite and sericite), which may indicate a more immature sediment source. Nevertheless, the metamorphic grade is believed to be within the biotite-zone. Chemically, on the Pettijohn et al. (1987) discrimination plot (**Fig. 2-3**), the Obabigan sample plots within the “greywacke” field, however it has a higher $\text{SiO}_2/\text{Al}_2\text{O}_3$ value relative to other ZHA samples.

Analytical Procedure

Zircon grains were liberated from approximately 7 – 10 kg of rock by using a jaw crusher followed by a steel disc mill. Disaggregated sediment was sieved between 106 – 250 μm . This range was chosen because 1) it is ideal for maximizing the number of non broken grains and 2) allows for analysis of core and rim domains using LA-ICPMS methods. An isodynamic magnetic separator and methylene iodide ($\text{SG} = 3.32 \text{ g/cm}^3$) heavy liquid separation was employed to concentrate a heavy mineral fraction. Zircon grains were handpicked and mounted in Epoxy resin. Cathodoluminescence imaging of each sample was carried out at the University of Ottawa

using a Gatan MNIN-CI detector attached to a JEOL 6610V scanning electron microscope operating at a 15 V accelerating voltage. Uranium-Pb isotopic analysis employed laser-assisted inductively coupled plasma mass spectrometer (LA-ICP-MS) methods at the University of New Brunswick using Resonetics M-50-LR 193 nm Excimer laser connected to Aglient 7700x quadruple ICP-MS. The operation conditions are a focused laser beam size of 24 μm , a repetition rate of 4 Hz, and energy attenuation of 3 J/cm². The calibration used FC-1 (Paces and Miller, 1993) and references of 91500 and NIST 610 synthetic glass were used to calculate U and Th concentrations.

The results with high common Pb ($> 2\%$ ^{204}Pb) and high discordance ($> 30\%$) in $\text{Pb}^{207}/\text{Pb}^{206}$ were also removed, following the previous work for Archean zircons by Gehrels (2012). A few results were removed due to low discordance from the majority of studied grains. Relative age probability plots were generated using Isoplot/Ex 3.00 (Ludwig, 2003) using the final $^{207}\text{Pb}/^{206}\text{Pb}$ ages and their respective internal standard error (2σ). Cumulative probability plots were generated from the same data as the relative age plots using CUMULATIVE PROB PLOT Excel program of Gehrels (2012). Detailed analytical procedure including sample preparation is described in the **Appendix A3a**.

Results

JD10-100: Heaton Lake meta-psammitic schist

Hundred-five zircons from the Heaton Lake meta-psammitic schist were mounted and 89 grains analyzed, with only 22 analyses rejected after filtering processes described above. The majority of the grains (69%) show even distribution between sub-angular to sub-rounded, 33% to 36%, respectively. The remaining grains are either rounded (16%) or angular (12%). The shapes of the

grains range from acicular to stubby-columnar, with most of the grains (60%) showing elongate (length: width = $l:w > 2$) shapes. The second most abundant group (32%) are stubby columnar ($2 > l:w > 1$), while only a few grains ($n=4$) are acicular ($l:w \gg 2$). Two grains were fragmented, thus their shapes could not be properly determined. As a result of sieving, the size of zircons range from 106 to 250 μm . Medium grained (150-200 μm) zircons comprise the bulk of the sample (35 grains), while fine grained (106-150 μm) and coarse grained fractions yielded 28 and 22 grains, respectively. There is no strong correlation between the size and shape of the grains; however the largest size group does contain the most angular (euhedral) grains. The colours of the grains vary from near opaque, reddish brown to medium, transparent pink. The largest fraction (i.e., 200 to 250 μm) seems to contain the deepest coloured grains, while the most transparent are the smallest.

The results from all LA-ICPMS analyses are presented in **Figure 2-6**. The range of $^{207}\text{Pb}/^{206}\text{Pb}$ ages are from 2674 ± 29 Ma to 3132 ± 36 Ma. The largest age population (**Fig. 2-6A**) is c. 2874 Ma ($n=28$). Minor, yet significant age populations occur at c. 2720 Ma ($n=12$) and c. 2956 Ma ($n=5$) with late Neoproterozoic population at c. 3039 ($n=6$). The youngest zircons analyzed from the Heaton Lake meta-psammitic schist (JD10-100) yielded 5 near concordant zircons with $^{207}\text{Pb}/^{206}\text{Pb}$ ages ranging from 2674 to 2712 Ma (**Fig. 3-3A; Table 3-2**). The youngest grain (#45) at 2674 ± 29 Ma represents the maximum age of deposition of the sediments in this area. The reproducibility of this age, c. 2674 Ma, zircons is absent in this sample, however, several grains fall within error of this age. For instance, zircon 4 (**Fig. 3-3A**), which shows a reverse discordance, yielded a similar $^{207}\text{Pb}/^{206}\text{Pb}$ age of 2684 ± 43 Ma. Slightly discordant grains (#46 and #71) yielded ages of 2681 ± 28 Ma and 2688 ± 26 Ma, respectively. Th/U weight ratios range 0.32 to 1.16 (**Fig. 3-3C**); the lowest value was obtained from grain 20 (most concordant

grain) and the highest value in grain 46 (the most discordant). The external morphology of these five zircons are generally subhedral, but euhedral grains are present (**Fig. 3-4; Appendix A3c**). Subhedral grains (e.g., #4) are small (~100 μm) with no apparent zoning. Aspect ratios (l: w) range from 1.25 to 2 with well developed pyramidal terminations. Minor rounding of crystal faces is visible in the larger grains. Internal structures of these large grains show thick (~ 5-10 μm) oscillatory zoning bands and well to moderately defined core and rim domains. Mineral and/or fluid inclusions were not ubiquitous and only seen in the core of grain 20.

JD10-71: Obabigan Lake meta-pelitic schist

The Obabigan Lake schist yielded 52 zircons, all of which were analyzed. Fifteen analyses were rejected due to high discordance. Grains from this sample range from sub-angular to well rounded. Similar to the Heaton Lake sample, the majority of the grains are sub-angular and sub-rounded at 34% and 38%, respectively. Approximately 12 zircons are rounded to well-rounded and only two were fragmental. Unlike the Heaton Lake schist, the shape of the zircons in the Obabigan Lake meta-pelite show greater variation with the presence of several equant grains (n=3). However, the abundance of other shapes were similar in both samples; 52% elongate-columnar, 29% stubby-columnar and 4% acicular. The main size population (38%) of the grains are generally fine grained (106-150 μm) while the medium and coarse grain populations are evenly distributed (30% each) among the remaining grains.

Compared the Heaton Lake area, sediments which deposited in the Obabigan Lake area reflect a narrower range of provenances. Ages ($^{207}\text{Pb}/^{206}\text{Pb}$) of zircons from these rocks range from 2710 $\pm$ 10 to 2999 $\pm$ 24 Ma. Three main age populations are present; two of which comprise the bulk of the cumulative age distribution (**Fig. 2-6B**). The first narrow peak at c. 2732 Ma is a result of eight grains ranging from 2710 to 2734 Ma. The second and most prominent age population

occurs at 2878 Ma from 8 grains with a minor ‘shoulder’ population at c. 2850 Ma. The third and least significant occurs at 2990 Ma (n=3). From the Obabigan Lake sample, 5 zircon grains yielded concordia ages < 2800 Ma, (**Fig. 3-3B**). Their $^{207}\text{Pb}/^{206}\text{Pb}$ ages range from 2723 to 2745 Ma with the youngest (# 44) representing the maximum age of sedimentation in this area. Th/U ratios in this group show a narrow range from 0.52 to 1.08 (**Fig. 3-3D**).

The most significant difference between the Obabigan and Heaton Lake detrital zircons is the grain morphology. Zircon grains from Obabigan Lake area are larger (i.e., ~100-175 μm), more rounded and do not display well developed pyramidal terminations (**Fig. 3-5**). The morphology suggests that these grains may have experienced longer erosion and/or transport than the Heaton Lake zircons. Overall, the grains are stubby to equate with aspect ratios ranging from unity to 1.5. Oscillatory zoning is evident in all the five zircons and several of them display distinct core and rim domains. Grains 21 and 24 contain ~1-3 μm size fluid and/or mineral inclusions centered in their cores. Nevertheless, these inclusions do not seem to disturb the isotopic ratios.

Discussion

The data collected from these two late-orogenic meta-sedimentary rocks from the ZHA suggest a complex sedimentary and structural evolution for the eastern NCGB. Despite similar field characteristics, such as near parallel foliation and close sample distance (~6 km), several lines of evidence exist which indicate unique depositional histories and thus differing provenance. Regardless, the youngest zircons from the Heaton and Obabigan Lake are 2674 ± 29 and 2723 ± 29 Ma, respectively. To date, these detrital zircons are among the youngest found in the NCGB and the degree to which their U-Pb compositions represent the maximum age of deposition is high, as discussed in **Chapter 2**. In addition, both zircons (#45 from JD10-100 and #44 from

JD10-71) plot on concordia, within error, and yield the same Th/U ratio of 0.52, which is above the range for igneous zircons ($\text{Th/U} > 0.1$; Hoskin and Schaltegger, 2003). The external morphology and occurrence of oscillatory zoning in several grains (**Table 2** and **Figs. 2-4 & 2-5**) suggest an igneous source. Therefore, these data diminish the possibility of these ages recording *in situ* nucleation events (e.g., metamorphic or hydrothermal growth). Nevertheless, the c. 50 Ma age gap between the two samples, along with differences in bulk chemistry and petrography indicate stark differences in provenances and therefore, rapid changes to sedimentation into the ZHA basin. The lack of polycrystalline quartz in the Obabigan Lake meta-pelitic schist (JD10-71) and the presence of perthitic K-feldspar indicate complexities in proto-sources. Likewise the variation in bulk composition (i.e., “arkose” vs. “greywacke”) is also important in determining the sources. The observations seen here, and the results from previous geochronological studies from the NCGB (e.g., Kalbfleisch, 2012, Biczok et al., 2012, McNicoll, 2013 and Van Lankvelt, 2013) permits us to develop a model for the evolution of a late to syn-orogenic sedimentary basin proximal to a large orogenic Au deposit.

Before discussion of depositional models of the ZHA and potential provenances for these late Neoproterozoic detrital zircons, it is important to discuss the validity of the maximum age of deposition for these rocks. The age of sedimentation of siliciclastic rocks is commonly assigned to the youngest, single zircon from a random or non-random sample set (Fedo et al., 2003; Andersen, 2005 and references therein). This method may lead to misinterpretation of the data and inaccurate age constraints. However, Andersen (2005) suggests this problem may be circumvented if 1) geology and geochronology of potential sources is known and 2) a large number (i.e., 35-70 grains per sample) is analyzed. Both conditions are satisfied in this study as sufficient grains were analyzed (i.e., condition 2) and geochronological work from other authors

(Wyman et al. 2011; Biczok et al., 2012; Van Lankvelt et al., 2012) have been carried out on potential provenances (i.e., condition 1). **Figure 2-6** illustrates that sufficient zircons were analyzed at random (between 106 – 250 μm size fraction) from both samples to ensure that – to a certain degree – every possible source is represented in the sample set. Andersen (2005) warns against using the term “maximum” age for a clastic sedimentary rock if the zircon in question does not occur within a significant age group. For this study, the youngest zircon, in both samples, is part of the youngest relative probability curve (**Fig. 2-6A**), and therefore, the maximum depositional ages for the Heaton and Obabigan Lake (meta)-sediments can be constrained at 2674 ± 29 Ma and 2723 ± 29 Ma, respectively.

Potential Provenances for the ZHA sediments

The most likely source of zircons in sedimentary rocks is 1) felsic to intermediate plutonic and volcanic rocks since they are commonly fractionated and saturated in Zr, thus precipitating zircon (Hanchar and Watson, 2003) or 2) concentrated heavy mineral fractions from older sediments. The NCGB lies within a granitoid-dominant terrane (**Fig. 3-1 inset**), and thus zircons in sedimentary rocks should be plentiful. However, the occurrence or recognition of late Neoproterozoic proto sources is limited. The youngest magmatism recorded thus far in the NCGB is a c. 2.67 Ga muscovite-bearing pegmatite dykes which intruded the 2.8-2.9 Ga mafic metavolcanic rocks (**Fig. 3-6**; Biczok et al., 2012). This age is similar to the youngest zircon (2674 ± 29 Ma) from the Heaton Lake meta-psammite, and thus a potential source region. Furthermore, the observed Th/U of this grain and the others in this sample, are within range of the igneous field of Hoskin and Schaltegger (2003) (**Fig. 3-3C**) and its external morphology (**Appendix A3d**) is characteristic of crystals derived from water-rich melts (cf., Corfu et al., 2003). However, it is impossible to unequivocally conclude that these zircons were a product of

these 2.67 Ga dykes. The small size of the grains (i.e., grains 45 and 4; **Fig. 3-4**), the minor amounts of rounding and lack of preserved bed forms at the outcrop scale indicate limited transportation potentially via a sub-aqueous sediment or fluid gravity flow from a volcanic centre. Zircons with similar morphologies occur within reworked volcanoclastic sediments from the Au-bearing Hemlo-Heron Bay greenstone in the Wawa Subprovince (**Fig. 3-1 inset**) (Davis and Lin, 2003). The occurrences of late Neoarchean felsic volcanics in the NCGB are limited, more so than young plutonic rocks. However, it is well known that rocks in the active margins (**Figs. 2-4A & B**) are uplifted and are also eroded quickly, < 5 km/million years (Fukahata and Matsu'ura, 2000) and sediments are commonly immature in compositions (**Fig. 2-3**) (McLennan et al., 1993). This rapid erosion and sedimentation is also applicable to active margins in the Archean. Timiskaming-type sedimentary rocks in the Kirkland Lake area of the Abitibi Subprovince (**Fig. 3-1 inset**) contain an abundance of felsic volcanic clasts (up to 70% andesites), but are only preserved as such with no outcropping of a provenance (Legault and Hattori, 1994). The evidence suggests that it is possible that the source for these young zircon grains in the NCGB may have totally lost through erosion and no longer present as mappable units. Petrographically, this rock contains abundant coarse-crystalline biotite (~ 10%) and K-feldspar (~20%) and is consistent with the interpretation. Likewise, whole geochemistry from this schist (JD10-100) shows high Al (~ 9 wt. %) and K (~ 2 wt. %) and low Na₂O (< 1 wt. %) (**Table 2-1**). If the source of the Heaton Lake sediments were from now eroded felsic volcanics, the Al₂O₃/Na₂O ratio of ~12.8 suggest Na-losses due hydrothermal alteration to the precursor rock (Fig. 3-8B from Piercey, 2008). Furthermore, the age of deposition (2674 Ma) is very similar to the lower age of the hydrothermal Sm-Nd garnet age (2664 Ma) from Biczok et al. (2012).

The Obabigan Lake zircons show a restricted range of ages > 2700 Ma. Nevertheless, the exposure of ~ 2700 Ma granites in the NCGB is present (**Fig. 3-1A**). The timing of deposition of the Obabigan Lake sediments is approximately coeval with emplacement ages of the Libert Lake pluton to the south, foliated granite (central Libert Lake) and eastern portion of the Southern Batholith (**Fig. 3-6**). Although the site is not close to either pluton, the existence of these intrusions indicates that there was magmatism at ~ 2700 Ma in the NCGB. The lack of ages younger than 2700 Ma in this meta-pelitic schist suggests sedimentation in the far eastern portion of the NCGB could have ended ~ 49 to 56 Ma before deposition of Heaton Lake detritus. This isolation is best illustrated by a narrow peak in the age population curve of zircon grains (**Fig. 2-6A**), reflecting accumulation of clastic components from a single source. In addition, recent dating of rhyolites south of Musselwhite, and along the NCTSZ, which are associated with massive pyrite-pyrrhotite and Au mineralization have yield ages of c. 2720 Ma (J. Biczok per. comm., 2012). The external morphology of the five zircons from the Obabigan Lake schist is quite different from the Heaton Lake zircons. In general, they more rounded and do not exhibit well defined prismatic crystal form. Grains 21, 24 and 71 are the only grains that show a dominant pyramidal crystal structure, while grains 37 and 44 are well rounded and very equant. The round and equant shape of zircon could be caused by high degrees of abrasion during transport or by re-absorption during dehydration metamorphic facies (e.g., greenschist to amphibolite; Corfu et al., 2003). The former is most likely in this case as it retains well-developed clear oscillatory zoning, high Th/U values (> 0.1 ; **Fig. 3-3D**) and very low common Pb (**Fig. 3-3B**). The evidence suggests the ultimate derivation of these zircons is from igneous rocks because metamorphic and hydrothermal zircons commonly show obliterated oscillatory zoning and contains high Pb. Rounded zircons may reflect that some have undergone several

sedimentary cycles. This difference in grain morphology correlates well with the variation in ages, suggesting that the detritus was supplied by different igneous rocks.

Significance of Timiskaming-type sedimentary rocks in the NCGB

This study provides the first evidence of Timiskaming-type sedimentary rocks in the NCGB, which outcrop proximal to the Musselwhite orogenic Au deposit and occur along the boundary between the NCGB and the ILD to the north. Deposition of Timiskaming-type sediments are generally synorogenic, occur at a regional unconformity and their clast composition is polymictic, most importantly containing strongly deformed granitoids (Bleeker, 2012). The significance of such clasts indicates exhumation and erosion of deeply buried and metamorphosed rocks. Timiskaming-type rocks commonly delineate major lithospheric faults/shear zones, which subsequently may serve as conduits for auriferous hydrothermal fluids or mark regional scale stratigraphic unconformities (i.e., Timiskaming-like unconformities, Dubé and Gosselin, 2007). In the NCGB, this structure may have been the NCTSZ, which lies just north of the Zeemal-Heaton Assemblage. Although late Neoproterozoic siliciclastic sedimentation has previously been documented in the WSP by Lin et al. (2006), this is the first record of deposition in the WSP proximal to a major Au deposit. The detrital ages reported here compare well with the timing of the youngest siliciclastic unit in other greenstone belts in eastern and southern Superior Province. These sedimentary rocks are spatially associated with large gold deposits and along major lithospheric-scale shear deformation zones. The most well known is the Timiskaming sandstone (i.e., type locality) along the Cadillac-Larder Lake deformation zone of the Abitibi greenstone belt. This deformation zone, itself, is accompanied by several Au deposits including the Kerr-Addison-Chesterville and Kirkland Lake deposits. Recent dating of the Timiskaming sandstone by Ispolatov et al. (2008) found zircons ranging from 2677 to 2682 Ma.

This range overlaps with previous age range of the alluvial Timiskaming sandstones of c. 2679 to 2680 Ma reported by Corfu et al. (1991). The Hemlo gold deposit (~ 20 Moz Au) which lies in the Hemlo-Heron Bay greenstone belt of the Wawa Province (**Fig. 3-1 inset**) contains c. 2690 to 2685 Ma detrital zircons from greywackes and calc-silicate wackes that over and underlie the main ore zone of the deposit (Davis and Lin, 2003). Furthermore, the Shebandowan greenstone in Wawa subprovince also contains Timiskaming-type sedimentary rocks (Lodge et al., 2013) and shoshonitic volcanic rocks (Shegelski, 1980) where detrital zircons range in age from 2690 to 2680 Ma (Corfu and Stott, 1998). Ispolatov et al. (2008) noted that such young zircons could potentially be associated with Au mineralization.

A Proposed Model for the Deposition of Timiskaming type sediments in the NCGB

The geochronology presented here, combined with regional mapping by Breaks et al. (2001) and U-Pb zircon dating of potential provenances by Biczok et al. (2012) and Van Lankvelt et al. (2013), along with timing of terrane deformation and metamorphism by Kalbfleisch (2012), provide a stable foundation for the development of a proposed depositional model for the Timiskaming-type sediments. In addition, several geological similarities (cf., Breaks et al., 2001) exist between the ZHA rocks and the Timiskaming Assemblage (Bleeker, 2012) of the Abitibi greenstone belt, which is host to some of Canada's largest Au and base metal mining camps.

The first similarity for both greenstone belts is the incipient formation of a marine basin (**Fig. 2-7A**), flanked by mafic to ultramafic volcanic rocks, which both contain deep-water turbidites. The model of Bleeker (2012) envisions deposition of clastic turbidites prior to the tectonic emplacement of older volcanic rocks atop of younger sediments (i.e., Porcupine assemblage c. 2685 – 2695 Ma; Bleeker and Parrish, 1996). Evidence for tectonic juxtaposition of volcanic and sedimentary rocks is present in the NCGB. At the Musselwhite mine, recent work by McNicoll

et al. (2013) suggest that c. 2967 Ma Au-bearing schists are overlain by c. 2978 Ma felsic volcanic. However, evidence of overturned bedding has yet to be documented in the ZHA.

As mentioned above, the ELS comprise a fining upward sequence with a basal polymictic conglomeratic unit, followed by immature turbidites and deep-marine mudstones (i.e., fall-out deposits) (de Kemp, 1987; Breaks et al., 2001). Despite lack of extensive outcrop in the ZHA, during field work for this study, a few of these prominent sedimentary facies were observed, most importantly are polymictic, hydrothermally-altered boulder to cobble conglomerate deposits within the NCTSZ (cf., Kalbfleisch, 2012). Likewise, the presence of late (?), xenoblastic garnets in the Heaton and Obabigan schists may support a hydrothermal history of the ZHA. The occurrence – and recognition – of similar lithologies in the Abitibi have been described by Bleeker (2012) as alluvial deposits coeval with regional erosion and uplift of surrounding metavolcanics due to emplacement of alkaline granitoids and nucleation of large crustal shear zones, in particular the Larder Lake Cadillac and Porcupine-Destor Deformation Zones. Low trace element ratios (**Fig. 2-4A**) from the ZHA rocks and angular to sub angular external morphologies of zircons (**Figs. 3-4 & 3-5**) suggest rapid deposition of mainly immature detritus into the basin, which may have facilitated by the formation of the NCTSZ. The c. 50 My depositional age difference between the Heaton and Obabigan Lake samples suggests temporal variation of the exposure, and erosion, of late Neoproterozoic proto-sources or exposure of various depths of crust. The range of ages from the Heaton Lake meta-psammite, for this study (c. 2674 to 2712 Ma) are similar to those of the Timiskaming assemblage in the Timmins mining camp (see **Fig. i** for location) of c. 2679 ± 4 to 2710 Ma (Ayer et al., 2005). The authors do not specify a provenance for these rocks, however, zircons from a near-by volcanic breccia associated with Au mineralization are compositionally and texturally similar to the detrital grains (Ayer et al.,

2005). This may be a similar case for the ZHA as potential sources of the Heaton Lake sediments are likely to be late S-type granites (cf., Biczok et al., 2012) or now eroded felsic volcanics (**Fig. 2-6A**) and/or their sub-volcanic equivalences. On the contrary, detritus from the Obabigan Lake area was potentially sources from older felsic volcanic centers and intrusive from the Libert Lake or Southern Batholith (cf., Biczok et al., 2012; Van Lankvelt, 2013). **Figure 3-6** shows that timing of the emplacement of these plutons are syn to post-accretion of the ILD to the NCT at c. 2707 Ma (Thurston et al., 1991). Since the youngest zircon from the Obabigan Lake schist post-dates peak -accretion, this would indicate exposure of the ~ 2723-2730 Ma granitoids prior to collision. However, the possibility of these plutons serving as sub-volcanic sources to felsic volcanic should not be overlooked, as recent dating of felsic flows in the eastern NCGB returned ages of c. 2720 Ma (J. Biczok, per. comm., 2012).

The high strain imposed in the ZHA metasedimentary rocks (**Figs. 3-2A & C**) and the intense flattening of granitoid clasts along the NCTSZ (cf., Kalbfleisch, 2012) indicates burial of the sediments sometime after deposition. Determining the exact age of this event is not trivial as detailed facies analysis is required. In the Abitibi greenstone belt, burial of the Timiskaming assemblage occurred at 2669 Ma, or short after, as the upper member of the assemblage, which is in tectonic contact with Porcupine-Destor Fault, yielded a detrital zircon of c. 2669 Ma (Bleeker, 2012). On the contrary, rocks from the ZHA do not clearly show way-up indicators due strong overprinting of east-west foliation (**Figs. 3-2A & C**), and so sample locations for this study may not have been taken at the upper portion of the ZHA. Nevertheless, maximum depositional ages from this study are with range with major accretionary events from c. 2.74 to 2.71 Ma and transpressive shearing from c. 2.69 to 2.56 Ma focused along the northern margin of the NCGB (Kalbfleisch, 2012). As is the case in many transpressive terranes, localized pull-apart basins

could have formed in response to horizontal tectonism (cf., Bleeker, 2012; Lodge et al., 2013 and references therein). The formation of these basins would prompt subsidence and greater accommodation space for detritus. Therefore, final deposition the Obabigan Lake detritus may have occur contemporaneously with the 2.74 - 2.71 Ma transpressive deformation event (Kalbfleisch, 2012). Likewise, the age of the later shearing (2.69 to 2.56 Ma) coincides with maximum depositional age from the Heaton Lake sediment and so similar tectonic-induced sedimentation may have been active during this time. Furthermore, the approximate age of mineralization (c. 2690 Ma Biczok et al., 2012; **Fig. 3-6**) is also contemporaneous (within error) with these tectonic events, and at which time, may have resulted in the inception of crustal-scale faulting and Au mineralization.

Conclusions

The new detrital U-Pb isotopic data of zircon grains show the deposition of immature detritus occurred at ~ 2680-2700 Ma, synchronous with late Neoproterozoic erosion of slightly older local granitoids and transpressive shearing events along the NCTSZ. The sample locations, which are proximal to the Musselwhite mine, suggest the development of sedimentary basin(s) along the major deformation zone separating the NCGB and ILD. Their deposition is contemporaneous with the latest episode of magmatism in the NCGB. All these features of the metasedimentary rocks are very similar to those of Timiskaming-type sedimentary rocks in other greenstone belts (e.g., the Abitibi) in the southern and eastern Superior Province. Tectonic processes which occurred in these belts (cf., Bleeker, 2012), and resulted in massive Au endowments, may aid in explaining the development of mineralization in the NCGB. The sedimentation may potentially be synchronous with the Au mineralization at Musselwhite.

The most likely sources of these zircons in the Timiskaming-type sediment is the late S-type granites, pegmatites (**Fig. 3-6**), although grains between 2700 to 2745 Ma may have been sourced from now eroded felsic volcanic rocks of the McGruer assemblage and/or near-by granitoids, such as the Libert Lake pluton and Southern Batholiths. The age range of these zircons is comparable to felsic volcanic rocks dated at 2720 Ma, which are spatially associated with sulphide and Au bearing bodies.

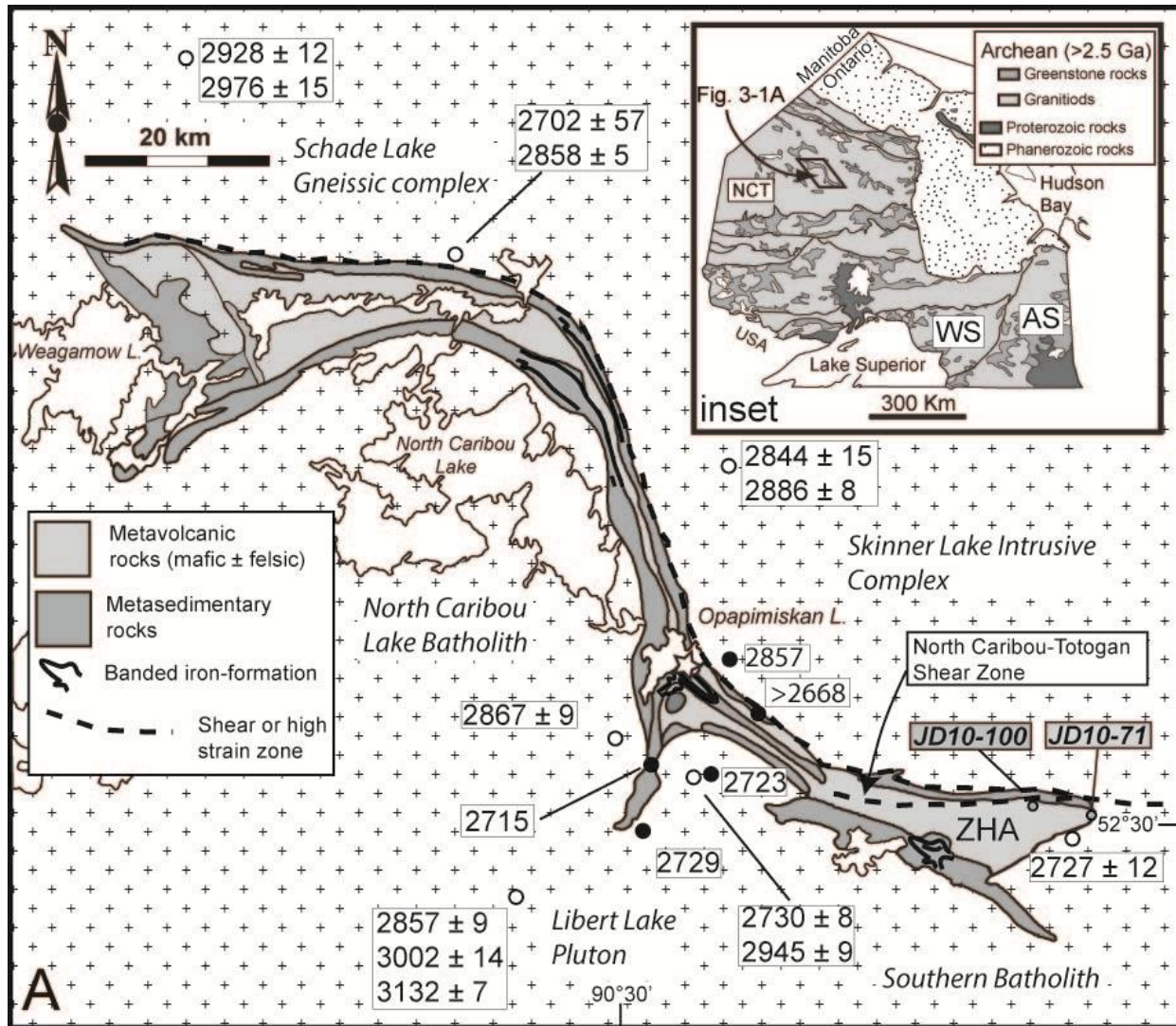


Figure 3-1: *inset*: Large scale geological map of the Western Superior Province (WSP) outlining the distribution of disseminated greenstone belts within granitoid rocks and the general east-west trend of the greenstone belts. Location of the NCGB within the NCT is shown in the black box. Black lines delineate the boundaries of several other terranes. The Wawa (WS) and Abitibi Subprovinces (AS) are shown. A: Simplified geological map of the NCGB showing distribution of metavolcanic and metasedimentary rocks surrounded by c. 3.0 – 2.7 Ga TTG-type rocks. Location of samples JD10-100 and JD10-71 are shown proximal to the Totogan-North Caribou Shear Zone and within the ZHA. Ages (in Ma) of select granitoid rocks - from Table 3-1 - are provided: open circles are from Van Lankvelt et al. (2011 and 2012) and closed circles are from Biczok et al. (2012). Open star shows the location of the Musselwhite deposit on the south shore of Opapimiskin Lake. Both figures modified from Breaks et al. (2001).

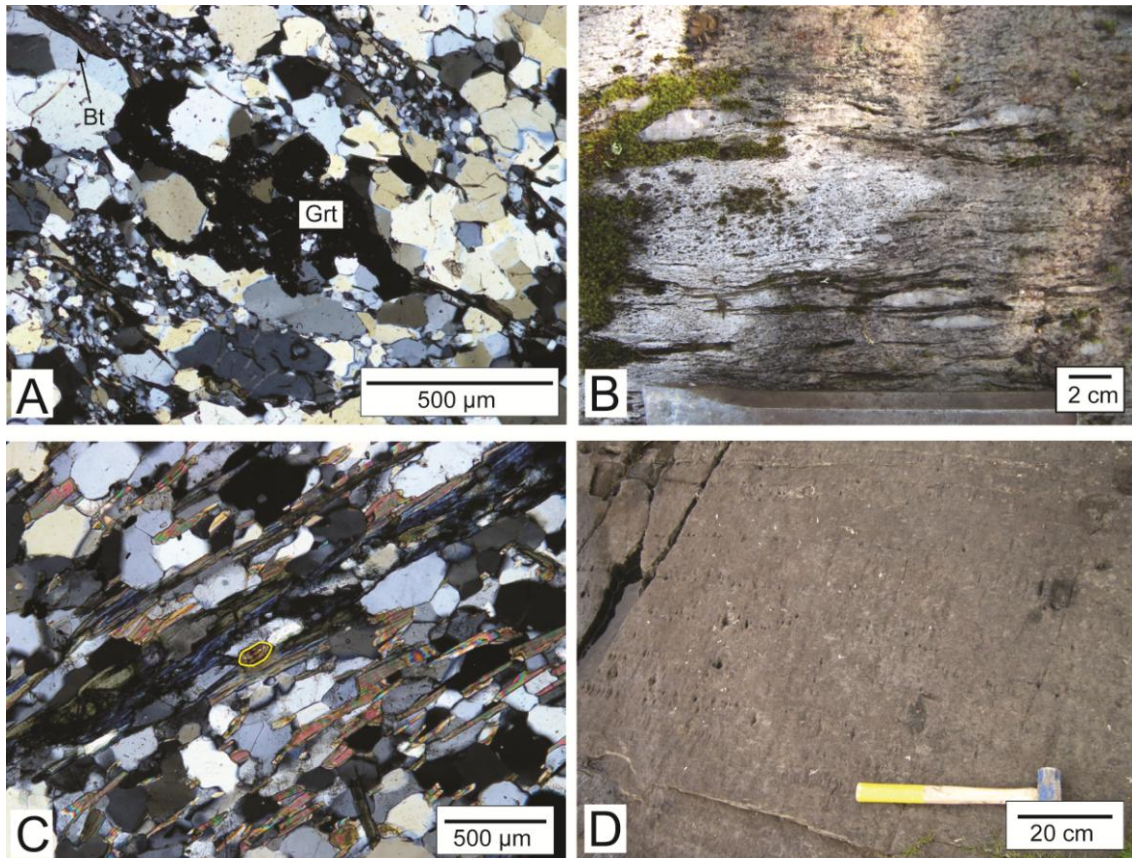


Figure 3-2: Photomicrographs and outcrop photos of the Heaton (A & B) and Obabigan Lake (C & D) samples. A: Photomicrograph showing coarse grain anhedral garnet. B: Weathered surface showing strongly developed foliation and strained quartz lenses. C: Cross polarized image showing wisps of biotite + chlorite with recrystallized quartz clasts. Note the large euhedral (outlined in yellow), zoned zircon in the centre of the image. D: Weathered surfaced of outcrop. Foliation is not evident, but length of the hammer is approximately east-west, parallel to foliation. Note the lack primary sedimentary structures.

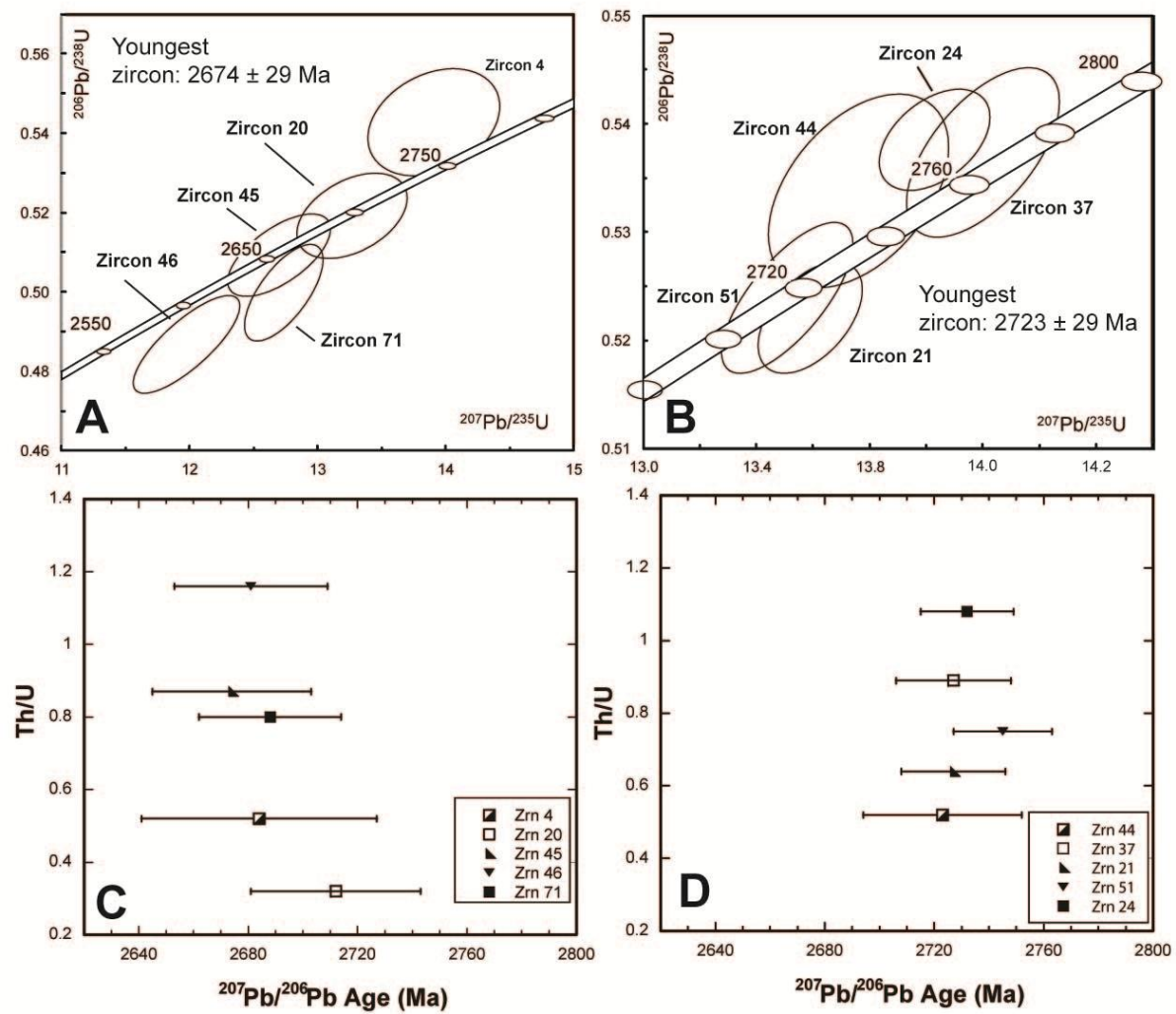


Figure 3-3: U-Pb Concordia and Th/U vs. $^{207}\text{Pb}/^{206}\text{Pb}$ age plots for the Heaton (A & C) and Obabigan (B & D) zircons. Error ellipses in A and B and error bars in C and D are 2σ . Th/U values are approximate values based on concentrations of each element during LA-ICPMS analysis.

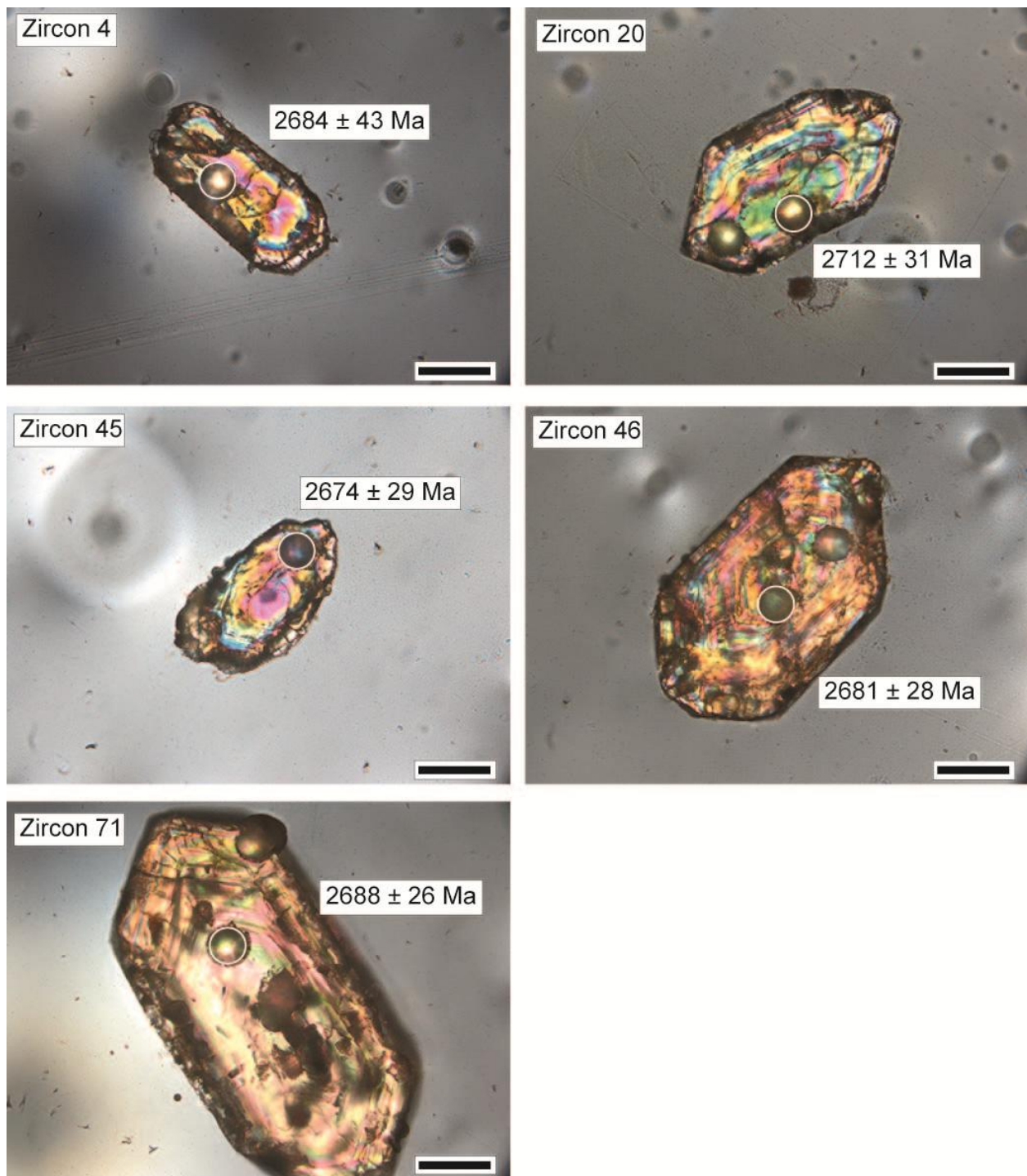


Figure 3-4: Cross polarized photomicrographs of zircons from the Heaton Lake meta-psammitic schist. Horizontal scales are 50 μm in length. White circles indicate the ablation spots with their respective $^{207}\text{Pb}/^{206}\text{Pb}$ ages and presented in Table 3-2. The diameter of each circle is approximately 24 μm .

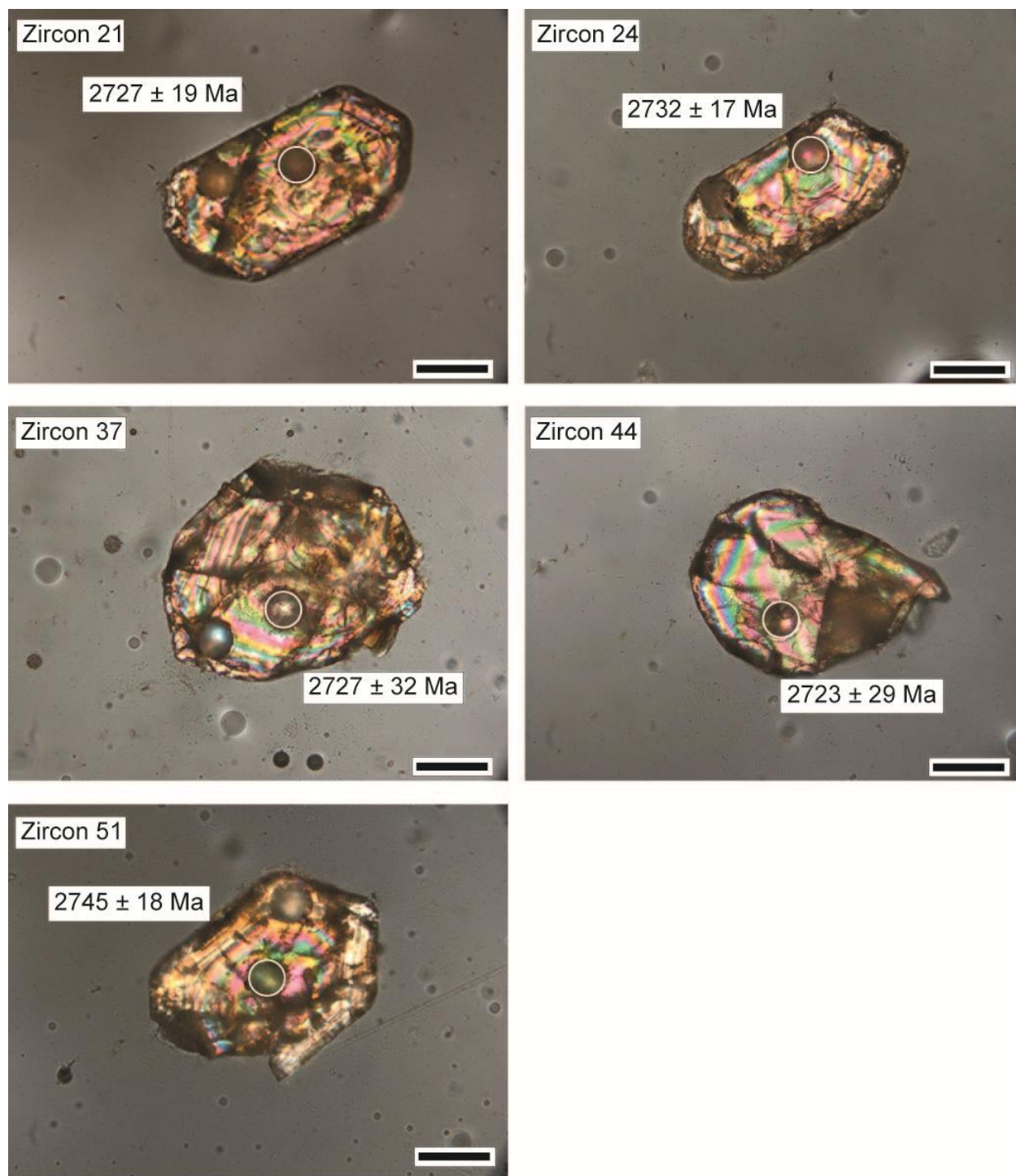


Figure 3-5: Cross polarized photomicrographs of zircons from the Obabigan Lake meta-pelitic schist. All horizontal scale bars are 50 μm in length. White circles indicate the ablation spots with their respective $^{207}\text{Pb}/^{206}\text{Pb}$ ages and presented in Table 3-2. The diameter of each circle is approximately 24 μm .

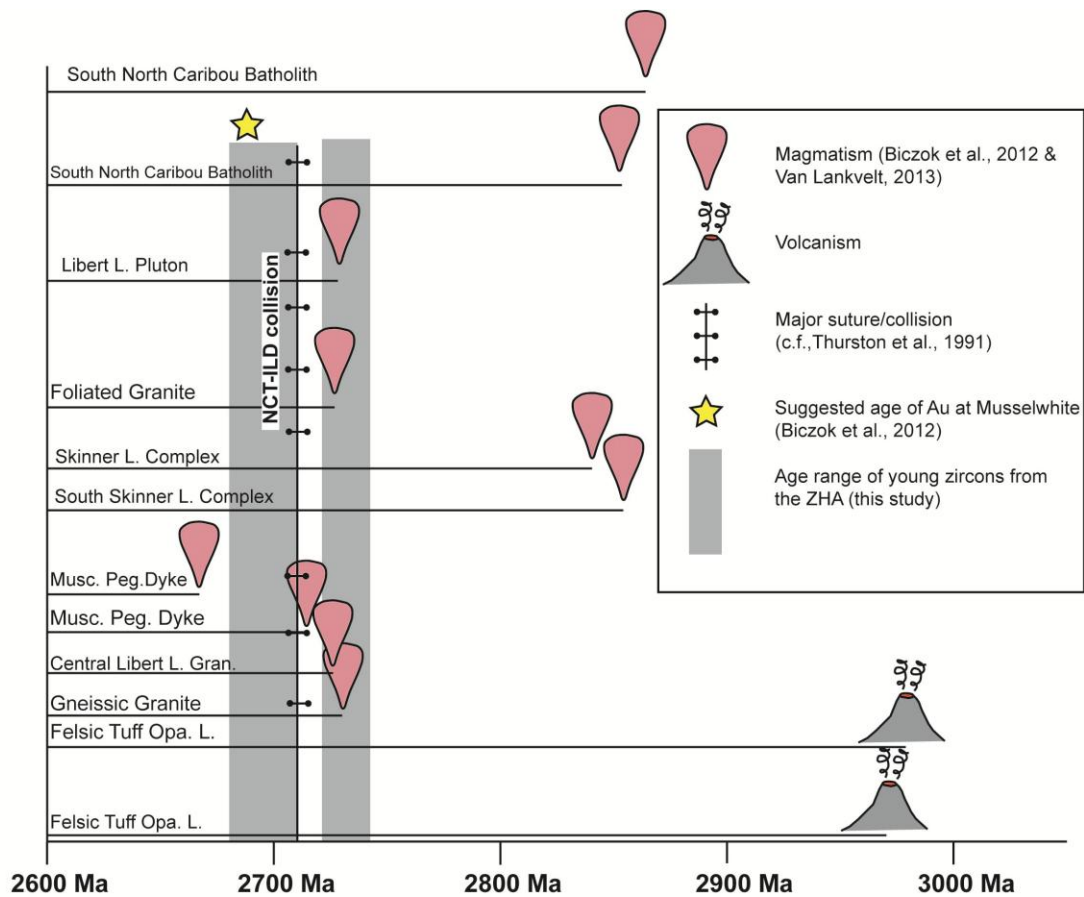


Figure 3-6: Schematic diagram showing the age of several plutonic and volcanic rocks in the NCGB listed in Table 3-1 from Biczok et al. (2012) and Van Lankvelt et al. (2011 & 2012). Thick grey bars show the age range of the youngest zircons from the Heaton and Obabigan Lake metasedimentary rocks. Yellow star shows the approximate, accepted age of mineralization at Musselwhite.

Table 3-1: Selected geochronological data of igneous rocks in the NCGB. See Figures 3-1A for the sample locations.

Lithology ^α	Location ^β	mineral ^χ	U-Pb age (Ma)	Reference ^δ
Ms pegmatite granite dyke	Cross-cutting the northern metavolcanics	Mnz	2668.8 ± 1.1	1
Ms pegmatite granite dyke	Cross-cutting the volcanic	Mnz	2715.8 ± 1.6	1
Granite	Central Libert Lake Pluton	Zrc	2723.1 ± 0.8	1
Gneissic granite	East Southern Batholith	Zrn	2727.7 ± 1.0	3
Foliated granite	Central Libert Lake Pluton	Zrn	2729.4 ± 7.1	1
Granite	Libert Lake Pluton	Zrn	2730 ± 8 & 2945 ± 9	3
Granodiorite	Skinner Lake Intrusive Complex	Zrn	2844 ± 15 & 2886 ± 8	2
Gneissic tonalite	South Skinner Lake Intrusive Complex	Zrn	2857.3 ± 1.4	3
tonalitic to granitic	South North Caribou L. Batholith	Zrn	2857 ± 9	3
tonalitic to granitic	South North Caribou L. Batholith	Zrn	2867 ± 9	3
Felsic tuff	UG	Zrn	2972.4 ± 1.6	1
Felsic tuff	UG	Zrn	2982.4 ± 0.8	1

α: Muscovite =Ms

β: locations are shown in Fig. 1, UG=underground of the Musselwhite mine

χ: Mnz=monazite, Zrn=zircon

δ: 1 = Biczok et al. (2012), 2 = Van Lanvelt et al. (2011), 3 = Van Lankvelt et al. (2012).

Table 3-2: LA-ICPMS U-Pb results of the zircons from the Heaton and Obabigan Lake arenites shown in Figures 3-4 and 3-5.

Sample	Description	$^{207}\text{Pb}/^{206}\text{Pb}$		$^{207}\text{Pb}/^{235}\text{U}$		$^{206}\text{Pb}/^{238}\text{U}$		Th/U	%
		Ratio	2 σ	Age	2 σ	Ratio	2 σ		Age
JD10-71	0306991 E, 5820283 N, NAD 27 [◻]							3.17*	
Zrn 44	1 subh, subeq, no c-r boun, OZ	0.1874 ± 0.0035	2723 ± 29	13.76 ± 0.26	2732 ± 18	0.5339 ± 0.0073	2757 ± 31	0.52	4.05
Zrn 37	1 subh, rnd, eq, OZ	0.1885 ± 0.0024	2727 ± 21	14.43 ± 0.19	2777 ± 13	0.5549 ± 0.0046	2845 ± 19	0.89	3.59
Zrn 21	1 euh, eq, no c-r boun, OZ, incl (center)	0.1885 ± 0.0022	2727 ± 19	14.45 ± 0.22	2780 ± 14	0.5522 ± 0.0073	2833 ± 31	0.64	4.53
Zrn 24	1 euh, subrnd, c-r boun, OZ, incl (core)	0.1891 ± 0.002	2732 ± 17	14.03 ± 0.16	2751 ± 10	0.5386 ± 0.0038	2777 ± 16	1.08	2.61
Zrn 51	1 frag, euh, spr, OZ	0.1903 ± 0.002	2745 ± 18	13.94 ± 0.2	2747 ± 13	0.5306 ± 0.0057	2743 ± 24	0.75	3.15
JD10-100	0312516 E, 5819109 N, NAD 83 [◻]							3.92*	
Zrn 4	1 small, subh, rnd, eq, no zoning	0.1833 ± 0.0047	2684 ± 43	13.9 ± 0.42	2740 ± 24	0.5429 ± 0.011	2801 ± 37	0.52	5.7
Zrn 20	1 euh, long, c-r boun, incl (core)	0.1869 ± 0.0035	2712 ± 31	13.26 ± 0.35	2700 ± 16	0.5194 ± 0.0087	2696 ± 18	0.32	3.01
Zrn 45	1 small, euh, long, c-r boun, no OZ	0.1826 ± 0.0032	2674 ± 29	12.69 ± 0.33	2659 ± 19	0.5095 ± 0.0085	2654 ± 25	0.87	3.16
Zrn 46	1 large, euh, no c-r boun, OZ	0.1826 ± 0.0029	2681 ± 28	12.05 ± 0.49	2606 ± 27	0.479 ± 0.011	2522 ± 45	1.16	4.8
Zrn 71	1 large, long, OZ, no c-r boun	0.1836 ± 0.0028	2688 ± 26	12.73 ± 0.25	2659 ± 17	0.5 ± 0.0099	2613 ± 26	0.8	3.47

* Ratios from whole-rock analysis

[§]Discordance on the $^{207}\text{Pb}/^{206}\text{Pb}$ ratio

[□]Both coordinates are in UTM Zone 16.

Abbreviations: c-r boun = core-rim boundary, eq = equant, frag = fragmental, incl = inclusions, long = long prismatic, OZ = oscillatory zoning, rnd = rounded, subeq = subequant, spr = short prismatic, subh = subhedral, subrnd = subrounded

SUMMARY OF CONCLUSIONS

Chapter 1

- Major and trace element compositional variations from core to rim of garnet crystals in auriferous rocks at Musselwhite and surrounding outcrops suggest a pre to syn amphibolite grade Au mineralizing event.
- The latest stage of mineralization, as recorded in the rims of garnets, was most likely a long-lived and more intense hydrothermal event, relative to the core.
- The proposed model for Au mineralization at Musselwhite suggests that the late-stage mineralizing event(s) may have been cotemporaneous with accretionary events in the NCT and granulite metamorphism in the WSP. Moreover, the timing of both events is broadly the same as the current age range of mineralization at Musselwhite.

Chapter 2

- Neodymium isotopic compositions from the meta-sedimentary rocks of the Zeemal-Heaton Assemblage suggest their provenances have both negative and positive ϵ_{Nd} values. These compositions are similar to those of the surrounding, proximal granitoids suggesting locally derived detritus.
- The possibility of locally derived sediments into the basins is further underpinned by their low Zr/Sc and Th/Sc ratios from the metasedimentary rocks of the ELS and ZHA, suggesting rapid erosion and deposition in an active tectonic margin. High Co and Cr abundances in the most immature samples suggest a significant proportion of mafic and ultramafic volcanic rocks may have been the provenance for the ZHA and ELS rocks.
- The maximum age of deposition, determined from detrital zircon populations suggest the ~ 100 My hiatus in sedimentation between the ELS and ZHA. Despite similarities in the whole rock data, these U-Pb zircon data favor two the basin modal of Thurston et al. (1992).
- Calculated depleted mantle model ages for the ZHA rocks suggest their provenance may have been contaminated with early Mesoarchean crustal components, potentially from older North Superior Superterrane rocks (cf., Skulski et al., 2000).

Chapter 3

- The maximum depositional ages of the ZHA samples show characteristics of “Timiskaming-type” rocks as they yield some of the youngest U-Pb ages from the NCGB and are located along a major crustal-scale shear zone; potentially a loci for hydrothermal auriferous fluid infiltration.
- The source regions of these rocks are interpreted to have been derived from late Neoproterozoic S-type granites and/or now eroded felsic volcanics. Evidence for this stems from the zircon morphology and the occurrence of minor felsic volcanics of similar age.

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Appendix A1a: Major element of garnet crystals and end-member compositions

Sample	Major Elements										Total
	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO		
JD10-07_g1pt 1 (Rim)	36.721	0.058	20.920	0.000	1.149	36.104	0.146	2.130	3.054		100.28
JD10-07_g1pt 2	36.739	0.052	20.904	0.000	1.193	35.850	0.180	2.123	3.248		100.29
JD10-07_g1pt 3	36.886	0.055	20.717	0.000	0.768	36.944	0.227	1.701	3.083		100.38
JD10-07_g1pt 4	36.761	0.044	20.863	0.000	0.889	36.110	0.115	2.151	3.072		100.01
JD10-07_g1pt 5	36.827	0.062	20.890	0.000	1.150	35.686	0.101	2.163	3.472		100.35
JD10-07_g1pt 6	36.738	0.104	20.899	0.000	0.956	36.004	0.124	2.106	3.231		100.16
JD10-07_g1pt 7	36.746	0.055	20.958	0.000	1.305	35.660	0.124	2.061	3.535		100.44
JD10-07_g1pt 8	36.743	0.049	20.966	0.000	0.997	36.102	0.140	2.114	3.097		100.21
JD10-07_g1pt 9	36.896	0.059	20.970	0.000	0.967	36.019	0.134	2.038	3.422		100.50
JD10-07_g1pt 10	36.773	0.057	20.876	0.000	0.930	35.764	0.123	2.089	3.443		100.05
JD10-07_g1pt 11	36.690	0.051	20.954	0.000	0.975	35.704	0.124	2.018	3.506		100.02
JD10-07_g1pt 12	36.818	0.071	20.902	0.000	0.722	35.803	0.116	2.068	3.499		100.00
JD10-07_g1pt 13	36.670	0.040	20.881	0.000	1.467	35.888	0.125	2.107	3.211		100.39
JD10-07_g1pt 14	36.726	0.055	20.882	0.000	1.092	36.100	0.099	2.027	3.240		100.22
JD10-07_g1pt 15	36.711	0.060	20.876	0.000	0.958	36.134	0.086	1.995	3.258		100.08
JD10-07_g1pt 16	36.369	0.064	20.587	0.000	1.107	37.286	0.139	1.332	2.923		99.81
JD10-07_g1pt 17	36.575	0.054	20.925	0.000	1.041	36.166	0.102	1.943	3.162		99.97
JD10-07_g1pt 18	36.569	0.028	21.115	0.000	1.424	35.874	0.106	2.011	3.268		100.39
JD10-07_g1pt 22	36.536	0.103	21.007	0.000	1.155	36.126	0.162	1.900	3.203		100.19
JD10-07_g1pt 23	36.646	0.068	20.860	0.000	1.084	36.293	0.140	1.710	3.433		100.23
JD10-07_g1pt 24	36.605	0.111	20.802	0.000	0.902	36.705	0.148	1.604	3.244		100.12
JD10-07_g1pt 25	36.508	0.075	20.874	0.000	1.256	36.302	0.189	1.493	3.565		100.26
JD10-07_g1pt 26	36.520	0.100	20.898	0.000	1.019	36.759	0.201	1.298	3.499		100.29
JD10-07_g1pt 27	36.652	0.097	20.902	0.000	0.902	37.244	0.247	1.243	3.282		100.57
JD10-07_g1pt 28	36.275	0.354	20.770	0.000	0.000	36.959	0.236	1.122	3.211		98.93
JD10-07_g1pt 29	36.323	0.075	20.889	0.000	1.220	36.895	0.302	1.156	3.309		100.17
JD10-07_g1pt 30	36.232	0.112	20.911	0.000	1.547	36.660	0.318	1.104	3.493		100.38
JD10-07_g1pt 31	36.406	0.084	20.831	0.000	1.273	36.709	0.359	1.013	3.692		100.37
JD10-07_g1pt 32	36.326	0.040	21.039	0.000	1.096	37.270	0.436	0.999	3.107		100.31
JD10-07_g1pt 33	36.542	0.161	20.912	0.000	0.685	37.288	0.480	0.957	3.403		100.43
JD10-07_g1pt 34	36.646	0.062	21.237	0.000	0.326	37.246	0.607	0.756	3.643		100.52
JD10-07_g1pt 35	36.295	0.107	20.856	0.000	1.206	36.956	0.660	0.941	3.274		100.29
JD10-07_g1pt 36	35.973	0.233	20.235	0.000	0.000	36.350	0.718	0.912	3.203		97.62
JD10-07_g1pt 37	32.522	4.196	18.957	0.000	2.078	36.717	0.846	0.711	2.982		99.01
JD10-07_g1pt 38	35.916	0.058	20.654	0.000	0.000	36.073	0.953	0.846	3.221		97.72
JD10-07_g1pt (Core)	36.093	0.154	21.076	0.000	1.731	36.165	1.237	0.808	3.465		100.73

Sample	tetrahedral 4-fold			octahedral 6-fold				cubic 8-fold				Sum	almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-TiGt	total
	Si	Ti	Sum	Al	Cr	Fe+3	Sum	Fe+2	Mn	Mg	Ca									
JD10-07_g1pt 1(Rim)	2.966	0.004	2.969	1.991	0.000	0.070	2.061	2.439	0.010	0.256	0.264	2.969	82.127	8.637	8.584	0.336	0.000	0.301	0.015	100
JD10-07_g1pt2	2.966	0.003	2.969	1.989	0.000	0.072	2.061	2.420	0.012	0.256	0.281	2.969	81.588	8.605	9.116	0.415	0.000	0.332	0.014	100
JD10-07_g1pt 3	2.985	0.003	2.989	1.976	0.000	0.047	2.023	2.500	0.016	0.205	0.267	2.989	83.667	6.867	8.724	0.521	0.000	0.206	0.015	100
JD10-07_g1pt 4	2.975	0.003	2.978	1.990	0.000	0.054	2.044	2.444	0.008	0.260	0.266	2.978	82.075	8.715	8.697	0.265	0.000	0.237	0.012	100
JD10-07_g1pt 5	2.969	0.004	2.973	1.985	0.000	0.070	2.055	2.406	0.007	0.260	0.300	2.973	80.935	8.745	9.728	0.232	0.000	0.342	0.018	100
JD10-07_g1pt 6	2.969	0.006	2.976	1.991	0.000	0.058	2.049	2.434	0.008	0.254	0.280	2.976	81.784	8.528	9.108	0.285	0.000	0.266	0.029	100
JD10-07_g1pt 7	2.962	0.003	2.965	1.991	0.000	0.079	2.070	2.404	0.008	0.248	0.305	2.965	81.067	8.352	9.886	0.286	0.000	0.393	0.017	100
JD10-07_g1pt 8	2.969	0.003	2.972	1.996	0.000	0.061	2.057	2.439	0.010	0.255	0.268	2.972	82.087	8.568	8.743	0.322	0.000	0.265	0.013	100
JD10-07_g1pt 9	2.972	0.004	2.975	1.991	0.000	0.059	2.049	2.426	0.009	0.245	0.295	2.975	81.543	8.225	9.625	0.307	0.000	0.283	0.017	100
JD10-07_g1pt 10	2.974	0.003	2.977	1.989	0.000	0.057	2.046	2.418	0.008	0.252	0.298	2.977	81.238	8.459	9.726	0.283	0.000	0.277	0.017	100
JD10-07_g1pt 11	2.968	0.003	2.971	1.998	0.000	0.059	2.057	2.416	0.008	0.243	0.304	2.971	81.296	8.191	9.917	0.286	0.000	0.295	0.015	100
JD10-07_g1pt 12	2.978	0.004	2.982	1.992	0.000	0.044	2.036	2.421	0.008	0.249	0.303	2.982	81.205	8.361	9.927	0.266	0.000	0.219	0.022	100
JD10-07_g1pt 13	2.960	0.002	2.962	1.986	0.000	0.089	2.075	2.422	0.009	0.254	0.278	2.962	81.779	8.559	8.961	0.288	0.000	0.402	0.011	100
JD10-07_g1pt 14	2.969	0.003	2.972	1.989	0.000	0.066	2.056	2.440	0.007	0.244	0.281	2.972	82.112	8.219	9.122	0.228	0.000	0.305	0.015	100
JD10-07_g1pt 15	2.971	0.004	2.975	1.991	0.000	0.058	2.050	2.446	0.006	0.241	0.283	2.975	82.214	8.091	9.210	0.198	0.000	0.270	0.017	100
JD10-07_g1pt 16	2.971	0.004	2.975	1.982	0.000	0.068	2.050	2.547	0.010	0.162	0.256	2.975	85.624	5.453	8.298	0.323	0.000	0.285	0.016	100
JD10-07_g1pt 17	2.965	0.003	2.969	1.999	0.000	0.063	2.063	2.452	0.007	0.235	0.275	2.969	82.601	7.911	8.953	0.236	0.000	0.284	0.015	100
JD10-07_g1pt 18	2.951	0.002	2.953	2.008	0.000	0.086	2.095	2.421	0.007	0.242	0.283	2.953	81.992	8.193	9.167	0.245	0.000	0.395	0.008	100
JD10-07_g1pt 22	2.957	0.006	2.963	2.004	0.000	0.070	2.074	2.445	0.011	0.229	0.278	2.963	82.516	7.736	9.028	0.375	0.000	0.317	0.028	100
JD10-07_g1pt 23	2.967	0.004	2.972	1.991	0.000	0.066	2.057	2.458	0.010	0.206	0.298	2.972	82.707	6.947	9.682	0.323	0.000	0.321	0.020	100
JD10-07_g1pt 24	2.971	0.007	2.978	1.990	0.000	0.055	2.045	2.491	0.010	0.194	0.282	2.978	83.667	6.518	9.188	0.342	0.000	0.254	0.031	100
JD10-07_g1pt 25	2.960	0.005	2.964	1.995	0.000	0.077	2.071	2.461	0.013	0.180	0.310	2.964	83.029	6.087	10.038	0.438	0.000	0.386	0.023	100
JD10-07_g1pt 26	2.963	0.006	2.970	1.999	0.000	0.062	2.061	2.495	0.014	0.157	0.304	2.970	84.003	5.288	9.905	0.465	0.000	0.308	0.030	100
JD10-07_g1pt 27	2.969	0.006	2.975	1.995	0.000	0.055	2.050	2.523	0.017	0.150	0.285	2.975	84.810	5.046	9.291	0.570	0.000	0.256	0.028	100
JD10-07_g1pt 28	2.984	0.022	3.006	2.014	0.000	0.000	2.014	2.543	0.016	0.138	0.283	2.980	85.332	4.618	9.396	0.552	0.000	0.000	0.102	100
JD10-07_g1pt 29	2.956	0.005	2.961	2.004	0.000	0.075	2.078	2.511	0.021	0.140	0.289	2.961	84.814	4.737	9.374	0.703	0.000	0.350	0.021	100
JD10-07_g1pt 30	2.944	0.007	2.951	2.003	0.000	0.095	2.097	2.492	0.022	0.134	0.304	2.951	84.421	4.532	9.808	0.742	0.000	0.463	0.034	100
JD10-07_g1pt 31	2.958	0.005	2.964	1.995	0.000	0.078	2.073	2.495	0.025	0.123	0.321	2.964	84.179	4.141	10.414	0.834	0.000	0.406	0.027	100
JD10-07_g1pt 32	2.955	0.002	2.958	2.017	0.000	0.067	2.084	2.536	0.030	0.121	0.271	2.958	85.732	4.096	8.851	1.016	0.000	0.294	0.011	100
JD10-07_g1pt 33	2.968	0.010	2.978	2.002	0.000	0.042	2.044	2.533	0.033	0.116	0.296	2.978	85.055	3.891	9.694	1.109	0.000	0.203	0.048	100
JD10-07_g1pt 34	2.972	0.004	2.975	2.030	0.000	0.020	2.049	2.526	0.042	0.091	0.316	2.975	84.890	3.072	10.515	1.401	0.000	0.103	0.020	100
JD10-07_g1pt 35	2.956	0.007	2.962	2.002	0.000	0.074	2.076	2.517	0.046	0.114	0.286	2.962	84.963	3.856	9.271	1.537	0.000	0.342	0.030	100
JD10-07_g1pt 36	3.004	0.015	3.019	1.992	0.000	0.000	1.992	2.539	0.051	0.114	0.287	2.990	84.917	3.798	9.516	1.699	0.000	0.000	0.070	100
JD10-07_g1pt 37	2.731	0.265	2.996	1.876	0.000	0.131	2.008	2.579	0.060	0.089	0.268	2.996	86.066	2.971	7.393	2.008	0.000	0.518	1.044	100
JD10-07_g1pt 38	2.993	0.004	2.997	2.029	0.000	0.000	2.029	2.514	0.067	0.105	0.288	2.974	84.534	3.534	9.653	2.262	0.000	0.000	0.017	100
JD10-07_g1pt (Core)	2.930	0.009	2.939	2.016	0.000	0.106	2.122	2.455	0.085	0.098	0.301	2.939	83.527	3.327	9.699	2.894	0.000	0.509	0.045	100

Sample	Major Elements									Total
	SiO2	TiO2	Al2O3	Cr2O3	Fe2O3	FeO	MnO	MgO	CaO	
JD10-07_g2 pt 1(Rim)	36.570	0.016	21.050	0.000	1.297	35.530	0.174	2.020	3.463	100.12
JD10-07_g2 pt 2	33.246	0.034	20.356	0.000	7.754	28.347	0.225	1.924	6.073	97.96
JD10-07_g2 pt 3	36.528	0.053	20.823	0.000	1.522	35.757	0.225	1.953	3.325	100.19
JD10-07_g2 pt 6	37.374	0.038	21.001	0.000	0.270	36.937	0.228	1.676	3.566	101.09
JD10-07_g2 pt 7	36.269	0.053	20.966	0.000	1.993	36.363	0.351	1.428	3.241	100.66
JD10-07_g2 pt 8	36.423	0.061	20.887	0.000	1.454	36.104	0.345	1.312	3.759	100.34
JD10-07_g2 pt 9	36.202	0.089	20.678	0.000	1.434	36.809	0.373	0.966	3.481	100.03
JD10-07_g2 pt 11	36.333	0.074	20.844	0.000	1.490	36.920	0.432	1.152	3.201	100.45
JD10-07_g2 pt 12	34.963	0.071	20.588	0.000	3.577	34.519	0.442	1.536	3.252	98.95
JD10-07_g2 pt 13	36.666	0.067	20.852	0.000	1.359	36.135	0.546	1.261	3.878	100.76
JD10-07_g2 pt 14	36.470	0.107	20.818	0.000	1.542	35.277	0.678	1.211	4.358	100.46
JD10-07_g2 pt 15	36.354	0.032	20.758	0.000	1.317	35.718	1.022	1.055	3.798	100.05
JD10-07_g2 pt 16	36.642	0.089	20.722	0.000	1.005	35.621	0.952	1.138	4.122	100.29
JD10-07_g2 pt 17	36.391	0.059	20.772	0.000	1.865	34.141	1.135	1.116	4.908	100.39
JD10-07_g2 pt 18	36.171	0.059	20.772	0.000	1.564	35.579	1.784	1.006	3.220	100.16
JD10-07_g2 pt 19	36.406	0.104	20.788	0.000	1.439	34.970	1.901	0.896	4.007	100.51
JD10-07_g2 pt 20	36.458	0.068	20.738	0.000	1.255	35.531	1.730	0.938	3.669	100.39
JD10-07_g2 pt 21	36.213	0.050	20.715	0.000	1.510	35.122	2.216	0.928	3.377	100.13
JD10-07_g2 pt 22	36.281	0.061	20.932	0.000	1.416	35.314	2.330	0.800	3.386	100.52
JD10-07_g2 pt 23	36.363	0.026	20.792	0.000	1.408	35.514	2.067	0.879	3.380	100.43
JD10-07_g2 pt 24	38.815	0.099	19.841	0.000	0.000	35.439	1.533	1.610	4.273	101.61
JD10-07_g2 pt 25	36.514	0.071	20.763	0.000	1.447	36.108	1.412	1.057	3.359	100.73
JD10-07_g2 pt 30	36.256	0.120	20.773	0.000	1.704	36.314	1.113	0.994	3.316	100.59
JD10-07_g2 pt 31	36.493	0.148	20.781	0.000	1.123	36.984	1.115	0.957	3.084	100.68
JD10-07_g2 pt 32	36.251	0.124	20.659	0.000	1.627	36.611	1.014	0.968	3.197	100.45
JD10-07_g2 pt 33	36.277	0.148	20.687	0.000	1.372	36.479	0.935	0.940	3.442	100.28
JD10-07_g2 pt 34	36.295	0.169	20.724	0.000	1.656	36.725	0.802	1.001	3.302	100.67
JD10-07_g2 pt 35	36.541	0.089	20.807	0.000	1.605	36.516	0.597	0.993	3.812	100.96
JD10-07_g2 pt 36	36.506	0.075	20.603	0.000	1.599	37.435	0.551	1.030	3.037	100.84
JD10-07_g2 pt 37	36.191	0.097	20.763	0.000	2.271	36.840	0.449	1.085	3.227	100.92
JD10-07_g2 pt 38	36.326	0.160	20.863	0.000	1.751	36.771	0.411	1.093	3.470	100.84
JD10-07_g2 pt 39	36.308	0.110	20.738	0.000	1.543	37.054	0.342	1.100	3.242	100.44
JD10-07_g2 pt 40 (Core)	36.298	0.060	20.789	0.000	1.812	36.879	0.315	1.130	3.314	100.60

Sample	tetrahedral 4-fold			octahedral 6-fold			cubic 8-fold					Sum	almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-Ti Gt	Total
	Si	Ti	Sum	Al	Cr	Fe+3	Sum	Fe+2	Mn	Mg	Ca									
JD10-07_g2 pt 1 (Rim)	2.957	0.001	2.958	2.006	0.000	0.079	2.085	2.402	0.012	0.243	0.300	2.958	81.223	8.232	9.754	0.403	0.000	0.384	0.005	100
JD10-07_g2 pt 2	2.760	0.002	2.762	1.992	0.000	0.484	2.476	1.968	0.016	0.238	0.540	2.762	71.250	8.621	15.717	0.573	0.000	3.823	0.017	100
JD10-07_g2 pt 3	2.957	0.003	2.960	1.987	0.000	0.093	2.079	2.421	0.015	0.236	0.288	2.960	81.775	7.962	9.293	0.521	0.000	0.434	0.015	100
JD10-07_g2 pt 6	2.997	0.002	2.999	1.985	0.000	0.016	2.001	2.477	0.015	0.200	0.306	2.999	82.589	6.680	10.120	0.516	0.000	0.083	0.012	100
JD10-07_g2 pt 7	2.936	0.003	2.939	2.000	0.000	0.121	2.122	2.462	0.024	0.172	0.281	2.939	83.754	5.863	9.003	0.819	0.000	0.546	0.015	100
JD10-07_g2 pt 8	2.954	0.004	2.957	1.996	0.000	0.089	2.085	2.449	0.024	0.159	0.327	2.957	82.792	5.363	10.555	0.801	0.000	0.469	0.020	100
JD10-07_g2 pt 9	2.956	0.005	2.961	1.990	0.000	0.088	2.078	2.513	0.026	0.118	0.304	2.961	84.875	3.971	9.821	0.871	0.000	0.435	0.027	100
JD10-07_g2 pt 11	2.952	0.005	2.956	1.996	0.000	0.091	2.087	2.509	0.030	0.140	0.279	2.956	84.850	4.719	8.994	1.006	0.000	0.411	0.020	100
JD10-07_g2 pt 12	2.884	0.004	2.888	2.001	0.000	0.222	2.223	2.381	0.031	0.189	0.287	2.888	82.441	6.539	8.939	1.069	0.000	0.992	0.020	100
JD10-07_g2 pt 13	2.962	0.004	2.966	1.985	0.000	0.083	2.068	2.441	0.037	0.152	0.336	2.966	82.304	5.120	10.843	1.260	0.000	0.451	0.022	100
JD10-07_g2 pt 14	2.953	0.007	2.960	1.987	0.000	0.094	2.081	2.389	0.047	0.146	0.378	2.960	80.715	4.939	12.160	1.571	0.000	0.575	0.040	100
JD10-07_g2 pt 15	2.961	0.002	2.963	1.993	0.000	0.081	2.074	2.433	0.071	0.128	0.331	2.963	82.111	4.323	10.740	2.380	0.000	0.435	0.011	100
JD10-07_g2 pt 16	2.973	0.005	2.979	1.982	0.000	0.061	2.043	2.417	0.065	0.138	0.358	2.979	81.151	4.621	11.638	2.197	0.000	0.361	0.032	100
JD10-07_g2 pt 17	2.948	0.004	2.952	1.983	0.000	0.114	2.097	2.313	0.078	0.135	0.426	2.952	78.363	4.566	13.627	2.639	0.000	0.781	0.025	100
JD10-07_g2 pt 18	2.950	0.004	2.954	1.997	0.000	0.096	2.093	2.427	0.123	0.122	0.281	2.954	82.160	4.141	9.073	4.172	0.000	0.436	0.016	100
JD10-07_g2 pt 19	2.955	0.006	2.962	1.989	0.000	0.088	2.077	2.374	0.131	0.108	0.349	2.962	80.158	3.661	11.235	4.413	0.000	0.497	0.036	100
JD10-07_g2 pt 20	2.964	0.004	2.968	1.987	0.000	0.077	2.064	2.416	0.119	0.114	0.320	2.968	81.389	3.830	10.346	4.014	0.000	0.400	0.022	100
JD10-07_g2 pt 21	2.955	0.003	2.958	1.992	0.000	0.093	2.085	2.396	0.153	0.113	0.295	2.958	81.025	3.816	9.523	5.178	0.000	0.443	0.015	100
JD10-07_g2 pt 22	2.950	0.004	2.954	2.006	0.000	0.087	2.093	2.401	0.160	0.097	0.295	2.954	81.298	3.283	9.556	5.433	0.000	0.413	0.018	100
JD10-07_g2 pt 23	2.958	0.002	2.960	1.994	0.000	0.086	2.080	2.416	0.142	0.107	0.295	2.960	81.633	3.602	9.534	4.812	0.000	0.412	0.008	100
JD10-07_g2 pt 24	3.099	0.006	3.105	1.867	0.000	0.000	1.867	2.367	0.104	0.192	0.366	3.027	78.170	6.330	12.037	3.425	0.000	0.000	0.038	100
JD10-07_g2 pt 25	2.960	0.004	2.964	1.984	0.000	0.088	2.072	2.448	0.097	0.128	0.292	2.964	82.578	4.309	9.403	3.271	0.000	0.418	0.021	100
JD10-07_g2 pt 30	2.946	0.007	2.953	1.989	0.000	0.104	2.093	2.468	0.077	0.120	0.289	2.953	83.554	4.077	9.256	2.594	0.000	0.485	0.034	100
JD10-07_g2 pt 31	2.963	0.009	2.972	1.988	0.000	0.069	2.057	2.511	0.077	0.116	0.268	2.972	84.495	3.898	8.688	2.580	0.000	0.300	0.039	100
JD10-07_g2 pt 32	2.951	0.008	2.959	1.982	0.000	0.100	2.082	2.493	0.070	0.117	0.279	2.959	84.242	3.971	8.941	2.363	0.000	0.450	0.034	100
JD10-07_g2 pt 33	2.956	0.009	2.965	1.986	0.000	0.084	2.071	2.486	0.065	0.114	0.300	2.965	83.838	3.851	9.680	2.176	0.000	0.410	0.044	100
JD10-07_g2 pt 34	2.947	0.010	2.958	1.983	0.000	0.101	2.085	2.494	0.055	0.121	0.287	2.958	84.324	4.097	9.196	1.865	0.000	0.469	0.048	100
JD10-07_g2 pt 35	2.954	0.005	2.960	1.983	0.000	0.098	2.080	2.469	0.041	0.120	0.330	2.960	83.418	4.044	10.605	1.381	0.000	0.522	0.029	100
JD10-07_g2 pt 36	2.962	0.005	2.966	1.970	0.000	0.098	2.068	2.540	0.038	0.125	0.264	2.966	85.624	4.200	8.461	1.276	0.000	0.419	0.020	100
JD10-07_g2 pt 37	2.933	0.006	2.939	1.983	0.000	0.138	2.122	2.497	0.031	0.131	0.280	2.939	84.957	4.460	8.887	1.049	0.000	0.621	0.026	100
JD10-07_g2 pt 38	2.941	0.010	2.951	1.991	0.000	0.107	2.098	2.490	0.028	0.132	0.301	2.951	84.373	4.471	9.637	0.955	0.000	0.516	0.047	100
JD10-07_g2 pt 39	2.952	0.007	2.959	1.987	0.000	0.094	2.082	2.520	0.024	0.133	0.282	2.959	85.153	4.506	9.083	0.796	0.000	0.431	0.031	100
JD10-07_g2 pt 40 (Core)	2.947	0.004	2.950	1.989	0.000	0.111	2.100	2.504	0.022	0.137	0.288	2.950	84.861	4.635	9.239	0.734	0.000	0.514	0.017	100

Sample	Major Elements										Sum	
	SiO2	TiO2	Al2O3	Cr2O3	Fe2O3	FeO	MnO	MgO	CaO			
JD10-11g1point 1(Rim)	36.923	0.021	21.021	0.000	1.948	30.103	2.112	1.418	7.337	100.88		
JD10-11g1point 2	37.028	0.013	20.984	0.000	1.886	30.245	2.138	1.426	7.287	101.01		
JD10-11g1point 3	36.881	0.000	21.088	0.000	2.175	30.241	2.411	1.368	7.009	101.17		
JD10-11g1point 4	36.885	0.022	20.962	0.000	1.844	30.236	2.726	1.373	6.776	100.82		
JD10-11g1point 5	36.959	0.022	21.087	0.000	1.813	30.220	3.126	1.423	6.472	101.12		
JD10-11g1point 6	36.816	0.019	21.012	0.000	2.018	30.014	3.301	1.467	6.297	100.94		
JD10-11g1point 7	36.631	0.046	21.117	0.000	2.164	29.631	3.596	1.472	6.202	100.86		
JD10-11g1point 8	36.915	0.065	21.029	0.000	1.779	29.876	3.853	1.580	5.936	101.03		
JD10-11g1point 9	36.807	0.080	20.877	0.000	1.676	29.734	3.927	1.545	5.947	100.59		
JD10-11g1point 10	36.815	0.028	21.122	0.000	1.736	30.153	4.056	1.580	5.440	100.93		
JD10-11g1point 11	36.714	0.064	21.064	0.000	1.989	29.965	4.261	1.600	5.328	100.99		
JD10-11g1point 12	36.775	0.091	21.091	0.000	1.807	30.199	4.334	1.642	5.105	101.04		
JD10-11g1point 13	36.703	0.044	21.039	0.000	2.121	30.001	4.361	1.638	5.144	101.05		
JD10-11g1point 14	36.686	0.030	21.143	0.000	1.642	30.457	4.442	1.632	4.706	100.74		
JD10-11g1point 15	36.750	0.059	21.072	0.000	1.970	30.633	4.568	1.631	4.551	101.23		
JD10-11g1point 16	36.786	0.088	21.054	0.000	1.721	30.620	4.705	1.612	4.533	101.12		
JD10-11g1point 17	36.618	0.075	21.085	0.000	1.889	30.128	4.687	1.509	4.909	100.90		
JD10-11g1point 18	36.666	0.088	20.926	0.000	1.439	30.696	4.788	1.505	4.445	100.55		
JD10-11g1point 19	36.632	0.125	20.827	0.000	1.450	30.688	4.990	1.491	4.305	100.51		
JD10-11g1point 20	36.485	0.148	20.804	0.000	1.749	30.796	4.912	1.506	4.141	100.54		
JD10-11g1point 21	36.611	0.087	21.118	0.000	1.652	31.044	4.616	1.480	4.292	100.90		
JD10-11g1point 22	36.604	0.118	20.903	0.000	1.672	31.799	3.525	1.465	4.601	100.69		
JD10-11g1point 23	36.744	0.140	20.716	0.000	1.602	29.480	4.374	1.339	6.062	100.46		
JD10-11g1point 24	36.938	0.117	20.858	0.000	1.280	30.637	4.822	1.431	4.841	100.92		
JD10-11g1point 25	36.755	0.072	20.586	0.000	1.247	30.980	5.178	1.425	4.098	100.34		
JD10-11g1point 26	36.807	0.108	21.027	0.000	1.311	31.134	5.141	1.432	4.071	101.03		
JD10-11g1point 27	36.781	0.046	20.932	0.000	1.386	29.435	4.976	1.231	5.740	100.53		
JD10-11g1point 28	36.533	0.094	20.830	0.000	1.286	30.287	4.942	1.284	4.830	100.09		
JD10-11g1point 29	36.555	0.163	20.842	0.000	1.328	30.484	5.024	1.374	4.555	100.33		
JD10-11g1point 30	36.423	0.080	20.925	0.000	1.853	30.335	5.172	1.382	4.362	100.53		
JD10-11g1point 31	36.407	0.125	20.829	0.000	1.674	30.820	4.549	1.413	4.449	100.27		
JD10-11g1point 32	36.368	0.078	20.984	0.000	1.666	30.465	5.364	1.371	4.071	100.37		
JD10-11g1point 33	36.372	0.113	21.010	0.000	1.966	29.920	5.810	1.291	4.284	100.77		
JD10-11g1point 34	36.517	0.055	20.939	0.000	1.264	30.321	5.866	1.294	4.017	100.27		
JD10-11g1point 35	36.646	0.084	20.909	0.000	1.387	30.349	5.956	1.257	4.116	100.70		
JD10-11g1point 36	36.583	0.059	20.884	0.000	1.293	30.498	6.015	1.215	3.935	100.48		
JD10-11g1point 37	36.441	0.138	20.718	0.000	1.573	29.722	5.870	1.168	4.644	100.27		
JD10-11g1point 38	36.393	0.077	20.765	0.000	1.772	29.874	6.007	1.176	4.318	100.38		
JD10-11g1point 39	36.674	0.077	20.650	0.000	1.100	30.126	5.934	1.126	4.511	100.20		
JD10-11g1point 40	36.396	0.074	20.769	0.000	1.312	30.317	6.225	1.129	3.866	100.09		
JD10-11g1point 41	36.439	0.058	20.902	0.000	1.514	29.980	6.245	1.100	4.183	100.42		
JD10-11g1point 42	36.448	0.080	20.759	0.000	1.559	30.075	6.383	1.082	4.048	100.43		
JD10-11g1point 43	36.363	0.087	20.733	0.000	1.445	30.040	6.402	1.159	3.879	100.11		
JD10-11g1point 44	36.435	0.056	20.796	0.000	1.644	29.805	6.292	1.155	4.200	100.38		
JD10-11g1point 45	36.509	0.078	20.761	0.000	1.455	30.167	6.396	1.248	3.791	100.40		
JD10-11g1point 46	36.478	0.078	20.703	0.000	1.333	29.906	6.517	1.285	3.818	100.12		
JD10-11g1point 47	36.494	0.092	20.813	0.000	1.312	30.106	6.638	1.307	3.561	100.32		
JD10-11g1point 48	36.522	0.117	20.709	0.000	1.455	30.114	6.532	1.456	3.475	100.38		
JD10-11g1point 49	36.385	0.069	20.919	0.000	1.527	29.990	6.594	1.417	3.415	100.32		
JD10-11g1point 50	36.637	0.072	20.790	0.000	1.419	30.149	6.546	1.397	3.594	100.60		
JD10-11g1point 51	35.544	1.269	20.159	0.000	1.179	30.419	6.292	1.372	3.439	99.67		
JD10-11g1point 52	36.471	0.098	20.715	0.000	1.734	29.790	6.470	1.461	3.709	100.45		
JD10-11g1point 53	36.647	0.114	20.800	0.000	1.094	30.398	6.324	1.597	3.336	100.31		
JD10-11g1point 54	36.432	0.061	20.720	0.000	1.432	30.109	6.579	1.245	3.612	100.19		
JD10-11g1point 55	36.372	0.080	20.775	0.000	1.345	29.911	6.497	1.356	3.634	99.97		
JD10-11g1point 56	36.538	0.063	20.909	0.000	1.073	30.276	6.459	1.469	3.365	100.15		
JD10-11g1point 57	36.340	0.065	20.770	0.000	1.658	29.655	6.384	1.381	3.848	100.10		
JD10-11g1point 58	36.374	0.075	20.786	0.000	1.841	29.517	6.494	1.285	4.041	100.41		
JD10-11g1point 59	36.436	0.094	20.598	0.000	1.523	29.544	6.413	1.254	4.198	100.06		
JD10-11g1point 60 (Core)	36.518	0.059	20.775	0.000	1.456	29.921	6.600	1.198	3.886	100.41		

Sample	tetrahedral 4-fold			octahedral 6-fold			cubic 8-fold					almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-Ti	Gt	total	
	Si	Ti	Sum	Al	Cr	Fe+3	Sum	Fe+2	Mn	Mg	Ca										
JD10-11 g1 point1 (Rm)	2.950	0.001		2.952	1.980	0.000	0.117	2.097	2.012	0.143	0.169	0.628	2.952	68.153	5.723	20.080	4.843	0.000	1.188	0.013	100
JD10-11 g1 point 2	2.956	0.001		2.956	1.974	0.000	0.113	2.087	2.019	0.145	0.170	0.623	2.956	68.292	5.740	19.928	4.889	0.000	1.143	0.008	100
JD10-11 g1 point 3	2.943	0.000		2.943	1.983	0.000	0.131	2.114	2.018	0.163	0.163	0.599	2.943	68.572	5.530	19.103	5.537	0.000	1.258	0.000	100
JD10-11 g1 point 4	2.954	0.001		2.955	1.978	0.000	0.111	2.090	2.025	0.185	0.164	0.581	2.955	68.523	5.547	18.616	6.257	0.000	1.046	0.012	100
JD10-11 g1 point 5	2.952	0.001		2.953	1.985	0.000	0.109	2.094	2.018	0.211	0.169	0.554	2.953	68.349	5.737	17.766	7.161	0.000	0.975	0.012	100
JD10-11 g1 point 6	2.947	0.001		2.948	1.982	0.000	0.122	2.104	2.009	0.224	0.175	0.540	2.948	68.152	5.938	17.251	7.591	0.000	1.058	0.010	100
JD10-11 g1 point 7	2.935	0.003		2.938	1.994	0.000	0.130	2.125	1.985	0.244	0.176	0.532	2.938	67.585	5.985	16.988	8.307	0.000	1.112	0.024	100
JD10-11 g1 point 8	2.952	0.004		2.956	1.982	0.000	0.107	2.089	1.998	0.261	0.188	0.509	2.956	67.593	6.372	16.293	8.829	0.000	0.880	0.032	100
JD10-11 g1 point 9	2.956	0.005		2.961	1.976	0.000	0.101	2.078	1.997	0.267	0.185	0.512	2.961	67.448	6.247	16.402	9.022	0.000	0.841	0.040	100
JD10-11 g1 point 10	2.949	0.002		2.951	1.994	0.000	0.105	2.099	2.020	0.275	0.189	0.467	2.951	68.457	6.394	15.022	9.326	0.000	0.788	0.013	100
JD10-11 g1 point 11	2.942	0.004		2.945	1.989	0.000	0.120	2.109	2.008	0.289	0.191	0.457	2.945	68.166	6.488	14.618	9.817	0.000	0.882	0.028	100
JD10-11 g1 point 12	2.945	0.005		2.950	1.990	0.000	0.109	2.099	2.022	0.294	0.196	0.438	2.950	68.547	6.644	14.039	9.964	0.000	0.768	0.039	100
JD10-11 g1 point 13	2.940	0.003		2.943	1.986	0.000	0.128	2.114	2.010	0.296	0.196	0.442	2.943	68.295	6.647	14.078	10.055	0.000	0.906	0.019	100
JD10-11 g1 point 14	2.948	0.002		2.949	2.002	0.000	0.099	2.101	2.046	0.302	0.195	0.405	2.949	69.388	6.628	13.075	10.249	0.000	0.648	0.012	100
JD10-11 g1 point 15	2.943	0.004		2.946	1.989	0.000	0.119	2.107	2.051	0.310	0.195	0.390	2.946	69.624	6.608	12.485	10.516	0.000	0.745	0.022	100
JD10-11 g1 point 16	2.948	0.005		2.954	1.989	0.000	0.104	2.093	2.052	0.319	0.193	0.389	2.954	69.486	6.521	12.493	10.814	0.000	0.652	0.033	100
JD10-11 g1 point 17	2.941	0.005		2.945	1.996	0.000	0.114	2.110	2.023	0.319	0.181	0.422	2.945	68.700	6.134	13.536	10.825	0.000	0.774	0.031	100
JD10-11 g1 point 18	2.957	0.005		2.962	1.989	0.000	0.087	2.076	2.070	0.327	0.181	0.384	2.962	69.886	6.108	12.388	11.041	0.000	0.544	0.033	100
JD10-11 g1 point 19	2.957	0.008		2.965	1.982	0.000	0.088	2.070	2.072	0.341	0.179	0.372	2.965	69.880	6.052	11.981	11.508	0.000	0.533	0.046	100
JD10-11 g1 point 20	2.947	0.009		2.956	1.981	0.000	0.106	2.087	2.081	0.336	0.181	0.358	2.956	70.373	6.135	11.457	11.369	0.000	0.615	0.052	100
JD10-11 g1 point 21	2.944	0.005		2.949	2.001	0.000	0.100	2.101	2.088	0.314	0.177	0.370	2.949	70.786	6.016	11.912	10.660	0.000	0.595	0.031	100
JD10-11 g1 point 22	2.950	0.007		2.957	1.985	0.000	0.101	2.087	2.143	0.241	0.176	0.397	2.957	72.476	5.952	12.738	8.137	0.000	0.651	0.046	100
JD10-11 g1 point 23	2.960	0.008		2.968	1.967	0.000	0.097	2.064	1.986	0.298	0.161	0.523	2.968	66.903	5.417	16.728	10.054	0.000	0.826	0.072	100
JD10-11 g1 point 24	2.967	0.007		2.974	1.975	0.000	0.077	2.052	2.058	0.328	0.171	0.417	2.974	69.199	5.762	13.434	11.031	0.000	0.526	0.048	100
JD10-11 g1 point 25	2.976	0.004		2.980	1.964	0.000	0.076	2.040	2.097	0.355	0.172	0.355	2.980	70.386	5.771	11.459	11.915	0.000	0.443	0.026	100
JD10-11 g1 point 26	2.958	0.007		2.965	1.992	0.000	0.079	2.071	2.093	0.350	0.172	0.351	2.965	70.584	5.787	11.336	11.804	0.000	0.451	0.037	100
JD10-11 g1 point 27	2.962	0.003		2.965	1.987	0.000	0.084	2.071	1.982	0.339	0.148	0.495	2.965	66.863	4.985	16.005	11.448	0.000	0.677	0.022	100
JD10-11 g1 point 28	2.960	0.006		2.966	1.989	0.000	0.078	2.068	2.052	0.339	0.155	0.419	2.966	69.197	5.229	13.564	11.436	0.000	0.535	0.039	100
JD10-11 g1 point 29	2.956	0.010		2.966	1.987	0.000	0.081	2.067	2.062	0.344	0.166	0.395	2.966	69.507	5.585	12.725	11.602	0.000	0.518	0.063	100
JD10-11 g1 point 30	2.943	0.005		2.947	1.992	0.000	0.113	2.105	2.050	0.354	0.166	0.378	2.947	69.535	5.647	12.097	12.007	0.000	0.684	0.030	100
JD10-11 g1 point 31	2.948	0.008		2.955	1.988	0.000	0.102	2.090	2.087	0.312	0.171	0.386	2.955	70.614	5.771	12.377	10.556	0.000	0.635	0.047	100
JD10-11 g1 point 32	2.944	0.005		2.948	2.002	0.000	0.101	2.103	2.062	0.368	0.165	0.353	2.948	69.943	5.611	11.371	12.473	0.000	0.576	0.027	100
JD10-11 g1 point 33	2.935	0.007		2.941	1.998	0.000	0.119	2.117	2.019	0.397	0.155	0.370	2.941	68.633	5.279	11.842	13.498	0.000	0.708	0.041	100
JD10-11 g1 point 34	2.958	0.003		2.962	1.999	0.000	0.077	2.076	2.054	0.403	0.156	0.349	2.962	69.360	5.277	11.317	13.591	0.000	0.436	0.019	100
JD10-11 g1 point 35	2.958	0.005		2.963	1.989	0.000	0.084	2.073	2.049	0.407	0.151	0.356	2.963	69.140	5.105	11.497	13.743	0.000	0.487	0.029	100
JD10-11 g1 point 36	2.961	0.004		2.965	1.992	0.000	0.079	2.071	2.064	0.412	0.147	0.341	2.965	69.635	4.945	11.054	13.910	0.000	0.437	0.020	100
JD10-11 g1 point 37	2.954	0.008		2.962	1.979	0.000	0.096	2.075	2.015	0.403	0.141	0.403	2.962	68.015	4.765	12.933	13.605	0.000	0.627	0.055	100
JD10-11 g1 point 38	2.950	0.005		2.954	1.983	0.000	0.108	2.092	2.025	0.412	0.142	0.375	2.954	68.540	4.810	12.009	13.958	0.000	0.654	0.028	100
JD10-11 g1 point 39	2.975	0.005		2.979	1.974	0.000	0.067	2.041	2.044	0.408	0.136	0.392	2.979	68.589	4.570	12.696	13.683	0.000	0.432	0.030	100
JD10-11 g1 point 40	2.960	0.005		2.964	1.991	0.000	0.080	2.071	2.062	0.429	0.137	0.337	2.964	69.555	4.617	10.899	14.465	0.000	0.440	0.025	100
JD10-11 g1 point 41	2.952	0.004		2.956	1.996	0.000	0.092	2.088	2.031	0.429	0.133	0.363	2.956	68.722	4.495	11.722	14.499	0.000	0.542	0.021	100
JD10-11 g1 point 42	2.956	0.005		2.960	1.984	0.000	0.095	2.079	2.040	0.438	0.131	0.352	2.960	68.893	4.418	11.310	14.809	0.000	0.542	0.028	100
JD10-11 g1 point 43	2.957	0.005		2.962	1.987	0.000	0.088	2.075	2.043	0.441	0.141	0.338	2.962	68.963	4.743	10.895	14.885	0.000	0.485	0.029	100
JD10-11 g1 point 44	2.953	0.003		2.957	1.987	0.000	0.100	2.087	2.020	0.432	0.140	0.365	2.957	68.333	4.720	11.724	14.610	0.000	0.592	0.020	100
JD10-11 g1 point 45	2.959	0.005		2.964	1.983	0.000	0.089	2.072	2.045	0.439	0.151	0.329	2.964	68.990	5.088	10.607	14.815	0.000	0.475	0.025	100
JD10-11 g1 point 46	2.963	0.005		2.968	1.982	0.000	0.081	2.064	2.032	0.448	0.156	0.332	2.968	68.453	5.243	10.729	15.108	0.000	0.441	0.026	100
JD10-11 g1 point 47	2.960	0.006		2.965	1.989	0.000	0.080	2.069	2.042	0.456	0.158	0.309	2.965	68.859	5.329	10.004	15.377	0.000	0.403	0.028	100
JD10-11 g1 point 48	2.960	0.007		2.967	1.978	0.000	0.089	2.067	2.041	0.448	0.176	0.302	2.967	68.789	5.929	9.700	15.112	0.000	0.435	0.035	100
JD10-11 g1 point 49	2.950	0.004		2.954	1.999	0.000	0.093	2.092	2.033	0.453	0.171	0.297	2.954	68.833	5.797	9.575	15.328	0.000	0.446	0.020	100
JD10-11 g1 point 50	2.962	0.004		2.966	1.981	0.000	0.086	2.067	2.038	0.448	0.168	0.311	2.966	68.718	5.676	10.035	15.111	0.000	0.437	0.022	100
JD10-11 g1 point 51	2.912	0.078		2.990	1.947	0.000	0.073	2.019	2.084	0.437	0.168	0.302	2.990	69.699	5.604	9.369	14.602	0.000	0.350	0.376	100
JD10-11 g1 point 52	2.953	0.006		2.959	1.977	0.000	0.106	2.082	2.017	0.444	0.176	0.322	2.959	68.170	5.960	10.293	14.996	0.000	0.550	0.031	100
JD10-11 g1 point 53	2.967	0.007		2.974	1.985	0.000	0.067	2.052	2.058	0.434</											

Sample	Major Elements									Sum	
	SiO2	TiO2	Al2O3	Cr2O3	Fe2O3	FeO	MnO	MgO	CaO		
JD10-11 g2 point 1 (rim)	36.690		0.016	21.013	0.000	1.778	29.950	2.344	1.380	7.105	100.28
JD10-11 g2 point 2	36.938		0.001	20.972	0.000	1.291	30.190	3.026	1.451	6.501	100.37
JD10-11 g2 point 3	36.761		0.055	20.862	0.000	1.316	30.274	3.939	1.531	5.475	100.21
JD10-11 g2 point 4	36.657		0.076	20.893	0.000	1.656	30.593	3.962	1.601	5.028	100.47
JD10-11 g2 point 5	36.627		0.143	20.853	0.000	1.277	31.248	3.806	1.557	4.720	100.23
JD10-11 g2 point 6	36.578		0.057	20.961	0.000	1.493	31.321	3.754	1.456	4.739	100.36
JD10-11 g2 point 7	36.672		0.076	20.883	0.000	1.459	30.799	4.183	1.551	4.776	100.40
JD10-11 g2 point 8	36.455		0.071	20.822	0.000	1.623	30.623	4.176	1.590	4.659	100.02
JD10-11 g2 point 9	36.598		0.051	20.859	0.000	1.475	30.745	4.301	1.611	4.555	100.19
JD10-11 g2 point 10	36.640		0.050	20.876	0.000	1.476	32.318	3.131	1.562	4.359	100.41
JD10-11 g2 point 11	36.619		0.061	20.753	0.000	1.117	33.467	2.352	1.203	4.565	100.14
JD10-11 g2 point 13	36.702		0.055	20.718	0.000	1.157	32.747	2.325	1.330	5.045	100.08
JD10-11 g2 point 15	36.376		0.097	20.826	0.000	1.862	31.943	2.386	0.986	5.828	100.30
JD10-11 g2 point 16	36.768		0.115	20.605	0.000	1.518	31.437	2.433	1.258	6.186	100.32
JD10-11 g2 point 17	36.793		0.049	20.739	0.000	0.888	33.472	2.680	1.331	4.278	100.23
JD10-11 g2 point 31	36.652		0.080	20.755	0.000	1.293	33.100	2.488	1.227	4.755	100.35
JD10-11 g2 point 32	36.595		0.099	20.811	0.000	1.655	31.621	2.817	1.424	5.335	100.36
JD10-11 g2 point 33	36.726		0.076	20.713	0.000	1.473	31.312	3.607	1.503	4.948	100.36
JD10-11 g2 point 34	36.686		0.098	20.798	0.000	1.361	30.920	4.214	1.534	4.709	100.32
JD10-11 g2 point 35	36.703		0.082	20.810	0.000	1.319	30.544	4.716	1.537	4.606	100.32
JD10-11 g2 point 36	36.717		0.079	20.793	0.000	1.453	30.512	4.717	1.525	4.658	100.45
JD10-11 g2 point 37	36.775		0.090	20.633	0.000	1.307	31.249	4.142	1.541	4.577	100.31
JD10-11 g2 point 38	36.922		0.030	20.817	0.000	1.113	32.067	3.566	1.534	4.499	100.55
JD10-11 g2 point 39	37.050		0.216	20.483	0.000	0.430	33.008	3.129	1.475	4.442	100.23
JD10-11 g2 point 40	37.070		0.133	20.566	0.000	0.824	32.743	3.320	1.472	4.462	100.59
JD10-11 g2 point 41	36.509		0.181	20.893	0.000	1.504	31.742	3.812	1.514	4.306	100.46
JD10-11 g2 point 42	36.617		0.384	20.606	0.000	1.428	29.726	4.197	1.406	5.969	100.33
JD10-11 g2 point 43	36.521		0.172	20.761	0.000	0.569	31.067	4.597	1.484	4.259	99.43
JD10-11 g2 point 44	36.678		0.116	20.608	0.000	1.571	30.364	4.838	1.525	4.668	100.37
JD10-11 g2 point 45	36.568		0.081	20.902	0.000	1.621	30.758	4.623	1.545	4.375	100.47
JD10-11 g2 point 46	36.613		0.374	20.679	0.000	1.104	31.394	4.011	1.496	4.678	100.35
JD10-11 g2 point 47	36.786		0.135	20.580	0.000	1.293	31.465	4.348	1.510	4.331	100.45
JD10-11 g2 point 48	36.570		0.125	20.617	0.000	1.472	30.528	4.874	1.451	4.520	100.16
JD10-11 g2 point 49	36.599		0.088	20.918	0.000	1.479	30.754	4.906	1.433	4.344	100.52
JD10-11 g2 point 50 (core)	36.479		0.072	20.772	0.000	1.852	30.544	4.880	1.469	4.355	100.42

Sample	tetrahedral 4-fold			octahedral 6-fold			cubic 8-fold				Sum	almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-Ti Gt	total	
	Si	Ti	Sum	Al	Cr	Fe+3	Sum	Fe+2	Mn	Mg										Ca
JD10-11 g2 point 1 (rim)	2.950	0.001	2.951	1.991	0.000	0.108	2.099	2.014	0.160	0.165	0.612	2.951	68.244	5.605	19.669	5.409	0.000	1.063	0.010	100
JD10-11 g2 point 2	2.968	0.000	2.968	1.986	0.000	0.078	2.064	2.029	0.206	0.174	0.560	2.968	68.349	5.856	18.143	6.939	0.000	0.713	0.001	100
JD10-11 g2 point 3	2.965	0.003	2.968	1.983	0.000	0.080	2.063	2.042	0.269	0.184	0.473	2.968	68.794	6.202	15.297	9.066	0.000	0.616	0.026	100
JD10-11 g2 point 4	2.953	0.005	2.958	1.984	0.000	0.100	2.084	2.061	0.270	0.192	0.434	2.958	69.686	6.501	13.935	9.140	0.000	0.705	0.032	100
JD10-11 g2 point 5	2.960	0.009	2.968	1.986	0.000	0.078	2.063	2.112	0.260	0.188	0.409	2.968	71.139	6.319	13.193	8.776	0.000	0.516	0.058	100
JD10-11 g2 point 6	2.954	0.003	2.957	1.995	0.000	0.091	2.086	2.115	0.257	0.175	0.410	2.957	71.525	5.927	13.240	8.683	0.000	0.602	0.023	100
JD10-11 g2 point 7	2.958	0.005	2.963	1.985	0.000	0.089	2.074	2.078	0.286	0.187	0.413	2.963	70.127	6.295	13.307	9.646	0.000	0.594	0.031	100
JD10-11 g2 point 8	2.952	0.004	2.957	1.987	0.000	0.099	2.086	2.074	0.286	0.192	0.404	2.957	70.146	6.493	12.998	9.688	0.000	0.647	0.028	100
JD10-11 g2 point 9	2.958	0.003	2.962	1.987	0.000	0.090	2.077	2.078	0.294	0.194	0.395	2.962	70.180	6.555	12.726	9.944	0.000	0.575	0.020	100
JD10-11 g2 point 10	2.959	0.003	2.962	1.987	0.000	0.090	2.076	2.182	0.214	0.188	0.377	2.962	73.687	6.349	12.165	7.230	0.000	0.549	0.019	100
JD10-11 g2 point 11	2.970	0.004	2.974	1.984	0.000	0.068	2.052	2.270	0.162	0.145	0.397	2.974	76.336	4.891	12.873	5.433	0.000	0.442	0.024	100
JD10-11 g2 point 13	2.973	0.003	2.976	1.978	0.000	0.070	2.048	2.218	0.159	0.161	0.438	2.976	74.533	5.396	14.181	5.360	0.000	0.506	0.024	100
JD10-11 g2 point 15	2.944	0.006	2.950	1.987	0.000	0.113	2.100	2.162	0.164	0.119	0.505	2.950	73.291	4.033	16.161	5.545	0.000	0.923	0.048	100
JD10-11 g2 point 16	2.967	0.007	2.974	1.960	0.000	0.092	2.052	2.122	0.166	0.151	0.535	2.974	71.336	5.089	17.118	5.592	0.000	0.805	0.061	100
JD10-11 g2 point 17	2.980	0.003	2.983	1.980	0.000	0.054	2.034	2.267	0.184	0.161	0.371	2.983	76.004	5.387	12.096	6.163	0.000	0.331	0.018	100
JD10-11 g2 point 31	2.966	0.005	2.971	1.980	0.000	0.079	2.058	2.240	0.171	0.148	0.412	2.971	75.400	4.982	13.315	5.740	0.000	0.529	0.033	100
JD10-11 g2 point 32	2.954	0.006	2.960	1.980	0.000	0.101	2.080	2.135	0.193	0.171	0.461	2.960	72.116	5.789	14.792	6.507	0.000	0.751	0.045	100
JD10-11 g2 point 33	2.965	0.005	2.970	1.971	0.000	0.090	2.060	2.114	0.247	0.181	0.428	2.970	71.190	6.091	13.756	8.306	0.000	0.625	0.032	100
JD10-11 g2 point 34	2.963	0.006	2.969	1.980	0.000	0.083	2.062	2.088	0.288	0.185	0.407	2.969	70.344	6.221	13.137	9.710	0.000	0.549	0.039	100
JD10-11 g2 point 35	2.964	0.005	2.969	1.981	0.000	0.080	2.061	2.063	0.323	0.185	0.399	2.969	69.480	6.232	12.870	10.865	0.000	0.521	0.032	100
JD10-11 g2 point 36	2.962	0.005	2.967	1.977	0.000	0.088	2.065	2.059	0.322	0.183	0.403	2.967	69.384	6.182	12.960	10.864	0.000	0.578	0.031	100
JD10-11 g2 point 37	2.972	0.005	2.978	1.965	0.000	0.079	2.045	2.112	0.284	0.186	0.396	2.978	70.932	6.235	12.759	9.522	0.000	0.516	0.036	100
JD10-11 g2 point 38	2.976	0.002	2.978	1.977	0.000	0.067	2.045	2.161	0.243	0.184	0.388	2.978	72.587	6.190	12.606	8.176	0.000	0.430	0.012	100
JD10-11 g2 point 39	2.997	0.013	3.010	1.953	0.000	0.026	1.979	2.233	0.214	0.178	0.385	3.010	74.180	5.909	12.537	7.122	0.000	0.168	0.084	100
JD10-11 g2 point 40	2.990	0.008	2.998	1.955	0.000	0.050	2.005	2.208	0.227	0.177	0.386	2.998	73.669	5.904	12.490	7.565	0.000	0.320	0.052	100
JD10-11 g2 point 41	2.949	0.011	2.960	1.989	0.000	0.091	2.080	2.144	0.261	0.182	0.373	2.960	72.440	6.159	11.973	8.811	0.000	0.550	0.066	100
JD10-11 g2 point 42	2.954	0.023	2.977	1.959	0.000	0.087	2.046	2.005	0.287	0.169	0.516	2.977	67.360	5.679	16.408	9.632	0.000	0.726	0.195	100
JD10-11 g2 point 43	2.975	0.011	2.986	1.993	0.000	0.035	2.028	2.117	0.317	0.180	0.372	2.986	70.889	6.036	12.173	10.624	0.000	0.213	0.064	100
JD10-11 g2 point 44	2.964	0.007	2.971	1.963	0.000	0.096	2.058	2.052	0.331	0.184	0.404	2.971	69.067	6.184	12.928	11.146	0.000	0.629	0.046	100
JD10-11 g2 point 45	2.952	0.005	2.957	1.988	0.000	0.098	2.087	2.076	0.316	0.186	0.378	2.957	70.225	6.288	12.165	10.690	0.000	0.603	0.030	100
JD10-11 g2 point 46	2.959	0.023	2.982	1.970	0.000	0.067	2.037	2.122	0.275	0.180	0.405	2.982	71.162	6.045	12.992	9.208	0.000	0.443	0.150	100
JD10-11 g2 point 47	2.973	0.008	2.981	1.960	0.000	0.079	2.039	2.126	0.298	0.182	0.375	2.981	71.334	6.102	12.046	9.984	0.000	0.483	0.050	100
JD10-11 g2 point 48	2.963	0.008	2.971	1.969	0.000	0.090	2.059	2.069	0.334	0.175	0.392	2.971	69.632	5.900	12.586	11.260	0.000	0.574	0.049	100
JD10-11 g2 point 49	2.955	0.005	2.960	1.990	0.000	0.090	2.080	2.076	0.335	0.172	0.376	2.960	70.146	5.826	12.114	11.333	0.000	0.547	0.033	100
JD10-11 g2 point 50 (core)	2.950	0.004	2.954	1.979	0.000	0.113	2.092	2.065	0.334	0.177	0.377	2.954	69.920	5.994	12.059	11.314	0.000	0.687	0.027	100

Sample	Major Elements										Total	
	SiO2	TiO2	Al2O3	Cr2O3	Fe2O3	FeO	MnO	MgO	CaO			
JD10-11 g3 point 1 (rim)	36.728	0.024	20.794	0.000	1.567	29.169	2.099	0.996	8.484		99.86	
JD10-11 g3 point 2	36.710	0.063	20.929	0.000	1.640	29.940	2.924	1.225	6.922		100.35	
JD10-11 g3 point 3	36.739	0.069	20.828	0.000	1.655	29.930	3.133	1.282	6.716		100.35	
JD10-11 g3 point 4	36.516	0.031	20.774	0.000	1.850	31.094	3.651	1.359	5.056		100.33	
JD10-11 g3 point 5	36.484	0.085	20.776	0.000	1.664	30.964	4.014	1.395	4.829		100.21	
JD10-11 g3 point 6	36.543	0.069	20.659	0.000	1.578	31.305	3.884	1.323	4.809		100.17	
JD10-11 g3 point 7	36.424	0.081	20.718	0.000	1.916	31.228	4.021	1.357	4.611		100.36	
JD10-11 g3 point 8	36.386	0.089	20.787	0.000	1.869	30.893	4.496	1.376	4.441		100.34	
JD10-11 g3 point 9	36.444	0.141	20.578	0.000	1.369	30.898	4.647	1.318	4.489		99.88	
JD10-11 g3 point 10	36.436	0.092	20.708	0.000	1.745	30.486	4.836	1.357	4.565		100.22	
JD10-11 g3 point 11	36.382	0.089	20.742	0.000	1.716	30.527	5.159	1.349	4.236		100.20	
JD10-11 g3 point 12	36.547	0.062	20.825	0.000	1.602	30.346	5.253	1.325	4.472		100.43	
JD10-11 g3 point 13	36.423	0.111	20.747	0.000	2.032	29.552	5.407	1.339	4.869		100.48	
JD10-11 g3 point 14	36.471	0.240	20.705	0.000	1.951	29.431	5.540	1.312	5.031		100.68	
JD10-11 g3 point 15	36.479	0.142	20.760	0.000	2.082	29.085	5.369	1.227	5.493		100.64	
JD10-11 g3 point 16	36.566	0.134	21.030	0.000	1.690	30.111	5.722	1.326	4.351		100.93	
JD10-11 g3 point 17	36.513	0.101	20.823	0.000	1.969	29.246	5.777	1.176	5.119		100.72	
JD10-11 g3 point 18	36.474	0.139	20.941	0.000	1.858	29.521	6.002	1.373	4.443		100.75	
JD10-11 g3 point 19	36.369	0.096	20.825	0.000	1.872	29.422	6.059	1.334	4.401		100.38	
JD10-11 g3 point 20	36.376	0.073	20.887	0.000	1.987	29.655	6.066	1.269	4.294		100.61	
JD10-11 g3 point 21	36.560	0.127	20.770	0.000	1.928	29.393	6.066	1.254	4.729		100.83	
JD10-11 g3 point 22	36.458	0.393	20.741	0.000	1.698	29.699	6.187	1.301	4.421		100.90	
JD10-11 g3 point 23	36.505	0.216	20.847	0.000	1.919	29.670	6.314	1.249	4.335		101.06	
JD10-11 g3 point 24	36.548	0.183	20.761	0.000	2.032	29.385	6.302	1.282	4.538		101.03	
JD10-11 g3 point 25	36.589	0.116	20.780	0.000	1.670	29.560	6.123	1.191	4.661		100.69	
JD10-11 g3 point 26	36.555	0.128	20.921	0.000	1.557	30.002	6.444	1.203	4.022		100.83	
JD10-11 g3 point 27	36.584	0.124	20.788	0.000	1.398	30.145	6.371	1.200	3.997		100.61	
JD10-11 g3 point 28	36.416	0.117	20.844	0.000	1.983	29.471	6.295	1.274	4.318		100.72	
JD10-11 g3 point 29	36.488	0.269	20.769	0.000	1.763	30.033	6.154	1.282	4.154		100.91	
JD10-11 g3 point 30	36.461	0.215	20.763	0.000	2.004	29.979	5.760	1.287	4.437		100.91	
JD10-11 g3 point 31	36.468	0.135	20.694	0.000	1.882	29.984	5.821	1.312	4.301		100.60	
JD10-11 g3 point 32	36.516	0.171	20.822	0.000	1.711	30.441	5.205	1.252	4.585		100.70	
JD10-11 g3 point 33	36.597	0.162	20.745	0.000	1.701	30.553	5.198	1.344	4.444		100.74	
JD10-11 g3 point 34	36.701	0.182	20.807	0.000	1.321	30.802	5.481	1.336	4.148		100.78	
JD10-11 g3 point 35	36.685	0.154	20.824	0.000	1.612	30.448	5.443	1.381	4.357		100.90	
JD10-11 g3 point 36	36.746	0.151	20.650	0.000	1.778	29.944	5.275	1.392	4.923		100.86	
JD10-11 g3 point 37	36.611	0.210	20.630	0.000	1.745	30.819	5.037	1.375	4.367		100.79	
JD10-11 g3 point 38	36.542	0.139	20.702	0.000	1.967	30.751	5.019	1.393	4.295		100.81	
JD10-11 g3 point 39	36.509	0.213	20.854	0.000	1.819	30.814	4.701	1.354	4.573		100.84	
JD10-11 g3 point 40	36.727	0.069	20.981	0.000	1.521	30.947	4.553	1.424	4.591		100.81	

Sample	tetrahedral 4-fold			octahedral 6-fold				cubic 8-fold														
	Si	Ti	Sum	Al	Cr	Fe+3	Sum	Fe+2	Mn	Mg	Ca	Sum	almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-Ti	Gt	total	
JD10-11 g3 point 1 (rim)	2.963	0.001		2.964	1.977	0.000	0.095	2.072	1.968	0.143	0.120	0.733	2.964	66.384	4.041	23.585	4.838	0.000	1.135	0.017	100	
JD10-11 g3 point 2	2.954	0.004		2.958	1.985	0.000	0.099	2.084	2.015	0.199	0.147	0.597	2.958	68.118	4.968	19.180	6.738	0.000	0.959	0.037	100	
JD10-11 g3 point 3	2.958	0.004		2.962	1.976	0.000	0.100	2.076	2.015	0.214	0.154	0.579	2.962	68.034	5.195	18.576	7.213	0.000	0.943	0.039	100	
JD10-11 g3 point 4	2.952	0.002		2.954	1.979	0.000	0.113	2.092	2.102	0.250	0.164	0.438	2.954	71.167	5.545	14.015	8.463	0.000	0.797	0.013	100	
JD10-11 g3 point 5	2.953	0.005		2.958	1.982	0.000	0.101	2.083	2.096	0.275	0.168	0.419	2.958	70.851	5.690	13.434	9.303	0.000	0.687	0.035	100	
JD10-11 g3 point 6	2.961	0.004		2.965	1.973	0.000	0.096	2.069	2.121	0.267	0.160	0.418	2.965	71.541	5.389	13.398	8.990	0.000	0.653	0.029	100	
JD10-11 g3 point 7	2.948	0.005		2.953	1.977	0.000	0.117	2.093	2.114	0.276	0.164	0.400	2.953	71.580	5.545	12.756	9.335	0.000	0.753	0.032	100	
JD10-11 g3 point 8	2.946	0.005		2.951	1.983	0.000	0.114	2.097	2.092	0.308	0.166	0.385	2.951	70.873	5.627	12.312	10.447	0.000	0.707	0.034	100	
JD10-11 g3 point 9	2.963	0.009		2.972	1.972	0.000	0.084	2.056	2.101	0.320	0.160	0.391	2.972	70.697	5.376	12.570	10.769	0.000	0.534	0.055	100	
JD10-11 g3 point 10	2.952	0.006		2.958	1.978	0.000	0.106	2.084	2.066	0.332	0.164	0.396	2.958	69.840	5.542	12.680	11.221	0.000	0.682	0.036	100	
JD10-11 g3 point 11	2.951	0.005		2.956	1.983	0.000	0.105	2.087	2.071	0.354	0.163	0.368	2.956	70.042	5.517	11.796	11.989	0.000	0.623	0.032	100	
JD10-11 g3 point 12	2.955	0.004		2.959	1.985	0.000	0.097	2.082	2.052	0.360	0.160	0.387	2.959	69.350	5.398	12.458	12.159	0.000	0.612	0.024	100	
JD10-11 g3 point 13	2.943	0.007		2.950	1.976	0.000	0.124	2.100	1.997	0.370	0.161	0.422	2.950	67.697	5.468	13.406	12.545	0.000	0.838	0.046	100	
JD10-11 g3 point 14	2.942	0.015		2.957	1.968	0.000	0.118	2.087	1.985	0.379	0.158	0.435	2.957	67.154	5.336	13.776	12.803	0.000	0.829	0.102	100	
JD10-11 g3 point 15	2.942	0.009		2.950	1.973	0.000	0.126	2.099	1.961	0.367	0.148	0.475	2.950	66.484	5.000	15.056	12.430	0.000	0.964	0.066	100	
JD10-11 g3 point 16	2.943	0.008		2.951	1.995	0.000	0.102	2.097	2.027	0.390	0.159	0.375	2.951	68.677	5.391	12.047	13.218	0.000	0.618	0.049	100	
JD10-11 g3 point 17	2.945	0.006		2.951	1.979	0.000	0.120	2.099	1.972	0.395	0.141	0.442	2.951	66.846	4.791	14.095	13.373	0.000	0.851	0.044	100	
JD10-11 g3 point 18	2.940	0.008		2.949	1.990	0.000	0.113	2.102	1.990	0.410	0.165	0.384	2.949	67.492	5.596	12.267	13.898	0.000	0.695	0.052	100	
JD10-11 g3 point 19	2.944	0.006		2.950	1.987	0.000	0.114	2.101	1.992	0.415	0.161	0.382	2.950	67.520	5.457	12.203	14.083	0.000	0.700	0.036	100	
JD10-11 g3 point 20	2.940	0.004		2.945	1.990	0.000	0.121	2.111	2.005	0.415	0.153	0.372	2.945	68.076	5.193	11.880	14.103	0.000	0.721	0.026	100	
JD10-11 g3 point 21	2.947	0.008		2.955	1.973	0.000	0.117	2.090	1.982	0.414	0.151	0.408	2.955	67.061	5.100	13.001	14.017	0.000	0.770	0.051	100	
JD10-11 g3 point 22	2.939	0.024		2.963	1.971	0.000	0.103	2.074	2.002	0.422	0.156	0.382	2.963	67.577	5.277	12.108	14.258	0.000	0.633	0.146	100	
JD10-11 g3 point 23	2.940	0.013		2.953	1.978	0.000	0.116	2.095	1.998	0.431	0.150	0.374	2.953	67.670	5.078	11.889	14.585	0.000	0.699	0.079	100	
JD10-11 g3 point 24	2.942	0.011		2.953	1.970	0.000	0.123	2.093	1.978	0.430	0.154	0.391	2.953	66.987	5.210	12.408	14.550	0.000	0.776	0.070	100	
JD10-11 g3 point 25	2.954	0.007		2.961	1.977	0.000	0.101	2.079	1.996	0.419	0.143	0.403	2.961	67.402	4.841	12.908	14.141	0.000	0.662	0.046	100	
JD10-11 g3 point 26	2.950	0.008		2.958	1.990	0.000	0.095	2.084	2.025	0.440	0.145	0.348	2.958	68.458	4.893	11.182	14.892	0.000	0.531	0.044	100	
JD10-11 g3 point 27	2.959	0.008		2.967	1.982	0.000	0.085	2.067	2.039	0.436	0.145	0.346	2.967	68.734	4.877	11.154	14.713	0.000	0.479	0.042	100	
JD10-11 g3 point 28	2.941	0.007		2.948	1.984	0.000	0.121	2.104	1.990	0.431	0.153	0.374	2.948	67.517	5.203	11.908	14.606	0.000	0.723	0.043	100	
JD10-11 g3 point 29	2.943	0.016		2.959	1.974	0.000	0.107	2.081	2.026	0.420	0.154	0.359	2.959	68.454	5.209	11.417	14.207	0.000	0.619	0.094	100	
JD10-11 g3 point 30	2.940	0.013		2.953	1.973	0.000	0.122	2.095	2.021	0.393	0.155	0.383	2.953	68.459	5.239	12.151	13.322	0.000	0.749	0.080	100	
JD10-11 g3 point 31	2.949	0.008		2.957	1.972	0.000	0.114	2.086	2.027	0.399	0.158	0.373	2.957	68.568	5.348	11.863	13.482	0.000	0.689	0.049	100	
JD10-11 g3 point 32	2.947	0.010		2.958	1.981	0.000	0.104	2.085	2.055	0.356	0.151	0.396	2.958	69.470	5.093	12.674	12.031	0.000	0.665	0.066	100	
JD10-11 g3 point 33	2.952	0.010		2.962	1.972	0.000	0.103	2.076	2.061	0.355	0.162	0.384	2.962	69.586	5.457	12.264	11.990	0.000	0.642	0.061	100	
JD10-11 g3 point 34	2.960	0.011		2.971	1.978	0.000	0.080	2.058	2.078	0.374	0.161	0.358	2.971	69.927	5.407	11.532	12.602	0.000	0.468	0.064	100	
JD10-11 g3 point 35	2.954	0.009		2.963	1.976	0.000	0.098	2.074	2.050	0.371	0.166	0.376	2.963	69.193	5.594	12.033	12.528	0.000	0.595	0.057	100	
JD10-11 g3 point 36	2.958	0.009		2.967	1.959	0.000	0.108	2.067	2.016	0.360	0.167	0.425	2.967	67.939	5.630	13.504	12.122	0.000	0.742	0.063	100	
JD10-11 g3 point 37	2.954	0.013		2.966	1.961	0.000	0.106	2.067	2.079	0.344	0.165	0.377	2.966	70.097	5.575	11.999	11.603	0.000	0.648	0.078	100	
JD10-11 g3 point 38	2.948	0.008		2.956	1.968	0.000	0.119	2.088	2.075	0.343	0.168	0.371	2.956	70.176	5.667	11.791	11.600	0.000	0.715	0.051	100	
JD10-11 g3 point 39	2.942	0.013		2.955	1.980	0.000	0.110	2.091	2.076	0.321	0.163	0.395	2.955	70.275	5.505	12.579	10.859	0.000	0.701	0.082	100	
JD10-11 g3 Line 040 (rim)	2.955	0.004		2.959	1.990	0.000	0.092	2.082	2.082	0.310	0.171	0.396	2.959	70.369	5.772	12.757	10.485	0.000	0.591	0.027	100	

Sample	Major Elements										Total
	SiO2	TiO2	Al2O3	Cr2O3	Fe2O3	FeO	MnO	MgO	CaO		
DS-18-garn01-01	36.154	0.062	20.394	0.000	1.805	29.657	6.055	10.18	4.436	99.58	
DS-18-garn01-02	36.109	0.075	20.313	0.003	1.911	30.457	6.179	10.45	3.643	99.73	
DS-18-garn01-03	35.994	0.081	20.391	0.008	1.990	29.734	6.999	0.922	3.627	99.75	
DS-18-garn01-04	36.083	0.202	20.164	0.044	1.099	29.411	7.188	0.906	3.920	99.02	
DS-18-garn01-05	36.099	0.164	20.024	0.000	2.137	28.644	7.575	0.804	4.343	99.79	
DS-18-garn01-06	35.756	0.115	20.083	0.039	2.440	28.138	7.446	0.677	4.662	99.36	
DS-18-garn01-07	35.915	0.084	20.049	0.000	1.885	28.341	6.915	0.813	4.861	98.86	
DS-18-garn01-08	35.864	0.114	20.271	0.000	2.565	28.520	6.314	0.907	5.039	99.59	
DS-18-garn01-09	35.922	0.062	20.256	0.000	1.981	29.945	5.568	0.804	4.677	99.22	
DS-18-garn01-10	36.103	0.100	20.338	0.021	2.040	29.338	5.629	0.922	5.134	99.63	
DS-18-garn01-11	36.113	0.059	20.400	0.000	1.584	29.497	5.461	0.907	5.144	99.17	
DS-18-garn01-12	35.994	0.027	20.573	0.010	1.997	29.479	5.453	0.908	5.030	99.47	
DS-18-garn01-13	35.991	0.095	20.428	0.020	2.498	29.594	4.770	0.934	5.489	99.82	
DS-18-garn01-14	35.762	0.018	20.386	0.018	2.490	29.857	4.120	0.997	5.442	99.09	
DS-18-garn01-15	35.960	0.025	20.506	0.010	2.332	31.187	3.526	1.054	4.984	99.58	
Sample	SiO2	TiO2	Al2O3	Cr2O3	Fe2O3	FeO	MnO	MgO	CaO	Total	
DS-18-garn02-01	36.073	0.117	20.230	0.009	2.133	28.548	6.322	0.892	5.229	99.55	
DS-18-garn02-02	36.106	0.100	20.403	0.034	2.399	28.388	6.312	0.901	5.368	100.01	
DS-18-garn02-03	36.020	0.094	20.342	0.000	2.341	28.228	6.491	0.857	5.328	99.70	
DS-18-garn02-04	36.073	0.091	20.398	0.000	2.619	28.446	6.356	0.849	5.323	100.16	
DS-18-garn02-05	35.951	0.067	20.497	0.000	2.037	28.646	6.089	0.881	5.203	99.37	
DS-18-garn02-06	36.140	0.057	20.483	0.013	2.122	29.424	5.773	0.937	4.937	99.89	
DS-18-garn02-07	35.366	0.059	20.447	0.000	2.808	28.337	5.494	0.909	5.324	98.74	
DS-18-garn02-08	35.799	0.048	20.203	0.003	2.755	28.754	5.346	0.883	5.548	99.34	
DS-18-garn02-09	35.851	0.003	20.495	0.044	2.214	30.086	4.520	0.973	5.053	99.24	
DS-18-garn02-10	35.829	0.016	20.438	0.000	2.536	30.602	3.681	1.133	5.079	99.31	
Sample	SiO2	TiO2	Al2O3	Cr2O3	Fe2O3	FeO	MnO	MgO	CaO	Total	
DS-18-garn03-01	35.922	0.075	20.203	0.026	2.717	26.906	8.255	0.774	4.976	99.85	
DS-18-garn03-02	35.690	0.108	20.246	0.000	3.285	25.767	8.366	0.761	5.602	99.83	
DS-18-garn03-03	36.024	0.084	20.246	0.000	2.322	26.825	8.229	0.722	5.234	99.69	
DS-18-garn03-04	35.687	0.106	20.270	0.010	2.221	27.098	7.548	0.727	5.253	98.92	
DS-18-garn03-05	36.109	0.149	20.300	0.000	2.138	28.049	7.127	0.803	5.162	99.84	
DS-18-garn03-06	35.692	0.151	20.392	0.005	2.695	27.585	6.688	0.855	5.411	99.47	
DS-18-garn03-07	35.961	0.094	20.376	0.000	2.310	28.541	6.152	0.849	5.308	99.59	
DS-18-garn03-08	35.936	0.055	20.601	0.070	2.613	29.201	5.306	0.923	5.308	100.01	
DS-18-garn03-09	36.334	0.043	20.455	0.019	2.095	30.458	4.237	1.004	5.422	100.07	
DS-18-garn03-10	36.172	0.000	20.667	0.049	2.253	31.275	3.346	1.125	5.139	100.03	

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Sample	Major Elements										Total	
	SiO2	TiO2	Al2O3	Cr2O3	Fe2O3	FeO	MnO	MgO	CaO			
DS-18-garn04-01	35.966	0.089	20.524	0.000	2.709	31.275	5.368	1.029	3.544	100.50		
DS-18-garn04-02	35.871	0.118	20.518	0.000	2.344	31.382	5.483	1.112	3.186	100.01		
DS-18-garn04-03	36.083	0.092	20.319	0.000	2.385	32.089	5.418	0.938	3.107	100.43		
DS-18-garn04-04	35.803	0.131	20.523	0.023	2.606	31.477	5.471	1.061	3.138	100.23		
DS-18-garn04-05	35.762	0.204	20.402	0.013	2.798	31.184	5.489	1.045	3.388	100.28		
DS-18-garn04-06	35.680	0.128	20.464	0.000	2.862	31.080	5.473	1.116	3.253	100.06		
DS-18-garn04-07	35.941	0.092	19.747	0.009	3.576	31.006	5.480	1.485	3.010	100.35		
DS-18-garn04-08	35.990	0.095	20.562	0.010	2.337	31.667	5.371	0.979	3.332	100.34		
DS-18-garn04-09	36.152	0.052	20.378	0.017	2.355	32.014	5.536	0.989	3.038	100.53		
DS-18-garn04-10	35.910	0.078	20.139	0.023	2.645	31.678	5.603	0.845	3.240	100.16		
DS-18-garn04-11	36.056	0.111	20.503	0.036	2.174	31.469	5.501	0.811	3.690	100.35		
DS-18-garn04-12	35.975	0.095	20.510	0.000	2.805	30.447	5.238	0.914	4.466	100.45		
DS-18-garn04-13	36.268	0.070	20.585	0.000	2.268	30.241	5.022	0.869	5.116	100.44		
DS-18-garn04-14	36.224	0.104	20.673	0.000	2.389	30.403	4.589	0.937	5.220	100.54		
DS-18-garn04-15	36.113	0.010	20.822	0.010	2.705	30.778	3.637	1.143	5.224	100.44		
Sample	Major Elements										Total	
	SiO2	TiO2	Al2O3	Cr2O3	Fe2O3	FeO	MnO	MgO	CaO			
DS-18-garn05-01	36.101	0.098	20.580	0.000	2.732	31.733	5.132	1.102	3.404	100.88		
DS-18-garn05-02	36.109	0.106	20.354	0.032	2.454	32.103	4.959	1.100	3.268	100.48		
DS-18-garn05-03	36.337	0.102	20.517	0.004	2.247	32.701	4.991	1.013	3.107	101.02		
DS-18-garn05-04	35.989	0.129	20.539	0.000	2.799	31.781	5.058	1.124	3.312	100.73		
DS-18-garn05-05	36.144	0.121	20.412	0.000	2.394	32.042	5.070	1.135	3.222	100.54		
DS-18-garn05-06	36.095	0.129	20.401	0.000	2.237	32.094	5.135	1.096	3.144	100.33		
DS-18-garn05-07	36.237	0.115	20.599	0.019	2.080	32.459	5.091	1.099	3.013	100.71		
DS-18-garn05-08	35.894	0.117	20.377	0.001	2.319	31.932	5.056	1.123	3.100	99.92		
DS-18-garn05-09	35.899	0.072	20.563	0.008	2.602	31.893	5.004	1.094	3.185	100.32		
DS-18-garn05-10	35.929	0.065	20.410	0.004	2.267	31.941	4.899	1.046	3.320	99.88		
DS-18-garn05-11	36.036	0.069	20.613	0.000	2.182	32.493	4.679	1.022	3.199	100.29		
DS-18-garn05-12	36.150	0.100	20.502	0.033	2.381	32.366	4.828	1.082	3.225	100.67		
DS-18-garn05-13	36.180	0.033	20.624	0.036	2.485	31.399	4.365	0.949	4.512	100.58		
DS-18-garn05-14	36.010	0.064	20.522	0.004	2.429	30.863	4.037	0.976	5.015	99.92		
DS-18-garn05-15	36.410	0.064	20.676	0.047	2.103	31.159	3.635	1.053	5.368	100.52		
Sample	Major Elements										Total	
	SiO2	TiO2	Al2O3	Cr2O3	MnO	Fe2O3	FeO	MgO	CaO			
DS-18-garn06-01	36.184	0.078	20.566	0.003	2.479	30.906	4.938	0.965	4.457	100.58		
DS-18-garn06-02	36.135	0.060	20.280	0.013	2.530	31.330	4.720	1.101	4.051	100.22		
DS-18-garn06-03	36.116	0.066	20.505	0.000	2.319	31.075	5.077	0.961	4.149	100.27		
DS-18-garn06-04	36.107	0.057	20.609	0.050	1.991	31.209	4.872	1.022	4.107	100.02		
DS-18-garn06-05	36.029	0.086	20.543	0.000	2.360	31.314	4.816	1.001	4.046	100.19		
DS-18-garn06-06	36.095	0.096	20.375	0.045	2.244	31.000	5.173	0.971	4.119	100.12		
DS-18-garn06-07	36.128	0.083	20.426	0.018	2.775	30.730	5.209	1.034	4.235	100.64		
DS-18-garn06-08	36.141	0.142	20.571	0.023	1.965	31.271	4.938	0.932	4.223	100.21		
DS-18-garn06-09	36.300	0.085	20.586	0.028	1.823	31.471	5.013	0.957	4.081	100.34		
DS-18-garn06-10	36.102	0.063	20.600	0.045	2.503	31.157	4.879	0.947	4.246	100.54		
DS-18-garn06-11	36.244	0.094	20.561	0.069	2.146	31.245	4.641	0.936	4.535	100.47		
DS-18-garn06-12	36.315	0.078	20.575	0.056	2.359	31.277	4.535	0.841	4.781	100.82		
DS-18-garn06-13	36.386	0.059	20.327	0.031	2.203	31.295	4.040	0.982	5.015	100.34		
DS-18-garn06-14	36.331	0.008	20.846	0.001	2.483	31.751	3.049	1.108	5.180	100.76		
DS-18-garn06-15	36.300	0.044	20.476	0.000	1.973	31.796	3.059	1.156	5.066	99.87		

Sample	tetrahedral 4-fold			Sum	octahedral 6-fold			Sum	cubic 8-fold				Sum	almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-Ti Gt	total
	Si	Ti			Al	Cr	Fe+3		Fe+2	Mn	Mg	Ca									
DS-18-garn04-01	2.927	0.005		2.933	1.969	0.000	0.166	2.135	2.129	0.370	0.125	0.309	2.933	72.587	4.257	9.694	12.618	0.000	0.817	0.027	100
DS-18-garn04-02	2.932	0.007		2.940	1.977	0.000	0.144	2.121	2.145	0.380	0.136	0.279	2.940	72.983	4.610	8.817	12.915	0.000	0.643	0.032	100
DS-18-garn04-03	2.944	0.006		2.950	1.954	0.000	0.146	2.100	2.190	0.374	0.114	0.272	2.950	74.230	3.868	8.543	12.694	0.000	0.640	0.025	100
DS-18-garn04-04	2.924	0.008		2.932	1.975	0.001	0.160	2.137	2.150	0.378	0.129	0.275	2.932	73.322	4.406	8.624	12.907	0.006	0.699	0.035	100
DS-18-garn04-05	2.920	0.013		2.932	1.963	0.001	0.172	2.136	2.129	0.380	0.127	0.296	2.932	72.611	4.338	9.235	12.945	0.004	0.809	0.059	100
DS-18-garn04-06	2.918	0.008		2.926	1.972	0.000	0.176	2.148	2.126	0.379	0.136	0.285	2.926	72.650	4.650	8.911	12.957	0.000	0.796	0.036	100
DS-18-garn04-07	2.934	0.006		2.940	1.900	0.001	0.220	2.120	2.117	0.379	0.181	0.263	2.940	72.007	6.148	8.004	12.890	0.002	0.926	0.024	100
DS-18-garn04-08	2.934	0.006		2.940	1.976	0.001	0.143	2.120	2.159	0.371	0.119	0.291	2.940	73.438	4.047	9.202	12.615	0.003	0.668	0.027	100
DS-18-garn04-09	2.946	0.003		2.949	1.957	0.001	0.144	2.102	2.181	0.382	0.120	0.265	2.949	73.976	4.074	8.359	12.956	0.005	0.617	0.014	100
DS-18-garn04-10	2.941	0.005		2.946	1.944	0.001	0.163	2.108	2.170	0.389	0.103	0.284	2.946	73.652	3.502	8.878	13.194	0.007	0.745	0.022	100
DS-18-garn04-11	2.940	0.007		2.947	1.970	0.002	0.133	2.106	2.146	0.380	0.099	0.322	2.947	72.822	3.345	10.202	12.893	0.012	0.691	0.035	100
DS-18-garn04-12	2.926	0.006		2.931	1.966	0.000	0.172	2.137	2.071	0.361	0.111	0.389	2.931	70.638	3.780	12.175	12.308	0.000	1.063	0.036	100
DS-18-garn04-13	2.942	0.004		2.947	1.968	0.000	0.138	2.107	2.052	0.345	0.105	0.445	2.947	69.630	3.567	14.071	11.711	0.000	0.990	0.031	100
DS-18-garn04-14	2.934	0.006		2.940	1.974	0.000	0.146	2.119	2.059	0.315	0.113	0.453	2.940	70.039	3.848	14.305	10.707	0.000	1.056	0.046	100
DS-18-garn04-15	2.923	0.001		2.924	1.987	0.001	0.165	2.152	2.084	0.249	0.138	0.453	2.924	71.259	4.717	14.300	8.529	0.005	1.186	0.004	100
Sample	tetrahedral 4-fold			Sum	octahedral 6-fold			Sum	cubic 8-fold				Sum	almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-Ti Gt	total
Si	Ti		Al		Cr	Fe+3	Fe+2		Mn	Mg	Ca										
DS-18-garn05-01	2.927	0.006		2.933	1.967	0.000	0.167	2.133	2.152	0.352	0.133	0.296	2.933	73.361	4.541	9.268	12.016	0.000	0.785	0.028	100
DS-18-garn05-02	2.941	0.006		2.947	1.954	0.002	0.150	2.106	2.186	0.342	0.134	0.285	2.947	74.187	4.531	8.947	11.607	0.009	0.689	0.030	100
DS-18-garn05-03	2.945	0.006		2.951	1.960	0.000	0.137	2.097	2.217	0.343	0.122	0.270	2.951	75.102	4.147	8.518	11.609	0.001	0.596	0.027	100
DS-18-garn05-04	2.923	0.008		2.931	1.966	0.000	0.171	2.137	2.159	0.348	0.136	0.288	2.931	73.651	4.643	9.013	11.872	0.000	0.784	0.036	100
DS-18-garn05-05	2.941	0.007		2.948	1.957	0.000	0.147	2.104	2.180	0.349	0.138	0.281	2.948	73.952	4.670	8.832	11.851	0.000	0.661	0.033	100
DS-18-garn05-06	2.943	0.008		2.951	1.961	0.000	0.137	2.098	2.189	0.355	0.133	0.275	2.951	74.161	4.514	8.666	12.017	0.000	0.607	0.035	100
DS-18-garn05-07	2.943	0.007		2.950	1.972	0.001	0.127	2.100	2.205	0.350	0.133	0.262	2.950	74.731	4.510	8.316	11.871	0.005	0.536	0.030	100
DS-18-garn05-08	2.938	0.007		2.946	1.966	0.000	0.143	2.109	2.186	0.351	0.137	0.272	2.946	74.215	4.653	8.576	11.902	0.000	0.623	0.031	100
DS-18-garn05-09	2.927	0.004		2.932	1.976	0.001	0.160	2.136	2.175	0.346	0.133	0.278	2.932	74.184	4.536	8.762	11.789	0.002	0.708	0.020	100
DS-18-garn05-10	2.941	0.004		2.945	1.969	0.000	0.140	2.109	2.187	0.340	0.128	0.291	2.945	74.246	4.334	9.214	11.533	0.001	0.653	0.019	100
DS-18-garn05-11	2.938	0.004		2.943	1.981	0.000	0.134	2.115	2.216	0.323	0.124	0.279	2.943	75.299	4.222	8.878	10.982	0.000	0.600	0.019	100
DS-18-garn05-12	2.938	0.006		2.944	1.964	0.002	0.146	2.112	2.200	0.332	0.131	0.281	2.944	74.720	4.453	8.845	11.289	0.010	0.656	0.028	100
DS-18-garn05-13	2.935	0.002		2.937	1.972	0.002	0.152	2.126	2.130	0.300	0.115	0.392	2.937	72.528	3.908	12.373	10.212	0.014	0.952	0.013	100
DS-18-garn05-14	2.936	0.004		2.940	1.972	0.000	0.149	2.121	2.104	0.279	0.119	0.438	2.940	71.581	4.035	13.827	9.483	0.002	1.045	0.028	100
DS-18-garn05-15	2.945	0.004		2.949	1.971	0.003	0.128	2.102	2.108	0.249	0.127	0.465	2.949	71.474	4.306	14.765	8.445	0.023	0.959	0.029	100
Sample	tetrahedral 4-fold			Sum	octahedral 6-fold			Sum	cubic 8-fold				Sum	almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-Ti Gt	total
Si	Ti		Al		Cr	Fe+3	Fe+2		Mn	Mg	Ca										
DS-18-garn06-01	2.936	0.005		2.941	1.967	0.000	0.151	2.118	2.097	0.339	0.117	0.387	2.941	71.314	3.969	12.206	11.540	0.001	0.940	0.030	100.000
DS-18-garn06-02	2.945	0.004		2.948	1.948	0.001	0.155	2.104	2.135	0.326	0.134	0.354	2.948	72.417	4.537	11.088	11.050	0.005	0.883	0.021	100.000
DS-18-garn06-03	2.941	0.004		2.945	1.968	0.000	0.142	2.110	2.116	0.350	0.117	0.362	2.945	71.857	3.961	11.442	11.890	0.000	0.826	0.023	100.000
DS-18-garn06-04	2.944	0.003		2.947	1.980	0.003	0.122	2.106	2.128	0.336	0.124	0.359	2.947	72.198	4.215	11.429	11.415	0.019	0.705	0.020	100.000
DS-18-garn06-05	2.936	0.005		2.941	1.973	0.000	0.145	2.118	2.134	0.332	0.122	0.353	2.941	72.554	4.134	11.162	11.302	0.000	0.819	0.030	100.000
DS-18-garn06-06	2.944	0.006		2.950	1.959	0.003	0.138	2.099	2.115	0.357	0.118	0.360	2.950	71.681	4.002	11.353	12.115	0.017	0.798	0.034	100.000
DS-18-garn06-07	2.933	0.005		2.938	1.954	0.001	0.169	2.125	2.086	0.358	0.125	0.368	2.938	71.012	4.259	11.503	12.191	0.007	0.998	0.030	100.000
DS-18-garn06-08	2.943	0.009		2.952	1.974	0.001	0.120	2.096	2.130	0.341	0.113	0.368	2.952	72.146	3.833	11.708	11.539	0.009	0.714	0.052	100.000
DS-18-garn06-09	2.952	0.005		2.957	1.973	0.002	0.112	2.086	2.140	0.345	0.116	0.356	2.957	72.376	3.923	11.343	11.677	0.010	0.641	0.030	100.000
DS-18-garn06-10	2.932	0.004		2.936	1.972	0.003	0.153	2.128	2.116	0.336	0.115	0.369	2.936	72.078	3.905	11.642	11.432	0.017	0.903	0.023	100.000
DS-18-garn06-11	2.943	0.006		2.948	1.967	0.004	0.131	2.103	2.122	0.319	0.113	0.395	2.948	71.953	3.842	12.483	10.825	0.028	0.832	0.036	100.000
DS-18-garn06-12	2.940	0.005		2.945	1.963	0.004	0.144	2.110	2.118	0.311	0.102	0.415	2.945	71.910	3.447	13.071	10.560	0.024	0.957	0.032	100.000
DS-18-garn06-13	2.955	0.004		2.959	1.946	0.002	0.135	2.082	2.126	0.278	0.119	0.436	2.959	71.840	4.018	13.758	9.393	0.014	0.952	0.025	100.000
DS-18-garn06-14	2.933	0.000		2.933	1.983	0.000	0.151	2.134	2.143	0.208	0.133	0.448	2.933	73.074	4.546	14.190	7.107	0.000	1.079	0.003	100.000
DS-18-garn06-15	0.003	0.003		1.964	0.000	0.121	2.085	2.164	0.211	0.140	0.442	2.957	73.187	4.743	14.055	7.131	0.000	0.865	0.019	100.000	

Sample	Major Elements											Total
	SiO2	TiO2	Al2O3	Cr2O3	MnO	Fe2O3	FeO	MgO	CaO			
JD10_90_grt_1Line 001	36.359	0.051	21.088	0.000	1.202	36.200	0.095	1.626	3.378			100.00
JD10_90_grt_1Line 003	37.332	0.041	21.117	0.000	0.000	36.951	0.127	1.366	3.685			100.62
JD10_90_grt_1Line 004	37.162	0.035	21.214	0.000	0.143	37.365	0.100	1.544	3.317			100.88
JD10_90_grt_1Line 005	36.968	0.056	20.972	0.000	0.341	37.256	0.080	1.636	3.124			100.43
JD10_90_grt_1Line 008	36.885	0.055	21.103	0.000	0.744	37.087	0.105	1.587	3.226			100.79
JD10_90_grt_1Line 009	36.561	0.045	20.909	0.000	0.997	36.732	0.095	1.587	3.201			100.13
JD10_90_grt_1Line 011	36.534	0.075	21.182	0.000	1.187	36.805	0.138	1.476	3.261			100.66
JD10_90_grt_1Line 012	36.622	0.086	21.101	0.000	0.667	37.039	0.172	1.555	3.031			100.27
JD10_90_grt_1Line 015	36.503	0.098	21.294	0.000	1.247	36.460	0.245	1.340	3.622			100.81
JD10_90_grt_1Line 016	36.562	0.069	21.111	0.000	0.850	37.111	0.259	1.392	3.065			100.42
JD10_90_grt_1Line 018	36.638	0.019	21.123	0.000	0.756	37.251	0.333	1.400	2.922			100.44
JD10_90_grt_1Line 019	36.709	0.037	21.095	0.000	0.764	36.889	0.387	1.358	3.299			100.54
JD10_90_grt_1Line 022	36.564	0.069	21.283	0.000	0.962	36.662	0.697	1.250	3.269			100.76
JD10_90_grt_1Line 023	36.404	0.060	21.175	0.000	1.448	36.436	0.815	1.245	3.203			100.79
JD10_90_grt_1Line 029	36.617	0.063	21.068	0.000	0.571	36.631	1.117	1.120	3.187			100.37
JD10_90_grt_1Line 031	36.893	0.095	20.986	0.000	0.408	36.524	1.137	1.119	3.536			100.70
JD10_90_grt_1Line 033	36.624	0.042	21.008	0.000	1.187	36.753	1.141	1.183	2.977			100.91
JD10_90_grt_1Line 035	36.860	0.012	21.097	0.000	0.563	36.791	1.238	1.173	3.084			100.82
JD10_90_grt_1Line 037	36.333	0.030	21.071	0.000	0.863	36.541	1.262	1.170	2.785			100.05
JD10_90_grt_1Line 044	36.515	0.052	21.261	0.000	0.701	37.025	0.902	1.221	2.806			100.48
JD10_90_grt_1Line 046	36.757	0.018	20.983	0.000	0.625	37.233	0.715	1.240	2.967			100.54
JD10_90_grt_1Line 049	36.613	0.085	21.152	0.000	0.752	37.365	0.561	1.292	2.826			100.65
JD10_90_grt_1Line 053	36.960	0.049	20.874	0.000	0.000	36.786	0.437	1.120	3.639			99.87
JD10_90_grt_1Line 055	36.322	0.057	21.506	0.000	1.243	37.145	0.368	1.247	2.922			100.81
JD10_90_grt_1Line 056	36.622	0.047	21.088	0.000	0.288	37.224	0.339	1.210	3.207			100.03
JD10_90_grt_1Line 057	36.343	0.033	21.001	0.000	0.686	36.993	0.324	1.182	3.168			99.73
JD10_90_grt_1Line 060	36.634	0.027	20.877	0.000	0.635	37.001	0.198	1.210	3.490			100.07
JD10_90_grt_1Line 061	36.547	0.094	20.990	0.000	0.553	37.264	0.209	1.250	3.186			100.09
JD10_90_grt_1Line 062	36.606	0.029	21.046	0.000	0.429	37.393	0.165	1.170	3.241			100.08
JD10_90_grt_1Line 063	36.672	0.062	20.789	0.000	0.435	37.368	0.152	1.241	3.257			99.98
JD10_90_grt_1Line 064	36.264	0.036	21.268	0.000	1.052	36.627	0.140	1.252	3.430			100.07
JD10_90_grt_1Line 067	37.057	0.043	21.205	0.000	0.062	37.942	0.090	1.335	3.073			100.81
JD10_90_grt_1Line 068	36.564	0.035	21.144	0.000	0.814	37.305	0.069	1.377	3.063			100.37
JD10_90_grt_1Line 070	36.851	0.087	21.279	0.000	0.546	37.455	0.032	1.472	3.147			100.87

Sample	tetrahedral 4-fold			octahedral 6-fold				cubic 8-fold					almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-Ti	Gt	total
	Si	Ti	Sum	Al	Cr	Fe-3	Sum	Fe+2	Mn	Mg	Ca	Sum									
JD10_90_grt_1Line 001	2.951	0.003		2.955	2.017	0.000	0.073	2.091	2.457	0.007	0.197	0.294	2.955	83.175	6.660	9.580	0.221	0.000	0.349	0.015	100
JD10_90_grt_1Line 003	3.009	0.002		3.012	2.006	0.000	0.000	2.006	2.491	0.009	0.164	0.318	2.982	83.532	5.505	10.659	0.291	0.000	0.000	0.013	100
JD10_90_grt_1Line 004	2.988	0.002		2.990	2.010	0.000	0.009	2.019	2.513	0.007	0.185	0.286	2.990	84.026	6.189	9.505	0.228	0.000	0.041	0.010	100
JD10_90_grt_1Line 005	2.988	0.003		2.991	1.997	0.000	0.021	2.018	2.518	0.005	0.197	0.270	2.991	84.183	6.590	8.936	0.183	0.000	0.093	0.015	100
JD10_90_grt_1Line 008	2.972	0.003		2.975	2.004	0.000	0.045	2.049	2.499	0.007	0.191	0.279	2.975	83.992	6.407	9.139	0.241	0.000	0.206	0.015	100
JD10_90_grt_1Line 009	2.967	0.003		2.970	2.000	0.000	0.061	2.061	2.493	0.007	0.192	0.278	2.970	83.943	6.465	9.083	0.220	0.000	0.277	0.012	100
JD10_90_grt_1Line 011	2.951	0.005		2.956	2.017	0.000	0.072	2.089	2.486	0.009	0.178	0.282	2.956	84.118	6.014	9.199	0.319	0.000	0.329	0.021	100
JD10_90_grt_1Line 012	2.967	0.005		2.972	2.015	0.000	0.041	2.055	2.510	0.012	0.188	0.263	2.972	84.432	6.319	8.655	0.397	0.000	0.175	0.023	100
JD10_90_grt_1Line 015	2.944	0.006		2.950	2.024	0.000	0.076	2.100	2.459	0.017	0.161	0.313	2.950	83.362	5.461	10.198	0.567	0.000	0.381	0.030	100
JD10_90_grt_1Line 016	2.962	0.004		2.966	2.016	0.000	0.052	2.068	2.514	0.018	0.168	0.266	2.966	84.764	5.668	8.726	0.599	0.000	0.224	0.018	100
JD10_90_grt_1Line 018	2.968	0.001		2.969	2.016	0.000	0.046	2.063	2.523	0.023	0.169	0.254	2.969	84.995	5.694	8.346	0.770	0.000	0.191	0.005	100
JD10_90_grt_1Line 019	2.969	0.002		2.971	2.011	0.000	0.047	2.057	2.495	0.027	0.164	0.286	2.971	83.976	5.511	9.394	0.892	0.000	0.217	0.011	100
JD10_90_grt_1Line 022	2.954	0.004		2.958	2.026	0.000	0.058	2.085	2.477	0.048	0.151	0.283	2.958	83.733	5.089	9.278	1.612	0.000	0.268	0.019	100
JD10_90_grt_1Line 023	2.943	0.004		2.947	2.018	0.000	0.088	2.106	2.464	0.056	0.150	0.277	2.947	83.599	5.092	9.006	1.894	0.000	0.393	0.016	100
JD10_90_grt_1Line 029	2.971	0.004		2.975	2.015	0.000	0.035	2.050	2.486	0.077	0.135	0.277	2.975	83.553	4.554	9.137	2.580	0.000	0.158	0.017	100
JD10_90_grt_1Line 031	2.982	0.006		2.988	1.999	0.000	0.025	2.024	2.469	0.078	0.135	0.306	2.988	82.633	4.513	10.095	2.605	0.000	0.125	0.029	100
JD10_90_grt_1Line 033	2.961	0.003		2.963	2.001	0.000	0.072	2.074	2.485	0.078	0.143	0.258	2.963	83.851	4.811	8.388	2.637	0.000	0.303	0.011	100
JD10_90_grt_1Line 035	2.978	0.001		2.979	2.009	0.000	0.034	2.043	2.486	0.085	0.141	0.267	2.979	83.451	4.743	8.809	2.844	0.000	0.150	0.003	100
JD10_90_grt_1Line 037	2.960	0.002		2.962	2.023	0.000	0.053	2.076	2.490	0.087	0.142	0.243	2.962	84.055	4.798	7.991	2.940	0.000	0.209	0.007	100
JD10_90_grt_1Line 044	2.960	0.003		2.963	2.031	0.000	0.043	2.074	2.510	0.062	0.148	0.244	2.963	84.706	4.980	8.043	2.090	0.000	0.169	0.013	100
JD10_90_grt_1Line 046	2.978	0.001		2.979	2.004	0.000	0.038	2.042	2.523	0.049	0.150	0.258	2.979	84.681	5.027	8.479	1.647	0.000	0.161	0.005	100
JD10_90_grt_1Line 049	2.963	0.005		2.968	2.018	0.000	0.046	2.063	2.529	0.038	0.156	0.245	2.968	85.198	5.251	8.052	1.296	0.000	0.183	0.021	100
JD10_90_grt_1Line 053	3.008	0.003		3.011	2.002	0.000	0.000	2.002	2.504	0.030	0.136	0.317	2.987	83.819	4.549	10.607	1.008	0.000	0.000	0.016	100
JD10_90_grt_1Line 055	2.935	0.003		2.938	2.048	0.000	0.076	2.124	2.510	0.025	0.150	0.253	2.938	85.422	5.112	8.289	0.857	0.000	0.306	0.014	100
JD10_90_grt_1Line 056	2.978	0.003		2.981	2.021	0.000	0.018	2.039	2.531	0.023	0.147	0.279	2.981	84.923	4.921	9.279	0.783	0.000	0.081	0.013	100
JD10_90_grt_1Line 057	2.967	0.002		2.969	2.020	0.000	0.042	2.063	2.525	0.022	0.144	0.277	2.969	85.067	4.845	9.133	0.755	0.000	0.191	0.009	100
JD10_90_grt_1Line 060	2.979	0.002		2.980	2.001	0.000	0.039	2.039	2.516	0.014	0.147	0.304	2.980	84.420	4.921	9.999	0.458	0.000	0.194	0.008	100
JD10_90_grt_1Line 061	2.972	0.006		2.977	2.011	0.000	0.034	2.045	2.534	0.014	0.152	0.278	2.977	85.106	5.089	9.142	0.483	0.000	0.154	0.026	100
JD10_90_grt_1Line 062	2.977	0.002		2.978	2.017	0.000	0.026	2.043	2.543	0.011	0.142	0.282	2.978	85.376	4.762	9.350	0.382	0.000	0.122	0.008	100
JD10_90_grt_1Line 063	2.986	0.004		2.989	1.995	0.000	0.027	2.021	2.544	0.010	0.151	0.284	2.989	85.107	5.038	9.361	0.351	0.000	0.125	0.018	100
JD10_90_grt_1Line 064	2.947	0.002		2.949	2.037	0.000	0.064	2.101	2.489	0.010	0.152	0.299	2.949	84.404	5.143	9.806	0.327	0.000	0.310	0.011	100
JD10_90_grt_1Line 067	2.988	0.003		2.991	2.015	0.000	0.004	2.019	2.558	0.006	0.160	0.265	2.991	85.551	5.366	8.849	0.206	0.000	0.017	0.011	100
JD10_90_grt_1Line 068	2.963	0.002		2.965	2.020	0.000	0.050	2.069	2.528	0.005	0.166	0.266	2.965	85.261	5.610	8.745	0.160	0.000	0.215	0.009	100
JD10_90_grt_1Line 070	2.968	0.005		2.973	2.020	0.000	0.033	2.053	2.523	0.002	0.177	0.272	2.973	84.849	5.944	8.963	0.073	0.000	0.147	0.023	100

Sample	Major Elements										Total
	SiO2	TiO2	Al2O3	Cr2O3	MnO	Fe2O3	FeO	MgO	CaO		
JD10_90_grt_2 Line 001	36.700	0.067	21.204	0.000	0.515	36.769	0.049	1.725	3.162	100.191	
JD10_90_grt_2 Line 002	36.531	0.066	21.141	0.000	0.875	36.269	0.042	1.756	3.356	100.037	
JD10_90_grt_2 Line 003	36.495	0.072	21.068	0.000	0.859	36.443	0.035	1.688	3.291	99.951	
JD10_90_grt_2 Line 004	36.697	0.074	21.076	0.000	0.600	36.696	0.048	1.669	3.300	100.160	
JD10_90_grt_2 Line 005	36.549	0.076	21.132	0.000	1.271	36.456	0.035	1.715	3.297	100.530	
JD10_90_grt_2 Line 007	36.722	0.069	21.233	0.000	0.637	36.474	0.063	1.728	3.399	100.325	
JD10_90_grt_2 Line 009	36.875	0.065	21.049	0.000	0.193	36.868	0.056	1.669	3.319	100.094	
JD10_90_grt_2 Line 010	36.562	0.046	21.080	0.000	0.635	36.428	0.035	1.629	3.429	99.845	
JD10_90_grt_2 Line 011	36.647	0.064	21.273	0.000	0.905	36.398	0.040	1.635	3.532	100.495	
JD10_90_grt_2 Line 012	36.767	0.039	21.125	0.000	0.462	36.349	0.034	1.616	3.696	100.088	
JD10_90_grt_2 Line 013	36.504	0.068	21.197	0.000	1.097	36.019	0.027	1.607	3.747	100.266	
JD10_90_grt_2 Line 014	36.635	0.059	21.126	0.000	0.819	35.784	0.038	1.547	4.121	100.129	
JD10_90_grt_2 Line 015	36.405	0.036	21.070	0.000	0.888	35.751	0.040	1.558	3.899	99.647	
JD10_90_grt_2 Line 016	36.619	0.037	21.135	0.000	0.875	36.110	0.033	1.571	3.807	100.187	
JD10_90_grt_2 Line 017	36.538	0.073	21.258	0.000	0.906	35.894	0.026	1.552	3.957	100.204	
JD10_90_grt_2 Line 018	36.518	0.060	21.251	0.000	1.086	36.141	0.042	1.526	3.760	100.384	
JD10_90_grt_2 Line 019	36.578	0.060	21.272	0.000	0.888	36.060	0.035	1.551	3.850	100.294	
JD10_90_grt_2 Line 020	36.607	0.068	21.228	0.000	0.629	36.250	0.033	1.519	3.780	100.114	
JD10_90_grt_2 Line 021	36.441	0.065	21.270	0.000	0.907	35.840	0.031	1.503	3.967	100.024	
JD10_90_grt_2 Line 022	36.174	0.069	21.319	0.000	1.442	35.182	0.037	1.482	4.259	99.963	
JD10_90_grt_2 Line 023	36.550	0.093	21.022	0.000	0.809	36.135	0.018	1.487	3.891	100.005	
JD10_90_grt_2 Line 024	36.898	0.063	21.145	0.000	0.493	36.462	0.031	1.517	3.887	100.496	
JD10_90_grt_2 Line 025	36.788	0.087	21.006	0.000	0.637	36.109	0.024	1.557	4.027	100.235	
JD10_90_grt_2 Line 026	36.838	0.070	21.203	0.000	0.319	36.319	0.043	1.457	4.022	100.271	
JD10_90_grt_2 Line 027	34.565	4.439	20.326	0.000	0.000	37.932	0.027	1.504	3.333	102.126	
JD10_90_grt_2 Line 028	36.632	0.053	21.037	0.000	0.742	36.763	0.035	1.555	3.341	100.158	
JD10_90_grt_2 Line 036	36.813	0.038	21.026	0.000	0.539	36.959	0.035	1.479	3.452	100.341	
JD10_90_grt_2 Line 037	36.527	0.063	21.339	0.000	0.534	36.679	0.045	1.418	3.498	100.104	
JD10_90_grt_2 Line 038	36.611	0.048	21.195	0.000	0.781	36.328	0.035	1.402	3.870	100.270	
JD10_90_grt_2 Line 039	36.558	0.022	21.187	0.000	0.932	36.640	0.045	1.444	3.493	100.320	
JD10_90_grt_2 Line 040	36.600	0.067	21.155	0.000	0.929	36.421	0.039	1.433	3.684	100.328	
JD10_90_grt_2 Line 042	36.765	0.069	21.024	0.000	0.070	36.956	0.039	1.414	3.519	99.856	
JD10_90_grt_2 Line 043	36.368	0.044	21.105	0.000	0.481	36.384	0.020	1.417	3.588	99.407	

Sample	Major Elements										Total
	SiO2	TiO2	Al2O3	Cr2O3	MnO	Fe2O3	FeO	MgO	CaO		
JD10_90_grt_2 Line 044	36.561	0.071	21.187	0.000	0.910	36.555	0.044	1.388	3.675	100.391	
JD10_90_grt_2 Line 045	36.577	0.040	21.134	0.000	0.585	36.815	0.040	1.388	3.468	100.048	
JD10_90_grt_2 Line 046	36.719	0.067	21.150	0.000	0.824	36.919	0.026	1.385	3.554	100.644	
JD10_90_grt_2 Line 047	36.470	0.094	21.189	0.000	0.833	36.708	0.038	1.356	3.536	100.225	
JD10_90_grt_2 Line 048	36.509	0.066	21.165	0.000	0.819	36.694	0.025	1.386	3.532	100.196	
JD10_90_grt_2 Line 049	36.365	0.040	21.070	0.000	0.843	36.376	0.025	1.335	3.699	99.752	
JD10_90_grt_2 Line 050	36.354	0.069	21.115	0.000	0.349	36.828	0.005	1.343	3.361	99.424	
JD10_90_grt_2 Line 051	36.572	0.070	21.193	0.000	0.800	36.448	0.045	1.383	3.774	100.285	
JD10_90_grt_2 Line 052	36.717	0.071	21.077	0.000	0.294	36.908	0.031	1.323	3.646	100.066	
JD10_90_grt_2 Line 053	36.456	0.068	21.193	0.000	0.734	36.575	0.035	1.361	3.604	100.025	
JD10_90_grt_2 Line 054	36.439	0.058	20.914	0.000	0.302	36.421	0.038	1.276	3.817	99.265	
JD10_90_grt_2 Line 055	36.477	0.079	20.921	0.000	0.658	36.520	0.042	1.362	3.667	99.726	
JD10_90_grt_2 Line 056	36.625	0.053	21.035	0.000	0.538	36.673	0.041	1.322	3.724	100.011	
JD10_90_grt_2 Line 057	36.459	0.099	21.010	0.000	0.935	36.495	0.025	1.364	3.695	100.082	
JD10_90_grt_2 Line 058	36.638	0.086	21.339	0.000	0.805	36.630	0.022	1.338	3.786	100.644	
JD10_90_grt_2 Line 059	36.557	0.042	21.177	0.000	0.906	36.409	0.051	1.368	3.787	100.297	
JD10_90_grt_2 Line 060	36.391	0.064	21.266	0.000	1.159	36.114	0.040	1.370	3.884	100.288	
JD10_90_grt_2 Line 061	36.685	0.055	21.090	0.000	0.519	36.522	0.045	1.376	3.821	100.113	
JD10_90_grt_2 Line 062	36.617	0.090	20.871	0.000	0.335	36.120	0.037	1.390	4.083	99.543	
JD10_90_grt_2 Line 065	36.367	0.031	21.000	0.000	1.034	35.901	0.020	1.467	3.885	99.706	
JD10_90_grt_2 Line 066	36.600	0.054	21.061	0.000	0.951	36.080	0.021	1.543	3.873	100.182	
JD10_90_grt_2 Line 067	36.620	0.044	21.258	0.000	0.585	36.404	0.032	1.535	3.634	100.112	
JD10_90_grt_2 Line 068	36.833	0.049	20.962	0.000	0.489	36.331	0.025	1.543	3.685	99.917	
JD10_90_grt_2 Line 072	36.650	0.078	21.183	0.000	0.988	36.331	0.033	1.694	3.521	100.478	
JD10_90_grt_2 Line 073	36.615	0.079	21.149	0.000	0.984	36.471	0.039	1.739	3.312	100.389	
JD10_90_grt_2 Line 074	36.735	0.062	21.062	0.000	0.118	36.732	0.036	1.695	3.272	99.712	
JD10_90_grt_2 Line 075	36.600	0.041	21.187	0.000	0.859	36.795	0.055	1.721	3.031	100.289	
JD10_90_grt_2 Line 076	36.600	0.041	21.294	0.000	0.751	36.584	0.051	1.720	3.200	100.241	
JD10_90_grt_2 Line 077	36.643	0.078	21.172	0.000	0.905	36.627	0.048	1.779	3.153	100.405	
JD10_90_grt_2 Line 078	36.626	0.075	21.182	0.000	0.691	37.021	0.094	1.690	2.915	100.294	
JD10_90_grt_2 Line 079	36.711	0.054	21.177	0.000	0.697	36.901	0.112	1.685	3.066	100.403	
JD10_90_grt_2 Line 080	36.421	0.067	21.217	0.000	1.198	36.682	0.103	1.706	2.953	100.347	

Sample	tetrahedral 4-fold			octahedral 6-fold				cubic 8-fold					almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-Ti	Gt	total
	Si	Ti	Sum	Al	Cr	Fe+3	Sum	Fe+2	Mn	Mg	Ca	Sum									
JD10_90_grt_2 Line 001	2.969	0.004		2.973	2.022	0.000	0.031	2.053	2.488	0.003	0.208	0.274	2.973	83.671	6.997	9.060	0.113	0.000	0.140	0.018	100
JD10_90_grt_2 Line 002	2.960	0.004		2.964	2.019	0.000	0.053	2.072	2.458	0.003	0.212	0.291	2.964	82.917	7.156	9.558	0.097	0.000	0.253	0.019	100
JD10_90_grt_2 Line 003	2.962	0.004		2.966	2.015	0.000	0.052	2.068	2.473	0.002	0.204	0.286	2.966	83.387	6.885	9.383	0.081	0.000	0.244	0.020	100
JD10_90_grt_2 Line 004	2.972	0.005		2.976	2.011	0.000	0.037	2.048	2.485	0.003	0.201	0.286	2.976	83.499	6.770	9.428	0.111	0.000	0.171	0.021	100
JD10_90_grt_2 Line 005	2.951	0.005		2.956	2.011	0.000	0.077	2.088	2.462	0.002	0.206	0.285	2.956	83.285	6.984	9.273	0.081	0.000	0.356	0.021	100
JD10_90_grt_2 Line 007	2.966	0.004		2.970	2.021	0.000	0.039	2.060	2.464	0.004	0.208	0.294	2.970	82.947	7.005	9.697	0.145	0.000	0.186	0.020	100
JD10_90_grt_2 Line 009	2.986	0.004		2.990	2.009	0.000	0.012	2.020	2.497	0.004	0.201	0.288	2.990	83.502	6.738	9.556	0.128	0.000	0.056	0.019	100
JD10_90_grt_2 Line 010	2.969	0.003		2.972	2.017	0.000	0.039	2.056	2.474	0.002	0.197	0.298	2.972	83.244	6.636	9.836	0.081	0.000	0.189	0.014	100
JD10_90_grt_2 Line 011	2.957	0.004		2.961	2.023	0.000	0.055	2.078	2.456	0.003	0.197	0.305	2.961	82.953	6.642	10.021	0.092	0.000	0.272	0.019	100
JD10_90_grt_2 Line 012	2.976	0.002		2.978	2.015	0.000	0.028	2.043	2.460	0.002	0.195	0.321	2.978	82.613	6.547	10.601	0.078	0.000	0.148	0.012	100
JD10_90_grt_2 Line 013	2.952	0.004		2.956	2.020	0.000	0.067	2.087	2.436	0.002	0.194	0.325	2.956	82.402	6.554	10.610	0.063	0.000	0.351	0.022	100
JD10_90_grt_2 Line 014	2.964	0.004		2.968	2.015	0.000	0.050	2.064	2.421	0.003	0.187	0.357	2.968	81.587	6.287	11.726	0.088	0.000	0.290	0.021	100
JD10_90_grt_2 Line 015	2.961	0.002		2.963	2.020	0.000	0.054	2.074	2.432	0.003	0.189	0.340	2.963	82.065	6.375	11.154	0.093	0.000	0.300	0.012	100
JD10_90_grt_2 Line 016	2.963	0.002		2.966	2.016	0.000	0.053	2.069	2.444	0.002	0.190	0.330	2.966	82.403	6.391	10.832	0.076	0.000	0.286	0.012	100
JD10_90_grt_2 Line 017	2.955	0.004		2.959	2.026	0.000	0.055	2.081	2.428	0.002	0.187	0.343	2.959	82.031	6.323	11.255	0.060	0.000	0.306	0.025	100
JD10_90_grt_2 Line 018	2.951	0.004		2.955	2.024	0.000	0.066	2.090	2.443	0.003	0.184	0.326	2.955	82.663	6.222	10.651	0.097	0.000	0.348	0.019	100
JD10_90_grt_2 Line 019	2.956	0.004		2.960	2.026	0.000	0.054	2.080	2.437	0.002	0.187	0.333	2.960	82.342	6.313	10.952	0.081	0.000	0.292	0.020	100
JD10_90_grt_2 Line 020	2.964	0.004		2.968	2.026	0.000	0.038	2.064	2.455	0.002	0.183	0.328	2.968	82.699	6.177	10.821	0.076	0.000	0.205	0.022	100
JD10_90_grt_2 Line 021	2.953	0.004		2.957	2.031	0.000	0.055	2.087	2.429	0.002	0.182	0.344	2.957	82.140	6.140	11.318	0.072	0.000	0.308	0.022	100
JD10_90_grt_2 Line 022	2.933	0.004		2.937	2.037	0.000	0.088	2.125	2.386	0.003	0.179	0.370	2.937	81.218	6.099	12.051	0.087	0.000	0.520	0.025	100
JD10_90_grt_2 Line 023	2.965	0.006		2.970	2.010	0.000	0.049	2.059	2.451	0.001	0.180	0.338	2.970	82.521	6.053	11.081	0.042	0.000	0.272	0.031	100
JD10_90_grt_2 Line 024	2.976	0.004		2.980	2.010	0.000	0.030	2.040	2.460	0.002	0.182	0.336	2.980	82.535	6.121	11.086	0.071	0.000	0.165	0.021	100
JD10_90_grt_2 Line 025	2.974	0.005		2.980	2.002	0.000	0.039	2.040	2.442	0.002	0.188	0.349	2.980	81.939	6.298	11.455	0.055	0.000	0.222	0.030	100
JD10_90_grt_2 Line 026	2.976	0.004		2.981	2.019	0.000	0.019	2.039	2.454	0.003	0.175	0.348	2.981	82.332	5.888	11.546	0.099	0.000	0.111	0.024	100
JD10_90_grt_2 Line 027	2.781	0.269		3.050	1.928	0.000	0.000	1.928	2.553	0.002	0.180	0.287	3.022	84.461	5.970	8.345	0.061	0.000	0.000	1.163	100
JD10_90_grt_2 Line 028	2.969	0.003		2.973	2.010	0.000	0.045	2.055	2.492	0.002	0.188	0.290	2.973	83.837	6.321	9.531	0.081	0.000	0.215	0.015	100
JD10_90_grt_2 Line 036	2.979	0.002		2.981	2.005	0.000	0.033	2.038	2.501	0.002	0.178	0.299	2.981	83.896	5.985	9.866	0.080	0.000	0.161	0.011	100
JD10_90_grt_2 Line 037	2.961	0.004		2.964	2.038	0.000	0.033	2.071	2.486	0.003	0.171	0.304	2.964	83.869	5.780	10.067	0.104	0.000	0.161	0.019	100
JD10_90_grt_2 Line 038	2.963	0.003		2.966	2.021	0.000	0.048	2.069	2.458	0.002	0.169	0.336	2.966	82.902	5.703	11.039	0.081	0.000	0.260	0.016	100
JD10_90_grt_2 Line 039	2.960	0.001		2.961	2.021	0.000	0.057	2.078	2.481	0.003	0.174	0.303	2.961	83.778	5.886	9.947	0.104	0.000	0.279	0.007	100
JD10_90_grt_2 Line 040	2.960	0.001		2.961	2.022	0.000	0.057	2.078	2.466	0.003	0.173	0.320	2.961	83.277	5.841	10.491	0.090	0.000	0.294	0.007	100
JD10_90_grt_2 Line 042	2.987	0.004		2.991	2.013	0.000	0.004	2.017	2.511	0.003	0.171	0.306	2.991	83.944	5.725	10.198	0.090	0.000	0.022	0.021	100
JD10_90_grt_2 Line 043	2.968	0.003		2.970	2.030	0.000	0.030	2.059	2.483	0.001	0.172	0.314	2.970	83.590	5.803	10.396	0.047	0.000	0.151	0.014	100

Sample	tetrahedral 4-fold			octahedral 6-fold				cubic 8-fold					almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-Ti	Gt	total
	Si	Ti	Sum	Al	Cr	Fe+3	Sum	Fe+2	Mn	Mg	Ca	Sum									
JD10_90_grt_2 Line 044	2.958	0.004		2.962	2.020	0.000	0.055	2.076	2.473	0.003	0.167	0.319	2.962	83.493	5.651	10.445	0.102	0.000	0.287	0.022	100
JD10_90_grt_2 Line 045	2.969	0.002		2.971	2.022	0.000	0.036	2.057	2.499	0.003	0.168	0.302	2.971	84.105	5.652	9.962	0.093	0.000	0.176	0.012	100
JD10_90_grt_2 Line 046	2.965	0.004		2.969	2.013	0.000	0.050	2.063	2.493	0.002	0.167	0.307	2.969	83.969	5.615	10.085	0.060	0.000	0.251	0.020	100
JD10_90_grt_2 Line 047	2.957	0.006		2.962	2.025	0.000	0.051	2.075	2.489	0.003	0.164	0.307	2.962	84.012	5.532	10.086	0.088	0.000	0.253	0.029	100
JD10_90_grt_2 Line 048	2.960	0.004		2.964	2.022	0.000	0.050	2.072	2.488	0.002	0.168	0.307	2.964	83.939	5.652	10.082	0.058	0.000	0.249	0.020	100
JD10_90_grt_2 Line 049	2.961	0.002		2.963	2.022	0.000	0.052	2.073	2.477	0.002	0.162	0.323	2.963	83.584	5.468	10.606	0.058	0.000	0.271	0.013	100
JD10_90_grt_2 Line 050	2.969	0.004		2.973	2.032	0.000	0.021	2.054	2.515	0.000	0.164	0.294	2.973	84.598	5.499	9.768	0.012	0.000	0.103	0.020	100
JD10_90_grt_2 Line 051	2.960	0.004		2.965	2.022	0.000	0.049	2.071	2.467	0.003	0.167	0.327	2.965	83.226	5.629	10.759	0.104	0.000	0.259	0.023	100
JD10_90_grt_2 Line 052	2.979	0.004		2.983	2.015	0.000	0.018	2.033	2.504	0.002	0.160	0.317	2.983	83.941	5.364	10.508	0.071	0.000	0.093	0.023	100
JD10_90_grt_2 Line 053	2.960	0.004		2.964	2.028	0.000	0.045	2.073	2.483	0.002	0.165	0.313	2.964	83.784	5.558	10.328	0.081	0.000	0.228	0.021	100
JD10_90_grt_2 Line 054	2.979	0.004		2.983	2.015	0.000	0.019	2.034	2.490	0.003	0.156	0.334	2.983	83.488	5.214	11.088	0.088	0.000	0.102	0.020	100
JD10_90_grt_2 Line 055	2.971	0.005		2.976	2.008	0.000	0.040	2.049	2.487	0.003	0.165	0.320	2.976	83.592	5.557	10.517	0.097	0.000	0.211	0.025	100
JD10_90_grt_2 Line 056	2.974	0.003		2.977	2.013	0.000	0.033	2.046	2.490	0.003	0.160	0.324	2.977	83.648	5.375	10.691	0.095	0.000	0.174	0.017	100
JD10_90_grt_2 Line 057	2.960	0.006		2.966	2.010	0.000	0.057	2.068	2.478	0.002	0.165	0.321	2.966	83.540	5.566	10.506	0.058	0.000	0.299	0.032	100
JD10_90_grt_2 Line 058	2.956	0.005		2.961	2.029	0.000	0.049	2.078	2.471	0.002	0.161	0.327	2.961	83.463	5.435	10.765	0.051	0.000	0.259	0.028	100
JD10_90_grt_2 Line 059	2.960	0.003		2.962	2.021	0.000	0.055	2.076	2.465	0.003	0.165	0.328	2.962	83.219	5.574	10.781	0.118	0.000	0.294	0.014	100
JD10_90_grt_2 Line 060	2.946	0.004		2.950	2.029	0.000	0.071	2.100	2.445	0.003	0.165	0.337	2.950	82.882	5.605	11.015	0.093	0.000	0.383	0.021	100
JD10_90_grt_2 Line 061	2.973	0.003		2.977	2.015	0.000	0.032	2.046	2.476	0.003	0.166	0.332	2.977	83.164	5.585	10.957	0.104	0.000	0.172	0.018	100
JD10_90_grt_2 Line 062	2.982	0.006		2.988	2.004	0.000	0.021	2.024	2.460	0.003	0.169	0.356	2.988	82.341	5.649	11.772	0.085	0.000	0.121	0.032	100
JD10_90_grt_2 Line 065	2.959	0.002		2.961	2.014	0.000	0.063	2.077	2.443	0.001	0.178	0.339	2.961	82.505	6.010	11.080	0.047	0.000	0.348	0.010	100
JD10_90_grt_2 Line 066	2.963	0.003		2.966	2.009	0.000	0.058	2.067	2.443	0.001	0.186	0.336	2.966	82.348	6.278	10.990	0.049	0.000	0.317	0.018	100
JD10_90_grt_2 Line 067	2.965	0.003		2.968	2.029	0.000	0.036	2.064	2.465	0.002	0.185	0.315	2.968	83.060	6.243	10.426	0.074	0.000	0.183	0.014	100
JD10_90_grt_2 Line 068	2.967	0.003		2.970	2.030	0.000	0.030	2.060	2.462	0.002	0.186	0.320	2.970	82.895	6.276	10.602	0.058	0.000	0.156	0.014	100
JD10_90_grt_2 Line 072	2.958	0.005		2.963	2.015	0.000	0.060	2.075	2.452	0.002	0.204	0.304	2.963	82.768	6.879	9.957	0.076	0.000	0.297	0.023	100
JD10_90_grt_2 Line 073	2.958	0.005		2.963	2.014	0.000	0.060	2.074	2.464	0.003	0.209	0.287	2.963	83.165	7.069	9.375	0.090	0.000	0.279	0.022	100
JD10_90_grt_2 Line 074	2.984	0.004		2.988	2.017	0.000	0.007	2.024	2.496	0.002	0.205	0.285	2.988	83.516	6.870	9.479	0.083	0.000	0.034	0.018	100
JD10_90_grt_2 Line 075	2.961	0.002		2.964	2.020	0.000	0.052	2.073	2.490	0.004	0.208	0.263	2.964	84.004	7.004	8.631	0.127	0.000	0.223	0.011	100
JD10_90_grt_2 Line 076	2.960	0.002		2.962	2.030	0.000	0.046	2.075	2.474	0.003	0.207	0.277	2.962	83.523	7.000	9.143	0.118	0.000	0.206	0.011	100
JD10_90_grt_2 Line 077	2.960	0.005		2.965	2.016	0.000	0.055	2.071	2.474	0.003	0.214	0.273	2.965	83.459	7.226	8.940	0.111	0.000	0.244	0.021	100
JD10_90_grt_2 Line 078	2.964	0.005		2.969	2.020	0.000	0.042	2.063	2.506	0.006	0.204	0.253	2.969	84.401	6.868	8.322	0.217	0.000	0.173	0.019	100
JD10_90_grt_2 Line 079	2.967	0.003		2.970	2.017	0.000	0.042	2.060	2.494	0.008	0.203	0.265	2.970	83.969	6.835	8.740	0.258	0.000	0.184	0.014	100
JD10_90_grt_2 Line 080	2.948	0.004		2.952	2.024	0.000	0.073	2.097	2.483	0.007	0.206	0.256	2.952	84.113	6.973	8.357	0.239	0.000	0.301	0.017	100

Sample	Major Elements										Total
	SiO2	TiO2	Al2O3	Cr2O3	Fe2O3	FeO	MnO	MgO	CaO		
JD10-16A_Grt_1 Line 001	36.633	0.053	21.220	0.000	1.716	33.251	2.770	2.428	2.706	100.78	
JD10-16A_Grt_1 Line 002	36.654	0.073	21.291	0.000	1.740	33.866	1.648	2.384	3.208	100.86	
JD10-16A_Grt_1 Line 003	36.398	0.058	21.166	0.000	2.153	33.545	1.642	2.310	3.317	100.59	
JD10-16A_Grt_1 Line 004	36.486	0.041	21.210	0.000	1.572	33.840	2.054	2.145	3.061	100.41	
JD10-16A_Grt_1 Line 005	36.369	0.042	21.105	0.000	1.939	33.185	2.666	2.154	2.967	100.43	
JD10-16A_Grt_1 Line 006	36.359	0.044	21.138	0.000	1.681	33.758	2.856	1.850	2.785	100.47	
JD10-16A_Grt_1 Line 007	36.328	0.080	21.242	0.000	2.017	33.425	3.197	1.655	3.043	100.99	
JD10-16A_Grt_1 Line 008	36.239	0.082	21.073	0.000	1.965	33.275	3.203	1.509	3.277	100.62	
JD10-16A_Grt_1 Line 009	36.299	0.053	21.108	0.000	1.889	33.416	3.256	1.459	3.230	100.71	
JD10-16A_Grt_1 Line 010	36.342	0.076	21.148	0.000	1.536	33.379	3.127	1.472	3.399	100.48	
JD10-16A_Grt_1 Line 011	37.514	0.060	20.859	0.000	0.000	34.212	3.007	1.534	3.450	100.64	
JD10-16A_Grt_1 Line 012	36.400	0.053	21.134	0.000	1.766	33.305	3.231	1.425	3.478	100.79	
JD10-16A_Grt_1 Line 013	36.446	0.075	21.010	0.000	1.713	33.450	3.661	1.325	3.222	100.90	
JD10-16A_Grt_1 Line 014	36.178	0.058	21.007	0.000	1.841	31.997	3.944	1.135	4.135	100.30	
JD10-16A_Grt_1 Line 015	36.218	0.112	21.229	0.000	2.034	31.650	4.200	1.101	4.326	100.87	
JD10-16A_Grt_1 Line 016	36.446	0.082	20.891	0.000	1.707	30.248	4.431	0.865	5.758	100.43	
JD10-16A_Grt_1 Line 017	36.491	0.079	21.107	0.000	1.788	29.859	4.763	0.811	5.914	100.81	
JD10-16A_Grt_1 Line 018	36.484	0.133	21.044	0.000	1.397	29.912	5.116	0.755	5.703	100.54	
JD10-16A_Grt_1 Line 019	36.371	0.160	20.957	0.000	1.630	29.510	5.531	0.770	5.581	100.51	
JD10-16A_Grt_1 Line 020	36.489	0.055	20.936	0.000	1.783	28.506	6.323	0.693	5.882	100.67	
JD10-16A_Grt_1 Line 021	36.548	0.074	20.984	0.000	1.668	28.743	6.338	0.702	5.741	100.80	
JD10-16A_Grt_1 Line 022	36.398	0.048	21.119	0.000	1.791	27.853	6.718	0.662	6.033	100.62	
JD10-16A_Grt_1 Line 023	36.303	0.095	20.984	0.000	1.917	27.397	7.310	0.645	5.889	100.54	
JD10-16A_Grt_1 Line 024	36.395	0.105	21.138	0.000	1.975	27.280	7.520	0.659	5.888	100.96	
JD10-16A_Grt_1 Line 025	36.445	0.117	21.003	0.000	1.967	26.946	7.560	0.612	6.237	100.89	
JD10-16A_Grt_1 Line 026	36.234	0.149	20.730	0.000	2.045	26.720	8.102	0.596	5.833	100.41	
JD10-16A_Grt_1 Line 027	36.466	0.151	20.786	0.000	1.604	27.086	7.844	0.605	5.957	100.50	
JD10-16A_Grt_1 Line 028	36.207	0.384	20.795	0.000	1.809	27.251	7.264	0.642	6.157	100.51	
JD10-16A_Grt_1 Line 029	36.525	0.047	20.937	0.000	1.785	28.204	6.306	0.747	6.084	100.64	
JD10-16A_Grt_1 Line 030	36.545	0.111	20.889	0.000	1.672	28.194	6.555	0.672	6.063	100.70	
JD10-16A_Grt_1 Line 031	36.500	0.098	20.867	0.000	1.551	28.855	6.080	0.709	5.820	100.48	
JD10-16A_Grt_1 Line 032	36.427	0.054	21.013	0.000	1.944	28.845	5.357	0.802	6.171	100.61	
JD10-16A_Grt_1 Line 033	36.399	0.083	20.995	0.000	1.434	29.363	4.957	0.839	6.026	100.10	
JD10-16A_Grt_1 Line 034	36.579	0.064	21.112	0.000	1.571	29.793	4.138	0.993	6.278	100.53	
JD10-16A_Grt_1 Line 035	36.584	0.045	21.232	0.000	1.439	31.978	3.799	1.284	4.427	100.79	
JD10-16A_Grt_1 Line 036	36.203	0.045	21.246	0.000	1.813	32.883	3.252	1.514	3.477	100.43	
JD10-16A_Grt_1 Line 037	36.460	0.036	21.114	0.000	1.731	32.993	2.887	1.607	3.784	100.61	
JD10-16A_Grt_1 Line 038	36.388	0.048	21.264	0.000	1.883	33.382	2.064	1.964	3.576	100.57	
JD10-16A_Grt_1 Line 039	36.383	0.068	21.321	0.000	2.079	32.777	2.222	2.210	3.590	100.65	
JD10-16A_Grt_1 Line 040	36.222	0.018	21.487	0.000	2.092	31.777	2.954	2.382	3.367	100.30	

Sample	tetrahedral 4-fold			octahedral 6-fold				cubic 8-fold														
	Si	Ti	Sum	Al	Cr	Fe+3	Sum	Fe+2	Mn	Mg	Ca	Sum	almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-Ti	Gt	total	
JD10-16A_Grt_1 Line 001	2.941	0.003		2.944	2.008	0.000	0.104	2.112	2.233	0.188	0.291	0.233	2.944	75.827	9.870	7.506	6.398	0.000	0.388	0.012	100	
JD10-16A_Grt_1 Line 002	2.938	0.004		2.942	2.011	0.000	0.105	2.116	2.270	0.112	0.285	0.275	2.942	77.153	9.682	8.880	3.803	0.000	0.463	0.019	100	
JD10-16A_Grt_1 Line 003	2.928	0.004		2.931	2.007	0.000	0.130	2.137	2.257	0.112	0.277	0.286	2.931	76.981	9.450	9.143	3.816	0.000	0.594	0.016	100	
JD10-16A_Grt_1 Line 004	2.942	0.002		2.944	2.016	0.000	0.095	2.111	2.282	0.140	0.258	0.264	2.944	77.498	8.757	8.565	4.764	0.000	0.405	0.011	100	
JD10-16A_Grt_1 Line 005	2.935	0.003		2.937	2.007	0.000	0.118	2.125	2.240	0.182	0.259	0.257	2.937	76.242	8.822	8.239	6.204	0.000	0.483	0.010	100	
JD10-16A_Grt_1 Line 006	2.939	0.003		2.942	2.014	0.000	0.102	2.116	2.282	0.196	0.223	0.241	2.942	77.575	7.578	7.793	6.647	0.000	0.396	0.010	100	
JD10-16A_Grt_1 Line 007	2.926	0.005		2.931	2.016	0.000	0.122	2.139	2.251	0.218	0.199	0.263	2.931	76.818	6.780	8.428	7.442	0.000	0.511	0.020	100	
JD10-16A_Grt_1 Line 008	2.931	0.005		2.936	2.009	0.000	0.120	2.128	2.251	0.219	0.182	0.284	2.936	76.657	6.197	9.107	7.474	0.000	0.542	0.023	100	
JD10-16A_Grt_1 Line 009	2.934	0.003		2.937	2.011	0.000	0.115	2.126	2.259	0.223	0.176	0.280	2.937	76.902	5.985	8.995	7.589	0.000	0.514	0.014	100	
JD10-16A_Grt_1 Line 010	2.940	0.005		2.945	2.017	0.000	0.094	2.110	2.258	0.214	0.178	0.295	2.945	76.690	6.029	9.541	7.276	0.000	0.442	0.022	100	
JD10-16A_Grt_1 Line 011	3.023	0.004		3.026	1.981	0.000	0.000	1.981	2.305	0.205	0.184	0.298	2.993	77.033	6.157	9.934	6.857	0.000	0.000	0.018	100	
JD10-16A_Grt_1 Line 012	2.938	0.003		2.941	2.010	0.000	0.107	2.118	2.248	0.221	0.171	0.301	2.941	76.434	5.830	9.693	7.510	0.000	0.517	0.016	100	
JD10-16A_Grt_1 Line 013	2.943	0.005		2.948	2.000	0.000	0.104	2.104	2.259	0.250	0.160	0.279	2.948	76.636	5.411	8.970	8.495	0.000	0.467	0.020	100	
JD10-16A_Grt_1 Line 014	2.936	0.004		2.939	2.009	0.000	0.112	2.121	2.171	0.271	0.137	0.360	2.939	73.875	4.671	11.564	9.223	0.000	0.647	0.020	100	
JD10-16A_Grt_1 Line 015	2.922	0.007		2.929	2.019	0.000	0.123	2.142	2.136	0.287	0.132	0.374	2.929	72.912	4.521	11.994	9.799	0.000	0.734	0.040	100	
JD10-16A_Grt_1 Line 016	2.947	0.005		2.952	1.991	0.000	0.104	2.095	2.046	0.304	0.104	0.499	2.952	69.289	3.532	16.022	10.280	0.000	0.836	0.040	100	
JD10-16A_Grt_1 Line 017	2.939	0.005		2.944	2.004	0.000	0.108	2.112	2.011	0.325	0.097	0.510	2.944	68.319	3.308	16.409	11.038	0.000	0.888	0.039	100	
JD10-16A_Grt_1 Line 018	2.948	0.008		2.956	2.004	0.000	0.085	2.089	2.021	0.350	0.091	0.494	2.956	68.377	3.077	15.961	11.845	0.000	0.677	0.064	100	
JD10-16A_Grt_1 Line 019	2.942	0.010		2.952	1.998	0.000	0.099	2.097	1.996	0.379	0.093	0.484	2.952	67.630	3.146	15.539	12.838	0.000	0.772	0.076	100	
JD10-16A_Grt_1 Line 020	2.946	0.003		2.950	1.992	0.000	0.108	2.101	1.925	0.432	0.083	0.509	2.950	65.260	2.828	16.336	14.661	0.000	0.888	0.027	100	
JD10-16A_Grt_1 Line 021	2.948	0.004		2.952	1.995	0.000	0.101	2.096	1.939	0.433	0.084	0.496	2.952	65.671	2.859	15.959	14.666	0.000	0.810	0.036	100	
JD10-16A_Grt_1 Line 022	2.938	0.003		2.941	2.009	0.000	0.109	2.118	1.880	0.459	0.080	0.522	2.941	63.932	2.709	16.807	15.618	0.000	0.910	0.024	100	
JD10-16A_Grt_1 Line 023	2.936	0.006		2.942	2.000	0.000	0.117	2.117	1.853	0.501	0.078	0.510	2.942	62.989	2.643	16.345	17.022	0.000	0.953	0.047	100	
JD10-16A_Grt_1 Line 024	2.931	0.006		2.937	2.006	0.000	0.120	2.126	1.837	0.513	0.079	0.508	2.937	62.548	2.693	16.273	17.463	0.000	0.971	0.052	100	
JD10-16A_Grt_1 Line 025	2.936	0.007		2.943	1.994	0.000	0.119	2.113	1.816	0.516	0.074	0.538	2.943	61.684	2.497	17.202	17.528	0.000	1.028	0.061	100	
JD10-16A_Grt_1 Line 026	2.938	0.009		2.947	1.981	0.000	0.125	2.106	1.812	0.556	0.072	0.507	2.947	61.480	2.445	16.106	18.881	0.000	1.014	0.074	100	
JD10-16A_Grt_1 Line 027	2.951	0.009		2.960	1.982	0.000	0.098	2.080	1.833	0.538	0.073	0.516	2.960	61.923	2.466	16.556	18.163	0.000	0.816	0.077	100	
JD10-16A_Grt_1 Line 028	2.930	0.023		2.953	1.983	0.000	0.110	2.093	1.844	0.498	0.077	0.534	2.953	62.444	2.622	16.935	16.859	0.000	0.940	0.200	100	
JD10-16A_Grt_1 Line 029	2.947	0.003		2.950	1.991	0.000	0.108	2.100	1.903	0.431	0.090	0.526	2.950	64.515	3.046	16.886	14.609	0.000	0.919	0.024	100	
JD10-16A_Grt_1 Line 030	2.949	0.007		2.956	1.987	0.000	0.102	2.088	1.903	0.448	0.081	0.524	2.956	64.372	2.735	16.818	15.158	0.000	0.860	0.057	100	
JD10-16A_Grt_1 Line 031	2.952	0.006		2.958	1.989	0.000	0.094	2.084	1.952	0.417	0.085	0.504	2.958	65.980	2.890	16.231	14.081	0.000	0.770	0.049	100	
JD10-16A_Grt_1 Line 032	2.939	0.003		2.942	1.998	0.000	0.118	2.116	1.946	0.366	0.096	0.533	2.942	66.149	3.279	17.093	12.442	0.000	1.009	0.028	100	
JD10-16A_Grt_1 Line 033	2.949	0.005		2.954	2.005	0.000	0.087	2.092	1.989	0.340	0.101	0.523	2.954	67.347	3.430	16.927	11.515	0.000	0.738	0.043	100	
JD10-16A_Grt_1 Line 034	2.946	0.004		2.950	2.004	0.000	0.095	2.099	2.007	0.282	0.119	0.542	2.950	68.025	4.042	17.499	9.569	0.000	0.832	0.034	100	
JD10-16A_Grt_1 Line 035	2.946	0.003		2.949	2.015	0.000	0.087	2.102	2.154	0.259	0.154	0.382	2.949	73.032	5.227	12.400	8.787	0.000	0.537	0.017	100	
JD10-16A_Grt_1 Line 036	2.929	0.003		2.932	2.026	0.000	0.110	2.136	2.225	0.223	0.183	0.301	2.932	75.890	6.229	9.737	7.601	0.000	0.531	0.013	100	
JD10-16A_Grt_1 Line 037	2.941	0.002		2.944	2.008	0.000	0.105	2.113	2.226	0.197	0.193	0.327	2.944	75.621	6.566	10.548	6.702	0.000	0.552	0.011	100	
JD10-16A_Grt_1 Line 038	2.931	0.003		2.934	2.018	0.000	0.114	2.133	2.248	0.141	0.236	0.309	2.934	76.643	8.038	9.942	4.800	0.000	0.562	0.014	100	
JD10-16A_Grt_1 Line 039	2.923	0.004		2.928	2.019	0.000	0.126	2.145	2.203	0.151	0.265	0.309	2.928	75.235	9.043	9.919	5.166	0.000	0.618	0.020	100	
JD10-16A_Grt_1 Line 040	2.916	0.001		2.917	2.039	0.000	0.127	2.166	2.139	0.201	0.286	0.290	2.917	73.340	9.800	9.368	6.905	0.000	0.582	0.005	100	

Sample	Major Elements										Total
	SiO2	TiO2	Al2O3	Cr2O3	Fe2O3	FeO	MnO	MgO	CaO		
JD10-16A_Grt_2 Line 001	36.638	0.037	20.879	0.000	1.053	33.435	2.890	2.090	2.932	99.95	
JD10-16A_Grt_2 Line 002	36.511	0.073	21.246	0.000	1.803	34.044	1.640	2.231	3.155	100.70	
JD10-16A_Grt_2 Line 003	36.258	0.072	20.995	0.000	2.259	34.091	1.496	2.129	3.137	100.44	
JD10-16A_Grt_2 Line 004	36.341	0.066	21.031	0.000	1.463	34.919	1.516	1.800	3.006	100.14	
JD10-16A_Grt_2 Line 005	36.434	0.055	21.090	0.000	1.673	35.039	1.842	1.639	2.958	100.73	
JD10-16A_Grt_2 Line 006	36.272	0.072	21.257	0.000	1.427	34.725	2.268	1.519	2.894	100.43	
JD10-16A_Grt_2 Line 007	36.298	0.064	21.138	0.000	1.739	34.061	2.872	1.380	3.147	100.70	
JD10-16A_Grt_2 Line 008	36.418	0.085	20.971	0.000	1.181	34.272	3.191	1.231	3.064	100.41	
JD10-16A_Grt_2 Line 009	36.355	0.057	20.994	0.000	1.561	33.569	3.354	1.194	3.457	100.54	
JD10-16A_Grt_2 Line 010	36.181	0.099	20.885	0.000	1.672	32.837	3.772	1.139	3.641	100.23	
JD10-16A_Grt_2 Line 011	36.093	0.076	21.032	0.000	1.606	32.204	4.127	1.028	3.911	100.08	
JD10-16A_Grt_2 Line 012	36.299	0.146	20.955	0.000	1.718	30.889	4.433	0.848	5.187	100.48	
JD10-16A_Grt_2 Line 013	36.311	0.101	20.901	0.000	1.886	30.290	4.740	0.797	5.463	100.49	
JD10-16A_Grt_2 Line 014	36.368	0.098	20.786	0.000	1.883	29.660	5.040	0.752	5.831	100.42	
JD10-16A_Grt_2 Line 015	36.254	0.122	20.899	0.000	1.823	29.066	5.636	0.711	5.791	100.30	
JD10-16A_Grt_2 Line 016	36.368	0.153	20.735	0.000	1.650	28.934	5.566	0.727	6.055	100.19	
JD10-16A_Grt_2 Line 017	36.268	0.147	20.666	0.000	1.706	29.450	5.885	0.726	5.304	100.15	
JD10-16A_Grt_2 Line 018	36.386	0.119	20.982	0.000	1.671	29.477	5.960	0.670	5.392	100.66	
JD10-16A_Grt_2 Line 019	36.273	0.114	20.860	0.000	1.833	28.755	6.053	0.681	5.758	100.33	
JD10-16A_Grt_2 Line 020	36.319	0.095	20.857	0.000	1.723	28.960	6.060	0.664	5.646	100.32	
JD10-16A_Grt_2 Line 021	36.514	0.081	20.920	0.000	1.799	29.145	5.586	0.688	6.015	100.75	
JD10-16A_Grt_2 Line 022	36.390	0.115	20.857	0.000	1.778	28.579	6.193	0.695	5.875	100.48	
JD10-16A_Grt_2 Line 023	36.250	0.103	20.853	0.000	1.718	29.196	5.531	0.717	5.747	100.12	
JD10-16A_Grt_2 Line 024	36.164	0.111	20.894	0.000	1.949	29.462	5.653	0.724	5.359	100.32	
JD10-16A_Grt_2 Line 025	36.266	0.149	20.826	0.000	2.020	29.744	5.351	0.756	5.455	100.57	
JD10-16A_Grt_2 Line 026	36.076	0.107	21.145	0.000	1.928	30.700	4.913	0.814	4.767	100.45	
JD10-16A_Grt_2 Line 027	36.101	0.086	21.111	0.000	2.209	30.905	4.197	0.888	5.079	100.58	
JD10-16A_Grt_2 Line 028	35.819	0.071	21.555	0.000	2.511	30.530	4.289	0.861	5.063	100.70	
JD10-16A_Grt_2 Line 029	36.741	0.054	20.708	0.000	1.534	31.908	3.851	1.022	4.958	100.78	
JD10-16A_Grt_2 Line 030	36.472	0.059	21.076	0.000	1.778	32.463	3.720	1.152	4.200	100.92	
JD10-16A_Grt_2 Line 031	36.340	0.046	21.128	0.000	2.089	32.956	3.391	1.234	3.829	101.01	
JD10-16A_Grt_2 Line 032	36.455	0.098	21.054	0.000	1.904	33.287	3.283	1.297	3.712	101.09	
JD10-16A_Grt_2 Line 033	36.419	0.084	21.011	0.000	1.870	33.789	3.025	1.319	3.450	100.97	
JD10-16A_Grt_2 Line 034	36.110	0.283	21.003	0.000	1.766	34.346	2.737	1.462	2.895	100.60	
JD10-16A_Grt_2 Line 035	36.331	0.136	21.237	0.000	1.942	34.330	2.570	1.498	3.093	101.14	
JD10-16A_Grt_2 Line 036	36.304	0.075	21.275	0.000	1.861	34.377	2.126	1.700	3.058	100.78	
JD10-16A_Grt_2 Line 037	36.157	0.049	21.247	0.000	2.114	33.866	2.249	1.776	3.098	100.56	
JD10-16A_Grt_2 Line 038	36.510	0.076	21.604	0.000	1.725	34.127	1.948	2.047	3.104	101.14	
JD10-16A_Grt_2 Line 039	36.480	0.072	21.362	0.000	2.160	32.874	2.403	2.375	3.235	100.96	
JD10-16A_Grt_2 Line 040	36.328	0.038	21.196	0.000	2.152	32.775	2.969	2.436	2.614	100.51	

Sample	tetrahedral 4-fold			octahedral 6-fold				cubic 8-fold														
	Si	Ti	Sum	Al	Cr	Fe+3	Sum	Fe+2	Mn	Mg	Ca	Sum	almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-Ti Gt	total		
JD10-16A_Grt_2 Line 001	2.969	0.002		2.971	1.994	0.000	0.064	2.058	2.266	0.198	0.252	0.255	2.971	76.259	8.498	8.291	6.676	0.000	0.267	0.009		100
JD10-16A_Grt_2 Line 002	2.935	0.004		2.939	2.013	0.000	0.109	2.122	2.288	0.112	0.267	0.272	2.939	77.861	9.096	8.751	3.799	0.000	0.474	0.019		100
JD10-16A_Grt_2 Line 003	2.928	0.004		2.932	1.998	0.000	0.137	2.135	2.302	0.102	0.256	0.271	2.932	78.514	8.740	8.643	3.490	0.000	0.594	0.019		100
JD10-16A_Grt_2 Line 004	2.946	0.004		2.951	2.010	0.000	0.089	2.099	2.368	0.104	0.218	0.261	2.951	80.247	7.374	8.458	3.529	0.000	0.376	0.017		100
JD10-16A_Grt_2 Line 005	2.942	0.003		2.946	2.007	0.000	0.102	2.109	2.366	0.126	0.197	0.256	2.946	80.335	6.699	8.257	4.277	0.000	0.418	0.014		100
JD10-16A_Grt_2 Line 006	2.938	0.004		2.942	2.029	0.000	0.087	2.116	2.352	0.156	0.183	0.251	2.942	79.942	6.234	8.168	5.288	0.000	0.350	0.018		100
JD10-16A_Grt_2 Line 007	2.936	0.004		2.940	2.015	0.000	0.106	2.121	2.304	0.197	0.166	0.273	2.940	78.370	5.660	8.798	6.693	0.000	0.462	0.017		100
JD10-16A_Grt_2 Line 008	2.956	0.005		2.961	2.006	0.000	0.072	2.078	2.326	0.219	0.149	0.266	2.961	78.563	5.030	8.664	7.409	0.000	0.312	0.022		100
JD10-16A_Grt_2 Line 009	2.946	0.003		2.950	2.005	0.000	0.095	2.100	2.275	0.230	0.144	0.300	2.950	77.129	4.890	9.699	7.805	0.000	0.460	0.017		100
JD10-16A_Grt_2 Line 010	2.942	0.006		2.948	2.002	0.000	0.102	2.104	2.233	0.260	0.138	0.317	2.948	75.745	4.683	10.207	8.812	0.000	0.522	0.031		100
JD10-16A_Grt_2 Line 011	2.937	0.005		2.942	2.017	0.000	0.098	2.116	2.192	0.284	0.125	0.341	2.942	74.500	4.239	11.028	9.670	0.000	0.538	0.025		100
JD10-16A_Grt_2 Line 012	2.939	0.009		2.948	2.000	0.000	0.105	2.104	2.092	0.304	0.102	0.450	2.948	70.951	3.472	14.444	10.313	0.000	0.756	0.064		100
JD10-16A_Grt_2 Line 013	2.939	0.006		2.946	1.994	0.000	0.115	2.109	2.051	0.325	0.096	0.474	2.946	69.615	3.265	15.165	11.034	0.000	0.874	0.047		100
JD10-16A_Grt_2 Line 014	2.945	0.006		2.951	1.984	0.000	0.115	2.098	2.008	0.346	0.091	0.506	2.951	68.066	3.076	16.160	11.714	0.000	0.935	0.049		100
JD10-16A_Grt_2 Line 015	2.939	0.007		2.946	1.997	0.000	0.111	2.108	1.970	0.387	0.086	0.503	2.946	66.879	2.916	16.114	13.134	0.000	0.897	0.060		100
JD10-16A_Grt_2 Line 016	2.949	0.009		2.959	1.982	0.000	0.101	2.083	1.962	0.382	0.088	0.526	2.959	66.325	2.971	16.847	12.922	0.000	0.856	0.079		100
JD10-16A_Grt_2 Line 017	2.949	0.009		2.958	1.980	0.000	0.104	2.085	2.002	0.405	0.088	0.462	2.958	67.702	2.975	14.776	13.702	0.000	0.779	0.067		100
JD10-16A_Grt_2 Line 018	2.942	0.007		2.949	2.000	0.000	0.102	2.101	1.993	0.408	0.081	0.467	2.949	67.584	2.738	15.020	13.840	0.000	0.764	0.054		100
JD10-16A_Grt_2 Line 019	2.941	0.007		2.948	1.993	0.000	0.112	2.105	1.949	0.416	0.082	0.500	2.948	66.139	2.792	16.013	14.101	0.000	0.898	0.056		100
JD10-16A_Grt_2 Line 020	2.945	0.006		2.951	1.993	0.000	0.105	2.098	1.964	0.416	0.080	0.491	2.951	66.552	2.720	15.747	14.105	0.000	0.831	0.046		100
JD10-16A_Grt_2 Line 021	2.946	0.005		2.951	1.989	0.000	0.109	2.098	1.966	0.382	0.083	0.520	2.951	66.640	2.804	16.664	12.936	0.000	0.915	0.041		100
JD10-16A_Grt_2 Line 022	2.944	0.007		2.951	1.989	0.000	0.108	2.097	1.934	0.424	0.084	0.509	2.951	65.523	2.840	16.311	14.380	0.000	0.888	0.057		100
JD10-16A_Grt_2 Line 023	2.943	0.006		2.950	1.996	0.000	0.105	2.101	1.983	0.380	0.087	0.500	2.950	67.212	2.942	16.055	12.896	0.000	0.845	0.051		100
JD10-16A_Grt_2 Line 024	2.935	0.007		2.941	1.998	0.000	0.119	2.117	1.999	0.389	0.088	0.466	2.941	67.973	2.978	14.902	13.210	0.000	0.887	0.051		100
JD10-16A_Grt_2 Line 025	2.936	0.009		2.945	1.987	0.000	0.123	2.110	2.014	0.367	0.091	0.473	2.945	68.377	3.098	15.065	12.459	0.000	0.933	0.069		100
JD10-16A_Grt_2 Line 026	2.925	0.007		2.931	2.020	0.000	0.118	2.138	2.081	0.337	0.098	0.414	2.931	71.009	3.356	13.308	11.509	0.000	0.775	0.043		100
JD10-16A_Grt_2 Line 027	2.921	0.005		2.926	2.013	0.000	0.134	2.148	2.091	0.288	0.107	0.440	2.926	71.464	3.660	14.070	9.829	0.000	0.940	0.037		100
JD10-16A_Grt_2 Line 028	2.893	0.004		2.898	2.052	0.000	0.153	2.205	2.062	0.293	0.104	0.438	2.898	71.173	3.578	14.047	10.127	0.000	1.045	0.030		100
JD10-16A_Grt_2 Line 029	2.965	0.003		2.969	1.970	0.000	0.093	2.063	2.154	0.263	0.123	0.429	2.969	72.548	4.142	13.768	8.868	0.000	0.651	0.023		100
JD10-16A_Grt_2 Line 030	2.941	0.004		2.945	2.003	0.000	0.108	2.111	2.189	0.254	0.138	0.363	2.945	74.345	4.703	11.673	8.629	0.000	0.629	0.021		100
JD10-16A_Grt_2 Line 031	2.930	0.003		2.933	2.008	0.000	0.127	2.134	2.222	0.232	0.148	0.331	2.933	75.768	5.057	10.595	7.896	0.000	0.669	0.015		100
JD10-16A_Grt_2 Line 032	2.937	0.006		2.943	1.999	0.000	0.115	2.114	2.243	0.224	0.156	0.320	2.943	76.207	5.293	10.264	7.612	0.000	0.593	0.030		100
JD10-16A_Grt_2 Line 033	2.939	0.005		2.944	1.998	0.000	0.114	2.112	2.280	0.207	0.159	0.298	2.944	77.455	5.390	9.564	7.023	0.000	0.544	0.024		100
JD10-16A_Grt_2 Line 034	2.926	0.017		2.943	2.006	0.000	0.108	2.113	2.327	0.188	0.177	0.251	2.943	79.078	6.000	8.039	6.382	0.000	0.431	0.069		100
JD10-16A_Grt_2 Line 035	2.925	0.008		2.934	2.015	0.000	0.118	2.133	2.312	0.175	0.180	0.267	2.934	78.800	6.129	8.561	5.975	0.000	0.500	0.035		100
JD10-16A_Grt_2 Line 036	2.928	0.005		2.932	2.022	0.000	0.113	2.135	2.319	0.145	0.204	0.264	2.932	79.067	6.970	8.516	4.952	0.000	0.476	0.019		100
JD10-16A_Grt_2 Line 037	2.921	0.003		2.924	2.023	0.000	0.129	2.152	2.288	0.154	0.214	0.268	2.924	78.251	7.315	8.611	5.263	0.000	0.547	0.013		100
JD10-16A_Grt_2 Line 038	2.924	0.005		2.928	2.039	0.000	0.104	2.143	2.286	0.132	0.244	0.266	2.928	78.048	8.345	8.635	4.512	0.000	0.440	0.019		100
JD10-16A_Grt_2 Line 039	2.922	0.004		2.927	2.017	0.000	0.130	2.147	2.202	0.163	0.284	0.278	2.927	75.251	9.691	8.894	5.571	0.000	0.574	0.019		100
JD10-16A_Grt_2 Line 040	2.926	0.002		2.929	2.012	0.000	0.130	2.143	2.208	0.203	0.293	0.226	2.929	75.391	9.989	7.227	6.917	0.000	0.469	0.008		100

Sample	Major Elements											Total
	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO			
JD10-16A_Grt_3 Line 001	36.667	0.052	21.210	0.000	1.509	31.589	2.967	2.164	4.246			100.40
JD10-16A_Grt_3 Line 002	36.577	0.039	21.396	0.000	1.367	31.999	2.219	2.130	4.472			100.20
JD10-16A_Grt_3 Line 003	36.448	0.083	21.249	0.000	1.883	31.999	2.250	2.043	4.479			100.43
JD10-16A_Grt_3 Line 004	36.661	0.062	21.456	0.000	1.708	31.876	2.355	1.987	4.754			100.86
JD10-16A_Grt_3 Line 005	36.591	0.042	21.532	0.000	1.730	32.028	2.691	1.909	4.399			100.92
JD10-16A_Grt_3 Line 007	36.486	0.072	21.147	0.000	1.496	30.980	3.271	1.877	4.726			100.05
JD10-16A_Grt_3 Line 008	36.420	0.095	21.320	0.000	1.796	30.866	3.564	1.894	4.514			100.47
JD10-16A_Grt_3 Line 009	36.574	0.069	21.230	0.000	1.677	30.703	4.033	1.773	4.564			100.62
JD10-16A_Grt_3 Line 010	36.638	0.082	21.290	0.000	1.736	30.069	4.217	1.730	5.042			100.80
JD10-16A_Grt_3 Line 011	36.509	0.068	21.192	0.000	1.644	29.578	5.269	1.555	4.707			100.52
JD10-16A_Grt_3 Line 012	36.475	0.134	21.204	0.000	1.995	29.067	5.432	1.568	4.974			100.85
JD10-16A_Grt_3 Line 013	36.346	0.111	21.216	0.000	1.002	27.323	6.159	1.173	6.173			99.50
JD10-16A_Grt_3 Line 014	36.615	0.090	21.203	0.000	1.596	26.270	6.612	0.981	7.141			100.51
JD10-16A_Grt_3 Line 015	36.480	0.048	21.003	0.000	2.095	26.841	6.421	0.959	6.721			100.57
JD10-16A_Grt_3 Line 016	36.419	0.102	21.053	0.000	1.876	26.615	6.422	0.979	6.850			100.32
JD10-16A_Grt_3 Line 017	36.377	0.142	21.105	0.000	2.141	26.530	6.271	1.001	6.994			100.56
JD10-16A_Grt_3 Line 018	36.502	0.207	20.979	0.000	1.585	27.683	6.009	0.922	6.573			100.46
JD10-16A_Grt_3 Line 019	36.416	0.150	20.933	0.000	1.619	27.514	5.761	0.879	6.841			100.11
JD10-16A_Grt_3 Line 020	36.469	0.138	21.059	0.000	1.807	28.140	5.837	0.876	6.337			100.66
JD10-16A_Grt_3 Line 021	36.423	0.148	21.011	0.000	1.661	28.228	5.879	0.853	6.231			100.43
JD10-16A_Grt_3 Line 022	36.193	0.325	20.981	0.000	1.580	28.732	6.116	0.871	5.535			100.33
JD10-16A_Grt_3 Line 023	36.294	0.222	21.002	0.000	1.725	27.830	6.130	0.757	6.409			100.37
JD10-16A_Grt_3 Line 024	36.414	0.257	20.996	0.000	1.225	28.599	6.712	0.824	5.392			100.42
JD10-16A_Grt_3 Line 025	36.489	0.203	20.960	0.000	1.415	28.567	6.595	0.805	5.568			100.60
JD10-16A_Grt_3 Line 026	36.362	0.456	21.041	0.000	1.466	28.016	7.303	0.777	5.536			100.96
JD10-16A_Grt_3 Line 027	36.580	0.205	20.957	0.000	1.419	27.865	7.095	0.787	5.832			100.74
JD10-16A_Grt_3 Line 028	36.229	0.277	20.784	0.000	1.479	27.513	7.561	0.795	5.450			100.09
JD10-16A_Grt_3 Line 029	36.500	0.217	20.873	0.000	1.311	28.210	7.725	0.767	5.026			100.63
JD10-16A_Grt_3 Line 030	36.259	0.264	20.743	0.000	1.869	27.241	7.955	0.733	5.456			100.52
JD10-16A_Grt_3 Line 031	36.523	0.208	20.862	0.000	1.336	27.886	7.724	0.739	5.334			100.61
JD10-16A_Grt_3 Line 032	36.556	0.216	20.725	0.000	1.439	27.639	7.585	0.795	5.595			100.55
JD10-16A_Grt_3 Line 033	36.369	0.348	20.894	0.000	1.414	27.893	7.380	0.846	5.406			100.55
JD10-16A_Grt_3 Line 034	36.355	0.304	20.825	0.000	1.242	27.992	7.367	0.755	5.422			100.26
JD10-16A_Grt_3 Line 035	36.605	0.178	20.692	0.000	1.406	28.239	7.686	0.808	5.048			100.66
JD10-16A_Grt_3 Line 036	36.382	0.178	20.932	0.000	1.905	27.615	7.665	0.837	5.303			100.82
JD10-16A_Grt_3 Line 037	36.350	0.224	20.863	0.000	1.831	27.686	7.147	0.813	5.693			100.61
JD10-16A_Grt_3 Line 038	36.541	0.235	21.008	0.000	1.752	28.113	7.086	0.869	5.516			101.12
JD10-16A_Grt_3 Line 039	36.469	0.309	20.723	0.000	1.654	28.194	7.083	0.855	5.459			100.75
JD10-16A_Grt_3 Line 040	36.340	0.171	20.926	0.000	2.298	27.469	6.710	0.925	6.005			100.84
JD10-16A_Grt_3 Line 041	36.342	0.300	20.910	0.000	1.985	28.259	6.723	0.886	5.525			100.93
JD10-16A_Grt_3 Line 042	36.340	0.220	20.839	0.000	2.187	28.248	6.585	0.850	5.635			100.90
JD10-16A_Grt_3 Line 043	36.434	0.207	21.004	0.000	1.808	28.733	6.548	0.865	5.343			100.94
JD10-16A_Grt_3 Line 044	36.289	0.189	20.886	0.000	2.307	28.344	6.428	0.867	5.591			100.90
JD10-16A_Grt_3 Line 045	36.492	0.097	21.121	0.000	2.105	27.717	6.149	0.867	6.426			100.97
JD10-16A_Grt_3 Line 046	36.568	0.206	20.986	0.000	1.928	27.785	6.336	0.956	6.249			101.01
JD10-16A_Grt_3 Line 047	36.469	0.062	20.999	0.000	2.370	26.851	6.414	0.925	6.766			100.86
JD10-16A_Grt_3 Line 048	36.475	0.435	20.901	0.000	1.707	27.980	6.393	1.113	5.907			100.91
JD10-16A_Grt_3 Line 049	36.403	0.430	20.949	0.000	1.766	27.332	6.435	1.155	6.250			100.72
JD10-16A_Grt_3 Line 050	36.503	0.307	20.940	0.000	2.272	26.592	5.902	1.196	7.199			100.91
JD10-16A_Grt_3 Line 051	36.638	0.137	21.140	0.000	1.810	28.509	5.844	1.388	5.488			100.95
JD10-16A_Grt_3 Line 052	36.623	0.101	21.169	0.000	2.026	30.131	5.134	1.691	4.323			101.20
JD10-16A_Grt_3 Line 053	36.697	0.098	21.271	0.000	1.847	31.139	4.067	1.820	4.267			101.21
JD10-16A_Grt_3 Line 054	36.593	0.059	21.219	0.000	1.687	31.390	3.369	1.966	4.295			100.58
JD10-16A_Grt_3 Line 055	36.685	0.087	21.319	0.000	1.523	31.915	3.002	2.035	4.185			100.75
JD10-16A_Grt_3 Line 056	36.739	0.090	21.469	0.000	1.879	31.829	2.798	2.231	4.193			101.23
JD10-16A_Grt_3 Line 057	36.619	0.047	21.579	0.000	2.003	31.092	3.022	2.112	4.615			101.09
JD10-16A_Grt_3 Line 058	36.782	0.062	21.401	0.000	1.991	31.135	2.771	2.287	4.699			101.13
JD10-16A_Grt_3 Line 059	36.740	0.051	21.623	0.000	2.209	31.053	2.478	2.197	5.073			101.42
JD10-16A_Grt_3 Line 060	36.757	0.039	21.374	0.000	1.899	30.882	2.840	2.254	4.848			100.89

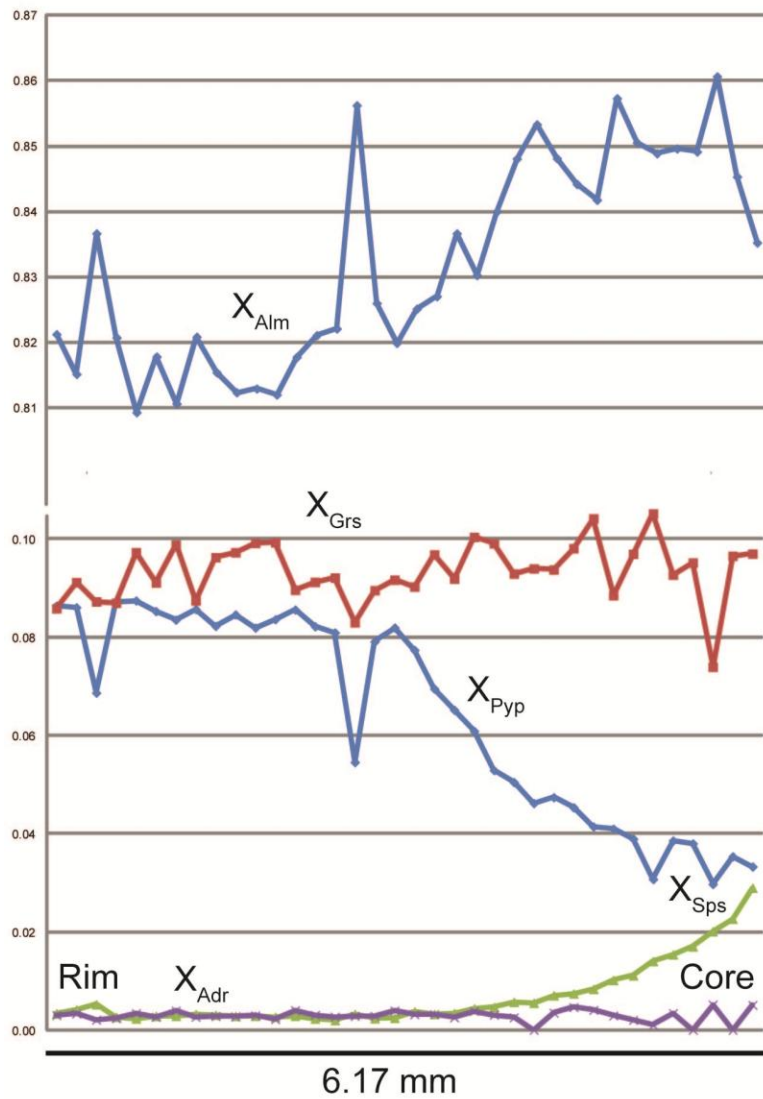
Sample	tetrahedral 4-fold			octahedral 6-fold				cubic 8-fold					almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-Ti Gt	Total
	Si	Ti	Sum	Al	Cr	Fe+3	Sum	Fe+2	Mn	Mg	Ca	Sum								
JD10-16A_Grt_3 Line 001	2.947	0.003		2.950	2.009	0.000	0.091	2.100	2.123	0.202	0.259	0.366	2.950	71.971	8.789	11.837	6.846	0.000	0.538	0.019
JD10-16A_Grt_3 Line 002	2.942	0.002		2.944	2.028	0.000	0.083	2.111	2.152	0.151	0.255	0.385	2.944	73.102	8.674	12.562	5.134	0.000	0.513	0.015
JD10-16A_Grt_3 Line 003	2.931	0.005		2.936	2.014	0.000	0.114	2.128	2.152	0.153	0.245	0.386	2.936	73.295	8.342	12.411	5.220	0.000	0.702	0.031
JD10-16A_Grt_3 Line 004	2.933	0.004		2.937	2.023	0.000	0.103	2.126	2.133	0.160	0.237	0.408	2.937	72.621	8.070	13.181	5.434	0.000	0.670	0.024
JD10-16A_Grt_3 Line 005	2.930	0.003		2.932	2.032	0.000	0.104	2.136	2.144	0.182	0.228	0.377	2.932	73.136	7.771	12.227	6.224	0.000	0.627	0.015
JD10-16A_Grt_3 Line 007	2.945	0.004		2.949	2.011	0.000	0.091	2.102	2.091	0.224	0.226	0.409	2.949	70.903	7.658	13.231	7.582	0.000	0.598	0.029
JD10-16A_Grt_3 Line 008	2.929	0.006		2.935	2.021	0.000	0.109	2.130	2.076	0.243	0.227	0.389	2.935	70.737	7.737	12.543	8.272	0.000	0.675	0.036
JD10-16A_Grt_3 Line 009	2.940	0.004		2.944	2.011	0.000	0.101	2.112	2.064	0.275	0.212	0.393	2.944	70.106	7.217	12.685	9.327	0.000	0.640	0.026
JD10-16A_Grt_3 Line 010	2.937	0.005		2.942	2.011	0.000	0.105	2.116	2.016	0.286	0.207	0.433	2.942	68.520	7.027	13.958	9.733	0.000	0.727	0.034
JD10-16A_Grt_3 Line 011	2.940	0.004		2.944	2.011	0.000	0.100	2.111	1.992	0.359	0.187	0.406	2.944	67.658	6.341	13.117	12.207	0.000	0.650	0.027
JD10-16A_Grt_3 Line 012	2.928	0.008		2.937	2.006	0.000	0.121	2.127	1.952	0.369	0.188	0.428	2.937	66.460	6.391	13.692	12.579	0.000	0.823	0.055
JD10-16A_Grt_3 Line 013	2.948	0.007		2.955	2.028	0.000	0.061	2.090	1.854	0.423	0.142	0.537	2.955	62.725	4.800	17.567	14.320	0.000	0.530	0.059
JD10-16A_Grt_3 Line 014	2.942	0.005		2.948	2.008	0.000	0.097	2.105	1.765	0.450	0.118	0.615	2.948	59.889	3.987	19.849	15.267	0.000	0.954	0.054
JD10-16A_Grt_3 Line 015	2.937	0.003		2.940	1.993	0.000	0.127	2.120	1.807	0.438	0.115	0.580	2.940	61.471	3.915	18.514	14.894	0.000	1.179	0.027
JD10-16A_Grt_3 Line 016	2.937	0.006		2.943	2.001	0.000	0.114	2.115	1.795	0.439	0.118	0.592	2.943	60.987	3.999	18.972	14.904	0.000	1.080	0.059
JD10-16A_Grt_3 Line 017	2.926	0.009		2.935	2.001	0.000	0.130	2.130	1.785	0.427	0.120	0.603	2.935	60.812	4.090	19.212	14.559	0.000	1.244	0.082
JD10-16A_Grt_3 Line 018	2.943	0.013		2.955	1.993	0.000	0.096	2.089	1.866	0.410	0.111	0.568	2.955	63.155	3.750	18.218	13.884	0.000	0.879	0.115
JD10-16A_Grt_3 Line 019	2.944	0.009		2.953	1.995	0.000	0.098	2.093	1.860	0.395	0.106	0.593	2.953	62.989	3.587	19.038	13.358	0.000	0.940	0.087
JD10-16A_Grt_3 Line 020	2.937	0.008		2.946	1.999	0.000	0.110	2.109	1.895	0.398	0.105	0.547	2.946	64.347	3.571	17.531	13.518	0.000	0.960	0.073
JD10-16A_Grt_3 Line 021	2.941	0.009		2.950	1.999	0.000	0.101	2.100	1.906	0.402	0.103	0.539	2.950	64.616	3.481	17.321	13.630	0.000	0.874	0.078
JD10-16A_Grt_3 Line 022	2.931	0.020		2.951	2.002	0.000	0.096	2.099	1.946	0.419	0.105	0.480	2.951	65.944	3.564	15.383	14.217	0.000	0.740	0.152
JD10-16A_Grt_3 Line 023	2.934	0.013		2.947	2.001	0.000	0.105	2.106	1.881	0.420	0.091	0.555	2.947	63.832	3.095	17.781	14.240	0.000	0.933	0.120
JD10-16A_Grt_3 Line 024	2.946	0.016		2.962	2.002	0.000	0.075	2.077	1.935	0.460	0.099	0.467	2.962	65.333	3.356	15.101	15.530	0.000	0.563	0.118
JD10-16A_Grt_3 Line 025	2.947	0.012		2.959	1.995	0.000	0.086	2.081	1.930	0.451	0.097	0.482	2.959	65.199	3.275	15.516	15.245	0.000	0.669	0.096
JD10-16A_Grt_3 Line 026	2.929	0.028		2.957	1.998	0.000	0.089	2.086	1.887	0.498	0.093	0.478	2.957	63.832	3.156	15.269	16.852	0.000	0.679	0.211
JD10-16A_Grt_3 Line 027	2.949	0.012		2.961	1.991	0.000	0.086	2.077	1.879	0.484	0.095	0.504	2.961	63.437	3.194	16.208	16.359	0.000	0.701	0.101
JD10-16A_Grt_3 Line 028	2.943	0.017		2.960	1.990	0.000	0.090	2.080	1.869	0.520	0.096	0.474	2.960	63.146	3.253	15.205	17.576	0.000	0.691	0.129
JD10-16A_Grt_3 Line 029	2.952	0.013		2.965	1.990	0.000	0.080	2.069	1.908	0.529	0.092	0.436	2.965	64.347	3.119	14.032	17.847	0.000	0.563	0.093
JD10-16A_Grt_3 Line 030	2.937	0.016		2.953	1.980	0.000	0.114	2.094	1.845	0.546	0.089	0.473	2.953	62.487	2.997	15.046	18.482	0.000	0.866	0.122
JD10-16A_Grt_3 Line 031	2.953	0.013		2.965	1.988	0.000	0.081	2.069	1.885	0.529	0.089	0.462	2.965	63.579	3.004	14.878	17.836	0.000	0.608	0.095
JD10-16A_Grt_3 Line 032	2.956	0.013		2.969	1.975	0.000	0.088	2.062	1.869	0.519	0.096	0.485	2.969	62.950	3.228	15.534	17.497	0.000	0.689	0.103
JD10-16A_Grt_3 Line 033	2.940	0.021		2.962	1.991	0.000	0.086	2.077	1.886	0.505	0.102	0.468	2.962	63.680	3.443	15.004	17.065	0.000	0.648	0.159
JD10-16A_Grt_3 Line 034	2.948	0.019		2.967	1.990	0.000	0.076	2.066	1.898	0.506	0.091	0.471	2.967	63.988	3.077	15.161	17.056	0.000	0.577	0.141
JD10-16A_Grt_3 Line 035	2.960	0.011		2.971	1.972	0.000	0.086	2.058	1.910	0.526	0.097	0.437	2.971	64.280	3.279	14.035	17.720	0.000	0.609	0.077
JD10-16A_Grt_3 Line 036	2.936	0.011		2.947	1.991	0.000	0.116	2.106	1.864	0.524	0.101	0.459	2.947	63.244	3.417	14.630	17.779	0.000	0.850	0.079
JD10-16A_Grt_3 Line 037	2.937	0.014		2.951	1.987	0.000	0.111	2.098	1.871	0.489	0.098	0.493	2.951	63.402	3.319	15.715	16.577	0.000	0.880	0.108
JD10-16A_Grt_3 Line 038	2.938	0.014		2.952	1.990	0.000	0.106	2.096	1.890	0.482	0.104	0.475	2.952	64.030	3.528	15.179	16.346	0.000	0.808	0.108
JD10-16A_Grt_3 Line 039	2.945	0.019		2.964	1.972	0.000	0.101	2.073	1.904	0.484	0.103	0.472	2.964	64.244	3.473	15.027	16.346	0.000	0.766	0.143
JD10-16A_Grt_3 Line 040	2.927	0.010		2.937	1.986	0.000	0.139	2.126	1.850	0.458	0.111	0.518	2.937	62.992	3.781	16.406	15.584	0.000	1.150	0.086
JD10-16A_Grt_3 Line 041	2.929	0.018		2.947	1.986	0.000	0.120	2.106	1.904	0.459	0.106	0.477	2.947	64.628	3.612	15.132	15.572	0.000	0.917	0.139
JD10-16A_Grt_3 Line 042	2.930	0.013		2.943	1.980	0.000	0.133	2.113	1.905	0.450	0.102	0.487	2.943	64.712	3.471	15.402	15.279	0.000	1.032	0.104
JD10-16A_Grt_3 Line 043	2.935	0.013		2.948	1.994	0.000	0.110	2.104	1.936	0.447	0.104	0.461	2.948	65.673	3.524	14.742	15.158	0.000	0.810	0.093
JD10-16A_Grt_3 Line 044	2.926	0.011		2.938	1.985	0.000	0.140	2.125	1.911	0.439	0.104	0.483	2.938	65.065	3.548	15.277	14.945	0.000	1.077	0.088
JD10-16A_Grt_3 Line 045	2.931	0.006		2.937	1.999	0.000	0.127	2.126	1.862	0.418	0.104	0.553	2.937	63.392	3.535	17.654	14.244	0.000	1.123	0.052
JD10-16A_Grt_3 Line 046	2.936	0.012		2.949	1.986	0.000	0.116	2.103	1.866	0.431	0.114	0.538	2.949	63.273	3.881	17.121	14.614	0.000	1.004	0.107
JD10-16A_Grt_3 Line 047	2.930	0.004		2.934	1.989	0.000	0.143	2.132	1.804	0.437	0.111	0.582	2.934	61.494	3.776	18.485	14.878	0.000	1.332	0.035
JD10-16A_Grt_3 Line 048	2.932	0.026		2.958	1.980	0.000	0.103	2.083	1.881	0.435	0.133	0.509	2.958	63.581	4.508	16.141	14.714	0.000	0.842	0.214
JD10-16A_Grt_3 Line 049	2.928	0.026		2.954	1.986	0.000	0.107	2.093	1.838	0.438	0.138	0.539	2.954	62.238	4.688	17.090	14.841	0.000	0.920	0.224
JD10-16A_Grt_3 Line 050	2.924	0.018		2.943	1.977	0.000	0.137	2.114	1.782	0.400	0.143	0.618	2.943	60.540	4.854	19.466	13.609	0.000	1.349	0.182
JD10-16A_Grt_3 Line 051	2.938	0.008		2.946	1.998	0.000	0.109	2.107	1.912	0.397	0.166	0.472	2.946	64.892	5.632	15.115	13.472	0.000	0.826	0.063
JD10-16A_Grt_3 Line 052	2.934	0.006		2.940	1.998	0.000	0.122	2.121	2.018	0.348	0.202	0.371	2.940	68.661	6.869	11.860	11.849	0.000	0.725	0.036
JD10-16A_Grt_3 Line 053	2.936	0.006		2.942	2.006	0.000	0.111	2.117	2.083	0.276	0.217	0.366	2.942	70.820	7.379	11.747	9.368	0.000	0.651	0.035
JD10-16A_Grt_3 Line 054	2.941	0.004		2.944	2.010	0.000	0.102	2.112	2.110	0.229	0.236	0.370	2.944	71.652	8.000	11.933	7.789	0.000	0.606	0.021
JD10-16A_Grt_3 Line 055	2.941	0.005		2.947	2.015	0.000	0.092	2.10												

Sample	Major Elements									Total
	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	
JD10-16A_Grt_4 Line 001	36.749	0.027	21.340	0.000	1.312	31.915	2.448	2.206	4.403	100.40
JD10-16A_Grt_4 Line 002	36.683	0.025	21.260	0.000	1.769	31.944	2.190	2.120	4.641	100.63
JD10-16A_Grt_4 Line 003	36.579	0.082	21.225	0.000	1.460	32.365	2.395	1.902	4.396	100.40
JD10-16A_Grt_4 Line 004	36.624	0.045	21.142	0.000	1.192	32.740	2.607	1.701	4.232	100.28
JD10-16A_Grt_4 Line 005	36.309	0.055	21.261	0.000	1.920	32.368	2.421	1.800	4.244	100.38
JD10-16A_Grt_4 Line 006	36.388	0.086	21.106	0.000	1.581	32.725	2.868	1.607	3.976	100.34
JD10-16A_Grt_4 Line 007	36.584	0.113	21.077	0.000	1.640	30.707	3.192	1.129	6.162	100.60
JD10-16A_Grt_4 Line 008	36.330	0.150	20.955	0.000	1.991	30.209	3.245	1.094	6.347	100.32
JD10-16A_Grt_4 Line 009	36.417	0.111	20.915	0.000	1.847	30.249	3.630	0.992	6.207	100.37
JD10-16A_Grt_4 Line 010	36.376	0.351	20.772	0.000	1.127	30.875	4.029	0.880	5.689	100.10
JD10-16A_Grt_4 Line 011	36.496	0.129	21.076	0.000	1.675	29.715	4.032	0.858	6.579	100.56
JD10-16A_Grt_4 Line 012	36.336	0.091	20.967	0.000	1.824	28.843	5.344	0.853	6.053	100.31
JD10-16A_Grt_4 Line 013	36.404	0.085	20.816	0.000	1.729	29.468	4.485	0.818	6.352	100.16
JD10-16A_Grt_4 Line 014	36.397	0.125	20.992	0.000	1.804	29.195	4.381	0.884	6.577	100.36
JD10-16A_Grt_4 Line 015	36.368	0.099	20.865	0.000	1.997	29.689	4.149	0.894	6.316	100.38
JD10-16A_Grt_4 Line 016	36.305	0.148	20.803	0.000	1.591	28.682	7.030	0.926	4.755	100.24
JD10-16A_Grt_4 Line 017	36.485	0.119	20.824	0.000	1.562	28.293	5.734	0.946	6.203	100.17
JD10-16A_Grt_4 Line 018	36.274	0.195	20.710	0.000	1.552	29.366	5.652	0.957	5.272	99.98
JD10-16A_Grt_4 Line 019	36.363	0.171	20.952	0.000	1.570	29.146	5.820	0.964	5.367	100.35
JD10-16A_Grt_4 Line 020	36.160	0.210	20.884	0.000	1.761	29.019	6.851	0.881	4.605	100.37
JD10-16A_Grt_4 Line 021	36.500	0.173	20.952	0.000	1.036	29.840	6.899	0.926	4.155	100.48
JD10-16A_Grt_4 Line 022	36.262	0.180	20.924	0.000	1.491	29.612	6.585	0.950	4.330	100.33
JD10-16A_Grt_4 Line 023	36.243	0.134	20.884	0.000	1.510	29.810	5.563	0.988	4.881	100.01
JD10-16A_Grt_4 Line 024	36.371	0.121	21.058	0.000	1.773	30.559	4.616	1.068	5.044	100.61
JD10-16A_Grt_4 Line 025	36.279	0.049	21.054	0.000	1.580	32.901	3.108	1.369	3.853	100.19
JD10-16A_Grt_4 Line 026	36.331	0.050	21.109	0.000	1.364	32.932	3.032	1.393	3.904	100.12
JD10-16A_Grt_4 Line 027	36.308	0.067	21.191	0.000	1.492	32.753	2.993	1.499	3.918	100.22
JD10-16A_Grt_4 Line 028	36.571	0.076	21.163	0.000	1.221	33.106	2.606	1.599	4.061	100.40
JD10-16A_Grt_4 Line 029	36.656	0.057	21.335	0.000	1.692	32.656	2.131	1.861	4.489	100.88
JD10-16A_Grt_4 Line 030	36.726	0.015	21.261	0.000	1.664	32.520	2.100	2.179	4.213	100.68

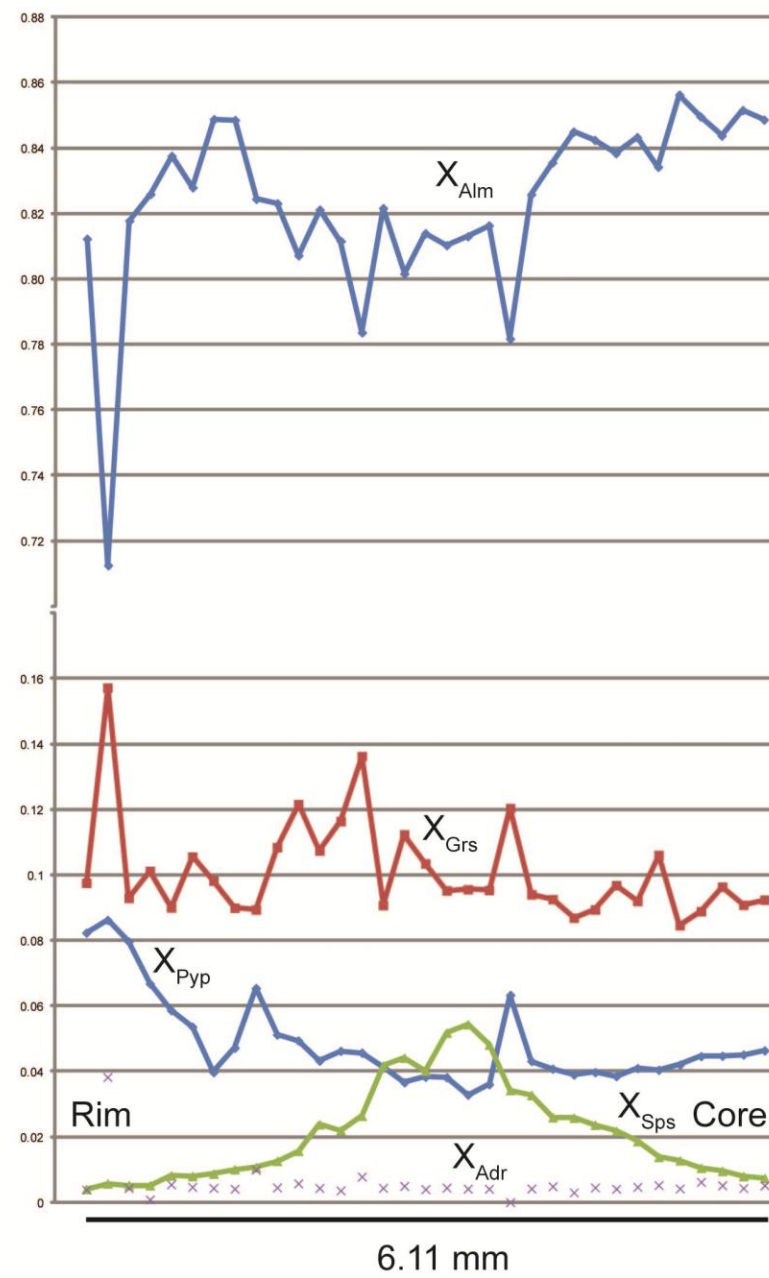
Sample	tetrahedral 4-fold			octahedral 6-fold				cubic 8-fold					almandine	pyrope	grossular	spessartine	uvarovite	andradite	Ca-TiGt	total
	Si	Ti	Sum	Al	Cr	Fe+3	Sum	Fe+2	Mn	Mg	Ca	Sum								
JD10-16A_Grt_4 Line 001	2.949	0.002	2.951	2.019	0.000	0.079	2.098	2.142	0.166	0.264	0.379	2.951	72.587	8.944	12.336	5.639	0.000	0.484	0.010	100
JD10-16A_Grt_4 Line 002	2.941	0.002	2.942	2.009	0.000	0.107	2.115	2.142	0.149	0.253	0.399	2.942	72.787	8.611	12.856	5.054	0.000	0.683	0.010	100
JD10-16A_Grt_4 Line 003	2.944	0.005	2.949	2.013	0.000	0.088	2.102	2.179	0.163	0.228	0.379	2.949	73.871	7.738	12.285	5.536	0.000	0.540	0.030	100
JD10-16A_Grt_4 Line 004	2.956	0.003	2.958	2.011	0.000	0.072	2.083	2.210	0.178	0.205	0.366	2.958	74.690	6.917	11.924	6.024	0.000	0.429	0.016	100
JD10-16A_Grt_4 Line 005	2.928	0.003	2.931	2.021	0.000	0.117	2.137	2.183	0.165	0.216	0.367	2.931	74.468	7.382	11.809	5.641	0.000	0.681	0.019	100
JD10-16A_Grt_4 Line 006	2.941	0.005	2.947	2.011	0.000	0.096	2.107	2.212	0.196	0.194	0.344	2.947	75.078	6.572	11.125	6.664	0.000	0.532	0.029	100
JD10-16A_Grt_4 Line 007	2.944	0.007	2.951	1.999	0.000	0.099	2.098	2.067	0.218	0.135	0.531	2.951	70.033	4.590	17.097	7.373	0.000	0.849	0.058	100
JD10-16A_Grt_4 Line 008	2.933	0.009	2.942	1.994	0.000	0.121	2.115	2.040	0.222	0.132	0.549	2.942	69.323	4.475	17.517	7.542	0.000	1.063	0.080	100
JD10-16A_Grt_4 Line 009	2.942	0.007	2.948	1.991	0.000	0.112	2.103	2.043	0.248	0.119	0.537	2.948	69.305	4.052	17.192	8.424	0.000	0.969	0.058	100
JD10-16A_Grt_4 Line 010	2.951	0.021	2.973	1.986	0.000	0.069	2.055	2.095	0.277	0.106	0.494	2.973	70.470	3.580	15.913	9.314	0.000	0.551	0.172	100
JD10-16A_Grt_4 Line 011	2.941	0.008	2.948	2.001	0.000	0.102	2.103	2.002	0.275	0.103	0.568	2.948	67.909	3.495	18.265	9.333	0.000	0.927	0.071	100
JD10-16A_Grt_4 Line 012	2.939	0.006	2.945	1.999	0.000	0.111	2.110	1.951	0.366	0.103	0.525	2.945	66.259	3.493	16.833	12.434	0.000	0.935	0.047	100
JD10-16A_Grt_4 Line 013	2.949	0.005	2.954	1.987	0.000	0.105	2.092	1.996	0.308	0.099	0.551	2.954	67.577	3.344	17.678	10.417	0.000	0.937	0.046	100
JD10-16A_Grt_4 Line 014	2.939	0.008	2.946	1.998	0.000	0.110	2.107	1.971	0.300	0.106	0.569	2.946	66.909	3.611	18.240	10.169	0.000	1.001	0.069	100
JD10-16A_Grt_4 Line 015	2.939	0.006	2.945	1.988	0.000	0.121	2.109	2.007	0.284	0.108	0.547	2.945	68.131	3.657	17.450	9.643	0.000	1.066	0.053	100
JD10-16A_Grt_4 Line 016	2.947	0.009	2.956	1.990	0.000	0.097	2.088	1.947	0.483	0.112	0.414	2.956	65.868	3.791	13.281	16.351	0.000	0.648	0.060	100
JD10-16A_Grt_4 Line 017	2.952	0.007	2.959	1.986	0.000	0.095	2.081	1.915	0.393	0.114	0.538	2.959	64.694	3.856	17.280	13.279	0.000	0.828	0.063	100
JD10-16A_Grt_4 Line 018	2.949	0.012	2.961	1.984	0.000	0.095	2.079	1.996	0.389	0.116	0.459	2.961	67.429	3.917	14.717	13.144	0.000	0.704	0.088	100
JD10-16A_Grt_4 Line 019	2.943	0.010	2.953	1.998	0.000	0.096	2.094	1.972	0.399	0.116	0.465	2.953	66.795	3.938	14.964	13.509	0.000	0.716	0.078	100
JD10-16A_Grt_4 Line 020	2.935	0.013	2.947	1.998	0.000	0.108	2.105	1.970	0.471	0.107	0.400	2.947	66.821	3.616	12.813	15.978	0.000	0.690	0.082	100
JD10-16A_Grt_4 Line 021	2.957	0.011	2.968	2.001	0.000	0.063	2.064	2.022	0.473	0.112	0.361	2.968	68.126	3.769	11.721	15.953	0.000	0.370	0.062	100
JD10-16A_Grt_4 Line 022	2.943	0.011	2.954	2.001	0.000	0.091	2.092	2.010	0.453	0.115	0.376	2.954	68.039	3.891	12.128	15.324	0.000	0.552	0.067	100
JD10-16A_Grt_4 Line 023	2.945	0.008	2.954	2.000	0.000	0.092	2.093	2.026	0.383	0.120	0.425	2.954	68.593	4.053	13.701	12.965	0.000	0.632	0.056	100
JD10-16A_Grt_4 Line 024	2.937	0.007	2.944	2.004	0.000	0.108	2.112	2.064	0.316	0.129	0.436	2.944	70.089	4.367	14.017	10.723	0.000	0.753	0.051	100
JD10-16A_Grt_4 Line 025	2.943	0.003	2.946	2.013	0.000	0.096	2.109	2.232	0.214	0.166	0.335	2.946	75.764	5.620	10.832	7.249	0.000	0.519	0.016	100
JD10-16A_Grt_4 Line 026	2.946	0.003	2.950	2.018	0.000	0.083	2.101	2.234	0.208	0.168	0.339	2.950	75.728	5.710	11.029	7.061	0.000	0.455	0.017	100
JD10-16A_Grt_4 Line 027	2.939	0.004	2.944	2.022	0.000	0.091	2.113	2.218	0.205	0.181	0.340	2.944	75.336	6.146	11.028	6.972	0.000	0.496	0.022	100
JD10-16A_Grt_4 Line 028	2.952	0.005	2.956	2.013	0.000	0.074	2.087	2.235	0.178	0.192	0.351	2.956	75.587	6.508	11.431	6.026	0.000	0.421	0.026	100
JD10-16A_Grt_4 Line 029	2.938	0.003	2.941	2.015	0.000	0.102	2.117	2.189	0.145	0.222	0.385	2.941	74.416	7.560	12.454	4.918	0.000	0.631	0.021	100
JD10-16A_Grt_4 Line 030	2.944	0.001	2.945	2.009	0.000	0.100	2.109	2.180	0.143	0.260	0.362	2.945	74.029	8.842	11.697	4.842	0.000	0.585	0.005	100

Appendix A1b: Transect profiles of garnet crystals

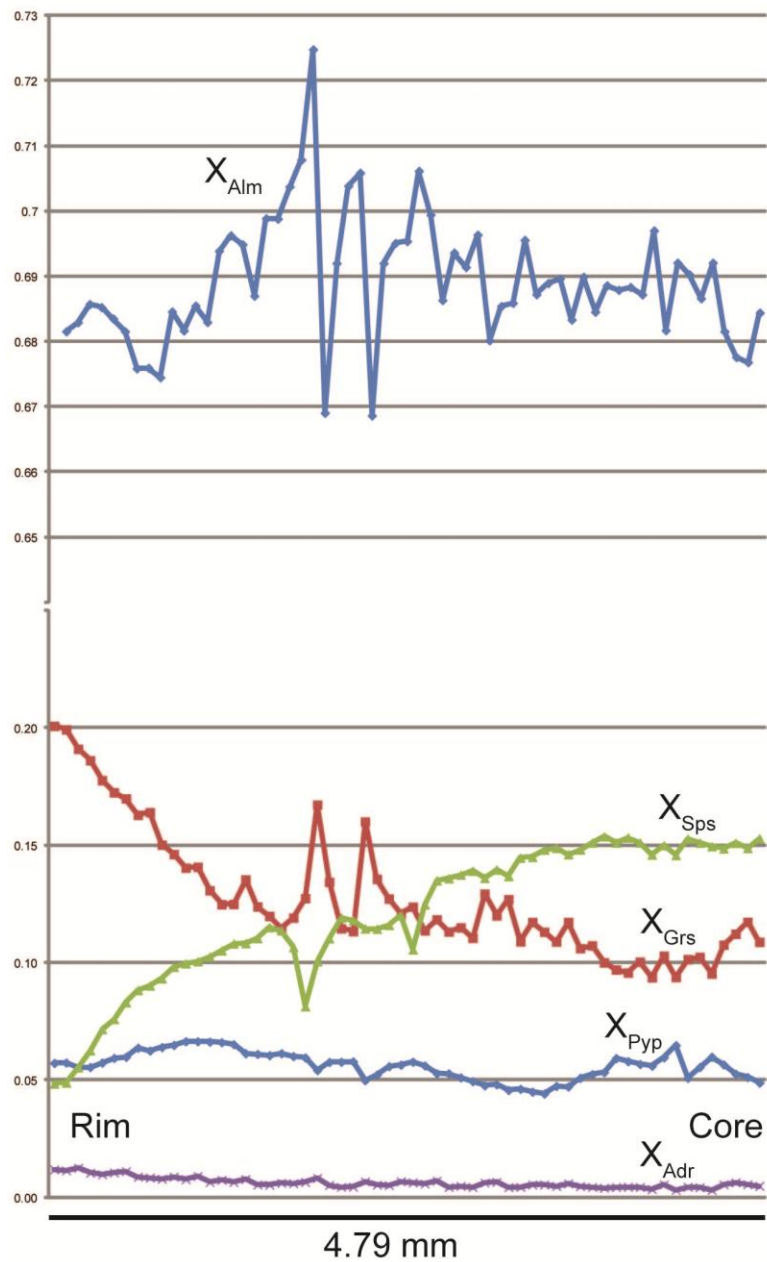
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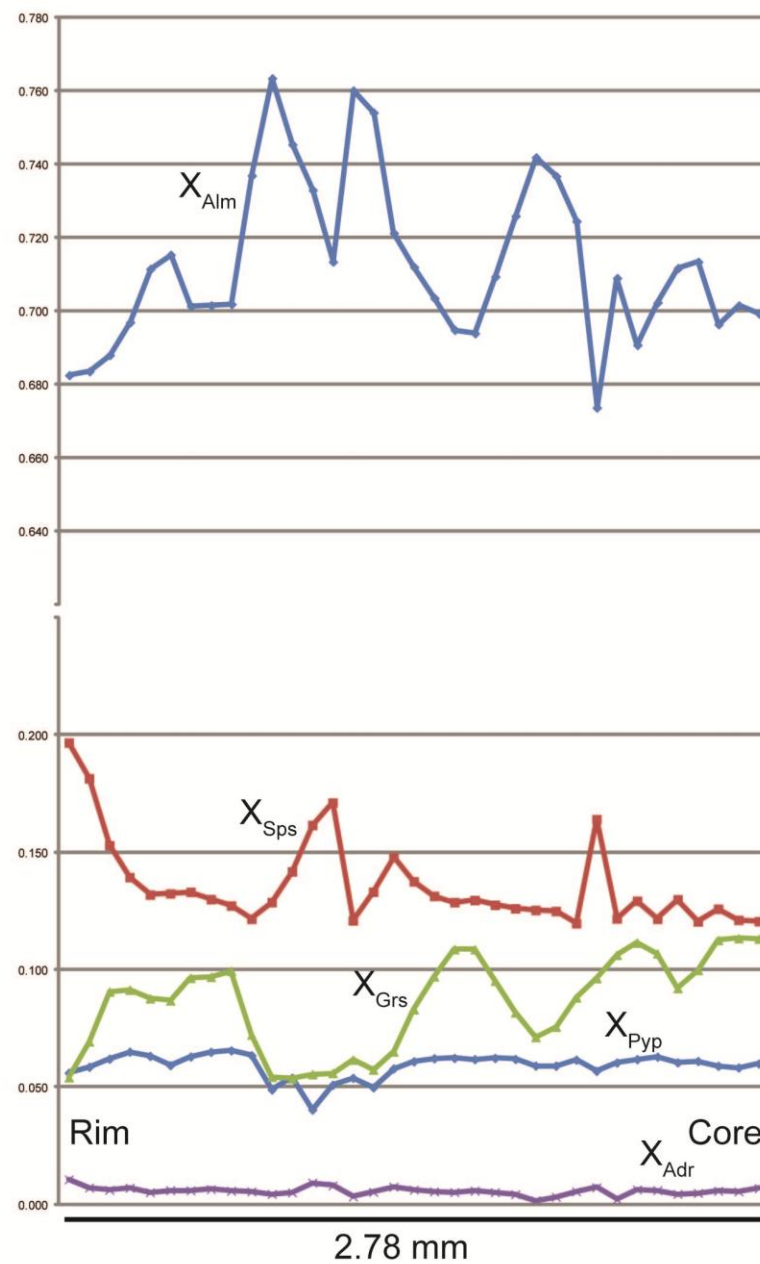
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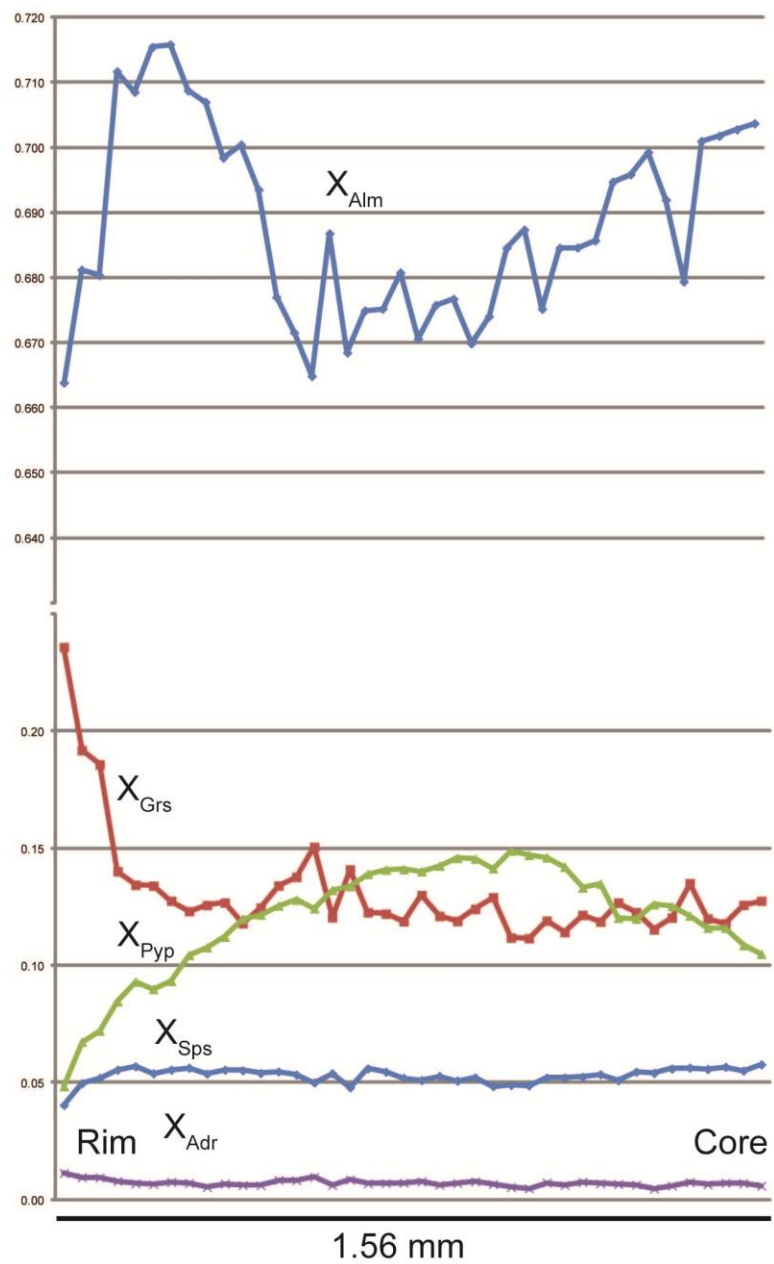
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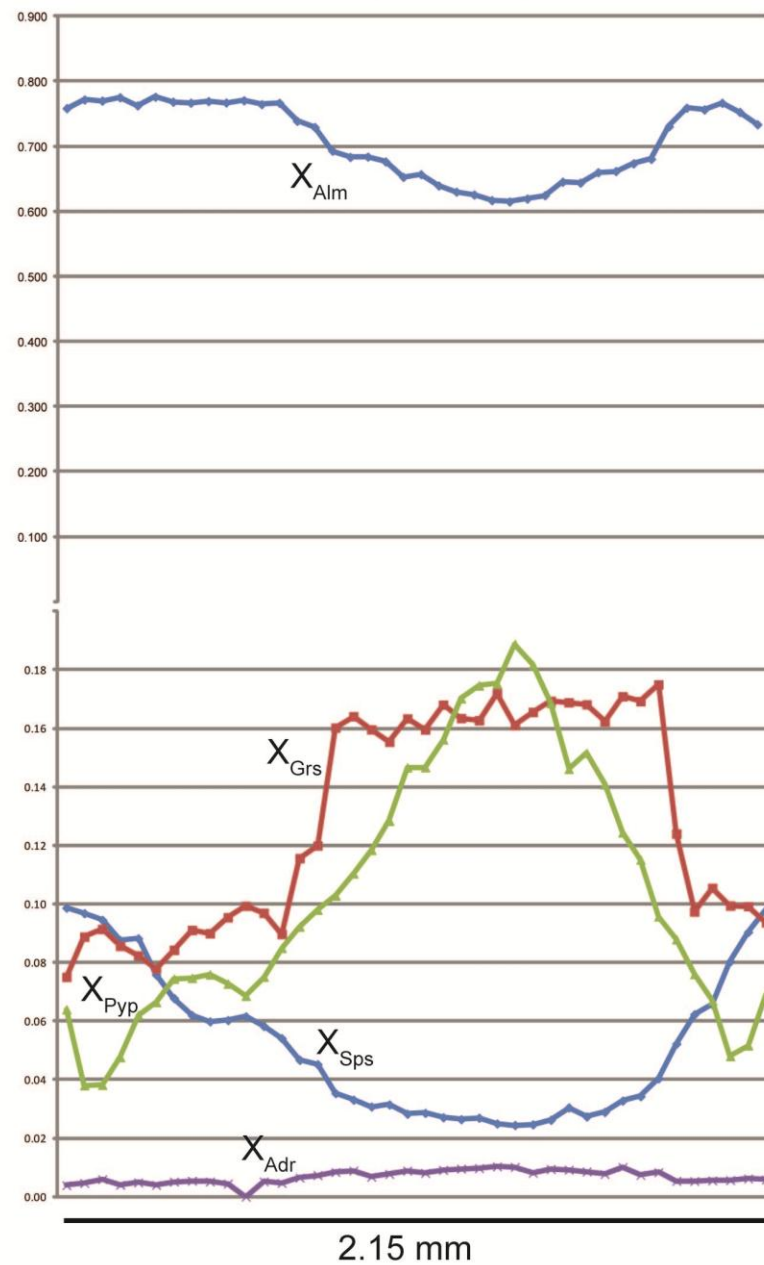
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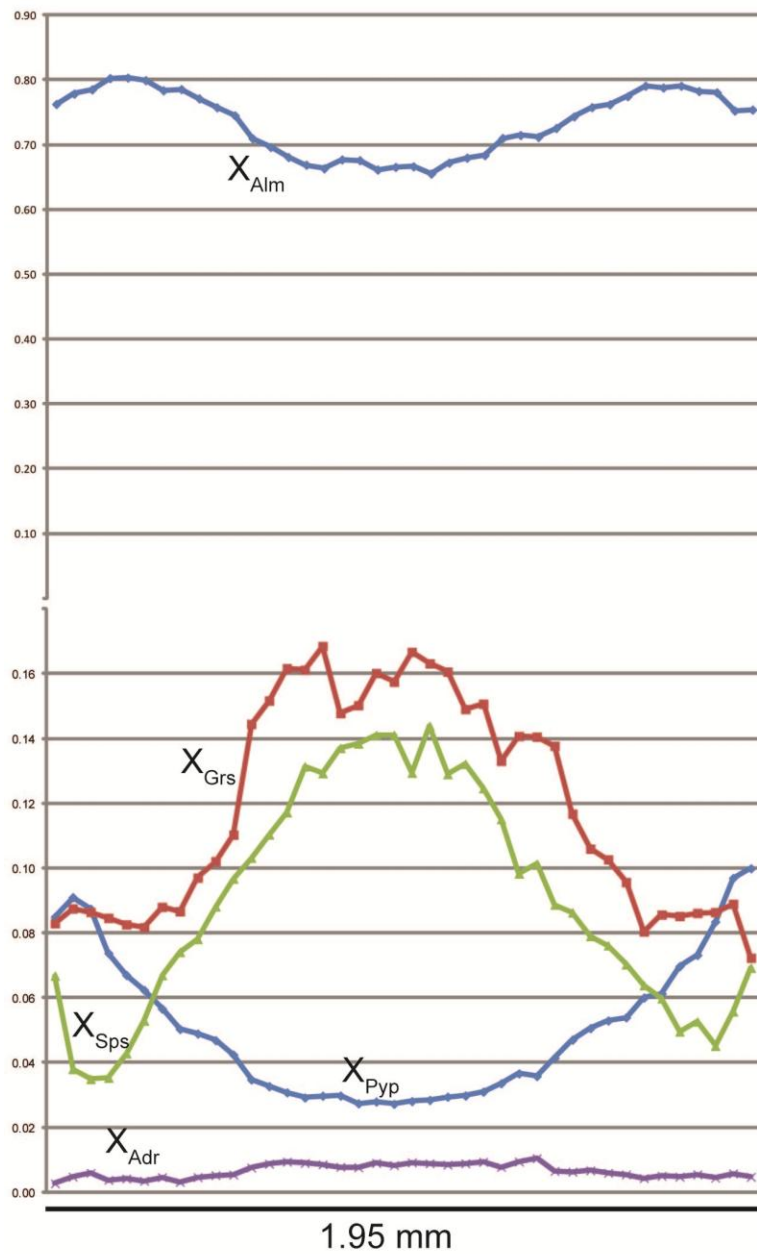
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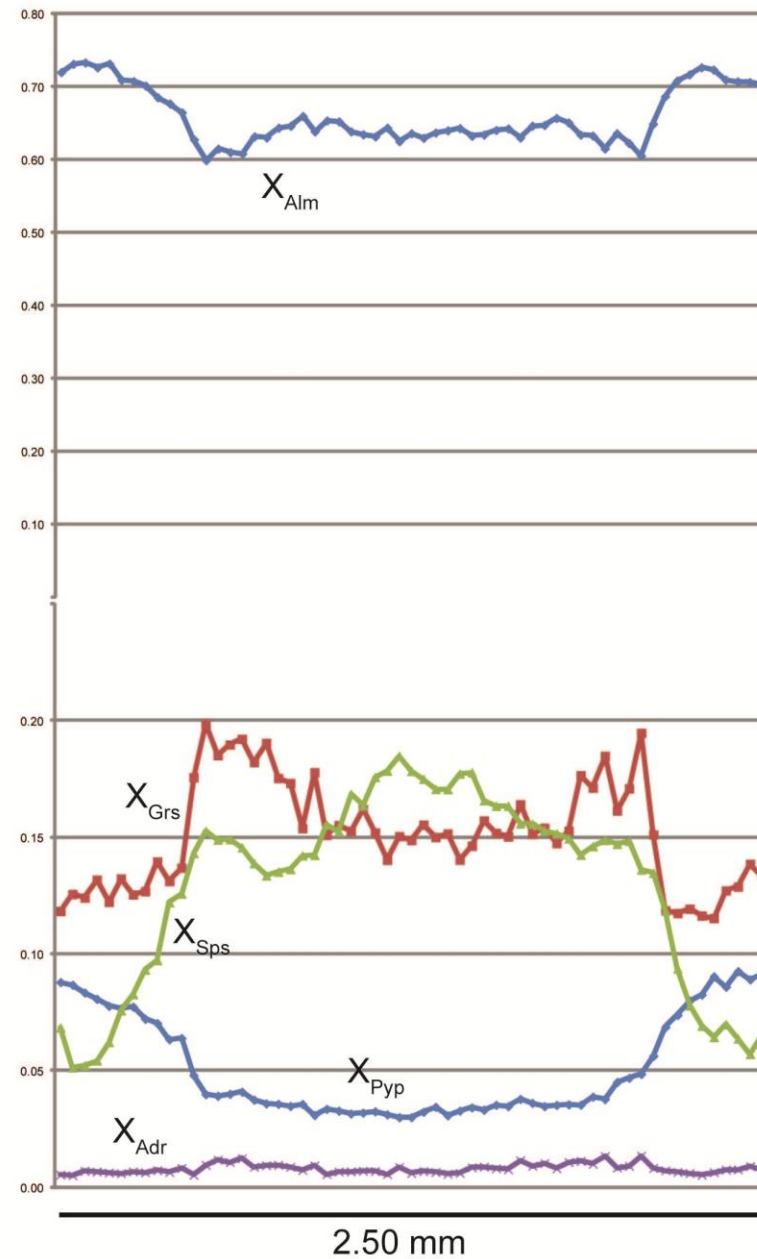
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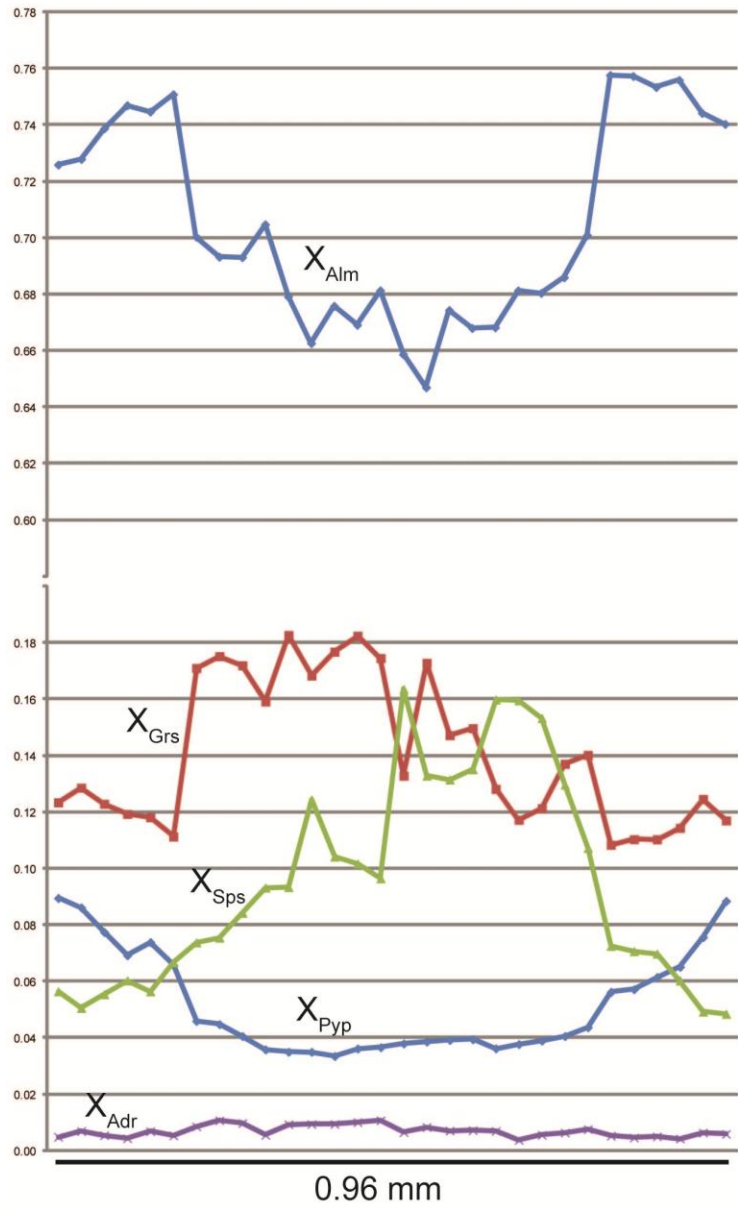
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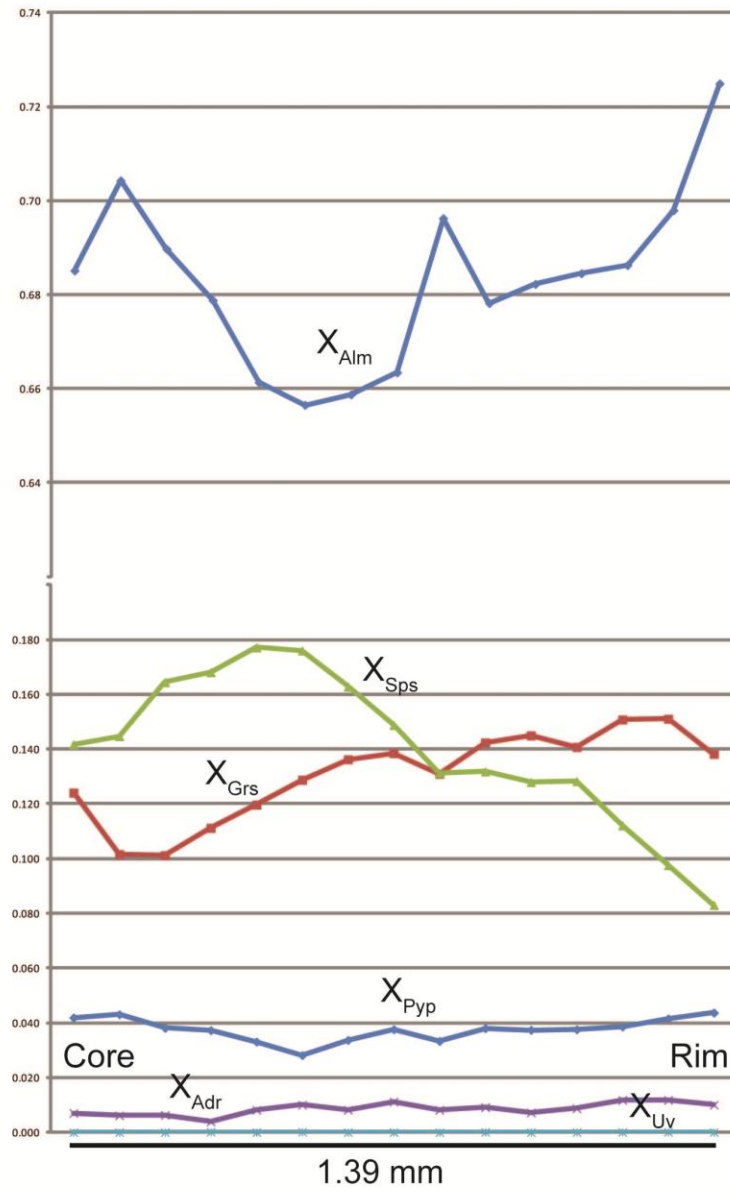
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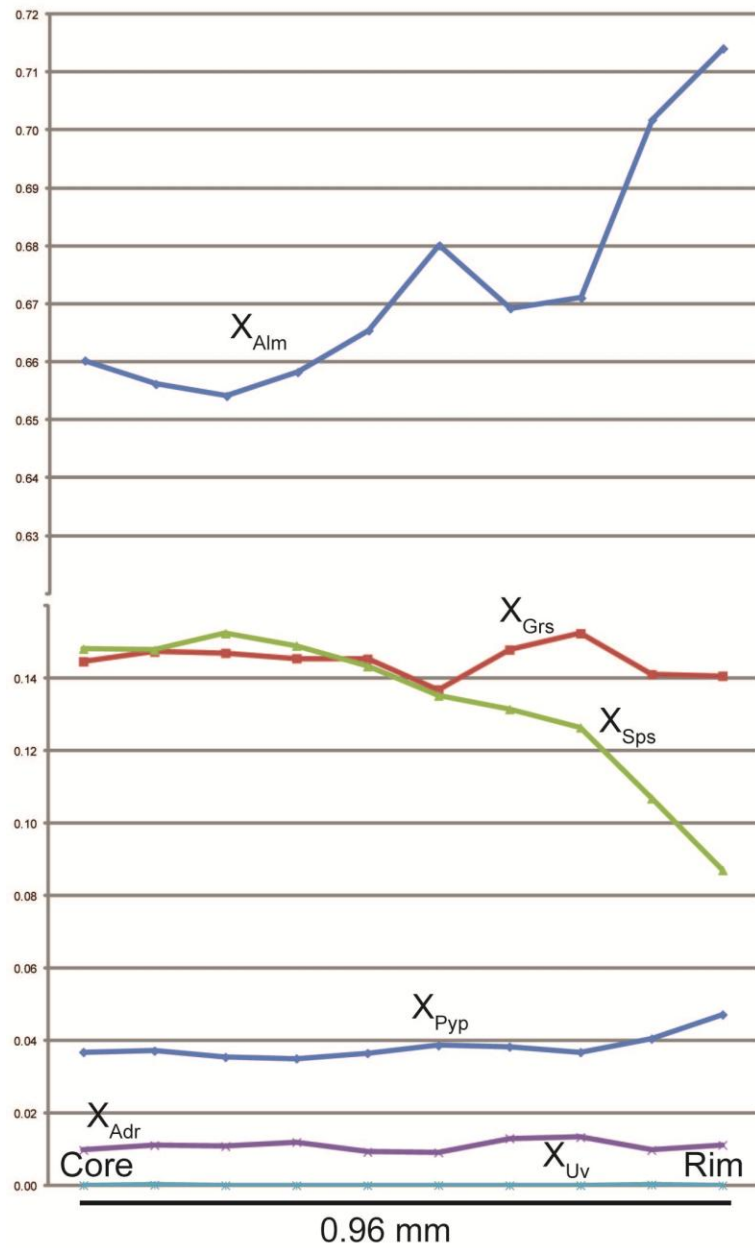
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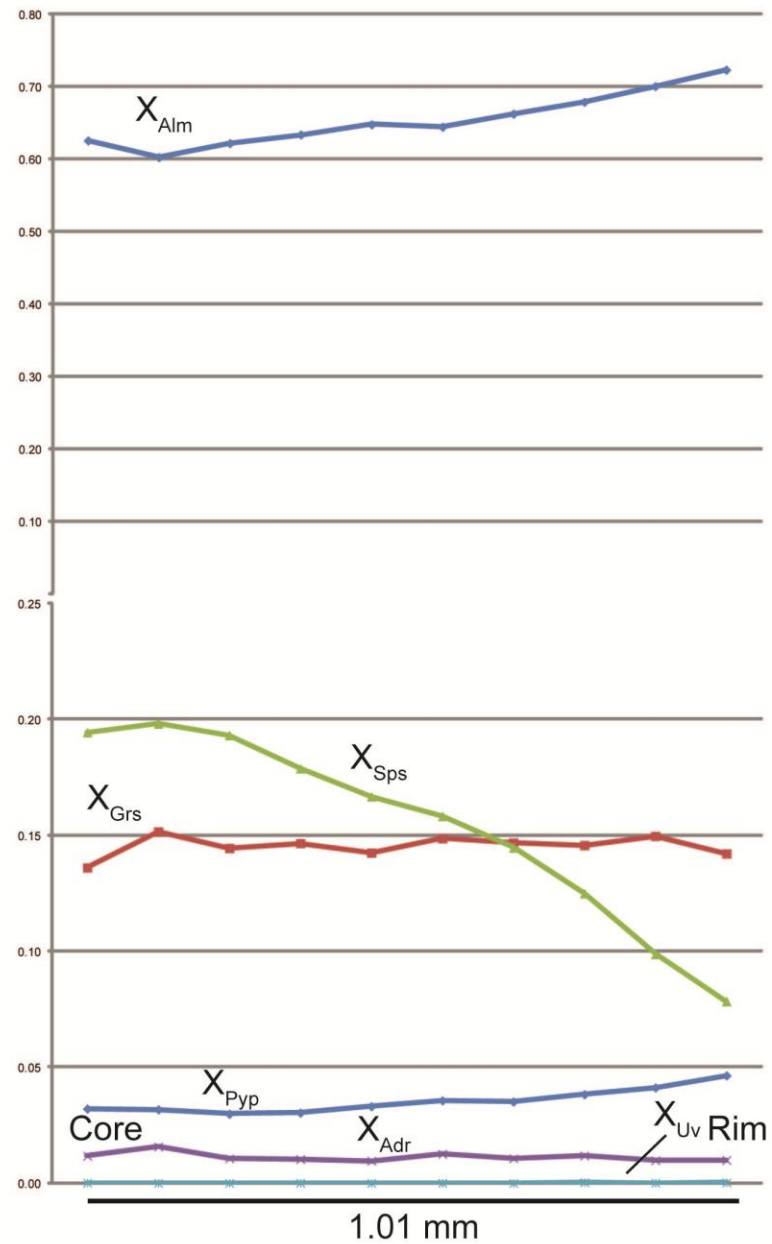
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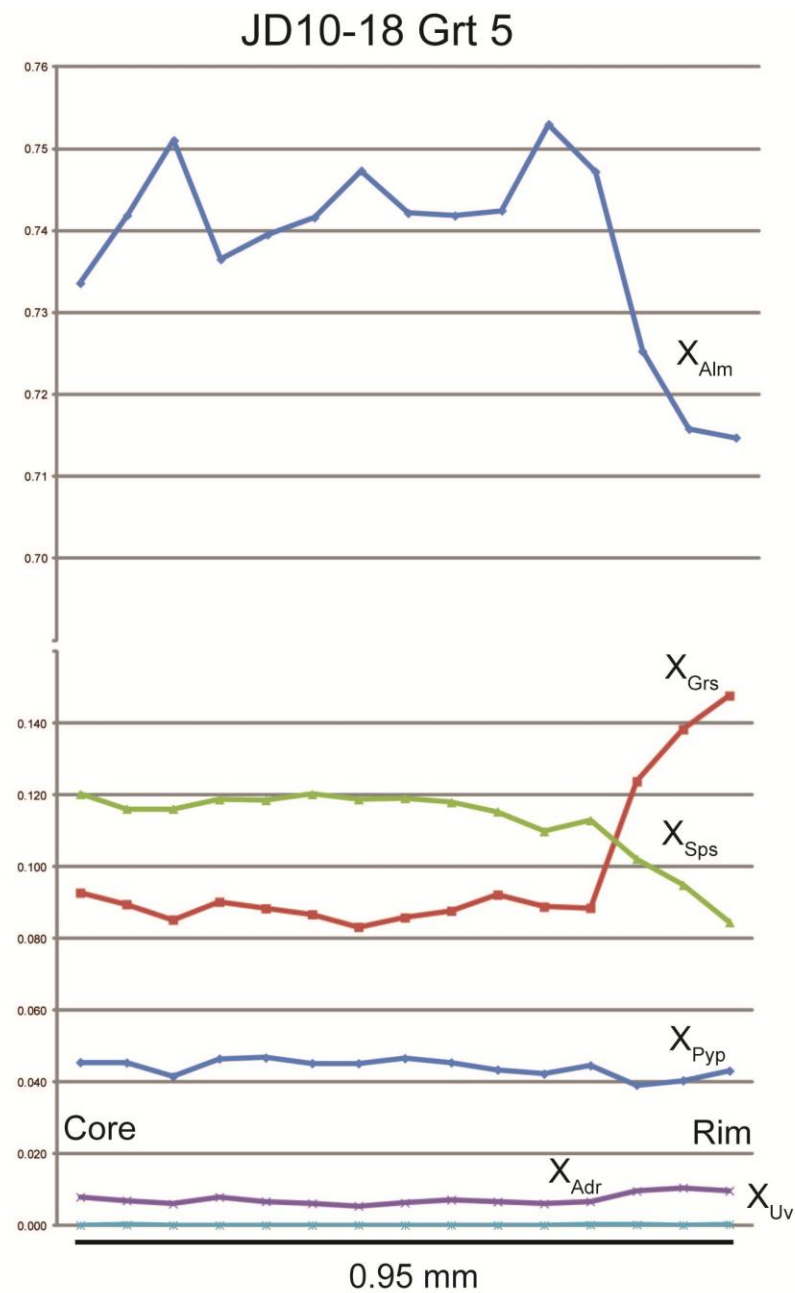
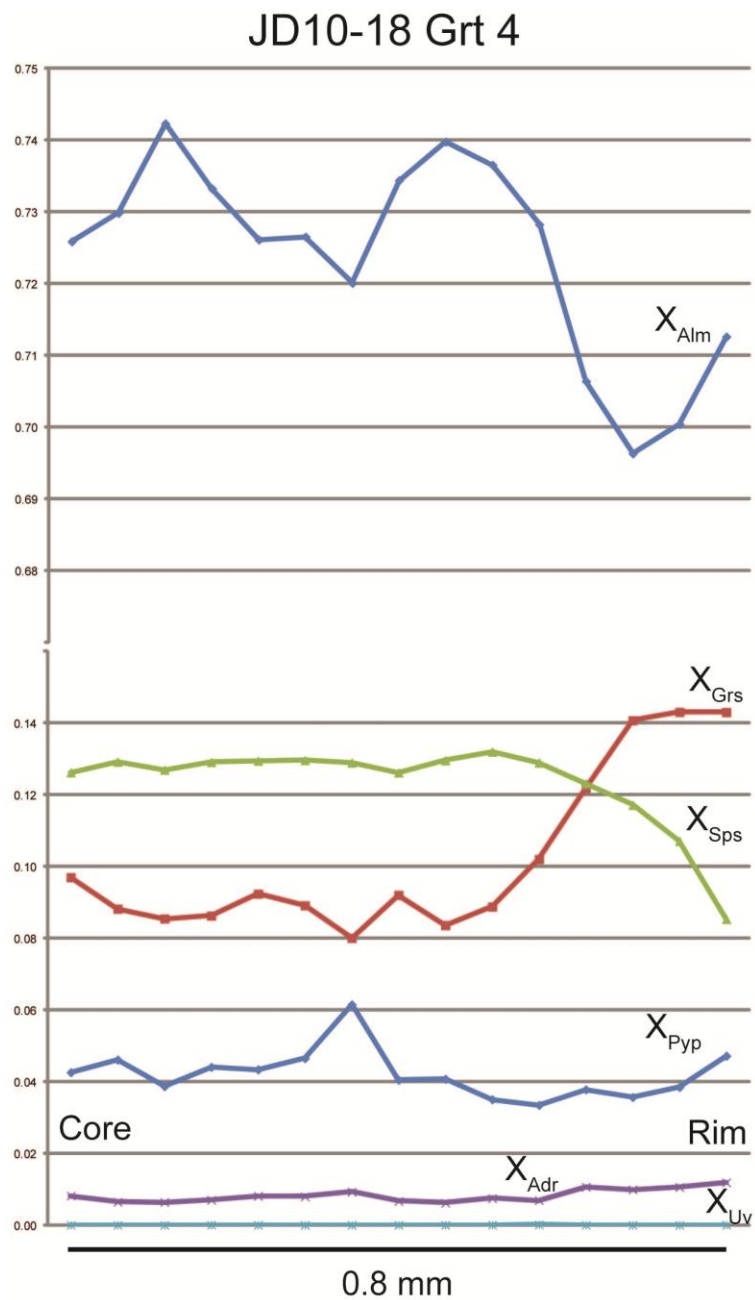


JD10-18 Grt 2

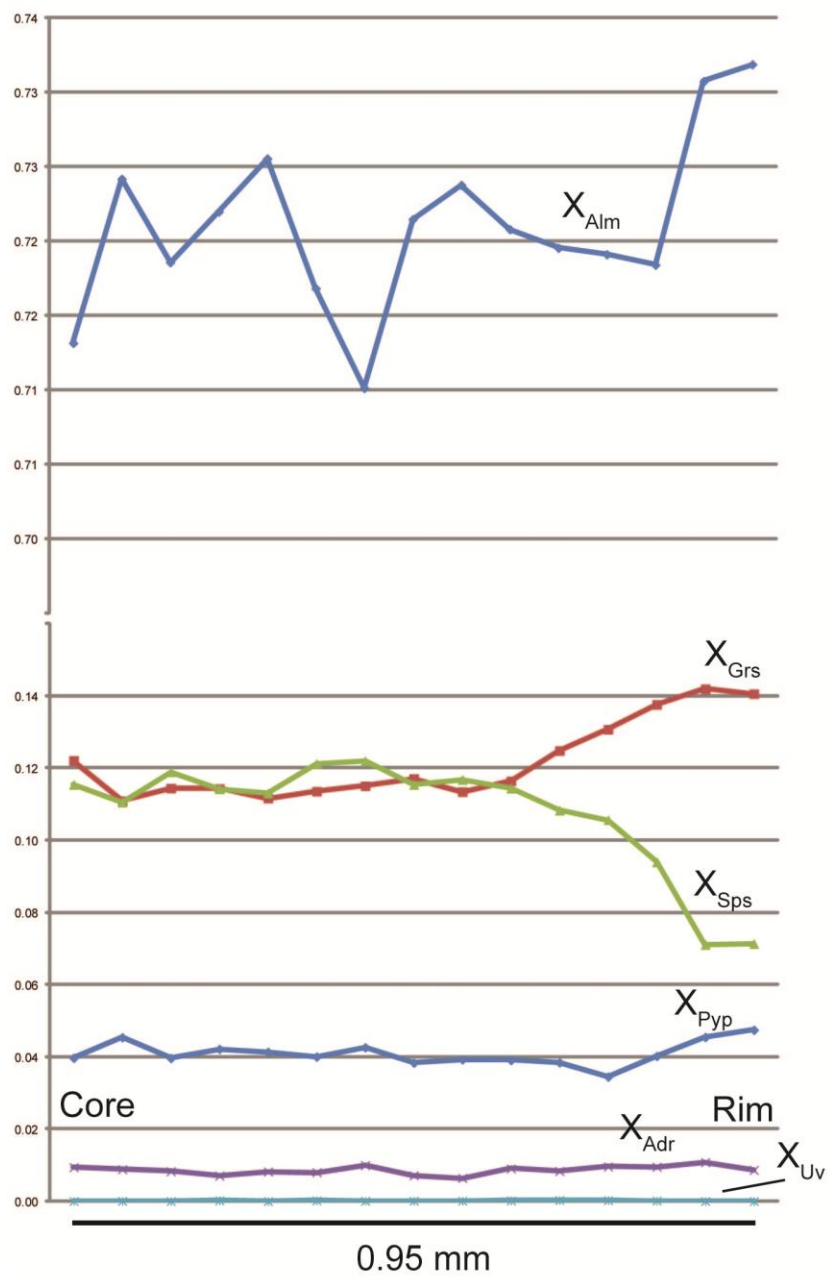


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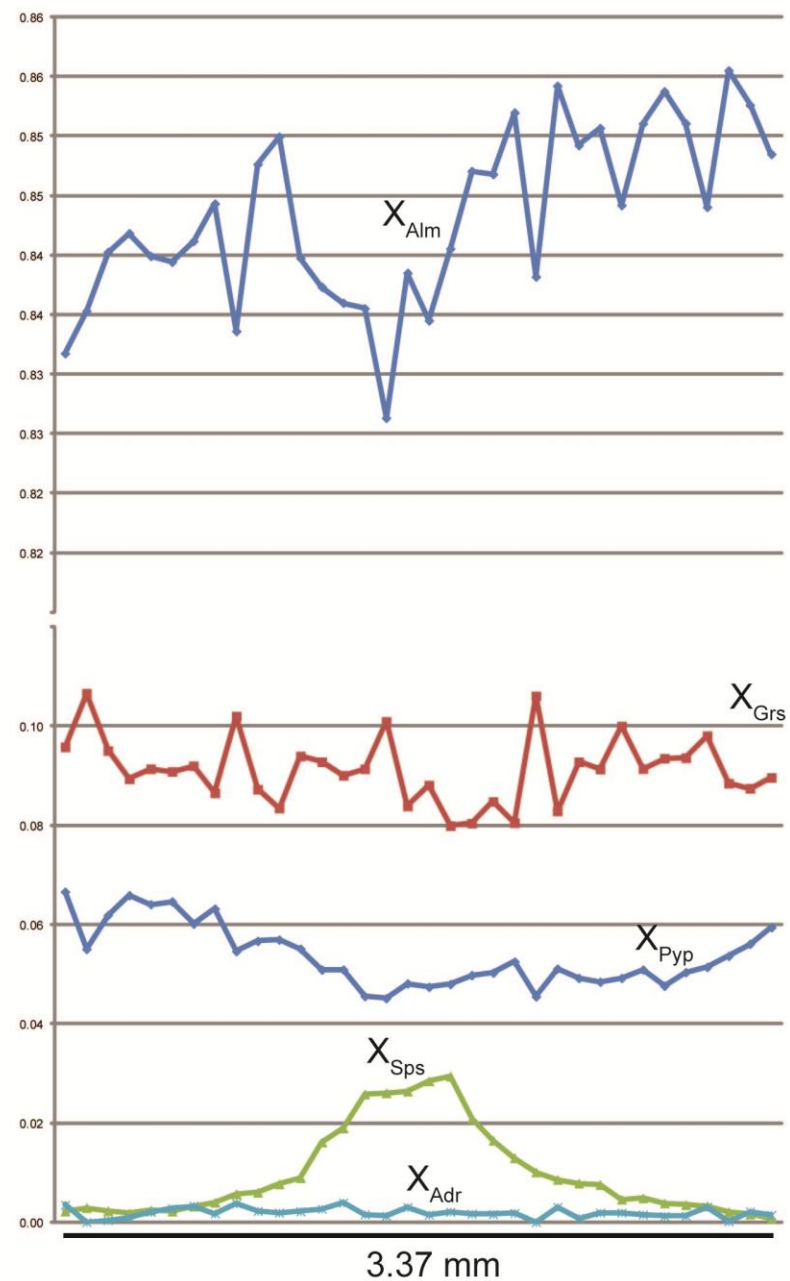


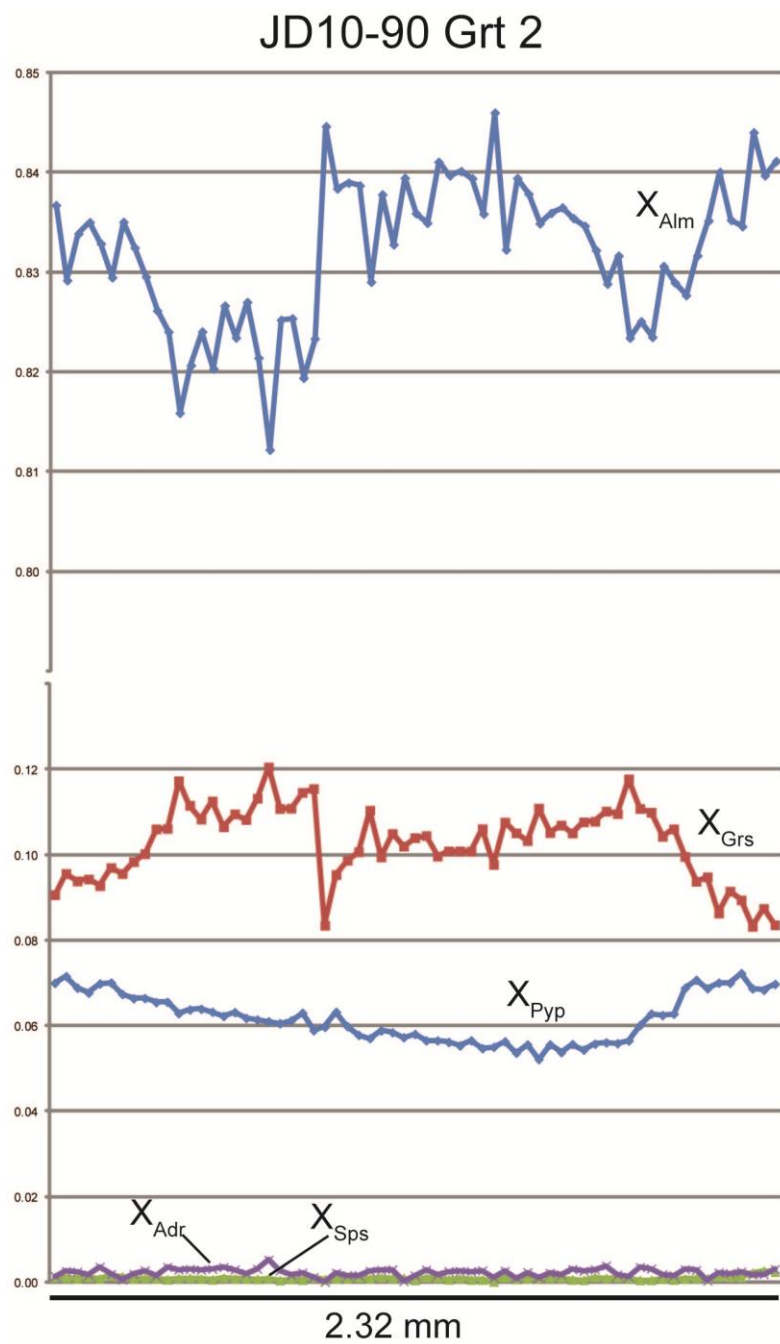


JD10-18 Grt 6



JD10-90 Grt 1





Appendix A2: Neodymium Sample Preparation and TIMS analysis

Samples used for Nd isotopic analysis were first crushed in a steel jaw crusher and then homogenized to a powder consistency in a ceramic pulveriser. Both steel plates and ceramic assemblage were pre-contaminated and cleaned with acetone between samples to minimize cross contamination. For isotope dilution, 30 mg of powder were digested, along with a known amount of spike, using 4:1 HF-HNO₃ solution in a screw top Teflon capsule at 150°C for 2 days. Samples were dried and washed repeatedly with 6 N HCl. The samples were then centrifuged until a clear 2.5 mL solution was yielded. The REEs were separated from other elements using 0.7 mm x 12 cm long cation exchange columns. Prior to REE chemotography, the columns were eluted with 30 mL of 2.5 N double distilled HCl. Two millilitres of dissolved samples were placed into the columns using long pipettes, to insure complete loading of the samples. The chemographic procedure employed three separate 10 mL aliquots of 2.5 N HCl, followed by a total of 6 mL aliquots of 6 N HCl. The REEs were collected with 7 mL of 6 N HCl. The resin in each column was washed with 40 mL of 6 N single distilled HCl to thoroughly regenerate and flush out any remaining sample. Collected samples were dried down at 90°C.

Neodymium and Sm was separated in a secondary column with an (internal diameter = 1.8 cm and length = 11 cm) packed with 2.5 cm (300 mg) of Ichrom LN resin. The columns were conditioned with 2.5 N HCl prior to loading 200 µL of samples eluted in 0.25 N HCl. The columns were washed with 3.5 mL of 0.25 N HCl before collection 4 mL of Nd. The resin was then eluted with 1.5 mL of 0.75 N HCl prior to the collection of 1.25 mL of Sm. Both element fractions were dried down at 90°C. Samples when loaded into Teflon loading blocks using a weak HNO₃. Again, the samples were dried down.

Samples were analyzed at Carleton University using a ThermoFinnigan Triton thermal ionization mass spectrometer. Samples homogenized with 3 µL of H₃PO₄ prior to mounting onto double Re filaments. Each solution was dried onto the filament by progressively heating the filament from 1.1 to 1.9 A. Accuracy of the analysis was monitored with an in-house standard, as well JR-1 rock standard. The in house standard has a reproducible ¹⁴³Nd/¹⁴⁴Nd value of 0.511849 +/- 10 at 2 σ (per. comm., E.A. Spencer, May 2011).

Isotopic masses were collected simultaneously in 8 blocks of analyses with 13 cycles per block and isotope dilution samples (Nd and Sm) were collected with 5 cycles per block. The Faraday cup configuration for Nd IC and ID run included ¹⁴⁴Nd, ¹⁴⁶Nd/¹⁴⁴Nd, ¹⁴⁵Nd/¹⁴⁴Nd, ¹⁴⁸Nd/¹⁴⁴Nd, ¹⁵⁰Nd/¹⁴⁴Nd and ¹⁴⁷Sm/¹⁴⁴Nd. Sm ID configuration included ¹⁴⁷Sm/¹⁴⁹Sm, ¹⁵²Sm/¹⁴⁹Sm, ¹⁵⁰Sm/¹⁴⁷Sm, ¹⁵²Sm/¹⁴⁷Sm, ¹⁴⁶Nd/¹⁴⁷Sm and ¹⁵⁵Gd/¹⁴⁷Sm. Filaments were progressively heated to >1800°C until a stable voltage of at least 0.6 V was achieved. Once achieved, the analyzer gate was opened and the data was collected.

Appendix A3a: Zircon Sample Preparation, LA-ICPMS Analysis and Data Filtering

Zircon Sample Preparation

Zircon grains were liberated from approximately 7 – 10 kg of rock by using a jaw crusher followed by a steel disc mill. Both machines were thoroughly cleaned with alcohol and pre-contaminated with a small amount of each sample. The disc mill plates were spaced apart far enough so the majority of the material was between 100-250 μm . This fraction range is ideal to yield the maximum un-fractured zircon (J. Hanchar, per. comm., 2008) and is also within the range of the ideal size for detrital provenance studies (Fedó et al., 2003). Although sampling bias may have been introduced during this stage, the physical handling of zircon <100 μm is very difficult and the ability to only ablate cores of zircon may have resulted in mixed core-rim ages. Approximately 100 ml aliquots of the fraction were washed and decanted in a graduated beaker to remove silt and clay size material and low specific gravity (SG) minerals. The aliquots were rinsed with alcohol and allowed to dry at $\sim 40^\circ\text{C}$ overnight.

Heavy mineral concentrates were collected using a methylene iodide ($\text{SG} = 3.32 \text{ g/cm}^3$) in a separator funnel apparatus. Grains were agitated in the funnel and allowed to settle for ~ 10 to 30 minutes or until enough concentrate sunk. Heavy minerals were collected in filter paper and thoroughly washed with alcohol. The concentrates were examined under a binocular microscope. If dia- and paramagnetic minerals abundant, the fractions were passed through a Franz isodynamic separator with a 0.6 amp current and shallow forward dip and back slope. Zircon grains were picked dry, using a lightly oiled “dental pick” and then placed on a piece of low common-Pb double-sided tape affixed to a clean glass plate. Grains were oriented with their crystallographic c-axis horizontal on the tape. The grains were cast in a mount epoxy which was allowed to cure for 24 hours.

Zircons were polished progressively using coarse to fine polished polishing mediums. First, 400 grit paper and 800 grit papers used to level the mount and remove excess epoxy covering the grains. The mount was polished with a 1000 grit carbide tungsten powder-water solution on a glass plate to coarsely abrade the zircon. The mount was examined periodically during this polishing stage to determine with grains were being plucked from the epoxy. A few grains were lost during this stage. Fine polishing employed 5 and 1 μm silicon powder on a felt polishing mat. Lastly, a 0.5 μm diamond powder mixed with polishing oil on a Teflon glass plate was used to polish the zircons flat. Prior to carbon coating, the mount was thoroughly cleaned with Liquinox laboratory soap to remove oil and polishing compound.

LA-ICPMS Analysis

Cathodoluminescence imaging of each sample was carried out at the University of Ottawa using a Gatan MNIN-CI detector attached to a JEOL 6610V scanning electron microscope operating at a 15 V accelerating voltage. Uranium-Pb isotopic analysis employed LA-ICP-MS methods carried out at the University of New Brunswick using Resonetics M-50-LR 193 nm Excimer laser coupled to Agilent 7700x quadrupole ICP-MS. Analysis spots were pre-determined on a motorized stage attached to Zeiss AxioMager microscope and spots were entered into the sequence imaging program AxioVision. Automated analysis run used a 24 μm static mode spot size at repetition rate of 4 Hz and energy attenuation of $3\text{J}/\text{cm}^2$. The ablation cell was continuously flushed with He (750 mL/min), Ar (630 mL/min) and N_2 (2.8 mL/min) gases. Analyses of the unknowns were bracketed by analysis of FC-1, 91500 and NIST 610 synthetic glass. These standard reference materials were mounted on a separate epoxy mount and their locations were programmed into the automated analysis runs.

Isotopic abundances of the unknown analyses were normalized to those of FC-1 (Paces and Miller, 1993) and integrated using Iolite (Paton et al., 2011). Vizual Age (Petrus and Kamber, 2012) was used to aid in selecting the optimal time-integrated signal in order to reduce the discordance of each analysis.

Data Filtering and Presentation

In order to detect the maximum number of age populations in each sample and limit sampling bias, zircons were randomly selected to include different shapes, colours and sizes. The number of zircon grains analyzed from sample is given in **Figure 2-5**. Both samples fall within a range 35 – 70 grains, which is ideal for minimizing the detection limit of finding zircons which represent all age populations in the sample (Andersen, 2005).

Only analyses with > 98% radiogenic Pb (e.g., < 2 % ^{204}Pb) were considered. The data was further filtered by only selecting analyses with a < 30 % $\text{Pb}^{207}/\text{Pb}^{206}$ discordance. Such a generous cut-off is acceptable and is routinely used for Archean studies (Gehrels, 2012). Nevertheless, this resulted in very few rejections considering the low discordance of the majority of zircons analyzed (**Appendix A3b**). Relative age probability plots were generated using Isoplot/Ex 3.00 (Ludwig, 2003) using the final $^{207}\text{Pb}/^{206}\text{Pb}$ ages and their associated internal standard error (2σ). Cumulative probability plots were generated using the same data as the relative age plots using CUMULATIVE PROB PLOT Excel program of Gehrels (2012).

Appendix A3b: Results from LA-ICPMS analysis after filtering

Analysis	²⁰⁷ Pb/ ²⁰⁶ Pb		²⁰⁷ Pb/ ²³⁵ U		²⁰⁶ Pb/ ²³⁸ U		²⁰⁶ Pb/ ²⁰⁴ Pb		Th/U	% Discordant	
	Ratio	2σ	Age	2σ	Ratio	2σ	Age	2σ			Ratio
JD10-71	03125156 E, 5819109 N, NAD 83, Zone 16										
Zrn 9	0.1862 ± 0.0014	2710 ± 13	14.25 ± 0.15	2766 ± 10	0.5568 ± 0.0042	2853 ± 17		3440	640	0.53	4.46
Zrn 44	0.1874 ± 0.0035	2723 ± 29	13.76 ± 0.26	2732 ± 18	0.5339 ± 0.0073	2757 ± 31		980	160	0.52	4.05
Zrn 37	0.1885 ± 0.0024	2727 ± 21	14.43 ± 0.19	2777 ± 13	0.5549 ± 0.0046	2845 ± 19		830	130	0.89	3.59
Zrn 21	0.1885 ± 0.0022	2727 ± 19	14.45 ± 0.22	2780 ± 14	0.5522 ± 0.0073	2833 ± 31		890	170	0.64	4.53
Zrn 31	0.1883 ± 0.002	2731 ± 18	14.54 ± 0.22	2784 ± 14	0.5592 ± 0.0051	2866 ± 21		1210	140	0.80	4.55
Zrn 24	0.1891 ± 0.002	2732 ± 17	14.03 ± 0.16	2751 ± 10	0.5386 ± 0.0038	2777 ± 16		1370	350	1.08	2.61
Zrn 43	0.1893 ± 0.0025	2734 ± 22	14.86 ± 0.23	2805 ± 15	0.5689 ± 0.0066	2903 ± 27		1360	270	1.14	5.28
Zrn 51	0.1903 ± 0.002	2745 ± 18	13.94 ± 0.2	2747 ± 13	0.5306 ± 0.0057	2743 ± 24		1350	230	0.75	3.15
Zrn 10	0.1917 ± 0.0029	2753 ± 25	14.97 ± 0.3	2810 ± 19	0.5658 ± 0.0087	2889 ± 36		637	86	0.71	5.2
Zrn 41	0.1933 ± 0.0023	2768 ± 20	14.9 ± 0.33	2808 ± 21	0.562 ± 0.012	2873 ± 48		880	150	0.81	5.57
Zrn 3	0.2012 ± 0.0019	2837 ± 16	15.46 ± 0.18	2843 ± 11	0.5563 ± 0.005	2851 ± 21		2180	210	0.58	2.84
Zrn 52	0.2015 ± 0.0026	2838 ± 21	15.15 ± 0.28	2822 ± 17	0.546 ± 0.007	2808 ± 29		1430	170	0.33	3.67
Zrn 36	0.2016 ± 0.003	2839 ± 24	15.7 ± 0.22	2859 ± 14	0.5649 ± 0.0046	2887 ± 19		1420	620	0.37	3.71
Zrn 32	0.202 ± 0.0023	2843 ± 18	15.8 ± 0.21	2864 ± 13	0.5669 ± 0.0037	2895 ± 15		2280	490	0.66	2.69
Zrn 13	0.2024 ± 0.0022	2847 ± 18	15.19 ± 0.2	2828 ± 13	0.5479 ± 0.0045	2816 ± 19		1290	230	0.57	3.18
Zrn 19	0.2028 ± 0.0029	2849 ± 24	16.14 ± 0.25	2884 ± 15	0.5736 ± 0.0061	2922 ± 25		471	72	0.33	3.72
Zrn 15	0.2033 ± 0.0027	2850 ± 21	16.1 ± 0.19	2882 ± 11	0.5735 ± 0.0059	2921 ± 24		1360	220	1.54	4.02
Zrn 4	0.2032 ± 0.0021	2851 ± 17	15.95 ± 0.22	2873 ± 13	0.5666 ± 0.0043	2894 ± 18		1400	400	0.48	2.61
Zrn 12	0.2033 ± 0.0025	2856 ± 19	16.61 ± 0.23	2911 ± 13	0.5928 ± 0.0059	3000 ± 24		679	74	0.70	4.67
Zrn 16	0.2047 ± 0.0024	2862 ± 19	16.01 ± 0.27	2879 ± 17	0.5652 ± 0.0074	2887 ± 30		430	140	0.70	4.02
Zrn 46	0.205 ± 0.0029	2863 ± 23	17.15 ± 0.32	2943 ± 18	0.609 ± 0.0064	3065 ± 26		610	100	0.44	6.51
Zrn 22	0.205 ± 0.0024	2867 ± 20	16.04 ± 0.23	2878 ± 14	0.5676 ± 0.0083	2902 ± 35		580	130	0.93	4.2
Zrn 35	0.2052 ± 0.0033	2868 ± 26	15.57 ± 0.27	2853 ± 16	0.5537 ± 0.0056	2840 ± 23		307	36	0.50	4.03
Zrn 26	0.206 ± 0.0021	2873 ± 16	16.03 ± 0.21	2877 ± 13	0.5622 ± 0.0044	2875 ± 18		1870	360	0.58	2.51
Zrn 27	0.2061 ± 0.0025	2878 ± 19	15.74 ± 0.24	2861 ± 14	0.5521 ± 0.0059	2833 ± 24		1130	150	0.71	3.58
Zrn 29	0.2069 ± 0.0021	2880 ± 16	16.72 ± 0.22	2918 ± 13	0.5861 ± 0.0057	2973 ± 23		2080	340	0.50	3.55
Zrn 34	0.2067 ± 0.0022	2880 ± 17	16.49 ± 0.22	2904 ± 13	0.5798 ± 0.0047	2947 ± 19		1510	180	0.60	2.91
Zrn 8	0.2071 ± 0.0023	2881 ± 18	17.29 ± 0.25	2950 ± 14	0.6049 ± 0.0067	3049 ± 27		580	140	0.69	5.84
Zrn 7	0.2075 ± 0.0026	2885 ± 20	16.58 ± 0.25	2912 ± 15	0.5807 ± 0.0058	2951 ± 24		800	200	0.54	3.2
Zrn 48	0.2081 ± 0.0028	2888 ± 21	17.03 ± 0.29	2934 ± 16	0.5907 ± 0.0079	2996 ± 31		1830	300	0.43	5.14
Zrn 18	0.208 ± 0.0039	2888 ± 30	16.49 ± 0.45	2903 ± 26	0.5824 ± 0.0071	2958 ± 29		1330	240	0.51	3.06
Zrn 11	0.2088 ± 0.0025	2894 ± 19	17.68 ± 0.26	2975 ± 14	0.616 ± 0.0061	3093 ± 25		1240	190	0.66	5.67
Zrn 1	0.2091 ± 0.0021	2898 ± 16	17.94 ± 0.28	2988 ± 14	0.6223 ± 0.0075	3118 ± 30		2770	780	0.56	6.68
Zrn 20	0.2119 ± 0.0028	2920 ± 21	16.39 ± 0.27	2898 ± 16	0.5612 ± 0.0068	2870 ± 28		840	100	0.94	4.16
Zrn 42	0.2193 ± 0.0032	2975 ± 24	18.64 ± 0.36	3026 ± 17	0.6222 ± 0.0076	3118 ± 30		1620	280	1.23	4.3
Zrn 39	0.2219 ± 0.0026	2992 ± 19	17.38 ± 0.23	2957 ± 13	0.5697 ± 0.0053	2906 ± 22		701	86	1.39	4.09
Zrn 50	0.222 ± 0.0031	2999 ± 24	18.96 ± 0.31	3038 ± 16	0.6114 ± 0.008	3074 ± 32		770	210	0.85	4.91

Appendix A3b: Results from LA-ICPMS analysis after filtering
xc = xenocrytic core, r = rim spot. Zrn was too small for both rim and core analysis
Zircons with 206Pb/204Pb values of < 0 contain negligible amounts of common Pb.

Analysis	²⁰⁷ Pb/ ²⁰⁶ Pb		²⁰⁷ Pb/ ²³⁵ U		²⁰⁶ Pb/ ²³⁸ U		²⁰⁶ Pb/ ²⁰⁴ Pb		Th/U	% Discordant
	Ratio 2σ	Age 2σ	Ratio 2σ	Age 2σ	Ratio 2σ	Age 2σ	Ratio 2σ			
JD10-100	0306991 E, 5820283 N, NAD 27, Zone 15									
Zrn 46	0.1826 ± 0.0029	2681 ± 28	12.05 ± 0.49	2606 ± 27	0.479 ± 0.011	2522 ± 45	1690	290	1.16	4.8
Zrn 71	0.1836 ± 0.0028	2688 ± 26	12.73 ± 0.25	2659 ± 17	0.5 ± 0.0099	2613 ± 26	32	247	0.80	3.47
Zrn 62_r	0.1861 ± 0.0032	2706 ± 29	11.1 ± 1.1	2540 ± 38	0.44 ± 0.043	2347 ± 70	1970	650	0.28	11.6
Zrn 45_r	0.1826 ± 0.0032	2674 ± 29	12.69 ± 0.33	2659 ± 19	0.5095 ± 0.0085	2654 ± 25	1100	310	0.87	3.16
Zrn 4	0.1833 ± 0.0047	2684 ± 43	13.9 ± 0.42	2740 ± 24	0.5429 ± 0.011	2801 ± 37	160	150	0.52	5.7
Zrn 7	0.1855 ± 0.0034	2699 ± 31	14.7 ± 0.64	2789 ± 40	0.569 ± 0.022	2900 ± 87	840	120	0.82	7.9
Zrn 74	0.187 ± 0.0028	2714 ± 24	13.24 ± 0.23	2695 ± 16	0.5135 ± 0.011	2671 ± 35	39	238	0.60	3.7
Zrn 20	0.1869 ± 0.0035	2712 ± 31	13.26 ± 0.35	2700 ± 16	0.5194 ± 0.0087	2696 ± 18	1460	290	0.32	3.01
Zrn 17_r	0.188 ± 0.003	2727 ± 25	14.15 ± 0.35	2764 ± 17	0.5448 ± 0.0093	2803 ± 30	1830	390	0.57	4.16
Zrn 60_r	0.1908 ± 0.0037	2755 ± 30	12.26 ± 0.46	2623 ± 27	0.465 ± 0.012	2461 ± 47	2970	120	0.15	8.6
Zrn 8_r	0.1884 ± 0.0029	2726 ± 25	13.86 ± 0.33	2739 ± 16	0.5303 ± 0.0094	2742 ± 29	1960	220	0.58	3.73
Zrn 14	0.1893 ± 0.0029	2734 ± 25	13.94 ± 0.44	2742 ± 25	0.532 ± 0.012	2759 ± 45	1390	210	1.30	3.97
Zrn 66	0.1859 ± 0.0035	2707 ± 30	14.59 ± 0.4	2786 ± 20	0.5702 ± 0.009	2908 ± 30	670	140	0.64	6.25
Zrn 19	0.1895 ± 0.0029	2741 ± 24	13.47 ± 0.34	2712 ± 18	0.5118 ± 0.0095	2663 ± 31	1590	270	0.73	3.43
Zrn 52	0.1872 ± 0.0024	2720 ± 21	13.97 ± 0.27	2748 ± 9.6	0.5396 ± 0.0088	2781 ± 24	2210	470	0.92	3.17
Zrn 16	0.1913 ± 0.0026	2751 ± 23	14.67 ± 0.37	2792 ± 18	0.5558 ± 0.0092	2849 ± 26	122	90	0.72	3.74
Zrn 84	0.2016 ± 0.0039	2837 ± 32	14.88 ± 5.1	2807 ± 20	0.535 ± 0.041	2762 ± 46	160	150	0.36	4.9
Zrn 63	0.1941 ± 0.004	2774 ± 33	12.89 ± 0.63	2673 ± 38	0.482 ± 0.02	2534 ± 73	3700	1300	0.37	8.5
Zrn 24	0.1972 ± 0.0027	2801 ± 22	12.68 ± 0.4	2653 ± 25	0.4649 ± 0.011	2460 ± 40	2010	320	0.43	10.8
Zrn 15	0.1973 ± 0.0028	2802 ± 23	13.43 ± 0.31	2709 ± 16	0.4898 ± 0.0087	2569 ± 27	2580	240	0.58	7.3
Zrn 56	0.1948 ± 0.0031	2785 ± 27	14.69 ± 0.55	2793 ± 24	0.542 ± 0.017	2789 ± 57	1800	280	0.34	5.5
Zrn 65	0.2007 ± 0.0028	2830 ± 23	16.52 ± 0.43	2909 ± 19	0.6046 ± 0.011	3048 ± 33	915	93	0.24	7.3
Zrn 57	0.1986 ± 0.0028	2816 ± 24	14.69 ± 0.39	2797 ± 19	0.5301 ± 0.0098	2741 ± 32	1920	350	0.60	3.62
Zrn 1	0.2034 ± 0.0051	2852 ± 40	17.8 ± 0.96	2976 ± 38	0.626 ± 0.028	3132 ± 73	743	78	0.54	7.8
Zrn 25	0.2049 ± 0.003	2864 ± 24	14.89 ± 0.4	2806 ± 20	0.5259 ± 0.011	2723 ± 37	1470	210	0.98	5.2
Zrn 88	0.2069 ± 0.0029	2880 ± 23	15.42 ± 0.26	2843 ± 15	0.546 ± 0.011	2808 ± 30	45	115	0.53	4.02
Zrn 59_r	0.1999 ± 0.0032	2827 ± 25	15.19 ± 0.38	2829 ± 18	0.5532 ± 0.011	2837 ± 37	2870	580	0.60	3.93
Zrn 22	0.2009 ± 0.0029	2831 ± 24	15.12 ± 0.42	2821 ± 21	0.5395 ± 0.011	2780 ± 40	1090	230	0.54	3.14
Zrn 39	0.2015 ± 0.0028	2837 ± 23	15.85 ± 0.35	2867 ± 14	0.5785 ± 0.01	2942 ± 30	1020	140	0.30	4.12
Zrn 32	0.2075 ± 0.0043	2884 ± 33	14.39 ± 0.47	2773 ± 28	0.498 ± 0.015	2603 ± 68	1320	270	0.31	9.7
Zrn 33	0.2027 ± 0.0031	2846 ± 25	16.51 ± 0.47	2904 ± 22	0.589 ± 0.012	2991 ± 39	1270	570	0.44	5.15
Zrn 72_r	0.2166 ± 0.0032	2957 ± 25	16.41 ± 0.35	2900 ± 18	0.5459 ± 0.01	2808 ± 24	41	130	0.53	4.89
Zrn 80	0.2015 ± 0.0024	2838 ± 20	15.46 ± 0.3	2843 ± 19	0.5538 ± 0.013	2840 ± 36	35	203	0.38	2.59
Zrn 81	0.2062 ± 0.0028	2874 ± 22	15.77 ± 0.43	2868 ± 25	0.556 ± 0.015	2848 ± 50	150	900	0.40	4.42

Appendix A3b: Results from LA-ICPMS analysis after filtering
xc = xenocrytic core, r = rim spot. Zrn was too small for both rim and core analysis
Zircons with 206Pb/204Pb values of < 0 contain negligible amounts of common Pb.

Analysis	²⁰⁷ Pb/ ²⁰⁶ Pb		²⁰⁷ Pb/ ²³⁵ U		²⁰⁶ Pb/ ²³⁸ U		²⁰⁶ Pb/ ²⁰⁴ Pb		Th/U	% Discondant
	Ratio	2σ	Age	2σ	Ratio	2σ	Age	2σ		
JD10-100 (continued)										
Zrn 10	0.2008 ± 0.0029		2839 ± 22		15.39 ± 0.37		2841 ± 19		0.69	3.22
Zrn 67	0.2038 ± 0.0033		2863 ± 24		15.31 ± 0.38		2833 ± 17		0.46	4.28
Zrn 29	0.2035 ± 0.0029		2857 ± 24		15.42 ± 0.41		2840 ± 20		1.23	2.48
Zrn 53	0.2051 ± 0.0035		2865 ± 27		12.37 ± 0.39		2630 ± 26		0.44	16.9
Zrn 6	0.2052 ± 0.0051		2875 ± 40		15.86 ± 0.49		2869 ± 25		0.45	5.3
Zrn 13	0.2042 ± 0.0032		2862 ± 24		15.96 ± 0.37		2873 ± 15		1.23	3.67
Zrn 3_r	0.2066 ± 0.0025		2878 ± 20		14.93 ± 0.34		2810 ± 13		0.37	5.9
Zrn 64	0.2069 ± 0.0041		2878 ± 32		16.83 ± 0.51		2922 ± 24		0.39	4.88
Zrn 27	0.2078 ± 0.0033		2886 ± 26		17.05 ± 0.47		2936 ± 21		0.68	4.22
Zrn 11	0.2058 ± 0.0032		2870 ± 26		16.53 ± 0.38		2909 ± 15		0.33	4.3
Zrn 38	0.2086 ± 0.0042		2890 ± 33		16.38 ± 0.42		2898 ± 19		0.48	4.53
Zrn 40	0.2184 ± 0.0046		2967 ± 34		14.63 ± 0.49		2790 ± 27		0.20	13.4
Zrn 28	0.208 ± 0.0026		2889 ± 20		17.02 ± 0.47		2934 ± 22		0.42	4.83
Zrn 2	0.2071 ± 0.0029		2885 ± 23		16.37 ± 0.43		2900 ± 20		0.81	3.48
Zrn 23	0.2144 ± 0.0035		2937 ± 27		18.02 ± 0.49		2989 ± 20		0.35	5.13
Zrn 58	0.2125 ± 0.0037		2922 ± 28		17.73 ± 0.49		2972 ± 23		0.68	5.25
Zrn 90	0.2293 ± 0.0029		3046 ± 20		18.31 ± 0.3		3005 ± 14		0.43	4.85
Zrn 69	0.2276 ± 0.0025		3034 ± 18		18.15 ± 0.25		2997 ± 11		0.77	3.97
Zrn 44	0.2158 ± 0.0037		2952 ± 26		18.22 ± 0.48		3000 ± 19		0.47	6.5
Zrn 18	0.2178 ± 0.0042		2962 ± 31		18.8 ± 0.61		3036 ± 25		0.09	5.1
Zrn 77	0.2156 ± 0.0034		2957 ± 26		17.6 ± 0.35		2967 ± 17		0.64	5
Zrn 73	0.2291 ± 0.0023		3045 ± 16		18.38 ± 0.27		3009 ± 12		0.66	2.94
Zrn 55	0.2182 ± 0.0033		2965 ± 24		18.1 ± 0.45		2993 ± 17		0.96	3.95
Zrn 21	0.2213 ± 0.0035		2988 ± 26		18.26 ± 0.47		3002 ± 19		0.61	4.02
Zrn 9_r	0.2276 ± 0.0031		3034 ± 22		20.32 ± 0.55		3105 ± 22		0.40	5.7
Zrn 54	0.2275 ± 0.0033		3033 ± 23		19.81 ± 0.5		3081 ± 18		0.39	4.78
Zrn 43	0.228 ± 0.0035		3037 ± 25		17.92 ± 0.61		2984 ± 21		0.25	4.23
Zrn 51	0.2288 ± 0.004		3042 ± 28		18.72 ± 0.57		3031 ± 20		0.62	2.2
Zrn 5	0.2288 ± 0.0037		3047 ± 27		19.49 ± 0.67		3062 ± 34		0.47	5.5
Zrn 30_r	0.2401 ± 0.0052		3118 ± 35		20.52 ± 0.74		3113 ± 29		0.43	5.3
Zrn 12_r	0.2423 ± 0.0056		3132 ± 36		21.97 ± 0.56		3181 ± 26		0.71	5.2

Appendix A3b: Results from LA-ICPMS analysis after filtering
xc = xenocrytic core, r = rim spot. Zrn was too small for both rim and core analysis
Zircons with 206Pb/204Pb values of < 0 contain negligible amounts of common Pb.

Analysis	²⁰⁷ Pb/ ²⁰⁶ Pb		²⁰⁷ Pb/ ²³⁵ U		²⁰⁶ Pb/ ²³⁸ U		²⁰⁶ Pb/ ²⁰⁴ Pb		Th/U	% Discondant
	Ratio 2σ	Age 2σ	Ratio 2σ	Age 2σ	Ratio 2σ	Age 2σ	Ratio 2σ			
<u>NCB11-01</u>	0628556 E, 5862912 N, NAD 27, Zone 15									
Zrn 45	0.2325 ± 0.0037	3070 ± 10	19.63 ± 0.41	3072 ± 17	0.6115 ± 0.013	3075 ± 27	4300	1700	0.59	3.25
Zrn 56	0.2219 ± 0.0047	2987 ± 17	17.76 ± 0.44	2975 ± 22	0.5837 ± 0.014	2969 ± 34	<0	<0	0.69	4.17
Zrn 52	0.2252 ± 0.0045	3022 ± 18	18.75 ± 0.41	3031 ± 18	0.5993 ± 0.014	3034 ± 39	740	420	0.54	5.03
Zrn 61	0.2242 ± 0.0034	3012 ± 11	18.33 ± 0.43	3005 ± 20	0.593 ± 0.014	3001 ± 33	2180	580	0.77	3.36
Zrn 42	0.22 ± 0.0042	2984 ± 14	17.57 ± 0.37	2965 ± 16	0.5793 ± 0.014	2945 ± 37	<0	<0	1.22	5.1
Zrn 53	0.2189 ± 0.0048	2986 ± 20	17.66 ± 0.51	2970 ± 19	0.5843 ± 0.013	2966 ± 33	670	460	0.32	4.2
Zrn 34	0.22 ± 0.0036	2984 ± 12	17.65 ± 0.45	2968 ± 23	0.5791 ± 0.013	2951 ± 37	<0	<0	0.94	3.43
Zrn 29	0.2192 ± 0.0036	2981 ± 16	17.64 ± 0.45	2972 ± 23	0.582 ± 0.014	2954 ± 42	420	660	0.87	4.1
Zrn 57	0.2185 ± 0.0041	2986 ± 14	17.62 ± 0.38	2967 ± 20	0.5743 ± 0.014	2925 ± 35	400	1300	0.49	4.57
Zrn 49	0.2181 ± 0.0039	2964 ± 14	17.49 ± 0.44	2960 ± 20	0.579 ± 0.013	2944 ± 35	<0	<0	0.51	4.2
Zrn 60	0.2379 ± 0.0028	3100 ± 7	20.11 ± 0.38	3095 ± 15	0.6125 ± 0.014	3080 ± 29	3300	1300	0.59	2.84
Zrn 39	0.2184 ± 0.0031	2974 ± 8	17.54 ± 0.38	2963 ± 19	0.5781 ± 0.014	2940 ± 37	2100	3600	0.48	3.39
Zrn 40	0.2193 ± 0.0033	2980 ± 14	17.15 ± 0.38	2942 ± 19	0.566 ± 0.013	2891 ± 27	110	830	0.97	2.82
Zrn 51	0.221 ± 0.0045	2989 ± 10	17.67 ± 0.39	2970 ± 18	0.5839 ± 0.014	2964 ± 29	600	1200	0.86	4.1
Zrn 15	0.2164 ± 0.0054	2965 ± 14	17 ± 0.39	2932 ± 29	0.566 ± 0.014	2891 ± 64	<0	<0	0.79	5.6
Zrn 32	0.2301 ± 0.0047	3056 ± 11	19.11 ± 0.46	3045 ± 23	0.596 ± 0.013	3012 ± 40	540	700	0.45	5.5
Zrn 50	0.2244 ± 0.0057	3022 ± 17	17.81 ± 0.49	2981 ± 23	0.577 ± 0.016	2934 ± 47	330	230	0.49	5.9
Zrn 58	0.2218 ± 0.0041	2993 ± 16	17.87 ± 0.41	2981 ± 18	0.5802 ± 0.014	2949 ± 34	1100	1700	1.05	4.57
Zrn 20	0.2196 ± 0.0028	2977 ± 8.6	17.28 ± 0.32	2949 ± 14	0.5704 ± 0.013	2909 ± 27	900	1400	0.97	2.99
Zrn 43	0.2189 ± 0.0032	2977 ± 16	17.48 ± 0.31	2961 ± 12	0.5725 ± 0.013	2917 ± 37	<0	<0	1.00	4.3
Zrn 21	0.2185 ± 0.0028	2974 ± 9	17.2 ± 0.34	2948 ± 13	0.5697 ± 0.013	2906 ± 24	500	1600	0.98	3.31
Zrn 59	0.2228 ± 0.0033	3000 ± 11	17.46 ± 0.32	2962 ± 14	0.5701 ± 0.012	2907 ± 26	6100	5900	1.14	4.4
Zrn 31	0.2206 ± 0.0047	2975 ± 15	17.38 ± 0.41	2958 ± 21	0.574 ± 0.015	2922 ± 42	<0	<0	0.82	5.7
Zrn 23	0.2165 ± 0.0032	2960 ± 17	16.83 ± 0.33	2924 ± 15	0.5635 ± 0.013	2880 ± 32	<0	<0	0.62	4.22
Zrn 5	0.2229 ± 0.0029	2990 ± 9	17.29 ± 0.32	2950 ± 14	0.5658 ± 0.012	2890 ± 25	1560	930	0.83	4.17
Zrn 27	0.2209 ± 0.0037	2988 ± 15	17.25 ± 0.34	2950 ± 17	0.5692 ± 0.013	2904 ± 30	660	810	1.24	3.89
Zrn 19	0.2225 ± 0.0042	2999 ± 12	17.18 ± 0.44	2946 ± 24	0.5638 ± 0.013	2882 ± 30	1000	1000	1.57	3.77
Zrn 14	0.2189 ± 0.0044	2972 ± 12	16.88 ± 0.47	2925 ± 25	0.5589 ± 0.012	2862 ± 27	430	690	0.83	4.09
Zrn 46	0.221 ± 0.0052	3002 ± 16	17.59 ± 0.47	2965 ± 24	0.5741 ± 0.013	2924 ± 31	<0	<0	0.74	4.72
Zrn 38	0.2223 ± 0.005	3005 ± 18	17.62 ± 0.4	2971 ± 19	0.5701 ± 0.014	2907 ± 40	900	1900	0.42	6.1
Zrn 55	0.2308 ± 0.0027	3057 ± 9	18.18 ± 0.36	2998 ± 15	0.5765 ± 0.013	2934 ± 29	<0	<0	0.41	4.21
Zrn 7	0.2184 ± 0.0039	2979 ± 14	16.98 ± 0.41	2931 ± 20	0.5646 ± 0.013	2885 ± 29	550	460	0.79	4.7
Zrn 26	0.2231 ± 0.0041	3002 ± 14	17.47 ± 0.41	2965 ± 20	0.5718 ± 0.013	2915 ± 29	<0	<0	1.06	4.16
Zrn 35	0.2243 ± 0.0035	3013 ± 13	17.77 ± 0.45	2975 ± 21	0.571 ± 0.014	2916 ± 39	200	1000	0.72	4.8
Zrn 36	0.2202 ± 0.0038	2989 ± 13	17.35 ± 0.45	2952 ± 22	0.5618 ± 0.013	2873 ± 34	<0	1600	1.15	4.2
Zrn 30	0.2219 ± 0.0035	2989 ± 11	17.28 ± 0.41	2953 ± 18	0.5669 ± 0.012	2895 ± 27	700	1900	0.62	4.07

Appendix A3b: Results from LA-ICPMS analysis after filtering
xc = xenocrytic core, r = rim spot. Zrn was too small for both rim and core analysis
Zircons with $^{206}\text{Pb}/^{204}\text{Pb}$ values of < 0 contain negligible amounts of common Pb.

Analysis	²⁰⁷ Pb/ ²⁰⁶ Pb		²⁰⁷ Pb/ ²³⁵ U		²⁰⁶ Pb/ ²³⁸ U		²⁰⁶ Pb/ ²⁰⁴ Pb		Th/U	% Discondant							
	Ratio	2σ	Age	2σ	Ratio	2σ	Age	2σ			Ratio	2σ					
<u>NCB11-01 (continued)</u>																	
Zrc 13	0.2208 ± 0.0043		2985 ± 10		16.86 ± 0.42		2925 ± 21		0.5586 ± 0.013		2860 ± 32		<0	<0	1.21		5.1
Zrc 48	0.2208 ± 0.0044		2996 ± 15		17.16 ± 0.43		2945 ± 20		0.5636 ± 0.013		2881 ± 27		100	400	0.54		4.4
Zrn 47	0.2253 ± 0.0031		3020 ± 16		17.33 ± 0.39		2955 ± 20		0.5623 ± 0.014		2875 ± 35		1490	850	0.32		5.3
Zrn 33	0.2212 ± 0.0042		2981 ± 18		16.68 ± 0.42		2915 ± 21		0.5513 ± 0.013		2830 ± 34		230	880	0.90		5.8
Zrn 9	0.2245 ± 0.0041		3012 ± 14		17.12 ± 0.41		2943 ± 19		0.5587 ± 0.013		2860 ± 34		700	3900	0.71		5.2
Zrn 10	0.2216 ± 0.0037		3000 ± 15		17.2 ± 0.38		2945 ± 19		0.5575 ± 0.013		2855 ± 34		490	770	0.62		4.8
Zrn 6	0.2252 ± 0.004		3010 ± 15		17 ± 0.44		2932 ± 22		0.5526 ± 0.013		2835 ± 40		40	940	0.84		6.9
Zrn 3	0.2154 ± 0.0041		2951 ± 12		16.3 ± 0.38		2893 ± 18		0.5487 ± 0.014		2819 ± 35		930	810	0.62		4.7
Zrn 1	0.2188 ± 0.0037		2981 ± 12		16.7 ± 0.33		2920 ± 15		0.5499 ± 0.013		2830 ± 30		<0	<0	0.68		5.5

NCB11-34B 0649138 E, 5867215 N, NAD 27, Zone 15

Zrn 64	0.2203 ± 0.0031	2998 ± 14	18.79 ± 0.38	3029 ± 20	0.614 ± 0.01	3094 ± 39	1500	1100	0.41	4.5
Zrn 54	0.2097 ± 0.0026	2894 ± 15	16.85 ± 0.76	2927 ± 41	0.577 ± 0.025	2930 ± 100	1500	1500	0.45	7.3
Zrn 43	0.2045 ± 0.0025	2865.2 ± 9.4	15.78 ± 0.25	2868 ± 15	0.5674 ± 0.0055	2897 ± 23	<0	<0	0.44	2.91
Zrn 23	0.2045 ± 0.0026	2859.4 ± 8.5	15.93 ± 0.21	2874 ± 14	0.5688 ± 0.0068	2902 ± 28	4600	8000	0.46	3.61
Zrn 20	0.2269 ± 0.0043	3041 ± 15	19.26 ± 0.73	3058 ± 38	0.616 ± 0.014	3092 ± 55	720	610	0.30	3.6
Zrn 94	0.2174 ± 0.0046	2972 ± 11	18.06 ± 0.32	2992 ± 17	0.593 ± 0.01	3002 ± 41	1100	1600	0.39	4.2
Zrn 49	0.2192 ± 0.0037	2977 ± 14	17.87 ± 0.35	2981 ± 19	0.5934 ± 0.0079	3002 ± 32	2700	1700	0.44	4.29
Zrn 9	0.2203 ± 0.0032	2984 ± 15	18.22 ± 0.34	3000 ± 18	0.5943 ± 0.0085	3006 ± 34	<0	<0	0.41	3.7
Zrn 17	0.2206 ± 0.0028	2976.4 ± 8.6	18.38 ± 0.45	3008 ± 24	0.6047 ± 0.0089	3048 ± 36	2100	2000	0.31	2.99
Zrn 1	0.211 ± 0.0025	2911 ± 10	16.44 ± 0.26	2902 ± 15	0.5644 ± 0.0087	2884 ± 36	2800	1700	0.41	4.16
Zrn 21	0.2311 ± 0.0024	3064.4 ± 8.4	19.49 ± 0.3	3068 ± 16	0.6107 ± 0.0059	3072 ± 23	<0	<0	0.65	2.69
Zrn 39	0.223 ± 0.0034	3006 ± 12	17.77 ± 0.27	2979 ± 15	0.5823 ± 0.0062	2958 ± 25	1680	610	0.51	3.35
Zrn 50	0.2046 ± 0.0029	2861 ± 12	16.01 ± 0.24	2876 ± 15	0.5622 ± 0.0053	2875 ± 22	<0	<0	0.47	2.17
Zrn 93	0.2061 ± 0.0028	2868.4 ± 9.9	15.59 ± 0.26	2851 ± 16	0.5516 ± 0.0061	2831 ± 25	1500	1300	0.27	3.13
Zrn 47_xc?	0.2115 ± 0.0029	2900 ± 13	16.11 ± 0.35	2882 ± 20	0.5582 ± 0.007	2858 ± 29	<0	1400	0.37	3.57
Zrn 14	0.2194 ± 0.0037	2976 ± 12	17.82 ± 0.28	2979 ± 15	0.5855 ± 0.0075	2970 ± 30	400	1200	0.36	3.92
Zrn 35	0.2567 ± 0.0036	3225 ± 11	22.74 ± 0.35	3215 ± 15	0.6466 ± 0.0097	3214 ± 38	351	25	0.44	3.49
Zrn 55	0.205 ± 0.0028	2868 ± 9.7	15.77 ± 0.23	2862 ± 14	0.5591 ± 0.0059	2863 ± 24	<0	<0	0.42	3.55
Zrn 88	0.2156 ± 0.0035	2944 ± 17	17.37 ± 0.29	2955 ± 16	0.5764 ± 0.0068	2940 ± 26	4000	3200	0.39	2.81
Zrn 45_xc?	0.2182 ± 0.005	2981 ± 18	17.46 ± 0.41	2959 ± 23	0.574 ± 0.011	2922 ± 43	600	2800	0.40	3.9
Zrn 52	0.207 ± 0.003	2896 ± 15	10.04 ± 0.34	2434 ± 32	0.458 ± 0.018	2443 ± 78	1000	1900	0.49	6.4
Zrn 71	0.2418 ± 0.0034	3137 ± 14	20.84 ± 0.52	3134 ± 23	0.624 ± 0.013	3125 ± 53	497	71	0.46	3.79
Zrn 58	0.2053 ± 0.0019	2866.7 ± 9.8	15.48 ± 0.24	2844 ± 15	0.5431 ± 0.0057	2796 ± 24	<0	<0	0.51	2.94
Zrn 7	0.2075 ± 0.0025	2896 ± 10	15.91 ± 0.28	2870 ± 17	0.5555 ± 0.0057	2847 ± 24	<0	<0	0.63	2.65

Appendix A3b: Results from LA-ICPMS analysis after filtering
xc = xenocrytic core, r = rim spot. Zrn was too small for both rim and core analysis
Zircons with 206Pb/204Pb values of < 0 contain negligible amounts of common Pb.

Analysis	$^{207}\text{Pb}/^{206}\text{Pb}$		$^{207}\text{Pb}/^{235}\text{U}$		$^{206}\text{Pb}/^{238}\text{U}$		$^{206}\text{Pb}/^{204}\text{Pb}$		Th/U	% Discordant
	Ratio	2 σ	Age	2 σ	Ratio	2 σ	Age	2 σ		
<u>NCB11-34B (continued)</u>										
Zrn 51	0.2196 $\pm$ 0.0027	2982.2 $\pm$ 6.5	17.58 $\pm$ 0.26	2966 $\pm$ 14	0.5784 $\pm$ 0.0054	2942 22	<0	<0	0.33	2.81
Zrn 84	0.218 $\pm$ 0.0034	2976.3 $\pm$ 7.5	17.28 $\pm$ 0.27	2952 $\pm$ 15	0.5716 $\pm$ 0.0064	2914 26	3100	3500	0.44	3.43
Zrn 25	0.2306 $\pm$ 0.0035	3063 $\pm$ 11	18.94 $\pm$ 0.29	3038 $\pm$ 14	0.5931 $\pm$ 0.0067	3002 27	<0	<0	0.71	3.36
Zrn 32	0.207 $\pm$ 0.0027	2891.9 $\pm$ 8.3	15.67 $\pm$ 0.29	2856 $\pm$ 18	0.543 $\pm$ 0.0074	2796 31	2100	1800	0.48	4.08
Zrn 70	0.2245 $\pm$ 0.0039	3009 $\pm$ 16	18.07 $\pm$ 0.36	2992 $\pm$ 19	0.5814 $\pm$ 0.0077	2954 31	1300	1300	0.37	3.67
Zrn 76	0.2157 $\pm$ 0.005	2955 $\pm$ 15	17.24 $\pm$ 0.38	2946 $\pm$ 21	0.5729 $\pm$ 0.0095	2919 39	2700	7500	0.27	4.3
Zrn 67	0.2029 $\pm$ 0.0029	2856 $\pm$ 12	15.4 $\pm$ 0.27	2842 $\pm$ 17	0.5428 $\pm$ 0.0067	2795 28	480	900	0.40	3.91
Zrn 61	0.2297 $\pm$ 0.0048	3047 $\pm$ 10	19.03 $\pm$ 0.4	3042 $\pm$ 20	0.5932 $\pm$ 0.0098	3001 40	3000	1500	0.52	3.9
Zrn 60	0.2077 $\pm$ 0.0032	2884.7 $\pm$ 9.4	15.63 $\pm$ 0.3	2853 $\pm$ 18	0.5421 $\pm$ 0.0062	2792 26	300	2000	0.54	4.3
Zrn 13	0.2235 $\pm$ 0.0028	3008.2 $\pm$ 8.7	17.57 $\pm$ 0.39	2964 $\pm$ 21	0.5638 $\pm$ 0.0098	2881 39	600	1500	0.63	6.6
Zrn 62	0.2106 $\pm$ 0.0026	2908.7 $\pm$ 7.4	16 $\pm$ 0.26	2876 $\pm$ 16	0.5414 $\pm$ 0.0053	2789 22	2700	4700	0.49	4.18
Zrn 36	0.2275 $\pm$ 0.0025	3044.5 $\pm$ 9.5	18.22 $\pm$ 0.26	3001 $\pm$ 14	0.5795 $\pm$ 0.0067	2946 27	1090	200	0.45	3.51
Zrn 80	0.2221 $\pm$ 0.0032	3001 $\pm$ 8.7	17.57 $\pm$ 0.27	2965 $\pm$ 15	0.5704 $\pm$ 0.0056	2909 23	900	2400	0.48	4.08
Zrn 85	0.2052 $\pm$ 0.0025	2875.1 $\pm$ 7.1	15.36 $\pm$ 0.18	2837 $\pm$ 11	0.5404 $\pm$ 0.006	2785 25	-60000	13000	0.43	4
Zrn 48	0.2191 $\pm$ 0.0044	2975 $\pm$ 16	16.82 $\pm$ 0.3	2923 $\pm$ 17	0.5616 $\pm$ 0.0081	2872 34	690	930	0.36	4.5
Zrn 91	0.2224 $\pm$ 0.0041	2995.3 $\pm$ 7.5	17.07 $\pm$ 0.4	2938 $\pm$ 22	0.5612 $\pm$ 0.007	2871 29	910	850	0.37	4
Zrn 41	0.2081 $\pm$ 0.0033	2903 $\pm$ 13	14.95 $\pm$ 0.22	2811 $\pm$ 14	0.5264 $\pm$ 0.0074	2726 31	1230	810	0.52	5.7
Zrn 74	0.218 $\pm$ 0.0034	2975.6 $\pm$ 7	17.01 $\pm$ 0.36	2933 $\pm$ 20	0.5627 $\pm$ 0.0077	2877 32	<0	<0	0.61	4.95
Zrn 37	0.2171 $\pm$ 0.0026	2962 $\pm$ 7	16.07 $\pm$ 0.28	2886 $\pm$ 15	0.546 $\pm$ 0.0074	2808 31	2500	1500	0.37	4.66
Zrn 86	0.2303 $\pm$ 0.003	3053.6 $\pm$ 8.4	15.64 $\pm$ 0.29	2857 $\pm$ 18	0.539 $\pm$ 0.011	2778 45	2400	5700	0.59	5.4
Zrn 92	0.2253 $\pm$ 0.003	3015 $\pm$ 15	17.39 $\pm$ 0.38	2954 $\pm$ 21	0.561 $\pm$ 0.0058	2870 24	650	130	0.49	4.66
Zrn 5	0.2316 $\pm$ 0.0027	3060 $\pm$ 12	18.54 $\pm$ 0.31	3017 $\pm$ 16	0.5732 $\pm$ 0.0056	2921 23	1110	550	0.52	4.7
Zrn 69	0.2074 $\pm$ 0.0036	2885 $\pm$ 14	15.19 $\pm$ 0.28	2832 $\pm$ 16	0.5298 $\pm$ 0.0069	2740 29	<0	<0	0.40	5.4
Zrn 24	0.2309 $\pm$ 0.0048	3056 $\pm$ 13	17.57 $\pm$ 0.32	2966 $\pm$ 17	0.56 $\pm$ 0.01	2867 43	376	63	0.26	5.4
Zrn 81	0.2186 $\pm$ 0.0049	2987 $\pm$ 19	17.14 $\pm$ 0.42	2944 $\pm$ 22	0.562 $\pm$ 0.011	2883 48	800	1900	0.34	7.1
Zrn 44	0.2328 $\pm$ 0.0057	3061 $\pm$ 13	18.61 $\pm$ 0.5	3020 $\pm$ 26	0.5755 $\pm$ 0.0087	2930 36	1450	520	0.34	4.9
Zrn 12	0.2266 $\pm$ 0.0035	3041 $\pm$ 16	17.72 $\pm$ 0.29	2973 $\pm$ 16	0.563 $\pm$ 0.0055	2879 23	<0	<0	0.61	5.8
Zrn 82	0.218 $\pm$ 0.004	2972.3 $\pm$ 9.3	16.54 $\pm$ 0.28	2907 $\pm$ 16	0.5445 $\pm$ 0.0057	2802 24	200	2500	0.53	5.6

Appendix A3b: Results from LA-ICPMS analysis after filtering
xc = xenocrytic core, r = rim spot. Zrn was too small for both rim and core analysis
Zircons with 206Pb/204Pb values of < 0 contain negligible amounts of common Pb.

Appendix A3c: Description of Timiskaming type zircons

JD10-71			
Grain	Description	$^{207}\text{Pb}/^{206}\text{Pb}$ Age (Ma)	2 σ error
Zircon 44	Subhedral and sub rounded grain. Aspect ratio ~1:1. Grain is “tear-drop” shaped. Some igneous characteristics are present. Oscillatory zoning is evident. No core-rim boundary. Single analysis of the rim.	2723	29
Zircon 37	Subhedral and rounded. Aspect ratio ~ 1:1. More equant than Zrn 44. No definite core, but oscillatory zone “rings” seem to terminate close to the center of the grain. Oscillatory zone in the outer part of the grain. Ablation spot hit the outer part within the oscillatory zoned part. Crystal form is poor.	2727	21
Zircon 21	Euhedral stubby to equate grain. Aspect ratio ~2:1. No core and rim boundary. Thick ~10um oscillatory bands parallel to grain faces. Core analysis (ablation) near grain center. Center of grain may have fluid inclusion ~1um, but not 100% sure.	2727	19
Zircon 24	Euhedral and sub rounded. Corners are rounded; oscillatory zoning in the rim. Core is more homogenous, although a lot of fluid inclusions (?) and mineral inclusions. Definitive core – rim boundary. Core analysis contains mineral inclusions (rutile?). Aspect ratio ~ 2:1.	2732	17
Zircon 51	Euhedral prismatic with definite rim overgrowth. Core is outlined by high birefringence zone. Core seems slightly more rounded by analysis is 2745 Ma, therefore cannot be xenocrystic. Oscillatory zoning in both core and rim ~12um thick zoning domains. Crystal is potentially metamict. Aspect ratio: 1:1.5	2745	18
JD10-100			
Zrn 45_r	Euhedral prismatic well developed crystals faces. Aspect ratio ~ 2:1. Core and rim are visible. No oscillatory zoning in the core, but is it prismatic and faces are parallel to rim. Oscillatory zoning in the rim.	2674	29
Zrn_46	Euhedral prismatic large igneous (?) grain. No evident core and rim, although zoning domains juxtaposed against zoning in the core. Zoning domains are ~5um in the rim. Corners of grains are slightly faceted.	2681	28
Zrn_4	Subhedral, rounded grain; perhaps reabsorbed or transported. Aspect ratio ~1.5:1. Homogeneous crystal with no zoning. Approximately 100um long.	2684	43
Zrn_71	Euhedral, large grain with well developed crystal faces. Aspect ratio ~2:1. Well developed prismatic edges and pyramidal terminations, yet are slightly rounded. Potentially igneous in origin. No evident core and rim boundary. Oscillatory zoning in both outer and center portion of grain.	2688	26
Zrn_20	Euhedral prismatic zircon. Definitive core rim boundary. Core shows no evident zoning, yet contains many fluid inclusions. The rim is potentially a magmatic overgrowth; definitely igneous.	2712	31

Appendix A4a: GSA Meeting – Minneapolis 2011 Abstract

Neodymium Isotopes & Geochemistry from the North Caribou Greenstone Belt, Superior Province

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The North Caribou Greenstone Belt (NCGB) is within the North Caribou Superterrane of the western Superior Province. This superterrane is the nucleus of the Superior Province to which smaller terranes, from north and south accreted on to it between 2.72 & 2.68 Ga. The NCGB comprises mainly metavolcano-sedimentary assemblages and is bounded by TTG-series plutons. We present recent geochemical and Nd isotopic data from the Eyapamikama Lake Assemblage (ELS), the most extensive assemblage of the NCGB which consists of quartz arenites, feldspathic arenites, lithic wackes and felsic volcanoclastics (?).

Variability in the mineralogical composition is reflected in the geochemical signature of the rocks. All rocks from the ELS show LREE enrichment $[(La/Sm)_{CN} = 2.61 \text{ to } 5.22]$ & $[(Gd/Yb)_{CN} = 1.04 \text{ to } 2.53]$. Extended REE patterns show significant negative Nb and negligible Eu anomalies. Conversely, trace element data show notable variations. Incompatible/compatible element ratios indicate the ELS evolved in an active margin tectonic setting ($Zr/Sc = 2 \text{ to } 32.6$ & $Th/Sc = 0.88 \text{ to } 1.45$). Likewise Sr/Y & La/Yb values range from 1.21 to 22.8 and 3.73 to 24.6, respectively. Heterogeneities in the trace element chemistry of these rocks may be attributed to alteration observed in petrographic analysis.

Whole-rock ϵ_{Nd} compositions of the metasedimentary rocks from the ELS range from -1.71 to 0.90 yielding T_{DM} between 3.04 and 3.57 Ga. Recent isotopic analysis of the 2.69-2.86 Ga external granitoids surrounding the NCGB show ϵ_{Nd} values ranging from -6.8 to 3.3, and more specifically, felsic volcanics yield values between -0.1 & 0.2. The latter is more isotopically similar to the ELS samples. In contrast, mafic metavolcanics (from this study) within the NCGB show a more evolved composition ($\epsilon_{Nd} = 4.0 \text{ to } 9.9$).

These recent isotopic compositions suggest the ELS show a greater genetic link to the felsic volcanics with respect to the mafic volcanics and the external granitoids. Calculated T_{DM} ages are 200-720 Ma older than known detrital age suggesting the idea of crust “re-processing” during the evolution of the NCGB. This is supported by the significant subduction signature (negative Nb and Ti anomalies). The Sr/Y may indicate the provenance of the ELS has seen a melt history commonly attributed to adakite genesis; either in the stability field of garnet or amphibole fractionation.

Appendix A4b: GAC-MAC Meeting – St. John’s 2012 Abstract

Garnet as a tracer for the mineralization in a banded-iron formation-hosted orogenic gold deposit; Evidence from the Musselwhite deposit, North Caribou Greenstone Belt, Western Superior Province.

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Musselwhite, an orogenic Au deposit, is located in the central portion of the North Caribou Greenstone Belt (NCGB). Mineralization is hosted within a meta(chemical) sedimentary banded-iron formation (BIF) which is overlain and underlain by regionally continuous c. 2.9 Ga amphibolite grade volcanics rocks. The NCGB is bounded by c. 2.72 – 2.87 Ga TTG-granitoids and granites. Samarium-neodymium geochronology of garnet from the ore zone has been reported to yield a 2.69 Ga age, which post-dates plutonism and volcanism in the NCGB. Recent detrital zircon analysis from the metasedimentary rocks overlying the Au-bearing unit returned ²⁰⁷Pb/²⁰⁶Pb peaks at c. 2.87 and 2.60 Ga. Here, we present recent LA-ICPMS trace element and EPMA major element compositions of garnet from Musselwhite. Samples were collected from auriferous garnet -grunerite schist, footwall and hanging wall schist in the mine, as well from auriferous schist outcrops north of Musselwhite. A sample was also collected from the non-mineralized meta-chemical sedimentary bed that is continuous 24 km from the deposit. Major elements of garnet from mineralized rocks show Mn and Mg rich rims and Ca rich rims. Mineralized samples show positive Eu anomalies in the ore zone in the mine, whereas auriferous rocks outside the mine show less prominent anomalies. Low Eu anomalies occur in the non-mineralized sample (Eu/Eu* = 0.706-2.19). The majority of garnet grains show high HREE concentrations with a mean (Sm/Lu)_{CN} value of 1.6 and low LREE ($\Sigma\text{HREE}/\Sigma\text{LREE} = 41$). Rims of garnet from mineralized samples show large variations in Ni/MgO from ~ 0.14 to 15.5, and Y concentrations from ~ 0.89 to 198 ppm. The high Ni and low Mg are recorded in the core of these grains from the ore, whereas their rims show low Ni. Trace element zonation in garnet from the non-mineralized rocks is minor compared these samples. The data suggests that garnet growth was contemporaneous with precipitation of pyrrhotite and chalcopyrite; both sulfides are closely associated with the introduction of Au. Gold-bearing fluid was derived from rocks during metamorphism or extensive alteration of mafic rocks as reflected by variably high Eu/Eu* values and Ca- rich rims in the garnet crystals in the mineralized rocks. The origin of BIF-hosted Au deposits remains enigmatic and the source fluids (magmatic or metamorphic) are still in debate. Results here indicate that garnet effectively records the history of hydrothermal activity associated with Au deposits and the data indicates metamorphic fluid as the principle transporter of Au.

Appendix A4c: GAC-MAC Meeting – Winnipeg 2013 Abstract

Timiskaming-type sedimentary rocks near the Musselwhite gold mine in the North Caribou greenstone belt, Western Superior Province of Canada

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Timiskaming-type sedimentary rocks are the youngest lithological unit overlying most rocks in Archean greenstone belts, and are common in the central and southern Superior Province of Canada. These immature sedimentary rocks are important in unravelling the evolution of the Superior Province as they were deposited along major crustal shear deformation zones and are spatially associated with large gold deposits, such as the Porcupine and Kirkland Lake gold camps. The North Caribou Terrane (NCT) is considered to have been the nucleus of the Archean Superior Province of Canada during accretionary growth of the continent as it contains old, ~ 3.0 Ga, supracrustal rocks. The North Caribou Greenstone belt (NCGB) is in the north-central part of the NCS and it contains a ~ 3.0 Ga sedimentary sequence including quartz arenites (Donaldson & de Kemp, 1998). The NCGB is also the host of the major orogenic gold deposit at Musselwhite, which occurs in banded iron-formation, <20 km from clastic rocks of the Zeemal-Heaton assemblage (ZHA). This assemblage occurs in the northern margin of the greenstone belt near the east-trending Totogan-North Caribou Shear Zone, the major shear deformation along the boundary between the North Caribou Terrain and the Island Lake Domain to the north. New U-Pb zircon ages from the ZHA show that at least parts of the sedimentary rocks were deposited at around 2680 Ma. The quartzofeldspathic arenite from the Heaton Lake area (~ 40 km east of Musselwhite) yielded concordant zircon ages ranging from 2681-2712 My. Sublithic arenites farther east ~ 7 km at Obabigan Lake yielded ages of 2723 -2745 My. The data suggest episodic development of basins and/or the change in the provenances in a basin along the deformation zone. In either case, the data proves the deposition of Timiskaming-type sedimentary rocks along the Totogan- North Caribou Shear Zone. Considering a Sm-Nd hydrothermal garnet age of 2690 Ma at the Musselwhite mine reported by Biczok *et al.* (2012), the new data suggest that the mineralization was likely synchronous with the crustal-scale shear deformation and the deposition of the Timiskaming-type sedimentary rocks.